CLIMATE CHANGE IN THE BARENTS SEA REGION, ITS IMPACTS ON LAND COVER AND BEYOND

Certificat de géomatique 2017

Université de Genève
Clément Hanser

Table des matières

Summary

Climate change is expected to be stronger in the Arctic than anywhere else in the world, therefore triggering more potent local and global consequences. In this work, I realized visual representations of the rise of temperatures that are expected in the Barents Sea region by 2050 and 2070, according to two different IPCC scenarios, and comparing them with 1960-1990 temperatures. The rise of temperature should be of respectively +3.2°C and +4.7°C by 2050 and 2070 for the best-case scenario, and +5°C for 2050 and +6.9°C for 2070 in the worst-case scenario, with winter temperatures systematically climbing up more significantly than summer temperatures. The impact of this rise of temperatures on land cover is also represented, again for 2050 and 2070 for both scenarios and compared with actual land cover, along with a discussion on direct consequences these changes will have on ecosystems, fauna and human population, at the local and global level. Ice and snow covers are expected to decrease significantly on Novaya Zemlya, the tree line will move north by around 100km by 2070, gradually replacing the tundra biome which will shrink, and menacing species living in that ecosystem. The work was realized using ArcGIS 10.3 and the Scenario Generator Proximity Based tool of the InVEST software.

Introduction

Overview

Our planet has been undergoing tremendous changes over the past decades. Since the Earth Summit in Rio de Janeiro of 1992, scientific evidence of a warming taking place at a global scale has been accumulating, making it nowadays undeniable that this rise in temperature is real, with most likely an important part of it caused by human activities and the release of greenhouse gases (GHGs), in particular carbon dioxide (CO_2). CO_2 is an unwanted product released when the burning fossil fuels (coal, petrol, gas) occurs, which is the case in many human activities such as transportation and energy production, activities that are today at the core of our society model, making it hard for now to bypass the use of these fossil fuels. CO_2 and other GHGs are responsible for trapping heat into our atmosphere, progressively warming it up (NASA, 2011). We now know that this warming is already happening, as average annual temperatures have increased by 0.6°C since pre-industrial levels (IPCC, 2001). This rise in temperatures is an issue for both humans and the environment we live in, the latter being destined to undergo many stresses and modifications as the climate warms up, therefore impacting our society and its whole lifestyle. Decision makers have started to become aware of that issue, and most of them are trying to push for a change that would prevent consequences from being too catastrophic, as materialized by the recent COP21 (Conference of the Parties) in Paris, where the objective of limiting the warming to 1.5°C was announced and agreed upon by most nations (Climate Central, 2016). Sadly, policies and actions are not implemented rapidly enough to respect this 1.5°C threshold, which will most likely be exceeded sooner or later. In order to know in what direction the decision makers should work, the IPCC (International Panel on Climate Change) has been working on the establishment of climate scenarios, which are representations of what our world might become in the future, depending on how the society acts in the next decades. The main characteristic of each scenario is the amount by which temperatures would rise, followed by all its cascade of consequences on the environment as well as on the population, as each additional degree being added to the average global temperature brings its own issues and problematics. In this study, I chose one specific region and observed the predicted rise of temperatures according to different scenarios, and then analyzed the impact this warming will have on the land cover, and all the other impacts it will trigger in the region and all over the world. The goal of that study is to better understand and grasp the magnitude of the consequences that the Arctic will be facing in the coming years because of climate change.

Area of interest

The region that I chose to focus on for this work is the Barents Sea region, in the northwestern part of Russia. It is part of the Arctic Circle, meaning the region experiences a wide range of temperatures throughout the year, from the cold sunless months of winter to the warmer summer temperatures, when the sun never leaves the sky. My area of interest extends from

36°06'E to 76°00'E and from 64°24'N to 77°03'N. It includes the Kola Peninsula in the west, up to the Yamal Peninsula and Siberia in the east. In the southernmost part of our area, figures a small section of the Ural mountain range, which extends around 2'500km and is often considered to be the geographical boundary Europe and Asia. Here, two sections of the Urals are present: the polar Urals, with peaks rising to around 1'000m above sea-level, and the Nether-Polar Urals, section which contains the highest peaks of the whole Ural mountain range (e.g. Mt Narodnaya, 1'895m above sea-level) (Yastrebov & Poulsen, 2016). In the north of our area of interest, the island of Novaya Zemlya is surrounded by the Barents Sea in the west and the Kara Sea in the east. The island of Novaya Zemlya is actually two islands, Yuzhny Island in the south and Severny Island in the north. Both are separated by a very narrow strait, the Matochkin Strait. Novaya Zemlya is a very mountainous archipelago, with Mount Sedova culminating at almost 1'600m above sea-level (depending on ice cover), and an average elevation of roughly 1'000m (Earth Observatory, 2009). All of these features are visible on Figure 1.

Figure 1: Area of study, in northwestern Russia (36°06'E to 76°00'E and 64°24'N to 77°03'N)

This whole area of the globe is still almost intact compared to other regions of the planet, mainly due to its remote location and harsh climate. For example, on Novaya Zemlya, winter temperatures vary between -16°C and -22°C and summer temperatures are comprised between 2°C and 7°C. This means the human population of this region is very low. Indeed, most of this region belongs to the Nenetsia district, an autonomous region whose total population is under 50’000 inhabitants. The largest city in the region is Arkhangelsk, in the southwest corner of our area of interest, with a population of around 350’000 inhabitants. It is the administrative capital of the region, which extends south of our region of interest and also includes the islands of Novaya Zemlya. Needless to say, the area is therefore fairly unpopulated, leaving most of it occupied by natural ecosystems. The predominant vegetation zones in the Barents Sea region are polar deserts, which are open patches of bare ground associated to a complete absence of any woody shrubs, and tundra, which has low-lying vegetation such as shrubland or grassland. In the south of the region lies the northern part of the boreal forest.

Data, concepts and methods

I have used two types of data to execute this work: climate data and land cover data. The land cover data come from the GlobCover Portal, (ESA, 2017), created by the European Space Agency (ESA) and which gives access to the results of the GlobCover project, a service delivering land cover maps resulting from observations of the ENVISAT satellite mission, via the 300m MERIS sensor. For this particular work, I have used the land cover maps covering the January – December 2009 period. As for climatic data, I have used several datasets, all found on the WorldClim portal (Global Climate Data, 2017). My work uses both climate data for current conditions, which consists of an interpolation of observed data from the 1960-1990 period, as well as climate data for future conditions, which are projections from global climate models (GCMs) made by the fifth assessment of the IPCC (International Panel on Climate Change). Out of the four representative concentration pathways (RCPs) available, I chose to work with the two most extreme ones: the RCP 2.6 and the RCP 8.5, named after the radiative forcing values by 2100 compared to pre-industrial values (IPCC, 2014), and which correspond to different greenhouse gas concentration trajectories predicted by the IPCC. For each RCP I have used the climate prediction model HadGEM2-AO (Hadley Centre Global Environment Model version 2) which includes a coupled atmosphere-ocean configuration (Met Office, 2016). For both RCPs I worked on two time periods: 2050 (average for 2041-2060) and 2070 (average for 2061-2080), giving us a total of four different scenarios. In both current and future conditions, I worked with data at 2.5-minute (of a longitude/latitude degree) spatial resolution, corresponding to around 4.5 km at the equator. And also I chose to work with monthly average minimum temperature (°C*10), again in both cases, average temperatures being unfortunately not available for the future conditions.

First, I had to preprocess the data to be able to use them. This involved, among other things, transforming the monthly climate data into annual climate data, simply by calculating the mean of all the monthly layers combined. I also had to reduce the extent of both the climate and land cover data, which initially covered the whole globe, to my area of interest, the Russian part of the Barents region. Regarding the land cover data, I also chose to reduce the number of classes shown in my area of interest, from 12 to 5 classes. I did so by combining all the classes that consisted of different forest types (broadleaved, needleleaved, evergreen, etc…) into just one category labeled "forest", therefore combining three classes into one. I repeated the process with the different classes of shrubland and grassland, combining another five classes into one called "Shrubland/Grassland", and again by combining the class "sparse vegetation" with "bare areas" the latter being almost inexistent in my area of study.

In order to make the climate data easier to read, I chose the option of adding isotherms over the temperature layers. To do so, I used the "contour" tool of the spatial analyst extension in ArcGIS, having previously calculated the mean of each pixel and several of its neighbors using the "focal statistics" tool. This resulted in the production of isotherms much smoother and easy on the eye than they would have been without the use of the "focal statistic" tool. The different actions performed on the original data are summarized in the following model builder (figure 2). This model builder can easily be used to perform the same analyses on any region of the world, by simply changing the clipping extent. In our case, these different operations have been realized with each temperature dataset, for a total of five runs (current temperatures, predicted temperatures in 2050 and 2070 for the RCP2.6 scenario and likewise for the RCP8.5 scenario).

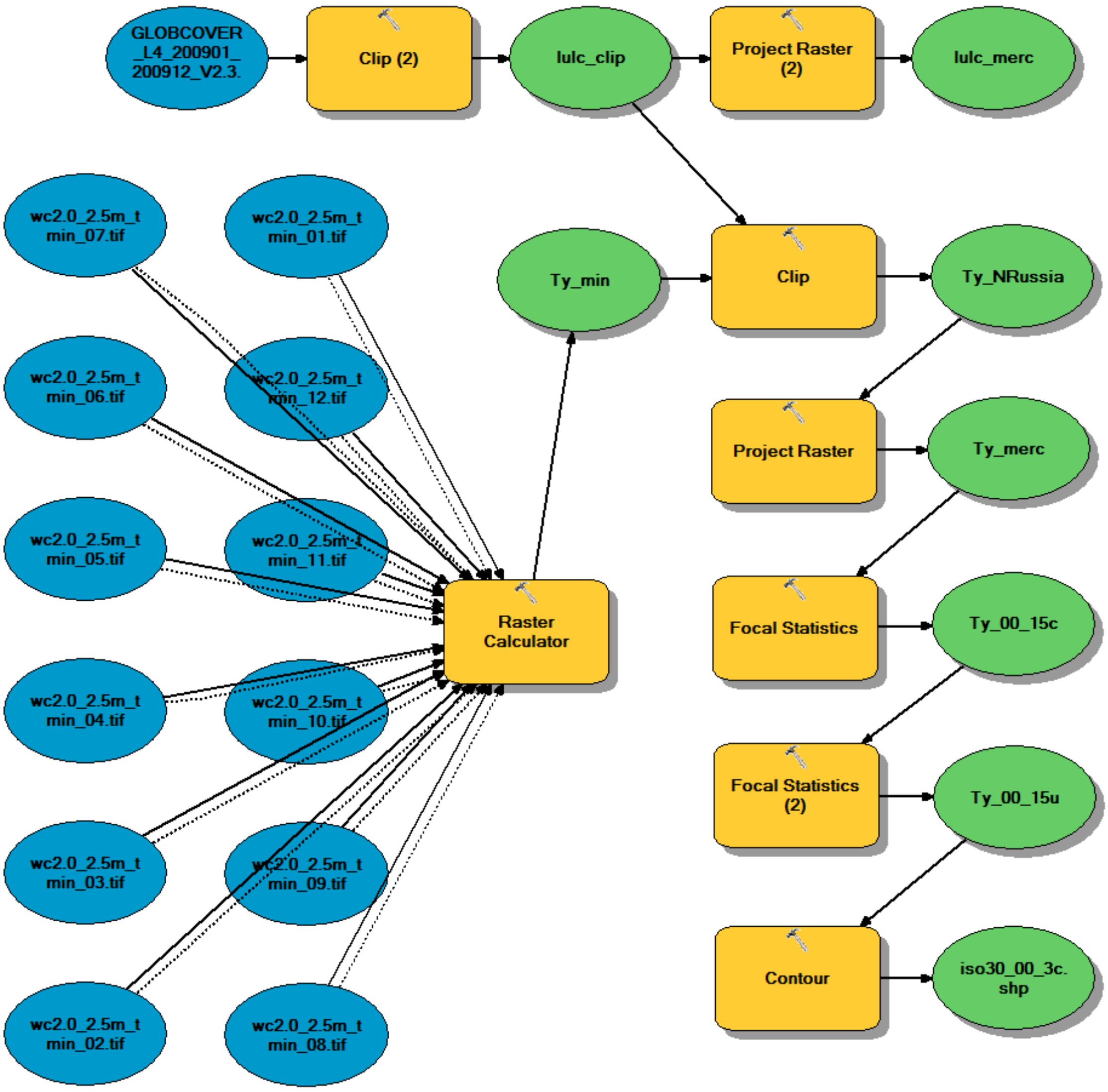

Figure 2: model builder of the transformation process from raw to final data

All of the above-mentioned manipulations have been realized using ArcGIS 10.3, a geographic information system used to work with maps and geographic data. The map shown in the introduction to describe our area of study (figure1) was also created with ArcGIS 10.3.

The rest of the work was done using the open-source software InVEST, developed by the natural capital project (NatCap), an initiative born from the partnership of Stanford University and the University of Minnesota, and inspired by two worldwide conservation NGOs, The Nature Conservancy (TNC) and the World Wide Fund for Nature (WWF) (Natural Capital Project, 2018). The purpose of the InVEST software is to evaluate several services provided by ecosystems throughout the world (e.g. food production, climate regulation, recreation…). One important component of the software is the scenario generator tool, which allows the user to create different scenarios of land use and land cover changes in the area of interest. For my work, I have used the Scenario Generator: Proximity Based, used to convert specific types of land cover into another type. This tool allowed me to modify the surface occupied by the different types of land cover to bring it close to what their extent could be in the future with the impact of climate change (e.g. decrease of snow and ice cover, increase in forest surface…). As the tool only allows us to convert land cover types into a single new one, I had to run the tool several times for each new scenario. To make the task less repetitive and time-consuming, I created a python script (see Annex) bringing together all the different steps needed for each scenario, making it easy to run and to modify. The tool suggests two different ways to convert land covers: *nearest to edge* and *farthest from edge*. As natural ecosystems are usually first modified at their edges (when excluding human interventions), I only worked with the *nearest to edge* scenario. I chose to exclude human impacts from my work as the region studied is poorly populated, and still fairly unaffected by any type of local human activity.

Results and discussion

Temperature rise in the Arctic

Climate change is considered a global issue, although this does not mean it has the same impact everywhere on the planet. The Arctic region is one of the few places on Earth where the increase in temperature will be stronger than elsewhere. Indeed, while we have seen earlier that global average temperatures have increased by 0.6°C since pre-industrial levels, in the Arctic this warming has been estimated to be around 1.5°C, and this solely in the last 50 years! This is even more alarming when looking at winter temperatures, which have gone up by as much as 3 to 4°C in Alaska and Western Canada since 1960 (ACIA, 2004). How can there be such a huge difference from the temperature rise observed globally? This unfortunate phenomenon can be explained by a series of positive feedbacks that are specific to the Arctic region. First of all, the increase of temperature triggers an extensive melting of sea ice, a surface that is very effective in reflecting sunlight without absorbing heat (albedo = 0.6). Once the ice is melted, it is replaced by sea, which has a much lower albedo (0.1) and therefore heats up a lot faster, in turn accelerating the melting of sea ice, and so on (Houghton, Callander, & Varney, 1992). Another positive feedback is the role of clouds: as models suggest, the increase of atmospheric CO_2 means that more clouds will be present in high latitudes, due to an increase in evaporation. And clouds are known to be very effective at trapping heat, preventing it from going back into space. This phenomenon could be contributing to as much as 40% of the warming observed in the Arctic region (Vavrus, 2004). This is why, when looking at future climate projections, the Arctic temperature is expected to rise by as much as 4 to 7°C by the year 2100, while this warming would “only” be around 2 to 5°C for the global temperature in the same period (ACIA, 2004). My results from the climatic model in the Barents Sea region from both scenarios are shown in figure 3.

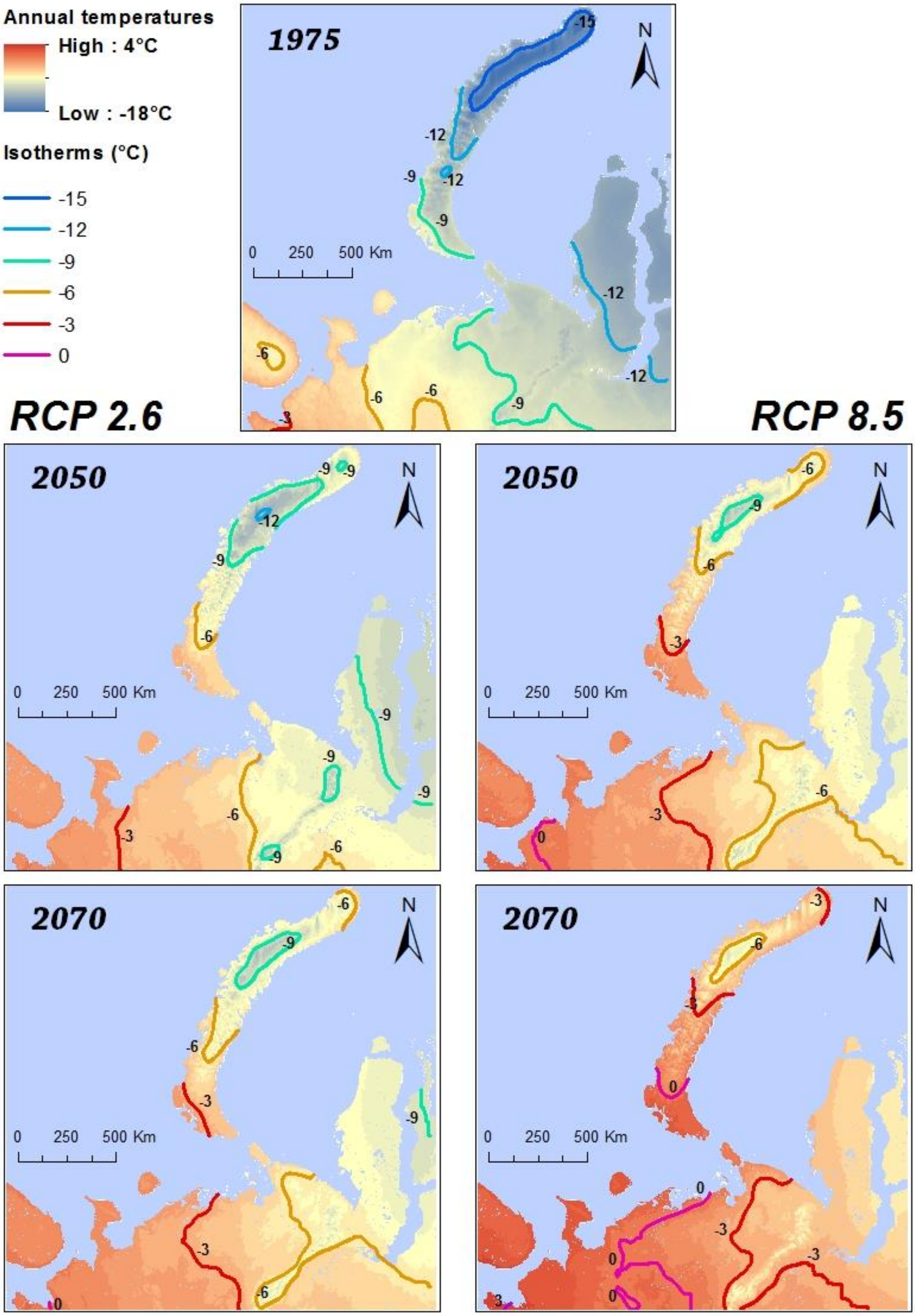

Figure 3: Annual minimum average temperatures of 1975 (mean of the 1960-1990 period) and temperatures forecast for 2050 and 2070 for RCP 2.6 and RCP 8.5, following the climate prediction model HadGEM2-AO.

This figure shows us that a real warming is expected in the Barents region, and so regardless of which scenario we consider. For the 1960-1990 period, annual average minimum temperatures were oscillating between -18.5°C and 0°C, with a mean of -9.5°C. In the most optimistic scenario of climate change, the RCP 2.6, theses temperatures are already expected to rise significantly, oscillating between -14°C and 0°C with an average of -6.3°C for the 2040-2060 period, and increasing furthermore for the 2060-2080 period, with values between -12°C and 1°C and an average of -4.8°C. This corresponds therefore to a rise in the average annual minimum temperature of almost 5°C between 1975 and 2070, from -9.5°C to -4.8°C. Numbers get even bigger when looking at the most pessimistic scenario, the RCP 8.5. From -9.5°C for the 1960-1990 period, the average annual minimum temperature would climb up to -4.5°C by 2050 and to a staggering -2.6°C by 2070, annual minimum temperatures respectively oscillating between -12°C and 2°C for 2050 and between -9°C and 4°C for 2070. This gives us therefore an increase of almost 7°C from 1975 to 2070 (from -9.5°C to -2.6°C) with the worst-case scenario. These numbers are coherent with the ACIA (2004), which preditcs an increase of temperatures by 5°C to 7°C in the Arctic region by the end of the century (with 1990 temperatures as baselines). It aslo matches other climate simulations carried out in the Barents Sea region (Keup-Thiel, Göttel, & Jacob, 2006).

It is worth noticing that the lower values of the interval of temperatures increases significantly more (from -18.5°C in 1975 to -12°C in 2070 for RCP 2.6 and to -9°C for RCP 8.5, so a maximum rise of +9.5°C) than the upper end of interval (from 0°C in 1975 to 1°C in 2070 for RCP 2.6 and to 4°C for RCP 8.5, so a maximum rise of +4°C). This is because winter temperatures are expected to increase a lot faster than summer temperatures, explained by the fact that the positive feedbacks taking place in the region and mentionned earlier on will be much more effective in the winter period, and this is especially true for the reflectivity (the reduction over time in ice cover will indeed be much more extented in the winter than in the summer) (ACIA, 2004).

Several other things can be observed on figure 3. We can immediately notice on the different maps that one region of mainland Russia is colder than its surroundings. This is especially obvious when focusing on the -6°C isotherm of the 2050 prediction for RCP 8.5. That region corresponds to the Ural Mountains, extending from the extreme south of our area of interest up to the sea in a southwest-northeast orientation. The figure 2 also shows us how much difference there is between the different scenarios. Even though these scenarios are mainly indicative, they nevertheless give a good range of how the climate could change according to how the society changes its consumption behavior (or does not). And in the worst case scenario (RCP 8.5), arctic temperatures by 2050 would already slightly higher than they would be in the best case scenario (RCP 2.6) by 2070 (with average annual minimum temperatures respectively averaging -4.5°C and -4.8°C). And by 2070, there is a +2°C difference between the worst case and best case scenario, a non-negligible variation. The way the society will evolve in the next decades will therefore play a huge role in how the temperatures will increase in the future, both in the Arctic and worldwide.

Impacts of a warming Arctic

The rise of temperature that we have described previously will have important consequences on the land cover and vegetation in the Arctic. As the temperatures go up, this will make the living conditions more suitable for many plant species that were previously unable to grow in the harsh arctic temperatures, resulting in an overall northward migration of the different types of vegetation. The rise of temperatures will also trigger a massive melting of ice and snow, which are often present all-year round in an important part of the Arctic. The figure 3 shows the changes in the land cover that will most likely arise from the increase of temperatures in the Arctic, more precisely in our area of interest, the Barents Sea region. These changes are compared to the 2009 land cover map, and are estimated for the RCP 2.6 and RCP 8.5 scenarios, both for the years 2050 and 2070.

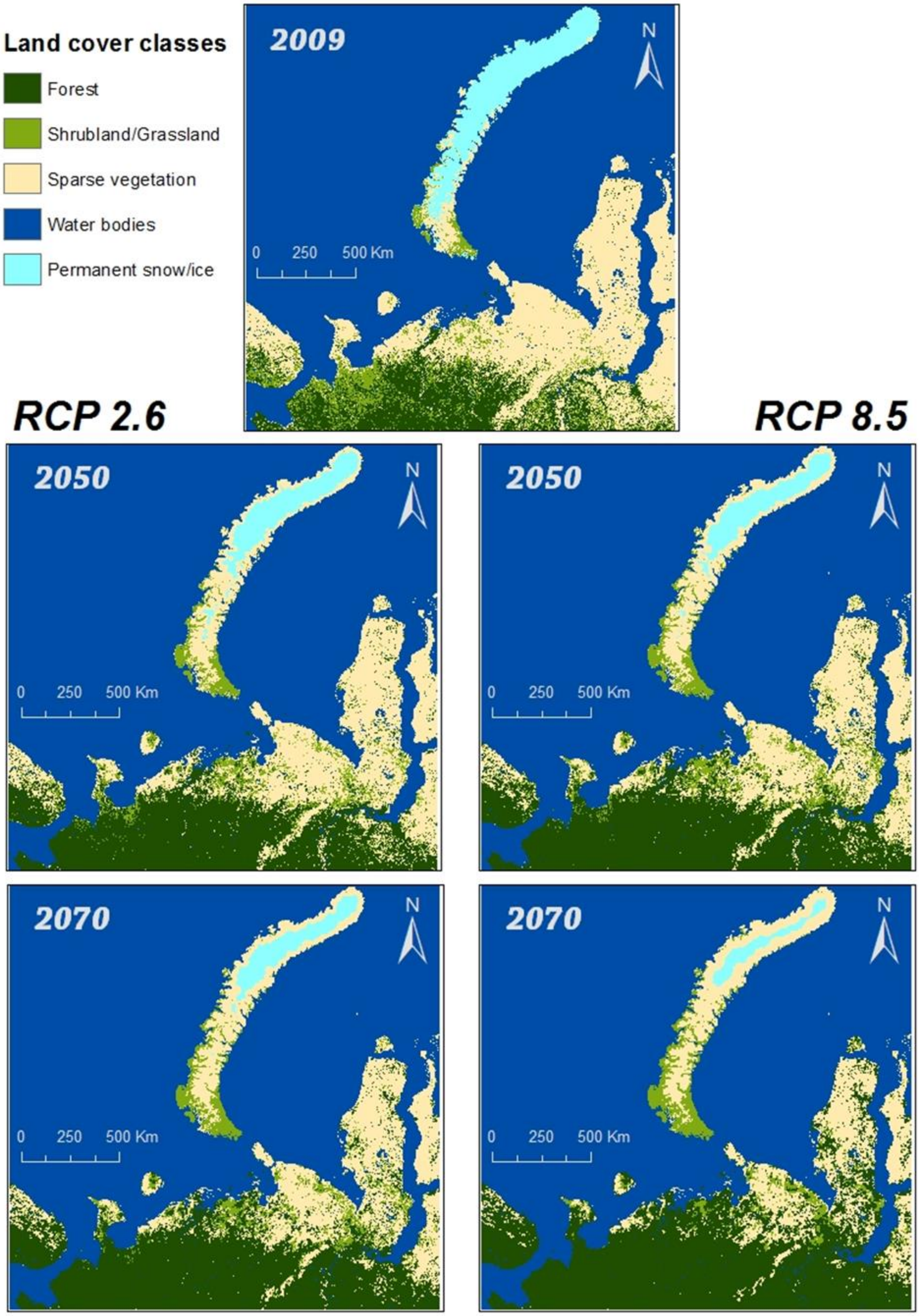

Figure 4: Map of the land cover in the Barents Sea region in 2009 and estimated future land covers for 2050 and 2070 for RCP 2.6 and RCP 8.5.

The first thing we can notice from figure 4 is the important decrease of land ice on Novaya Zemlya that will result from the rise of temperatures. In 2009, the almost entire surface of the north island is covered in snow and ice for the longest part of the year, extending into the most northern and inner part of the south island. In the RCP 2.6 scenario, this ice in the south island has almost completely disappeared by 2050, and is completely gone by 2070, while in the north island the ice cover has retracted inland by several dozens of kilometers. In the RCP 8.5 scenario things escalate a lot faster, the ice being already completely gone of the south island by 2050, and by 2070 is restricted to the most inland parts of the northern island. All this ice disappearing uncovers bare rock formations, which are quickly colonized by some sparse vegetation.

In the south of Novaya Zemlya, shrublands and grasslands are expected to expand more and more as the temperature rises. Back in 2009, they were confined to the coastal areas of the south island, but they slowly move northward and inward as time goes by, reaching the coasts of the north island by 2070 in the RCP 2.6 scenario, and a bit sooner in the RCP 8.5 scenario. On the mainland, both shrublands/grasslands and forests biomes keep moving northward as the climate warms, shrublands and grasslands progressively colonizing areas that previously contained only sparse vegetation. In the RCP 2.6 scenario, shrublands and grasslands expand mainly around preexistent patches, especially in coastal areas. Forests also make a strong northward migration, roughly 100km by 2070 for the RCP 2.6 scenario and a little bit under 150km for the RCO 8.5 scenario. This is coherent with other researches done on the matter, which predict that the tree line would move northward by sometimes up to 250-300 km a hundred years from now (Wolf, Callaghan, & Larson, 2008).

The forest is also expected to become a lot denser in more southern regions, where trees are already present, but more scattered. The overall change that we therefore observe in the area is an important greening of the region, with previously bare areas with sparse vegetation being gradually replaced by shrublands, grasslands and forests. But the dynamic is a bit more complicated than a simple increase in surface of the latter vegetation classes. Indeed, forest tend to take over areas that were previously covered by shrublands and grasslands, as trees need mature soil in order to grow, which as the moment is not present in bare areas (ACIA, 2004). In order to have trees in an area with sparse vegetation, it first needs to be colonized by shrublands and grasslands, which can grow without the need for much soil, and only then can it be colonized by trees. This means that, with the rise of temperatures, forests will quite rapidly start colonizing shrubland and grassland areas, while they in turn colonize bare areas, but at a rate significantly lower, due to the absence of good quality soil that would allow a rapid expansion.

The changes that we could therefore expect in the region are an important reduction in land ice cover, areas containing only sparse vegetation slowly transforming into shrublands and grasslands, which are themselves more rapidly converted into forested areas. This means that, on the mainland, the low-lying vegetation classes are expected to contract (Pearson, et al., 2013), making way for larger vegetation classes, especially trees and other large shrubs (Sturm, Racine, & Tape, 2001). On the other hand, the picture should be quite different in islands, and in our case on Novaya Zemlya. The fact that trees are not yet present on the island means that shrublands and grasslands will have the opportunity to expand into areas sparsely vegetated without being replaced on their southern border by trees. But this is only true when looking at the 2070 predictions, as the migrating tree line would eventually reach the south island of Novaya Zemlya if the trend observed nowadays in the rise of temperature persists throughout this century.

When comparing figure 4 with figure 3, something else can be noticed: climate zones are moving northward a lot faster than the land cover types. Indeed, nowadays the forest biome is mainly found around the -6°C isotherm, while in 2070 they are rather found around the -3°C isotherm for the RCP 2.6 scenario, and even around the 0°C isotherm in the RCP 8.5 scenario! This is because ecosystems cannot follow the pace at which temperatures are rising, especially forest which take time to settle into one location (McKenney, Pedlar, Lawrence, Campbell, & Hutchinson, 2007). This means that temperatures are rising so fast that, when a forest starts growing in a location where temperatures have just become suitable for them to grow, by the time the forest is fully established temperatures are already higher than the ideal temperatures needed by the forest to be in good health. So while forests are expected to expand with the rising temperatures, the overall health of these forest could not follow the same trend, perhaps even causing a loss of productivity, although that will also depend on other regional factors such as precipitations (Gauthier, Bernier, Kuuluvainen, Shvidenko, & Schepaschenko, 2015).

All of this will have important consequences. First, as we have seen, trees will expand northward, into the tundra biome. As we know, trees are darker than the tundra. This means that their albedo is lower, so they retain more heat, which then creates a positive feedback, accelerating therefore the warming of the area. The same thing happens with the melting of land ice, under which we often find bare areas and dark rock formations, with a much lower albedo than the ice which used to sit above it. This phenomenon not only applies on land, but in the sea as well, where sea ice extent will keep decreasing as temperatures go up. Ice is a surface that is a lot more reflective than water, which retains a lot of the heat that is receives from the sun (albedo around 0.1, against an albedo of around 0.6 for sea ice). A temperature rise would also mean a lengthening of the snow-free season, again increasing the heat absorption of the land surface (Chapin, et al., 2005). Pearson et al (2013) have estimated that, because of these two factors, annual albedo could decrease by 2% to 18%, depending on the tree dispersal restriction. More vegetation also means more evapotranspiration, increasing the amount of water vapor in the atmosphere, which is a very strong green-house gas, giving us another positive feedback that would accelerate yet again the rise of temperatures in the Arctic (Swann, Fung, Levis, Bonan, & Doney, 2010). This particular factor is predicted to increase by 1% to 13%, again depending on tree dispersal restriction (Pearson, et al., 2013). Many positive feedbacks therefore emanate from the greening of the region, greatly reinforcing the amplitude of the rising temperatures.

Some negative feedbacks will also be triggered by the rise of temperatures. As we have already seen, the warming climate will allow more vegetation to grow in the Arctic, which is at the moment too cold to have an important presence of vegetation. Indeed, the Above Ground Biomass (AGB) is expected to rise by 15 to 68% in this region by the 2050s (Pearson, et al., 2013). As vegetation needs carbon to grow, more carbon would be sequestrated by plants. This phenomenon has for example been observed in Saskatchewan, Canada, where a boreal deciduous forest has been shown to capture a lot more carbon during the 1998 El Niño event than in normal years (Black, et al., 2000). El Niño events being typically characterized by warmer temperatures, this is a phenomenon that should become more and more important in the future with the rise of temperatures. This means it will cause an increase in carbon sequestration by the vegetation present in the Arctic region. Although it is tricky to precisely measure the amplitude of these countervailing forces, some recent studies showed that the increase of solar radiation should be higher than the increase in carbon storage, therefore resulting in a net increase in warming (ACIA, 2004). Another expected consequence of the warming will be the increase in the number, severity and duration of wildfires taking place in the region (Murphy, et al., 2000), which will again increase the amount of CO_2 rejected in the atmosphere.

The rise in temperatures will also have many consequences on fauna. With their environment warming up, species may have to migrate northward in order to follow the conditions most favorable to them, which can only be done to a certain extent. This phenomenon has already been observed in recent years for the Arctic fox (*Alopex lagopus*), of which numbers are steadily declining in many parts of the Arctic region, while at the same time being replaced by red foxes (*Vulpes vulpes*), which see their range expand in the north, consequence of the warming observed (Killengreen, et al., 2007). This is true for many other arctic species, which will face more and more competition from species arriving from the south, as climate conditions become less harsh. The need for species to migrate in order to follow their most favorable living conditions may even be more of an issue for mountainous areas, such as the Urals that is present in our region of interest. Species living in this region can only migrate upwards, which means they face a higher risk of extinction (La Sorte & Jetz, 2010). This is sometimes referred to as the escalator effect (Marris, 2007). The rise of temperature will also most likely cause a lengthening of the growing season, as it has already done over the last decade, with for some species a lengthening of up to 20 days of the growing season (Høye, Post, Meltofte, Schmidt, & Forchammer, 2007). This will also have consequences on fauna, as seen in Greenland, where the plant-growing season has advanced as a result of the rise of temperature, whereas the timing of caribou (*R. tarandus*) calving has not changed, resulting in a mismatch between the two species, with an offset between the time when the reproductive females need resources, and the moment at which said resources are the most available, causing therefore a lower survival rate among the calves (Post & Forchhammer, 2008). Consequences will be different for migratory species, such as birds, whose breeding ranges will be affected by temperature rises. The ability of these species to survive this change will depend on their capacity to expand their range. In general, species that will be the most affected are the ones that have a limited distribution and specific diets, for example relying on the presence of ice for reproduction, hunting, predator avoidance, etc… This is the case for species such as the ivory gull (*Pagophila* *eburnean*), Pacific walrus (*Odobenus rosmarus divergens*), several species of seals, narwhal (*Monodon monoceros*), and polar bear (*Ursus maritimus*) (Laidre, et al., 2008). The vegetation shift described previously will also have consequences on species that live within these ecosystems. As we said earlier, the tundra biome is expected to diminish, due to the gradual expansion of forests. The tundra is indeed projected to shrink to its lowest extent in the past 21'000 years. This will be a real threat to species living in these ecosystems, reducing their grazing or breeding areas. And although the total number of species in the Arctic should increase, warmer temperatures allowing the arrival of many species from the south, this shift of ecosystems is very likely to provoke a number of extinctions among the highly specialized species of the Arctic (ACIA, 2004). Despite all these negative impacts, we should keep in mind that this warming also has an upside to it, with some species benefiting from less extreme temperatures in winter, as it is the case for the Svalbard reindeer (*Rangifer tarandus platyrhynchus*), which has seen its fecundity and abundance increase with the progressive melting of ice (Tyler, Forchhammer, & Øritsland, 2008). And generally speaking, consequences of climate change on fauna in the Arctic region are therefore numerous, but they can sometimes be hard to predict and are not always unequivocal.

Beyond having a strong impact on species and the way they interact, the rise of temperatures in the Arctic will have important consequences on human population, both at the local and global scale. First of all, local communities rely heavily on hunting and fishing as their source of food, activities that can be particularly sensitive to climate change. For example, in Chukotka, Russia, walrus and seal hunting are highly dependent on spring weather, as well as on the presence of ice, first because it has an impacts on the presence of these animals, but also because it plays a role in the ability of the hunters to get to them (Searles, et al., 1999). The problem also exists on land: hunters often need to travel throughout the country in order to find preys, and their ability to travel depends on snow and ice conditions. In Barrow, Alaska, snow is melting earlier with every coming spring, meaning that in order to hunt geese, hunters have to go inland sooner. This is problematic because historically, goose hunting was taking place immediately after whale hunting, but now both activities are competing, taking place at the same period (Hinzman, et al., 2005). For many communities of the arctic region, hunting and fishing are a necessity to survive, meaning they now need to take more risks in order to be able to hunt, by forcing them for example to travel on thinner sea ice, making this activity more dangerous (Ashford & Castleden, 2001), with risks most likely to become even higher as temperatures keep rising. Climate change will also have an impact on the construction and infrastructure sector, and in fact it already has important consequences nowadays. Indeed, the rise of temperatures is causing a thawing of the permafrost, which has warmed by around 3°C since the end of the 1980s in the Alaskan Arctic Coastal Plain (Clow & Urban, 2002), results that are consistent with findings in other parts of the Arctic (Hinzman, et al., 2005). This thawing of permafrost makes the ground very unstable, destabilizing infrastructures already built and complicating the construction of new roads, buildings and pipelines. In Alaska, the runway to access the Prudhoe Bay oil fields had to be rebuilt after the melting of the permafrost. Still in Alaska, the period during which off-road driving is allowed, when the ground is stable and the snow layer is thick enough to protect vegetation, has been getting gradually shorter, this period lasting around 200 days in the 1970s and being now down to just about 100 days, which is a major problem for local industries, as well as for oil and gas exploration (Osterkamp, Esch, & Romanovsky, 1998). The thawing permafrost will also weaken some coastal areas, making them more vulnerable to erosion and flooding, especially coupled with the sea-level rise which is discussed more thoroughly later on. This could increase costs for disaster prevention and even force several communities to relocate (ACIA, 2004). Generally speaking, environmental conditions in the Artic are expected to become more and more unpredictable, making it very hard for local communities to anticipate these changes and adapt their behavior. Local hunters, but also policy makers are therefore facing more uncertainties than before, and it is certain that adaptation will be a key element to overcome changes that in some cases are inevitable. But just like in the case of environmental impacts, social impacts of climate change will not all be negative, with some positive impacts. To start with, the tourism sector is expected to grow as temperatures become less extreme, therefore extending the touristic season and increasing the attractiveness of some areas. Heating costs will decrease, which might at first seem like a minor advantage, but which is actually of significant interest. Indeed, at the moment local industries spend an important amount of money on heating their premises, increasing their production costs and therefore making their products less competitive on the global market. This will most likely change with the increase of temperatures (Hinzman, et al., 2005). Agriculture will also be able to expand northward and will beneficiate from the longer growing season and warmer temperatures, a great advantage for local communities. And as the temperatures increase, industrial fishing should become more productive, benefiting the economy of the region. The marine transportation will increase in the region, as the sea ice quickly disappears, also lengthening the navigation season. Access to natural resources, such as offshore gas and petrol reservoirs, will become easier. Another industry that will most certainly develop is the logging industry, because of the significant expansion of boreal forests that climate change is expected to trigger. This means the logging industry could be an important economic player in the region in the coming decades, as it already is the case in other arctic countries (Canada, Finland...) (ACIA, 2004).

Beyond the local impacts caused by the increase of arctic temperatures, there is also a number of consequences that will arise at the global level. To start with, the warming up of the Arctic will trigger a major positive feedback: the thawing of the permafrost. This permafrost, a layer of the soil that stays frozen all year round, contains an enormous quantity of organic carbon, which comes from the accumulation of dead plants and animals over the years in that completely frozen soil, therefore preventing it from decomposing. But the melting of this permafrost now allows microorganisms to decompose this organic carbon, which then releases huge quantities of carbon dioxide (CO_2) and methane (CH_4), two very powerful GHGs, into the atmosphere. While this release of GHGs by the thawing permafrost is expected to be gradual rather than abrupt, it will still contribute to the acceleration of climate change at the global scale over the next decades to centuries (Schuur, et al., 2015), adding therefore another positive feedback to the overall reduction in albedo of the region discussed earlier. The increase of temperatures in Arctic also has another worldwide consequence: the sea-level rise. The Arctic pole region is mainly covered by water, which means it contains significantly less ice than the Antarctic ice cap: if all the Antarctic ice melted, the sea-level would rise by approximatively 57m, whereas it would "only" rise by 7m if the Greenland ice sheet (the largest volume of ice in the Arctic by far) melted. (Board, O. S. & National Research Council, 2012). But the Greenland ice sheet and, in a more generalized way all the Arctic land ice, is more likely to undergo a rapid melting than the Antarctic ice sheet. Indeed, for the 2002-2009 period, the ice loss rates are 0.56 ± 0.13mm yr^{-1} for the Greenland ice sheet, against 0.37 ± 0.14mm yr^{-1} for the Antarctic ice sheet. And by 2100, the melting of the Greenland ice sheet could contribute to a sea-level rise of 20.1 ± 2.7cm, close to what the contribution of the melting Antarctic ice sheet (a lot harder to estimate) should be (24.0 ± 8.3cm) (Board, O. S. & National Research Council, 2012). This projected sea-level rise is a real threat to a great number of people around the world. For example, in China alone, it has been estimated that around 50 million of persons are living in areas that will be considered at risk by 2100, with current emissions trends continuing. Many other countries are vulnerable to sea-level rise and are also expected to be affected (Japan, Vietnam, Netherlands…) (Strauss & Kulp, 2014). The rise of temperatures in the Arctic is therefore expected to have important consequences, both at the local and global scale, making it a priority to study in the field of research.

Recommendations and critics of the study

This work was all about looking at how temperatures would change in the Barents Sea region in the future, according to different scenarios, and how this rise of temperature would impact first of all the land cover in the region, but also all the cascading impacts it would have on species living in these ecosystems, the human communities of the region and all others worldwide. This study could have been improved in several ways. To start off, I have used the global climate prediction model HadGEM2-AO in order to show the extent to which temperatures would rise in the future according to different scenarios. In order to have more solid results, it would have been a lot better to compare the predictions of different climate prediction models, and maybe combine them, which would have resulted in a stronger output. This could have been especially important in such a region of study, the Arctic being a region where many parameters are expected to come into play when looking at temperature rise, parameters such as the decrease of reflectivity, the increase in evapotranspiration or the thawing of the permafrost (all discussed above), just to name a few. Not all global climate models (GCMs) give the same importance to these different factors, giving a real importance to the comparison of different models. Even more relevant would have been the use of regional climate models (RCMs) instead of global ones, regional models giving more importance to parameters such as the ones mentioned previously, compared to GCMs. Working at a monthly timescale rather than at a yearly one could also have been a lot more instructive, especially in the Arctic where seasonal variations are so significant. To realize this work I also had to use average minimum temperatures instead of just using average temperatures, which would have been more significant but were sadly non-existent for the climate models. Another option would have been to use both minimum average temperatures and maximum average temperatures, available for the climate models. While it would probably have been a bit redundant in some ways, it would certainly have brought more information on the way temperatures will be modified in the future.

Considering the land cover data, a few questions could be raised on how I chose to use them. At first, my area of interest contained 12 different classes of land cover. I took the choice to reduce that number to 5 classes, especially by bringing together the different classes of forest, and also by combining different classes of low-lying vegetation into one. Although this choice has made the data easier to manipulate and the results easier to read, there is no doubt that an important amount of information is lost, such as how needleleaved forests are progressively replaced by broadleaved forests, or how shrublands gradually replace grasslands. In my work, I also chose not to take into account the direct impact of human activities on future land cover. Although it is true that currently the direct human impacts are close to null in the Barents Sea region, this could potentially change significantly in the future, especially with the rise of temperatures. It would indeed make the living conditions less harsh, allowing more people to settle. It could also allow the development of some industries in the region, for example mining/gas companies, and the impact of logging companies could increase, as we have seen earlier. This means it could have a significant impact on land cover in the region, which I did not take into consideration, mainly as it would be quite tricky to evaluate.

All these simplifications I made regarding the different land cover classes are also due to the program I used for the analysis, InVEST. This is probably the biggest critic I could make towards my work. Indeed, the InVEST software was not originally developed to study the change in land cover induced by climate change, but rather to evaluate ecosystem services. Although it does possess a tool to convert land cover types from one to another (Scenario Generator: Proximity Based), this tool is extremely simplified compared to the number of parameters that come into play in the real world (temperatures, precipitation, soil quality, microclimate zones…). In InVEST, the only inputs needed to run the Scenario Generator: Proximity Based tool are a land cover map, and which land cover type to convert into what, the surface to be converted and the method (nearest to edge or farthest from edge). This means that, when running the models for the different years and scenarios, I had to manually choose how much land I wanted to be converted from one type into another. Although this choice was not made randomly, but based on literature and other studies that were made in the region or elsewhere in the Arctic, a part of it is still based on my own interpretation and understanding of the dynamics at play in the region, meaning the results of this study probably lack some accuracy.

Conclusion

In this study, we have seen how important climate change is expected to be in the Arctic Circle, amplified by a number of positive feedbacks that will take place in the region (decrease of surface reflectivity, release of GHGs from thawing permafrost…), and resulting in a rise of temperatures significantly greater than what is expected at the worldwide scale. Two scenarios developed by the IPCC were analyzed throughout this work, the RCP 2.6 and the RCP 8.5, which are respectively the best-case and worst-case scenario. The results (+5°C and +7°C by 2070 for each scenario) are unequivocal. They show us that, no matter what we do to stem this spiral and lower our GHGs emissions, an important warming will still occur in the Arctic Circle. But it also shows us that the lack of meaningful actions to diminish our emissions will have a price. This price is roughly 2°C. An additional 2°C of warming that the Artic region will undergo if nothing changes. This 2°C has for a long time now been the threshold that the international community had chosen as the value not to be exceeded in order to avoid drastic changes taking place in the environment we are familiar with. Even though this threshold will surely be exceeded in the Arctic, as it will also probably be the case elsewhere in the world, this does not mean an additional +2°C of warming is of no consequences. As I tried to show it in this work, this extra warming will cause a further disruption of the different ecosystems of the region, with a northward migration of the tree line, which will gradually expand into the low-lying vegetation classes such as shrublands and grassland, where extinctions rates will most likely experience an important rise. Land ice and snow will slowly melt, turning into bare areas, and contributing to the sea-level rise, one of the most problematic issues of the century for coastal populations around the world. Animal species will be disturbed by their changing environment, and will face more and more competition from other species arriving from the south, better adapted to live in a warmer climate. Local communities that rely on fishing and hunting for their survival will be challenged, as the seasonal movements of seals, caribou, reindeers and fish will become more and more unpredictable. Cities will have to deal with the issue of thawing permafrost, disrupting land transportation, increasing the cost of road and pipelines maintenance, threatening the stability of buildings and complicating the development of new infrastructure. But the expected consequences of the warming are not all negative. Warmer temperatures will make the region more attractive for tourism. It will also make the region more suitable for agriculture, industries will save important amounts of money on heating costs, and specific industries such as fishing and logging should become more productive. With the rise of temperatures, marine transportation in the region will also increase, and with it bringing a substantial amount of revenues, allowing the region to further develop. The future is therefore not entirely gloomy for the Barents Sea region, which will for sure undergo a lot of changes in the coming decades. But while many uncertainties surround these changes and their amplitudes, one thing is certain: the more the temperature increases, the more the negative consequences will outweigh the positive ones, therefore calling for some strong decision-making and the urgent implementation of actions to protect the Barents Sea region, as well as the rest of the Arctic.

References

ACIA. (2004). *Impacts of a Warming Arctic: Arctic Climate IMpact Assessment.* Cambridge University Press.

Ashford, G., & Castleden, J. (2001). *Inuit observations on climate change.* International Institute for Sustainable Development.

Board, O. S. & National Research Council. (2012). *Sea-level rise for the coasts of California, Oregon, and Washington: past, present and future.* National Academies Press.

Climate Central. (2016, 04 20). *Flirting with the 1.5°C Threshold*. Récupéré sur Climate Central: http://www.climatecentral.org/news/world-flirts-with-1.5C-threshold-20260

Clow, G. D., & Urban, F. E. (2002). Large permafrost warming in northern Alaska during the 1990's determined from GTN-P borehole temperature measurements. *AGU Fall Meeting Abstracts*.

Earth Observatory. (2009, 07 30). *Novaya Zemlya*. Récupéré sur Earth Observatory: https://earthobservatory.nasa.gov/IOTD/view.php?id=39591

ESA. (2017, 10 15). *GlobCover*. Récupéré sur ESA: http://due.esrin.esa.int/page_globcover.php

Gauthier, S., Bernier, P., Kuuluvainen, T., Shvidenko, A. Z., & Schepaschenko, D. G. (2015). Boreal forest health and global change. *Science*, pp. 819-822.

Global Climate Data. (2017, 10 15). *WorldClim*. Récupéré sur http://www.worldclim.org/

Groisman, P. Y., & Gutman, G. (2012). *Regional environmental changes in Siberia and their global consequences.* Springer Science & Business Media.

Hinzman, L. D., Bettez, N. D., Bolton, W. R., Chapin, F. S., Dyurgerov, M. B., Fastie, C. L., & Jensen, A. M. (2005). Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change*, pp. 251-298.

Houghton, J. T., Callander, B. A., & Varney, S. K. (1992). *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment.* Cambridge University Press .

Høye, T. T., Post, E., Meltofte, H., Schmidt, N. M., & Forchammer, M. C. (2007). Rapid advancement of spring in the High Arctic. *Current Biology*, pp. R449-R451.

IPCC. (2001). *Climate Change 2000 - Third Assesment Report.* Cambridge University Press.

IPCC. (2014). *Climate Change 2014: Synthesis Report.* Geneva, Switzerland: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].

Keup-Thiel, E., Göttel, H., & Jacob, D. (2006). Regional climate simulations for the Barents Sea region. *Boreal environment research*, pp. 329-339.

Killengreen, S. T., Ims, R. A., Yoccoz, N. G., Brathen, K. A., Henden, J. A., & Schott, T. (2007). Structural characteristics of a low Arctic tundra ecosystem and the retreat of the Arctic fox. *Biological Conservation*, pp. 459-472.

La Sorte, F. A., & Jetz, W. (2010). Projected range contractions of montane biodiversity under global warming. *Proceedings of the Royal Society of London B: Biological Sciences*.

Laidre, K. L., Stirling, I., Lowry, L. F., Wiig, Ø., Heide-Jorgensen, M. P., & Ferguson, S. H. (2008). Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications*.

Marris, E. (2007). The escalator effect. *Nature Reports Climate Change*, pp. 94-96.

McKenney, D. W., Pedlar, J. H., Lawrence, K., Campbell, K., & Hutchinson, M. F. (2007). Potential impacts of climate change on the distribution of North American trees. *AIBS Bulletin*, 939-948.

Met Office. (2016, 04 15). *Met Office climate prediction model: HadGEM2 family*. Récupéré sur Met Office: https://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2

Murphy, P. J., Mudd, J. P., Stocks, B. J., Kasischke, E. S., Barry, D., Alexander, M. E., & French, N. H. (2000). Historical fire records in the North American boreal forest. *Fire, climate change, and carbon cycling in the boreal forest*, pp. 274-288.

NASA. (2011, 10 26). *What Are Climate and Climate Change ?* Récupéré sur NASA: https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-climate-change-58.html

Natural Capital Project. (2018, 01 7). Récupéré sur Natural Capital Project: https://www.naturalcapitalproject.org

Osterkamp, T. E., Esch, D. C., & Romanovsky, V. E. (1998). Chapter 10: Permafrost. implications of global change in Alaska and the Bering Sea region. Dans G. Weller, & Anderson P., *Proceedings of a Workshop at the University of Alaska Fairbanks, 3–6 June 1997* (pp. 115-127). University of Alaska Fairbanks: Center for Global Change and Arctic System Research.

Pearson, R. G., Phillips, S. J., Loranty, M. M., Beck, P. S., Damoulas, T., Knight, S. J., & Goetz, S. J. (2013). Shifts in Arctic vegetation and associated feedbakcs under climate change. *Nature Climate Change*, pp. 673-677.

Post, E., & Forchhammer, M. C. (2008). Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. . *Philosophical Transactions of the Royal Society of London: Biological Sciences*, 2367-2373.

Schuur, E. A., McGuire, A. D., Schädel, C., Grosse, G., Harden, J. W., Hayes, D. J., & Natali, S. M. (2015). Climate change and the permafrost carbon feedback. *Nature*, pp. 171-179.

Searles, E., Freeman, M. M., Bogoslovskaya, L., Caulfield, R. A., Egede, I. K., & Stevenson, M. G. (1999). *Init, Whaling and Sustainability.*

Strauss, B., & Kulp, S. (2014, 09 25). *20 Countries Most At Risk From Sea Level Rise*. Récupéré sur weather.com: https://weather.com/science/environment/news/20-countries-most-risk-sea-level-rise-20140924#/!

Sturm, M., Racine, C., & Tape, K. (2001). Climate change: increasing shrub abundance in the Arctic. *Nature*, pp. 546-547.

Tyler, N. J., Forchhammer, M. C., & Øritsland, N. A. (2008). Nonlinear effects of climate and density in the dynamics of a fluctuating population of reindeer. *Ecology*, pp. 1675-1686.

Vavrus, S. (2004). The impact of clouds feedbacks on Arctic climate under greenhouse forcing. *Journal of Climate*, 603-615.

Wolf, A., Callaghan, T. V., & Larson, K. (2008). Future changes in vegetation and ecosystem function of the Barents Region. *Climatic Change*, pp. 51-73.

Yastrebov, Y. V., & Poulsen, T. M. (2016, 02 23). *Ural Mountains*. Récupéré sur Encyclopedia Britannica: https://www.britannica.com/place/Ural-Mountains

Annexes

Python scripts for land cover change in InVEST

RCP 2.6, 2050

```
""""
This is a saved model run from natcap.invest.scenario_gen_proximity.
Generated: 12/27/17 12:52:40
InVEST version: 3.3.3
"""

import natcap.invest.scenario_gen_proximity
import copy


args = {
        u'aoi_path': u'',
        u'area_to_convert': u'3300000',
        u'base_lulc_path': u'D:/C.H/Memoire/N_Russia2/lulc_merc.tif',
        u'convert_farthest_from_edge': False,
        u'convert_nearest_to_edge': True,
        u'convertible_landcover_codes': u'220',
        u'focal_landcover_codes': u'220',
        u'n_fragmentation_steps': u'1',
        u'replacment_lucode': u'150',
        u'results_suffix': '1',
        u'workspace_dir': u'D:\\C.H\\Memoire\\2050hd26',
}

if __name__ == '__main__':
    natcap.invest.scenario_gen_proximity.execute(args)

    args_list = []

    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path'] =
u'D:\\C.H\\Memoire\\2050hd26\\nearest_to_edge_1.tif'
    args_copy[u'area_to_convert'] = u'100000000'
    args_copy[u'convertible_landcover_codes'] = u'150 200'
    args_copy[u'focal_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'replacment_lucode'] = u'110'
    args_copy[u'results_suffix'] = '2'


    args_list.append(args_copy)


    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path'] =
u'D:\\C.H\\Memoire\\2050hd26\\nearest_to_edge_2.tif'
    args_copy[u'area_to_convert'] = u'130000000'
    args_copy[u'convertible_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'focal_landcover_codes'] = u'50 90 100'
    args_copy[u'replacment_lucode'] = u'50'
    args_copy[u'results_suffix'] = '3'
```

```
    args_list.append(args_copy)


    for args in args_list:
        natcap.invest.scenario_gen_proximity.execute(args)
```

RCP 2.6, 2070

```
""""
This is a saved model run from natcap.invest.scenario_gen_proximity.
Generated: 12/27/17 12:52:40
InVEST version: 3.3.3
"""

import natcap.invest.scenario_gen_proximity
import copy


args = {
        u'aoi_path': u'',
        u'area_to_convert': u'50000000',
        u'base_lulc_path': u'D:/C.H/Memoire/N_Russia2/lulc_merc.tif',
        u'convert_farthest_from_edge': False,
        u'convert_nearest_to_edge': True,
        u'convertible_landcover_codes': u'220',
        u'focal_landcover_codes': u'220',
        u'n_fragmentation_steps': u'1',
        u'replacment_lucode': u'150',
        u'results_suffix': '1',
        u'workspace_dir': u'D:\\C.H\\Memoire\\2070hd26',
}

if __name__ == '__main__':
    natcap.invest.scenario_gen_proximity.execute(args)

    args_list = []

    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path'] =
u'D:\\C.H\\Memoire\\2070hd26\\nearest_to_edge_1.tif'
    args_copy[u'area_to_convert'] = u'160000000'
    args_copy[u'convertible_landcover_codes'] = u'150 200'
    args_copy[u'focal_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'replacment_lucode'] = u'110'
    args_copy[u'results_suffix'] = '2'


    args_list.append(args_copy)


    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path'] =
u'D:\\C.H\\Memoire\\2070hd26\\nearest_to_edge_2.tif'
    args_copy[u'area_to_convert'] = u'190000000'
    args_copy[u'convertible_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'focal_landcover_codes'] = u'50 90 100'
```

```
    args_copy[u'replacment_lucode'] = u'50'
    args_copy[u'results_suffix'] = '3'


    args_list.append(args_copy)



    for args in args_list:
        natcap.invest.scenario_gen_proximity.execute(args)
```

RCP 8.5, 2050

```
""""
This is a saved model run from natcap.invest.scenario_gen_proximity.
Generated: 12/27/17 12:52:40
InVEST version: 3.3.3
"""

import natcap.invest.scenario_gen_proximity
import copy


args = {
        u'aoi_path': u'',
        u'area_to_convert': u'45000000',
        u'base_lulc_path': u'D:/C.H/Memoire/N_Russia2/lulc_merc.tif',
        u'convert_farthest_from_edge': False,
        u'convert_nearest_to_edge': True,
        u'convertible_landcover_codes': u'220',
        u'focal_landcover_codes': u'220',
        u'n_fragmentation_steps': u'1',
        u'replacment_lucode': u'150',
        u'results_suffix': '1',
        u'workspace_dir': u'D:\\C.H\\Memoire\\2050hd85',
}

if __name__ == '__main__':
    natcap.invest.scenario_gen_proximity.execute(args)

    args_list = []

    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path']                                            =
u'D:\\C.H\\Memoire\\2050hd85\\nearest_to_edge_1.tif'
    args_copy[u'area_to_convert'] = u'140000000'
    args_copy[u'convertible_landcover_codes'] = u'150 200'
    args_copy[u'focal_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'replacment_lucode'] = u'110'
    args_copy[u'results_suffix'] = '2'


    args_list.append(args_copy)


    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path']                                            =
u'D:\\C.H\\Memoire\\2050hd85\\nearest_to_edge_2.tif'
```

```
    args_copy[u'area_to_convert'] = u'165000000'
    args_copy[u'convertible_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'focal_landcover_codes'] = u'50 90 100'
    args_copy[u'replacment_lucode'] = u'50'
    args_copy[u'results_suffix'] = '3'


    args_list.append(args_copy)



    for args in args_list:
        natcap.invest.scenario_gen_proximity.execute(args)
```

RCP 8.5, 2070

```
""""
This is a saved model run from natcap.invest.scenario_gen_proximity.
Generated: 12/27/17 12:52:40
InVEST version: 3.3.3
"""

import natcap.invest.scenario_gen_proximity
import copy


args = {
        u'aoi_path': u'',
        u'area_to_convert': u'65000000',
        u'base_lulc_path': u'D:/C.H/Memoire/N_Russia2/lulc_merc.tif',
        u'convert_farthest_from_edge': False,
        u'convert_nearest_to_edge': True,
        u'convertible_landcover_codes': u'220',
        u'focal_landcover_codes': u'220',
        u'n_fragmentation_steps': u'1',
        u'replacment_lucode': u'150',
        u'results_suffix': '1',
        u'workspace_dir': u'D:\\C.H\\Memoire\\2070hd85',
}

if __name__ == '__main__':
    natcap.invest.scenario_gen_proximity.execute(args)

    args_list = []

    args_copy = copy.copy(args)

    args_copy[u'base_lulc_path']                                          =
u'D:\\C.H\\Memoire\\2070hd85\\nearest_to_edge_1.tif'
    args_copy[u'area_to_convert'] = u'220000000'
    args_copy[u'convertible_landcover_codes'] = u'150 200'
    args_copy[u'focal_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'replacment_lucode'] = u'110'
    args_copy[u'results_suffix'] = '2'


    args_list.append(args_copy)


    args_copy = copy.copy(args)
```

```
    args_copy[u'base_lulc_path']                                                              =
u'D:\\C.H\\Memoire\\2070hd85\\nearest_to_edge_2.tif'
    args_copy[u'area_to_convert'] = u'260000000'
    args_copy[u'convertible_landcover_codes'] = u'110 120 130 140 180'
    args_copy[u'focal_landcover_codes'] = u'50 90 100'
    args_copy[u'replacment_lucode'] = u'50'
    args_copy[u'results_suffix'] = '3'


    args_list.append(args_copy)



    for args in args_list:
        natcap.invest.scenario_gen_proximity.execute(args)
```