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Forecasted Climate Analysis from 2000 to 2100 Using RCP 4.5 and RCP 8.5 Model Scenario as A Hazard Early-Warning System in Prague City, Czech Republic

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Forecasted Climate Analysis from 2000 to 2100 Using Recipient Concentration Pathway as A Hazard Early-Warning System in Prague City, Czech Republic

ABSTRACT

In the last decades, the increasing number of populations in urban areas is dramatically increased. According to the 2018 Revision of World Urbanization Prospects, more people live in urban areas, around 55 percent of the world's population in 2018, and are projected into two-thirds of global population in 2050. As the world continues to grow, the lands need to be converted therefire deforestation happens. If this continues, greenhouse gas emissions will increase, and climate change will become a threat in the future. Therefore, it becomes essential to understand how the climate will change in the future through a model scenario. The study will assess three aspects of environments: precipitation, near-surface air temperature, and maximum wind speed in Prague City. The objectives were to analyze the future climate based on these three aspects and predict what future hazards might come in the upcoming years. The outcome can be a basis for an early-warning system in urban areas. The methods were employed using Recipient Concentration Pathways (RCP) scenarios of 4.5 and 8.5 in Regional Model RCA4. The study found that in several years until 2060, Prague will face more urban flooding based on the model scenario RCP 8.5.

Keywords: *climate; precipitation, Recipient Concentration Pathway (RCP); temperature; wind speed*

INTRODUCTION

Climate change has become a trending topic these recent years. The 26th United Nations Climate Change Conference, commonly referred to as COP26 in Glasgow, United Kingdom, that happened recently was held to discuss the acceleration action to combat the effect from the climate crisis. This is cannot be denied that the effect of these changes on earth climate will present horrible impact to the people.

Climate change is affecting the world by increasing the temperature dan creating a catastrophic climate drift to these days. This global trend affects negatively all forms of life since it leads to many issues such as land degradation, crop failure, freshwater problem, food shortages/insecurity, flooding and health issues (Matawal and Maton, 2013). Some archipelagic and island state countries have raised this issue to the world, for example, Tuvalu, Fiji and Solomon Island, since their islands keep sinking due to the rise of mean sea level. According to the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions increasing and causing average temperatures to rise by 0.2˚C per decade, reaching by 2050 the threshold of 2˚C above pre- industrial levels.

Recent evidence suggests even more rapid change will greatly damage the ecosystem and people (Adedeji et al., 2014). In the study by Kassai et al. (2012) about environmental balance sheet based on a model scenario in 7 countries from America, Europe and Asia, found that in 2050 scenario, the planet is facing a crisis of bankruptcy. The report suggests creating coordinated action involving social, environmental, cultural, and economic aspects in a global scale.

For urban areas like Prague City, climate change will also affect the people and urban environment. Especially with the heavy population as UN reported in 2018 Revision of World Urbanization Prospects more people live in urban areas, around 55 percent of the world’s population in 2018 and are projected into two-thirds of global population in 2050 (United Nations, 2019). As the world continues to grow, climate change becomes a threat and a danger for humankind. Climate change or the increasing of temperature will bring discomfort to the human that live in urban areas since the temperature will keep increasing. This will affect human's mental and physical health, leading to the decrease of human life expectancy in urban regions.

Furthermore, the temperature and climate change will increase the likelihood of urban flood. The increase of temperature will also create a phenomenon called Urban Heat Island. The monitoring of temperature can be employed by using thermal bands in satellite Imageries (Unger et al., 2009; Naughton et al., 2019; Gherraz et al., 2020). Meanwhile the rainfall intensity from ground meteorological station is a factor that contribute to urban flood and crop failure to food insecurity (Natayu et al., 2021). Another climate factor that could lead to crop failure and flooding is wind speed. The higher the wind speed, the more likely of flooding to happen is increasing.

Thus, this study is conducted to see how climate change scenario in a hundred years ranging from 2000 to 2100 with a thirty-year mean interval to see the prediction on rainfall, temperature and wind speeds as climate parameters using the scenario of global framework RCP 4.5 and RCP 8.5. RCP itself stands for 'Representative Concentration Pathway' and was used to understand how climate may change in future. By agreeing on a limited set of scenarios and using the same set of parameters, we can appreciate the climate policy outcome (IPCC, 2013).

The four RCPs range from very high (RCP 8.5) to very low (RCP 2.6) future concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0 and 8.5) refer to the attention in 2000-2100. RCPs provide a unique set of data concerning comprehensiveness and detail and the spatial scale of information for climate model projections (Van Vuuren et al., 2011). RCP 2.6 scenario represents the emission pathway that resulted in minimizing the greenhouse gas emission level. RCP 2.6 is a radiative forcing level that first went to around 3.1 W/m2 by 2050 and returns to 2.6 W/m2 by 2100 (Masui et al., 2011). Meanwhile, RCP 4.5 is a scenario that stabilized radiative forcing at 4.5 W/m2 in 2100 without ever exceeding the long-run radiative forcing target level (Thomson et al., 2011; Wayne, 2013). It included the global emission in the long term, short-lived species, and land use in the same framework as parameters (Granier et al., 2011; Meinshausen et al., 2011).

RCP 6, tested in Japan, stabilizes radiative forcing at 6.0 W/m2 in 2100 (Masui et al., 2011), and RCP 8.5 leads to the highest scenario level of green gas emission. RCP 8.5 is characterized by increasing greenhouse gas emissions over time using the assumption of high population, land transformation, slow income growth, and technology improvement. It was found that it technically possible to limit forcing from RCP 8.5 to lower levels compared to the other RCPs (Riahi et al., 2011; Lamarque et al., 2011).

In this research, the less pessimistic scenario as RCP 4.5 and the pessimistic scenario as RCP 8.5 were used to compare them in the climate change model analysis from 2000- 2100 with 30-year means and 10 years interval per each series. RCP 4.5 were used instead RCP 2.6 because it is more stable compared RCP 2.6 result. RCP 2.6 produce very low concentration amount so the emission pathway is not that stable compared to RCP 4.5 in the long period. The assessment in long period should be utilizing the stable one such as RCP 4.5 (Van Vuuren et al., 2011). The data was downloaded freely from CORDEX. The output of the research can be a basis to better understand climate in the future and become a data foundation to create policy making regarding the climate change in that region.

STUDY AREA

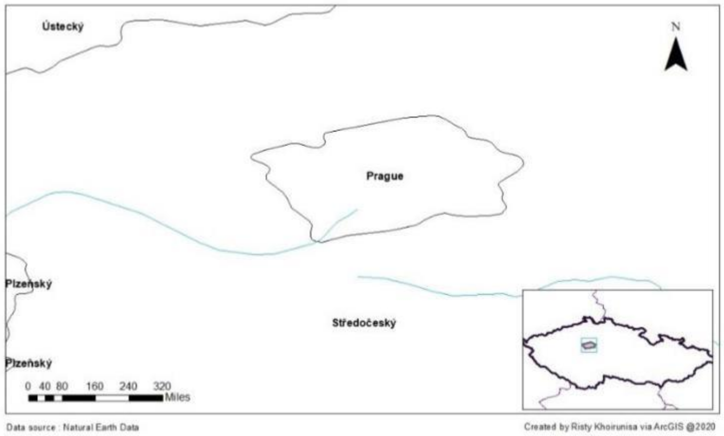

Figure 1. Study area maps (data extracted from natural earth data)

The study area is in Prague, Czech Republic are depicted in figure 1. Lying at the heart of Europe, it is one of the continent's most acceptable cities and the major Czech economic and cultural center. It is heavily populated and fits with the characteristic of urban areas. The availability and feasibility of the data also become a consideration. The city is also a popular destination spot for tourists to come. Therefore, it becomes essential to assess its future climate by predicting through a climate model to avoid hazards or disasters that could bring many casualties and damage to the city.

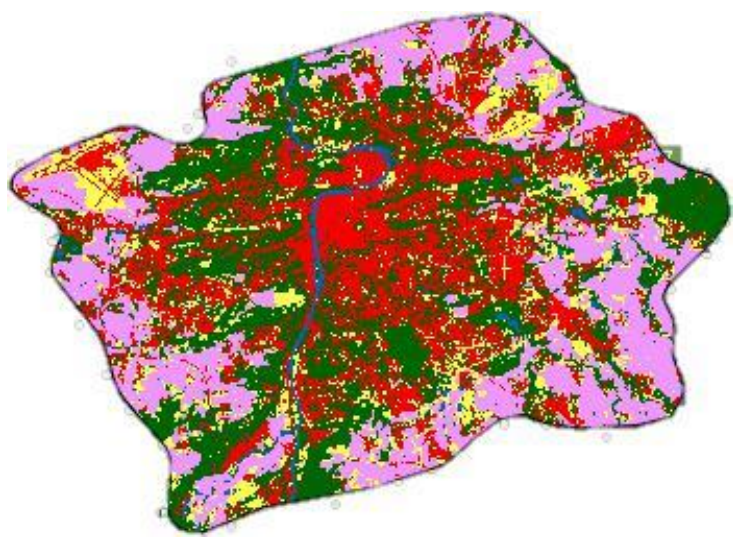

Figure 2. Land cover maps in Prague using Sentinel (10 m resolution) and Google Earth Engine with an overall accuracy of 94,6. The urban area is indicated with red color, and it is heavily concentrated in the center of the city and riverside.

The urban area is concentrated in the riverside of Vltava river as shown in the figure 2 and there could be a chance of urban flooding as a hazard as the climate change becomes more dramatic. Therefore, the climate model assessment becomes more critical as the urban environment will grow exponentially and contribute to the increase of Greenhouse gas emissions through modeling employed by RCP 4.5 and RCP 8.5. It will create more problems in the future, such as urban floods or urban heat islands.

METHODS

Data were obtained from several sources, most are free of use. The climate datasets used precipitation, surface temperature and wind speed as a parameter of upcoming hazards in the future. The data provided in the table 1.

Table 1. Data for research

No	Data	Source
1	Prague dataset and landcover	Google Earth Engine Analysis
2	Prague daily precipitation database (prc) from 2000 to 2100	EURO-CORDEX
3	Prague daily temperature database (tas) from 2000 to 2100	EURO-CORDEX
4	Prague maximum wind speed database (tas) from 2000 to 2100	EURO-CORDEX
5	Satellite Imageries extracted data as validation	Earth Explorer and other sources

The software which was used for the research was PuTTY. This program is necessary to connect to the command line of the server. However, before using PuTTY, Xming and WinSCP must be used first. Xming is essential to get the graphical user interface from the server, while WinSCP is used for downloading and uploading the files to the server.

The data was downloaded through EURO Cordex in the same model selection; Climate Model, such as Driving GCM, driving model or regional model. This study will be employed by using the selected scenario RCP 4.5 as optimistic scenario and 8.5 as a pessimistic scenario. In this scenario, the Regional Climate Model (RCM) RCA4 was selected. Before downloaded, the coordinate data of study area was required to select the area for downloading NETCDF files. The download of the data will be employed by using WinSCP to upload and download from the climate server. The data is in NC files and the extraction and processing will use CDO (Climate Data Operator).

After the extraction and process finish, the data should be grouped or merged in time series for analysis. The grouping data was in 30 years with 10 years interval in each group. The analysis could be done by using some statistical software or map software if necessary. The flowchart can be seen in figure 3.

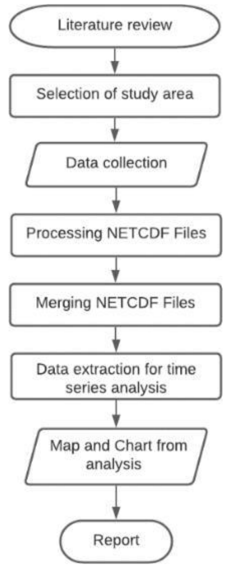

Figure 3. Research Flowchart

RESULTS AND DISCUSSION

The climate data resulted to several analyses based on the three indicators as mentioned in the previous sections. The average of the daily dataset from 2000 to 2100 calculated in thirty years for each series with 10 years interval of precipitation, near-surface air temperature and wind speed are presented in table 2-4 and charts 4-6. The extracted data then should be validated with other methods, such as satellite imageries (Gherraz et al., 2020).

Precipitation

In general, Prague's precipitation classified as moderate ranged from 2.9 mm to 3.8 mm per year. In the precipitation scenario, the less pessimistic scenario RCP 4.5 have a relatively similar value through the time series while the worst scenario, RCP 8.5 have a more unstable range. The precipitation has increased through the time series and only started to decrease in 2070-2100 as depicted in table 2 and figure 4.

Table 2. Precipitation from 2000 to 2100 with a 30-year mean value and 10-year as an interval with scenario of RCP 4.5 and RCP 8.5

Time Series	RCP45 (mm)	RCP85 (mm)
2000-2030	31.9312717	29.7125881
2010-2040	31.4075049	30.9984923
2020-2050	33.1837792	33.9605932
2030-2060	33.3362718	35.3965529
2040-2070	34.4346461	36.1015210
2050-2080	33.2023836	36.1532937
2060-2090	34.4346461	37.5220546
2070-2100	34.6607631	34.4782332

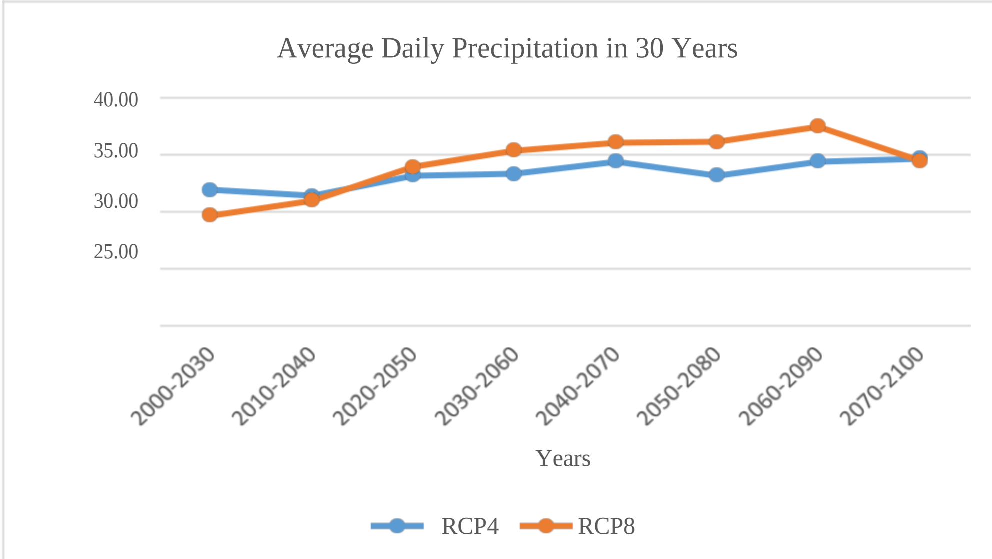

Figure 4. The amount of precipitation in RCP 4.5 and RCP 8.5 scenario

With this projection, the intensity of rainfall will likely increase shortly. Throughout both scenarios, rainfall intensity is increasing, noticeable enough at RCP 8.5. Thus, it means the risk of urban flooding is getting higher as well, especially in spring time, for the upcoming years in this city. Even though the precipitation is still classified as moderate, it is recommended to focus on establishing good water and run-off management system and preparing the early warning system for the chance of flooding, especially in spring time in Prague City.

Near surface air temperature

In the temperature scenario, the less pessimistic scenario RCP 4.5 have a relatively similar value through the time series while the worst scenario, RCP 8.5, have a more unstable range of value, even decreasing so rapidly in 2020-2050 and 2030-2060 time series. However, after that the temperature increased so drastically and started to increase through the time series, as depicted in table 3 and figure 5.

Table 3. Near surface air temperature from 2000 to 2100 with 30-year mean value and 10 years as interval with scenario of RCP 4.5 and RCP 8.5

Time Series	RCP 4.5 (Kelvin)	RCP 8.5 (Kelvin)
2000-2030	281.4488389	281.5480655
2010-2040	281.6296619	281.7845545
2020-2050	281.7479323	277.37
2030-2060	282.1264397	262.225
2040-2070	282.3058977	282.9605496
2050-2080	282.5218435	283.2776492
2060-2090	282.7469780	283.8528445
2070-2100	282.7059656	284.5666243

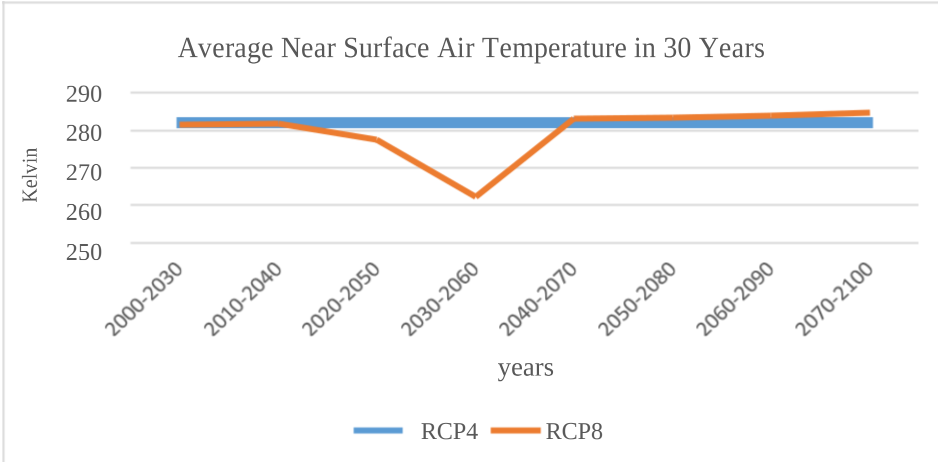

Figure 5. The temperature prediction in RCP 4.5 and RCP 8.5 scenario

The temperature is predicted to be decreased in RCP 8.5 which can be a good thing, however, there might be La Nina or flooding event that becomes a factor of temperature decrease. While in RCP 4.5 the temperature is stabilized through the time series. The data is in average to be remembered, it means that it might have lower temperatures to contribute to the data means. The data also can be interpreted as Prague will experience a long season without a sun, winter and autumn to be exact, in the coming future.

The maximum speed

In the maximum wind speed scenario, the less pessimistic scenario RCP 4.5 have a relatively similar value through the time series. It has some unstable range but not as drastic as RCP 8.5. The worst scenario, RCP 8.5, have more unstable range of value. The wind speed increase happened so rapidly in the beginning of the time series. However, from 2030 starting to decline and drop to the lowest point in 2060-2100 periods as seen in table 4 and figure 6.

Table 4. Wind speed maximum from 2000 to 2100 with 30-year mean value and 10 years as an interval with scenario of RCP 4.5 and RCP 8.5

Time Series	RCP 4.5 (mph)	RCP 8.5 (mph)
2000-2030	10.45832283	10.38491513
2010-2040	10.46234562	10.42816661
2020-2050	10.46803792	10.55619952
2030-2060	10.44902282	10.53144386
2040-2070	10.34345679	10.40198682
2050-2080	10.32058795	10.35612975
2060-2090	10.28709881	10.21574068
2070-2100	10.28968619	10.22331351

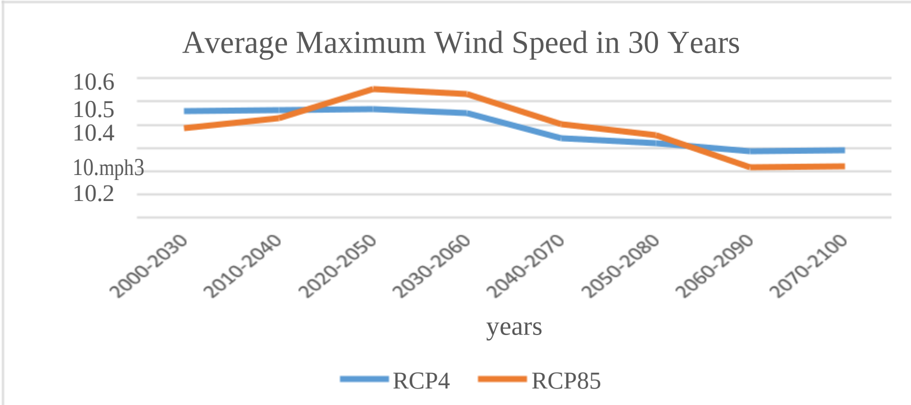

Figure 6. The maximum wind speed in RCP 4.5 and RCP 8.5 scenario

The wind speed can indicate the La Nina phenomenon, which will bring flood to that region. The wind speed is increasing in both RCP 4.5 and RCP 8.5. With the decrease in temperature and the increase of rainfall intensity in the beginning of the time series (2020-2050 and 2030-2060), it will affect the people in an urban environment. However, the ranging speed is still classified as light. It was also found in some year, such as 2028, 2032, 2034, 2039, 2041, 2050 and 2053, there are maximum wind speed with more than 20 mph which can be classified as a storm.

The output model result predicts the data from 2000 to 2100. In model scenario RCP 4.5 as less pessimistic scenario with radiative forcing from greenhouse gas emission around 4.5 w/m2, it was found that all the three climate aspects used here are stable. However, wind speed has a noticeable decrease in the upcoming years. Meanwhile, model scenario RCP 8.5 as a more pessimistic scenario with radiative forcing around 8.5 w/m2 as more pessimistic scenario is having some dramatic decrease and increase, especially in temperature and maximum wind speed's projection. The finding supported the literature review from Riahi et al. (2011) and Meinshausen et al. (2011) that provide a stable graph for RCP 4.5 compared to other recipient concentration pathways.

From those results, it could be seen that the climate will goes for some uncertainty in the upcoming years. The climate is predicted to have more rain and wind which will be an indicator for early warning of flooding shortly. However, after that period, the city will experience a humid weather and the temperature will slowly increase. Likewise, the rain intensity and the wind speed are decreasing. If this continues to increase in a more rapid situation, drought might happen in the future. The probability of this disaster is also mentioned in study by Adedeji et al., (2014).

The future models of RCP 4.5 and RCP 8.5 indicate the probability of flood since both models for precipitation are increasing throughout time series. RCP 4.5 which was a stabilization scenario adapted from greenhouse gas emission, land conversion and short-lived species create more stabilize future climate scenario. However, RCP 8.5 concentrated on high population assumption that increasing greenhouse gas emissions over time, slow-income growth, land conversion and technological improvement gave more hazardous scenarios, from more flooding and drought likely to happen in the future. In categorizing this RCP, urban areas like Prague City, is much more fitting for adapting RCP 8.5 scenario rather than RCP 4.5 scenario. The past temperature data, rainfall and wind speed could also be seen from satellite imageries as other inputs for predicting the hazards, to see the correlation of future scenarios based on RCP model scenario.

Validation result

The model needs to be evaluated by some method to ensure the reliability of the data (Gherraz et al., 2020). They are using extracted data of ECWMF from September to November 2021 for Czech Republic. Prague, especially has lower precipitation compared to other areas in Czech Republic. Gathered from ECMWF, 35 data of rainfall in 2021 that were collected every 10 days are depicted in figure 7. The average precipitation in 2021 based on the data extracted is 19 mm, which was not that close with the model precipitation from both RCP, however, the model was using 30 years data average; therefore, the difference is possible.

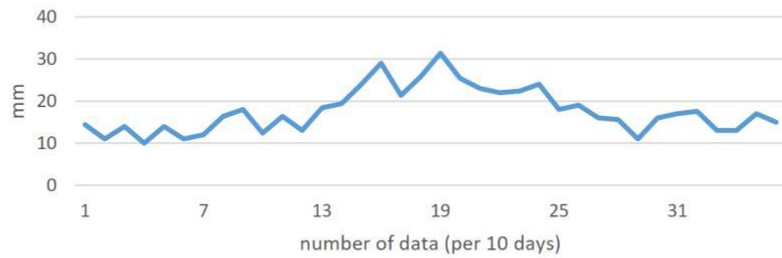

Figure 7. The extracted data for daily precipitation in every 10 days each month from ECWMF in 2021.

The temperature prediction can be validated using MODIS dataset, Terra Land Surface Temperature and Emissivity Daily Global with resolution 1 km, the data unit was is in ^{0}C which was different with prediction model used. The prediction with RCP used Kelvin (K) as unit.

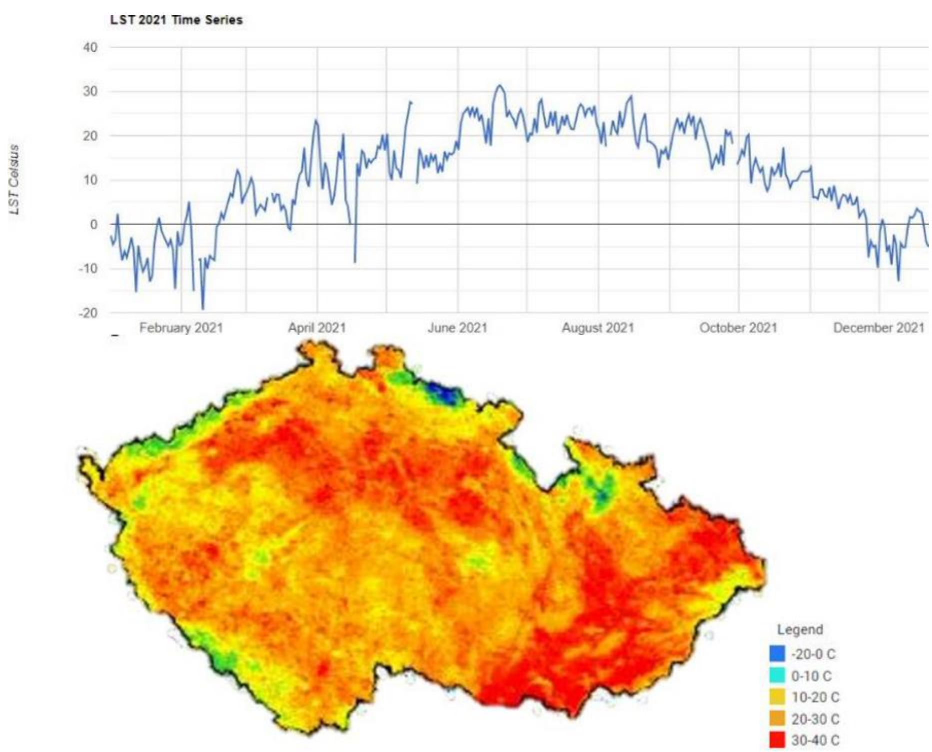

Figure 8. The land Surface Temperature Map and Chart from MODIS dataset in 2021

The average data prediction for 2000 to 2030 is around 282 K which was around 8.8^0 C and we compared them to the average of 2021 by MODIS Terra dataset for Czech Republic which calculated 11.3^0 C. With the difference around 1.5^0 C, it still can be accepted due to the foreseen in the coming years. Nevertheless, the city center which was location of urban areas of Prague and the southeastern part of Czech Republic, are depicted to have higher average temperature compared to the other areas in Czech Republic as illustrated in figure 8.

Meanwhile, the data of wind speed from model is expected to be around 10 m/s per period. The result is the same as the data of average wind speed in the present days by global wind atlas provided in figure 9. The wind speed is ranging from 6 to 12 m/s with an average of 9.57 m/s in 2021. The Prague itself ranging from 6 to 8 m/s. The data was extracted from NOAA dataset. From the validation data it could be seen that Czech Republic and the city of Prague has mild to strong wind speeds throughout the year.

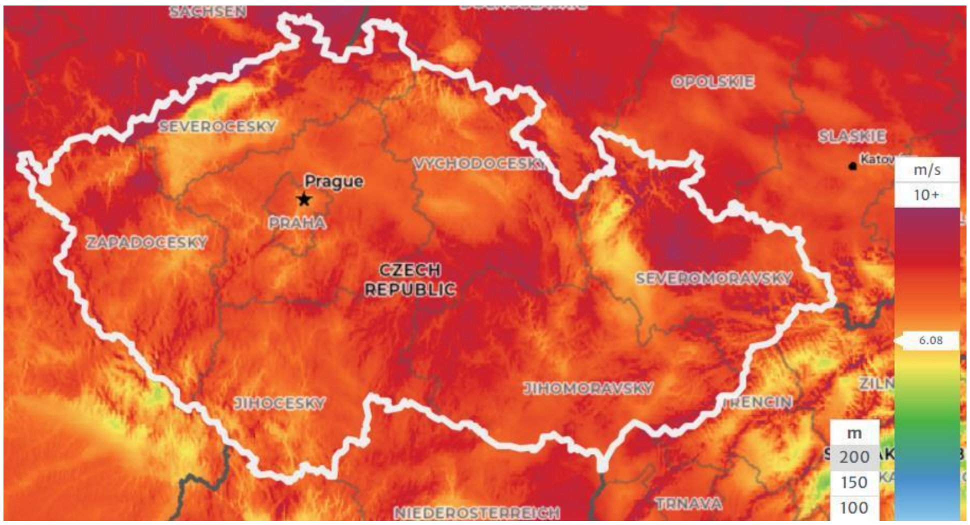

Figure 9. The wind speed from NOAA dataset in 2021

CONCLUSION

From the graphic of the chart and data that are presented in the table, we can conclude that the stabilization scenario, known as RCP 4.5 shows stable change throughout the time series 2000-2100 while the pessimistic scenario, known as RCP 8.5 shows the drastic change that might be happened in the future. With prediction from scenario RCP 8.5, flood will be one of hazards that would come in the near future, and after that period, drought will be a threat for the human and urban environment. The government should prepare to minimize the damage when flood and drought come to the city.

The comparison with the existing situation in 2021 through some satellite imageries shows a similar number in the prediction, which can validate the model scenario of RCP 4.5 and RCP 8.5. The output result could be used as a data foundation to predict the food insecurity or crop failure, especially in Prague City and tools for policy making in combating the climate change. It could also be used as reference data for an early-warning system for upcoming hazards and disasters in Prague City, such as urban floods and droughts that are predicted to happen in RCP 8.5 scenario. Further research could also employ the collaboration between GIS and remote sensing techniques and regional/global climate model scenarios to create a more accurate model for forecasting climate change in the future.

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