Assignment 5:
Environmental niche modelling

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Part 1

Exercise 1

a) The map showed here represents each continent and the information given by the layer considered. The command `colorbar` adds a bar beside the map with the range of the matrix element magnitude (temperature or mm in this case), `axis xy` draws the plot using the standard Cartesian axes, while `axis image` sets the aspect ratio so that the data units are the same in every direction and makes the plot box fitting the data.

b) The plot of mask is shown in Figure 1.

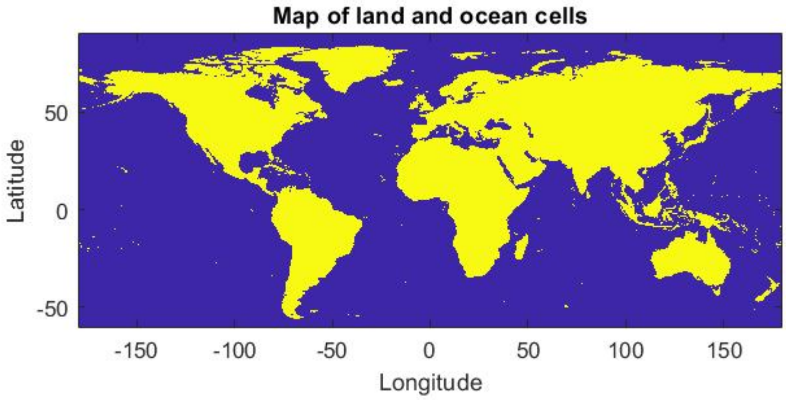

Figure 1: *Plot of matrix mask.*

The plot of pixX is shown in Figure 2.

The plot of pixY is shown in Figure 3.

From Figure 2 it can be noticed that the values of `pixX` decreases as the latitude increases. In fact, the distance between 2 meridians (pixX) decreases as we approach the poles. On the other hand, the distance between 2 parallels (pixY) is constant throughout the entire surface of the Earth.

c) The percentage of land area could be approximately calculated using the as the mean of the matrix `mask`: `land = mean(mean(mask));`. In this way, the value we obtain is

$$Land_{perc} = 30.07\%$$

However, this calculation does not take into account the spherical shape of Earth: the real size of the land corresponding to a pixel near the pole is smaller than the one at the level of the Equator. A more accurate calculation then takes into account the real size of each pixel:

```
LandPercent = mean(mean(pixX.*pixY.*mask))/mean(mean(pixX.*pixY));
```

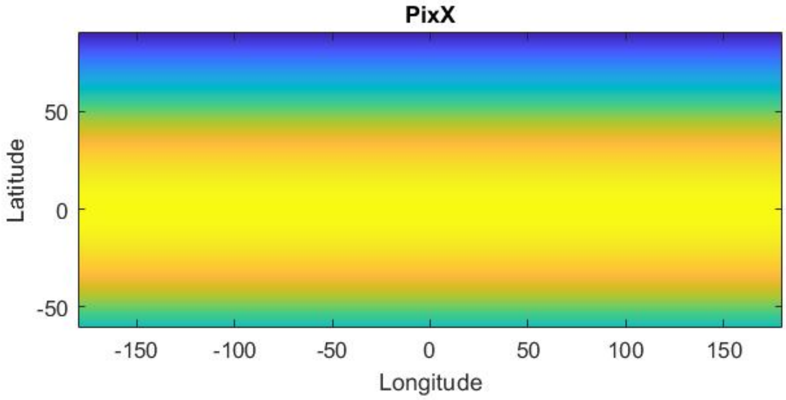

Figure 2: *Plot of matrix pixX.*

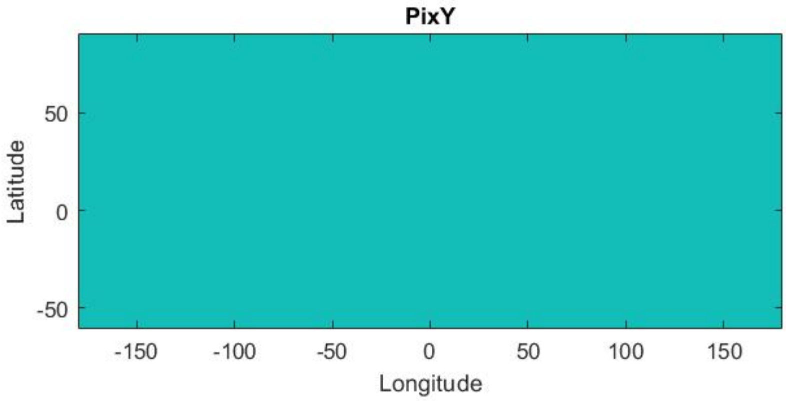

Figure 3: *Plot of matrix pixY.*

In this way the share of land is

$$Land_{perc} = 29.67\%$$

Exercise 2

In a logistic function (Figure 4) the sign of the parameter α determines whether the function increases as the variable increases (negative α) or if it decreases (positive α). On the other hand, the magnitude of α changes the steepness of the function: the bigger α, the more rapid is the transition from 0 to 1 (or vice-versa). The parameter β determines the center of symmetry of the function.

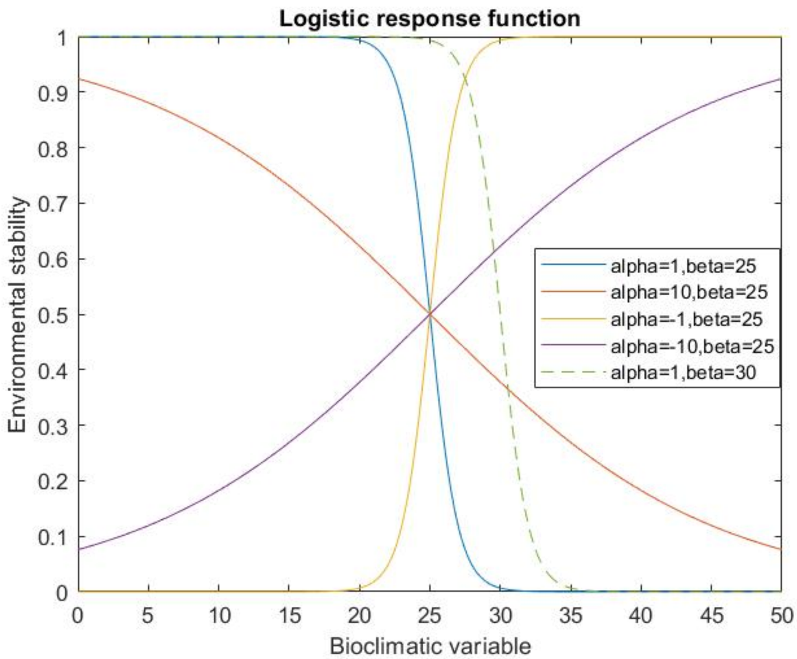

Figure 4: *Logistic function for different values of α and β.*

In a Gaussian function (Figure 5) , the parameter σ is related to the wideness of the distribution: smaller σ implies a sharper distribution. The parameter μ determines the position of the peak of the distribution.

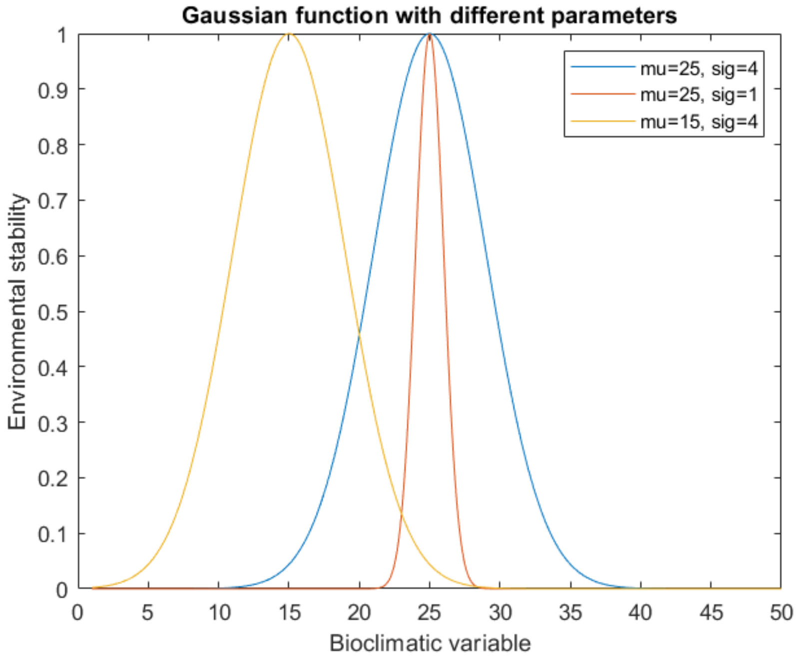

Figure 5: *Gaussian function for different values of μ and σ.*

Exercise 3

In Figure 6, 7, 8 the suitability maps for each of the 3 species analyzed are reported.

For Species 1, a Gaussian with $\mu = 20°C$ and $\sigma = 5°C$ applied on the Annual mean temperature map. The code used to obtain this map is:

```
   suit=gauss(BIO(:,:,1),mu,sigma);
imagesc(x,y,suit);
axis xy
colorbar
axis image
xlabel('Latitude');
ylabel('Longitude');
title('Suitability map for species 1');
```

Species 2 and 3 have the same code, except for using a Logistic function instead of the Gaussian and different values for α and β.

For Species 2, a Logistic function with $\alpha = -10°C$ and $\beta = 0°C$ is applied to the Minimum temperature of the coldest month map.

For Species 3, a Logistic function with $\alpha = -10\ mm$ and $\beta = 50\ mm$ is applied to the Precipitation of driest month map.

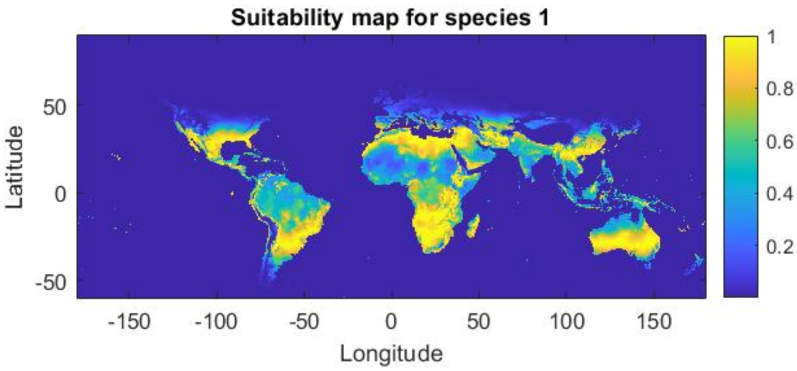

Figure 6: *Suitability map for Species 1 based on the Annual mean temperature map. A Gaussian function with $\mu = 20°C$ and $\sigma = 5°C$ is used.*

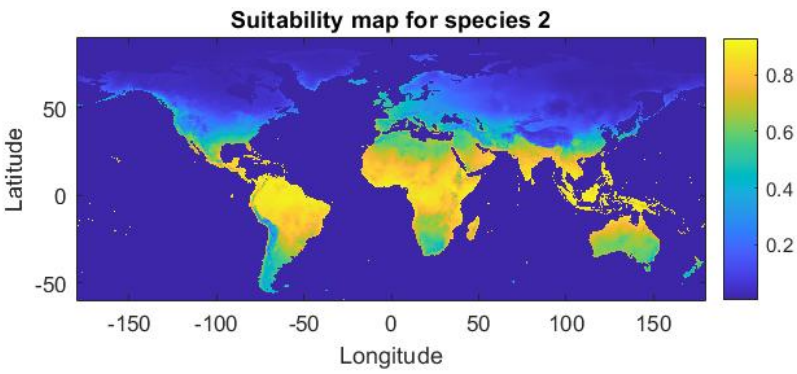

Figure 7: *Suitability map for Species 2 based on the Minimum temperature of the coldest month. A Logistic function with $\alpha = -10°C$ and $\beta = 0°C$ is used.*

Exercise 4

a) Function `rescale` makes the following passages for each value in the matrix:

- Subtracts the minimum absolute value of the matrix, so that now each number is

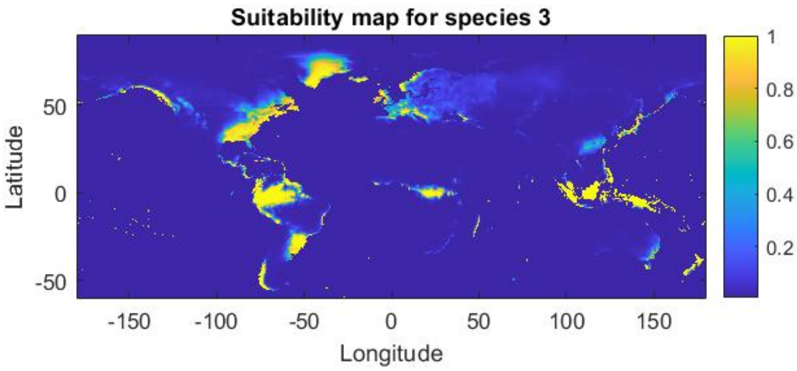

Figure 8: *Suitability map for Species 3 based on the Precipitation of driest month map. A Logistic function with* $\alpha = -10$ *mm and* $\beta = 50$ *mm is used.*

greater or equal to 0

- Divides the matrix by the new maximum value. In this way, each element of the matrix is now between 0 and 1
- Multiplies for the difference between the upper bound and the lower bound of the desired scale (in a probability 0 and 1, but the range could be arbitrary)
- In order to make the scale starting from the lower desired lower bound, `mmin` is summed to the matrix

Hence, mathematically speaking, is equivalent to do the following: given a matrix y, its minimum value (min_y) and maximum value (MAX_y) and given the upper and lower bounds of the decided scale (UB_{scale} and LB_{scale}), the rescaled matrix is

$$rescale(y) = (\frac{y - min_y}{MAX_y - min_y}) * (UB_{scale} - LB_{scale}) + LB_{scale} \tag{1}$$

b) A new species needs an annual temperature of 10 °C and an annual rainfall of 600 mm. Therefore, a Gaussian function is used with $\mu = 10°C$, $\sigma = 5$ and $\mu = 600\ mm$, $\sigma = 100\ mm$ respectively. The suitability map of this species is represented in Figure 9. The code used to obtain the map is the following:

Exercise 5

a) To obtain the probability map for Species 4, the following code has been used:

```
sig1 = 5;
sig2 = 100;
```

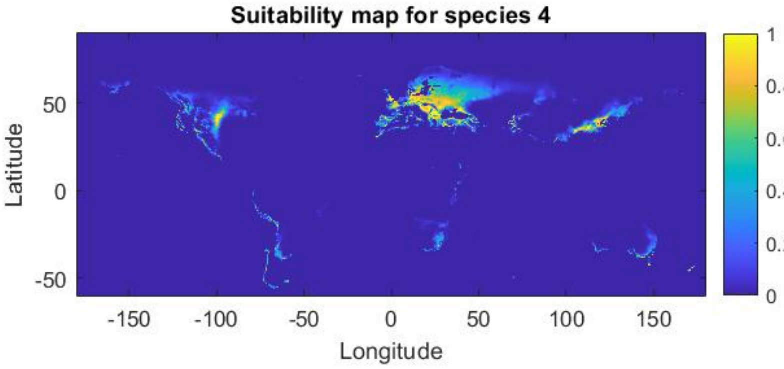

Figure 9: *Suitability map for Species 4 based on the Annual mean temperature and Annual precipitation map. A Gaussian function with* $\mu = 10°C$, $\sigma = 5°C$ *and* $\mu = 600mm$, $\sigma = 100\ mm$ *is used.*

```
mu1 = 10;
mu2 = 600;
mmin1 = 0;
mmax1 = 0.5;
mmin2 = 0.2;
mmax2 = 0.5;

suit4_1=gauss(BIO(:,:,1),mu1,sig1);
suit4_2=gauss(BIO(:,:,12),mu2,sig2);
rescale1=rescale(suit4_1,mmin1,mmax1);
rescale2=rescale(suit4_2,mmin2,mmax2);
```

With different plot titles for each one.
The first plot has mmin=0 and mmax=0.5 and is shown in Figure 10.

The second plot has mmin=0.2 and mmax=0.5 and is shown in Figure 11.

b) Now a matrix with the same dimension of the previous ones and containing random values is created and compared element by element with the two matrices of the previous point (a)). The objective is to create a presence/absence map in which is showed the probability that the species is present.
If the element in the matrices is higher than the correspondent element of the random matrix, then this means that the species is present in that cell.
The following code has been used:

```
sig1 = 5;
sig2 = 100;
```

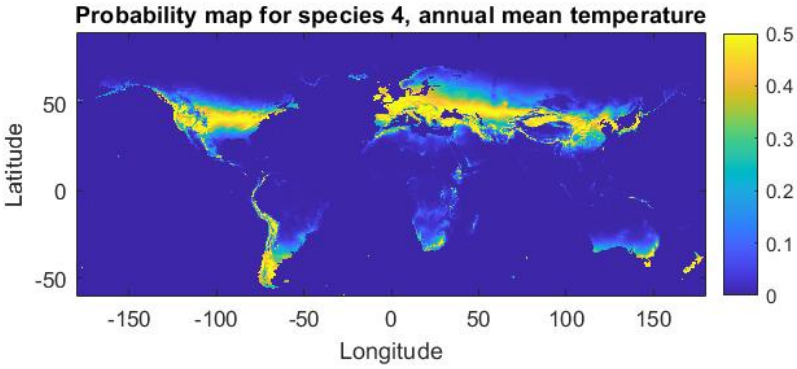

Figure 10: *Probability map for Species 4 based on the annual mean temperature. A Gaussian function with* $\mu = 20°C$, $\sigma = 10°C$ *is used.*

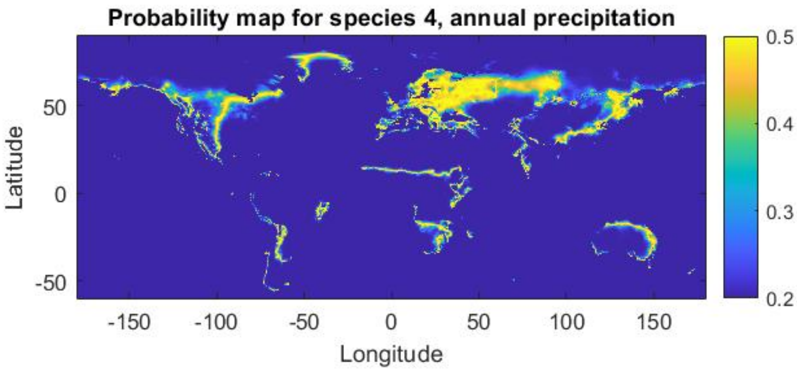

Figure 11: *Probability map for Species 4 based on the annual mean temperature. A Gaussian function with* $\mu = 600$ *mm*, $\sigma = 100$ *mm is used.*

```
mu1 = 10;
mu2 = 600;
mmin1 = 0;
mmax1 = 0.5;
```

```
mmin2 = 0.2;
mmax2 = 0.5;

suit4_1=gauss(BIO(:,:,1),mu1,sig1);
suit4_2=gauss(BIO(:,:,12),mu2,sig2);
rescale1=rescale(suit4_1,mmin1,mmax1);
rescale2=rescale(suit4_2,mmin2,mmax2);

random=rand(900,2160);
presence1=rescale1>random;
presence2=rescale2>random;
```

The two obtained presence maps are showed in Figure 12 and Figure 13.

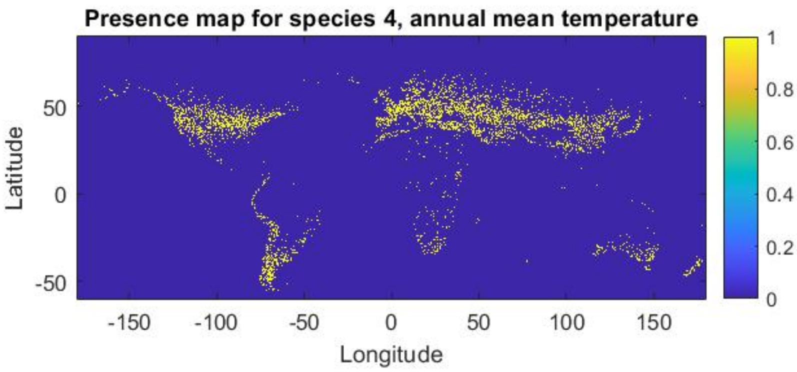

Figure 12: *Presence map for Species 4 based the annual mean temperature. A Gaussian function with $\mu = 20°C$, $\sigma = 10°C$ is used and compared with random matrix.*

Looking at the Presence map in Figure 12, it is possible to notice that the highest presence is registered in at the latitudes of the Tropics. This distribution reflects the probability distribution shown in Figure 10. Therefore, the effect of other factors only influences the presence density. On the other hand, from Figure 13 is immediately noticeable that the annual rainfall does not really influence the presence distribution for Species 4. Differently from the Presence map related to the annual mean temperature, this one shows that Species 4 can be present virtually worldwide, with a higher density in some parts of Eurasia.

Mathematically, this is explained because we set a lower bound of 0 for the first presence map, while we set it to 0.2 for the second one. Setting the lower bound to 0.2 means that, with a frequency of 1/5, the species 4 will be found everywhere regardless of the annual precipitations. Conversely, setting it to 0 makes some places to be absolutely not suitable for the presence of Species 4.

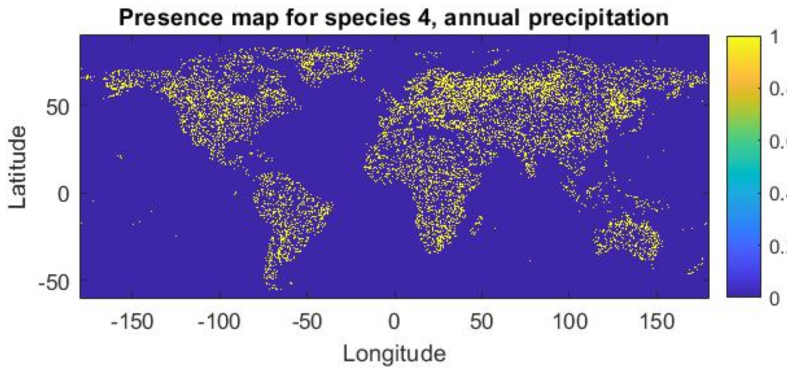

Figure 13: *Presence map for Species 4 based the annual mean temperature. A Gaussian function with $\mu = 600$ mm, $\sigma = 100$ mm is used and compared with random matrix.*

c) The two maps are based on different ambient conditions (the first one with Annual temperature of 10 C and σ=5, the second one with Annual rainfall of 600 mm and σ= 100) so the fact that they look very different from each other makes perfectly sense. However, the probability that the matrix composed by random values may respect a correct distribution is low. Because of this it could be likely that the presence maps correspond to the actual species distribution, but with a low probability.

Moreover, each of these presence map takes into account only one environmental factor. Since the suitable environmental conditions for the presence of a species involve more than one environmental parameter, these maps are unlikely to represent the actual distribution of the species. In addition, in these maps the factor of time is completely overlooked. The presence of a species in a territory is a dynamic process. The timescale has a deep influence on the actual species distribution, since the environmental conditions vary over time and migration processes are not instantaneous.

Exercise 6

Comparing the suitability map of Figure 9 and the map based on the IPCC projection for 2050, pathway rcp45 (Figure 14) it is possible to notice that the suitability of species 4 slightly increases in the North America and in the Northern East parts of Russia. In addition, the suitability of this species in Central Eurasia and part of Southern East Asia is greater.

Overall, the suitable area of this species undergoes a moderate shift upwards.

In order to explain these changes, looking at the differences in annual mean temperature and annual rainfall between this IPCC projection for 2050 and the average data from 1950 to 2000 may be insightful (Figure 16.

The annual mean temperature significantly increases at the latitude of the Artic Circle, making those places more suitable for species 4. A small increment in the temperature

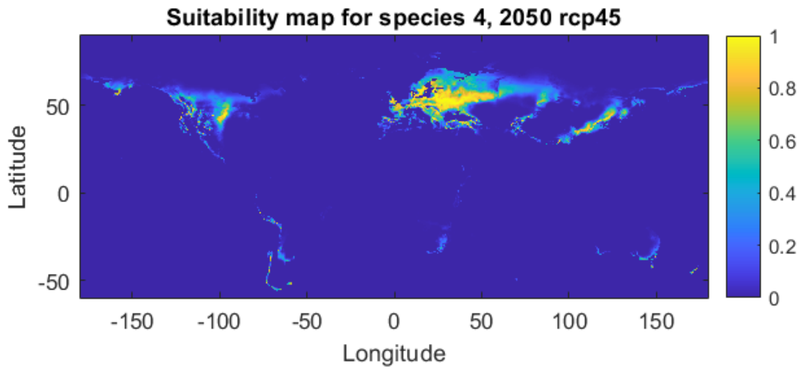

Figure 14: *Suitability map for Species 4 based on the projection of annual mean temperature and precipitation for the year 2050 with the scenario rcp45. A Gaussian function with* $\mu = 10°C$, $\sigma = 5°C$ *and* $\mu = 600mm$, $\sigma = 100$ *mm is used.*

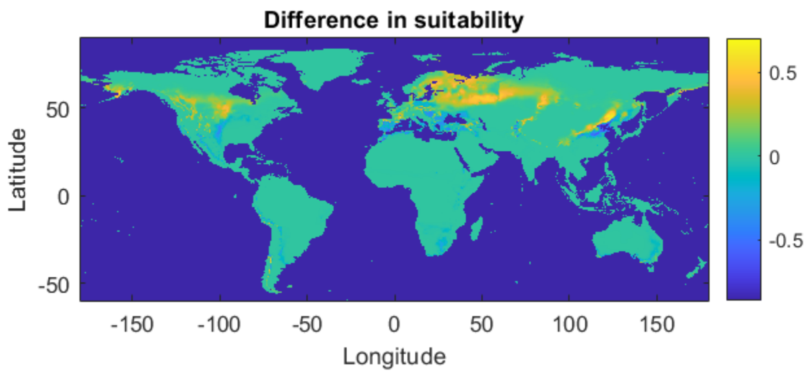

Figure 15: *Difference in suitability for species 4 compared with the IPCC projection fro 2050, pathway rcp45*

is present also in the Central Eurasia area, which explains the relative increase of the suitability.

Changing in the annual rainfall appear to have a negligible influence on the suitability map of species 4.

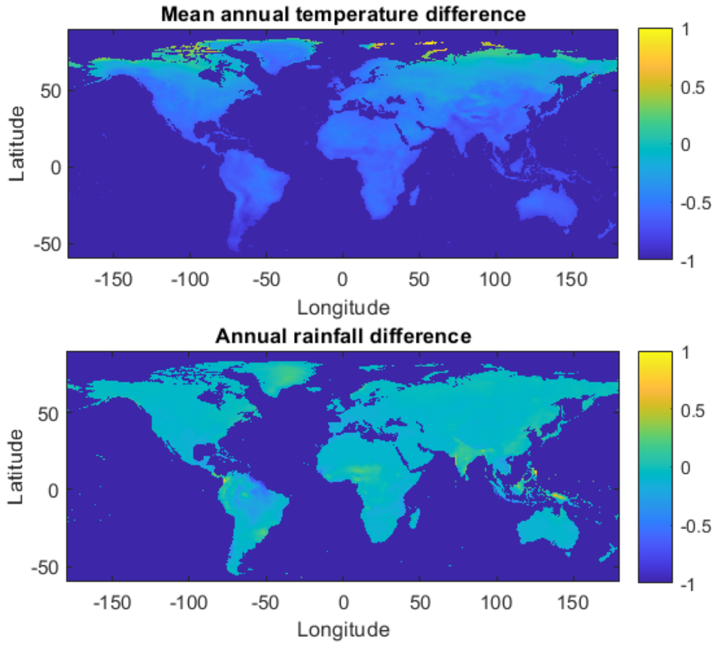

Figure 16: *Difference in mean annual temperature and precipitation for Species 4 between the suitability map in year 2050 with the scenario rcp45 and the one in Exercise 4. A Gaussian function with* $\mu = 10°C$, $\sigma = 5°C$ *and* $\mu = 600mm$, $\sigma = 100\ mm$ *is used.*

Exercise 8

a) In the self-organizing systems assignment, the model used are based on dynamical equations (either theoretical or empirical) which produce a certain output in a deterministic way.

Conversely, environmental niche models are based on a statistical analysis of the relevant data of the problem. Therefore, predictions are extrapolated fitting environmental variables with the distribution of a species.

The units of the each gradient component are

$$g_y = \frac{°C}{pixY\ km} = \frac{°C}{18.52\ km}$$

$$g_x = \frac{°C}{pixX\ km}$$

In order to convert them into $\frac{°C}{km}$ is therefore sufficient to divide element-wise g_y and g_x by $pixY$ and $pixX$.

In Figure 17 the temperature gradient per km is reported. It is possible to notice that the highest temperature gradient is found in mountainous regions. In correspondence of the Himalaya mountains, Andes and Caucasus it is possible to find the greatest temperature gradient. On the other hand, flat areas present no temperature change over space.

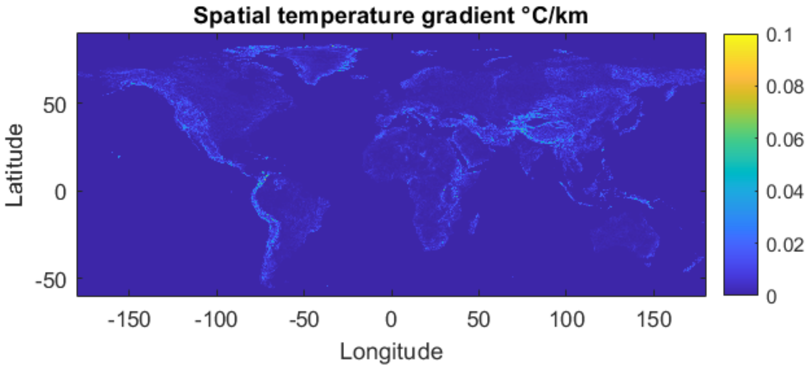

Figure 17: *Spatial temperature gradient (°C/km) across the globe*

b) Figure 18 shows the temperature gradient over time. As it possible to notice, the northern hemisphere will experience the highest temperature change over the next decades. In particular, at the latitude of the Artic Circle the temperature increase will be more than $1°C$ per decade.

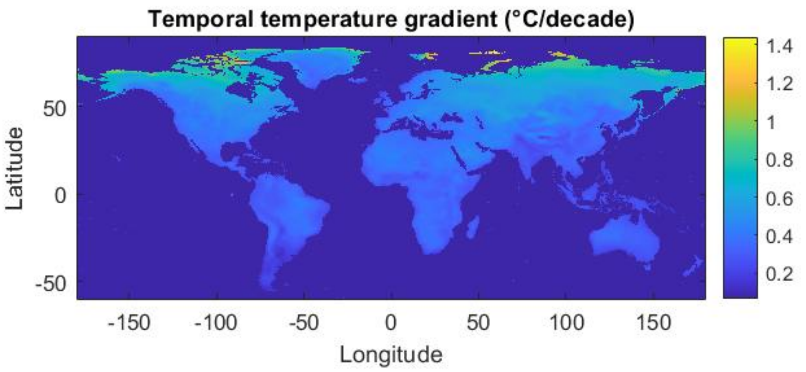

Figure 18: *Temporal temperature gradient (°C/decade) across the globe*

Figure 18 has been found using the following code:

```
map_new=BIO(:,:,1);

map1=imread('he45bi501.tif');
map1=double(map1);
map1(mask==0)=NaN;
map1=map1/10;

Diff = (map1 - map_new)/7.5;
```

c) Figure 19 the velocity at which the suitability of each place for species 4 is moving.

From Figure 18 it can be seen that the velocity is in most of the places around 20 km/decade or even more.

From Figure 5.3 of the assignment, it can be seen that trees and herbaceous have a median velocity around 2 km/decade, thus they will not be able to move at this velocity; the same is for most of rodents and primates. Differently, other mammals (i.e. carnivorous mammals and split-hoofed mammals) and plant-feeding insects have a higher median velocity (higher than 60 km/decade) thus in most of the map they won't have problems with moving at this velocity.
However, there are some spots where the velocity is around 80 km/decade, and there only split-hoofed mammals could move sufficiently fast.

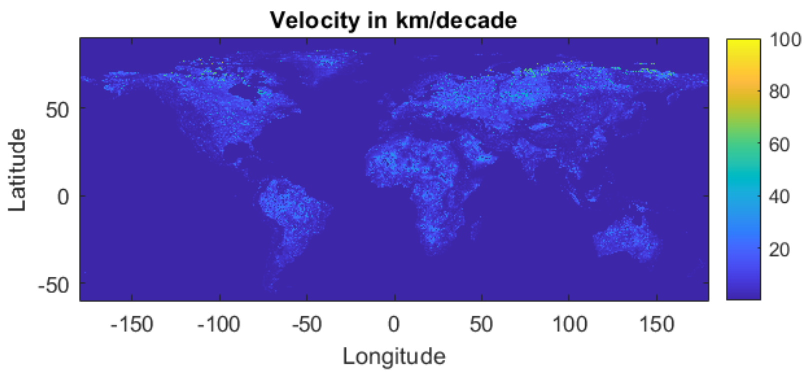

Figure 19: *Velocity map in km/decade across the globe*

The areas where even split-hoofed mammals can not reach the speed is presented in Figure 20. As it can be noticed, these animals are able to withstand the velocity of change of the suitability areas, except for one tiny spot in Northern Russia.

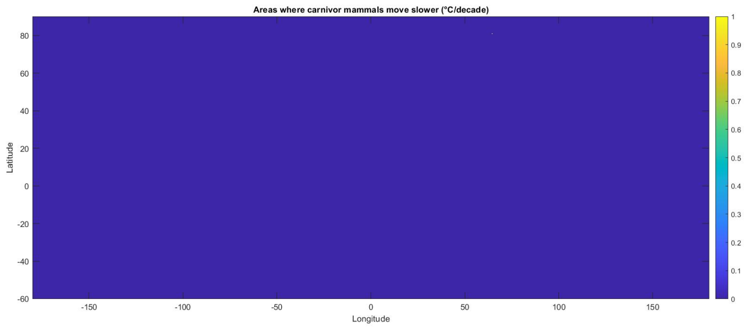

Figure 20: *Areas where split-hoofed mammals move slower than the gradient*