Antarctic Penguin Population Analysis

Final Report

by

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Introduction:

Climate change is a topic that is front and center in today's day and age. While much of the public debate is centered on whether or not climate change exists, our goal is to model how the population of Antarctic penguin species are being affected by numerous relevant climate change factors. While penguins exist in numerous countries around the globe we focused on those species that only exist on the Antarctic continent. This enabled us to maintain a focused outlook, and provide a succinct model and visualization for the public. We are specifically concentrating on the Emperor, Adélie, Gentoo, and Chinstrap penguin species that populate the Antarctic continent. The Emperor penguins are the largest and presumably the most negatively affected by climate change, and the Adélie penguins are the most abundant with an increasing population in more recent years.

Problem Definition:

Existing models available to the public are not interactive, and as a result are boring for most people. A single interactive model that shows Antarctic penguin population combined with numerous stressors would provide the ability to educate non-scientists and the public much more easily. While there are many population modeling techniques currently being used, there are very few instances of machine learning.

Literature Survey:

Global average temperatures have increased every decade over the past 40 years[1] and ocean surface temperatures have followed. High latitude regions are warming two to three times faster than the global average[2]. These changes in climate affect biodiversity in the Antarctic region, including the populations of our focus: penguins.

Global warming has resulted in rapid ice loss from ice shelves[3], decreasing sea-ice extent in winter, and increasing sea level, all of which influence penguin habitats[4]. An increase in temperature (especially 2 degrees Celsius above pre-industrial levels) leads to a decrease in Adélie and Emperor[6] penguin populations. Using satellite imagery of snow, shadow, and guano[7], the total population of Emperor penguins in Antarctica can be estimated, providing a more accurate population count methodology than presence-absence data. Their population estimates will be valuable to our model.

Climate change also alters the food web[10] and disrupts predator-prey and plant-insect interactions.[11] Decreases in Antarctic krill populations have been cited as a primary cause for declines in populations of both the "ice-loving" Adélie and "ice-avoiding" Chinstrap penguins.[12–14] Our model will benefit by looking deeper into food web interactions. This includes predators moving into penguin territories. Even small numbers of Cetaceans foraging in the southwestern Ross Sea can affect food availability for Emperor penguins.[15]

Climate change affects the breeding timeline and habits of penguins. Compared to 1960s, Royal and Macaroni penguins laid eggs three days earlier.[8] Adélie penguins have had to move inland to adjust to increased snowfall and the flooding of eggs and chicks.[9] Throughout the literature detailed above, we see various mechanisms by which climate change affects the penguin population, but not all of the articles pull it all together. We will incorporate all of the knowledge learned from the references above to create a more holistic tool.

Because long-term studies allow for insight and predictions that short-term studies don't[16], our models will focus on long-term datasets as much as possible. [17] uses IPCC climate change model projections paired with historical population data to predict the probability of quasi-extinction. [18] uses moving-habitat models (which measure population changes on two axes: continuous spatial and discrete temporal) to identify factors involved in population changes. To the best of our knowledge from reading [16-18], there is little mention of machine learning in the literature of population forecasting. We plan to improve our predictions with the use of machine learning, while also incorporating the science behind the studies above. There also seems to be little attention paid to creating innovative visualizations to help people better understand the climate and population data available. We will make this a focus of our project.

Proposed Method:

All current models are static, and do not integrate multiple stressors on the penguin population. Our model will provide the user the ability to pick and choose the stressors and then see how the population of any/all Antarctic penguins populations change over time. The flexible approach can aid penguin researchers in problem solving and allow them to focus on the stressors that accurately affect population fluctuations.

The stressors we selected are the annual global temperature anomalies, the annual temperature anomalies specifically for Antarctica continent, sea ice extent (SIE), sea ice area (SIA), and human krill fishery activities [21] around Antarctic oceans. In theory, the penguin population should follow periodic pattern for all the penguin species breed in the summer (December to February) and decrease in the harsh winter (June and August). In order to involve the vector of season, the global temperature and Antarctica temperature vectors were further split into summer and winter. Sea ice is important in breeding season.[17] The penguins must nest on the rocky surface of the Antarctic continent and not on ice, so if ice extends far the penguins must travel longer distances to forage for food for the hatchlings. A longer distance means that the energy costs for these trips is too high, and results in lower provisioning for the offspring. On the other hand, if there is too little sea ice, the colony space is smaller, which also leads to lower hatchling success. Sea ice also has a positive impact on the reproduction cycle for krill, a major food source for Adélie penguins. According to the wide distribution of different species, SIE and SIA are divided by the nearby waters. In the end, we have 16 stressors which are :

- ❏ Global temperature anomalies in summer
- ❏ Global temperature anomalies in winter
- ❏ Annual Antarctica temperature anomalies
- ❏ SIE around Weddell Sea
- ❏ SIE around Bellingshausen Sea and Amundsen Sea
- ❏ SIE around Ross Sea
- ❏ SIE around Indian Ocean
- ❏ SIE around West Pacific Ocean
- ❏ SIE of whole Antarctic Continent
- ❏ SIA around Weddell Sea
- ❏ SIA around Bellingshausen Sea and Amundsen Sea
- ❏ SIA around Ross Sea
- ❏ SIA around Indian Ocean
- ❏ SIA around West Pacific Ocean
- ❏ SIA of whole Antarctic Continent
- ❏ Human Krill catch

For the penguins population record is limited from 1985 to 2017, it is not suitable for map all the stressors in the model. To avoid overfitting, the importance of stressors to each penguin species is ranked on Pearson Correlation and the top 3 were chosen in the Linear Regression model to predict the annual average penguin population. Because the penguin population is a continuous number, the accuracy score did not work. The evaluation of the mode in our project is based on the Pearson Correlation between expected and predicted penguin population.

Database:

A SQLite database was created. The data was collected and mapped to individual tables to allow easy access and joining of the datasets. We decided on this method as it allows us to add and use specific datatables which represent the population and stressors. This is of particular interest to our project as the data for populations and the various stressors all come from different sources with different schema and structures. We scrubbed the raw data to remove extraneous information and saved only the relevant data from each source. The schema is given in Appendix B.

Evaluation:

Among all the 16 stressors, the top 10 related vectors for each species are shown in the figures 1-4 which is ranked on the square of Pearson Correlation. In this way, only the absolute value of Pearson are considered.

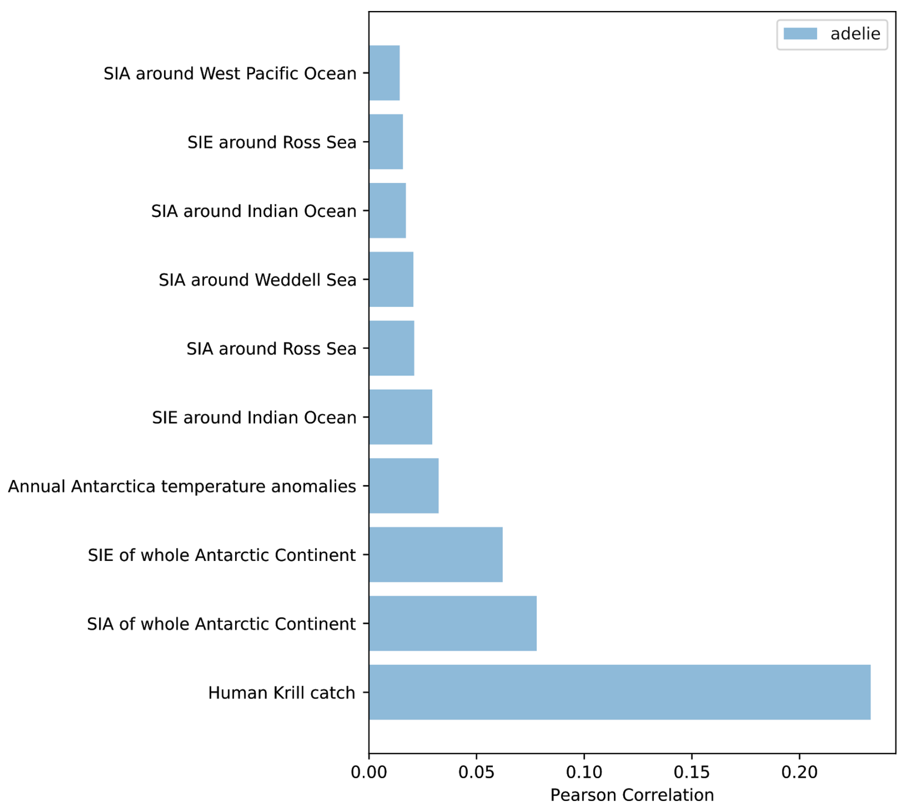

Figure 1. The stressor rank of Pearson Correlation of Adélie penguins.

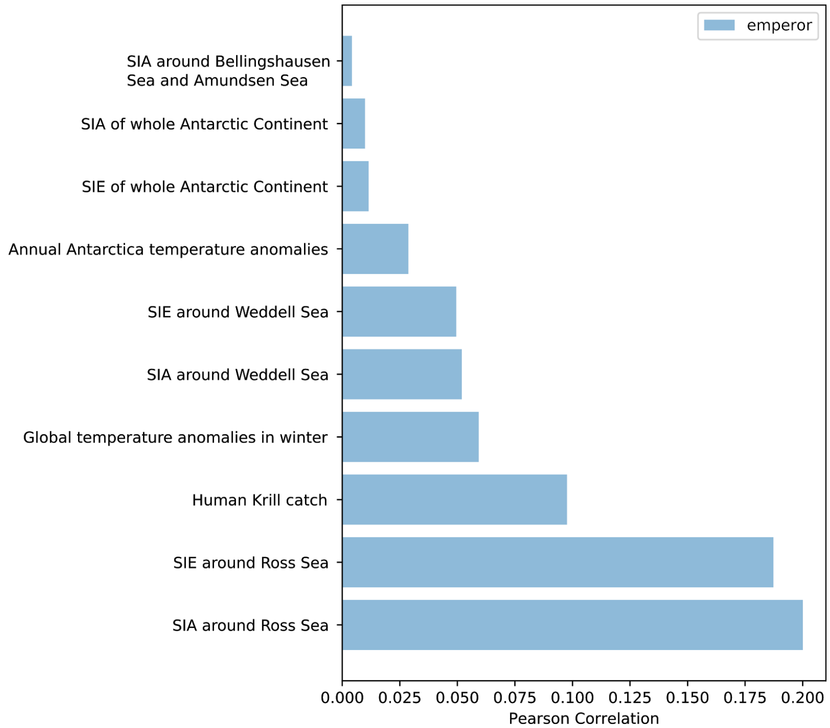

Figure 2. The stressor rank of Pearson Correlation of Emperor penguins.

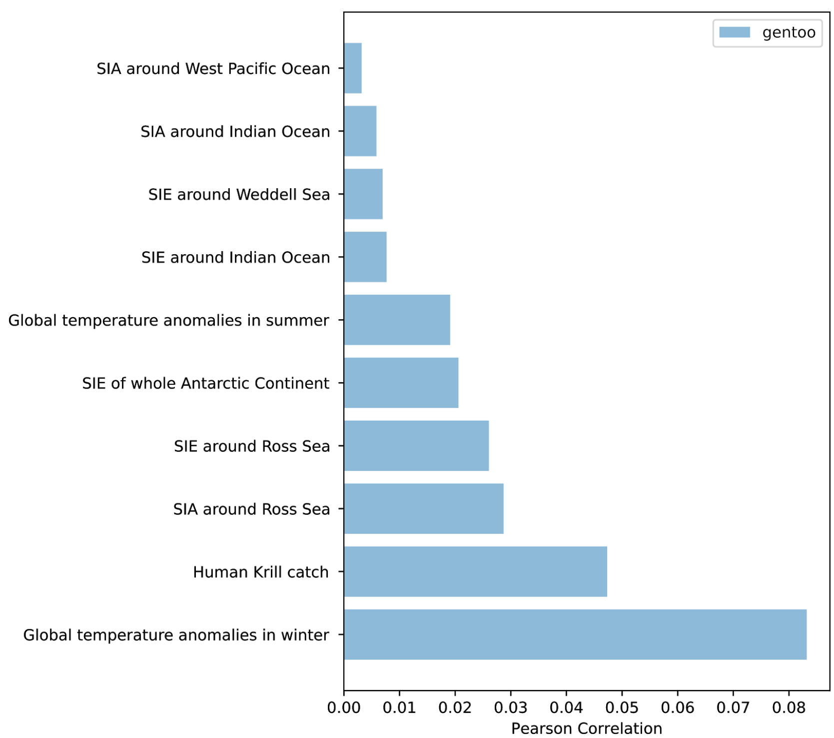

Figure 3. The stressor rank of Pearson Correlation of Gentoo penguins.

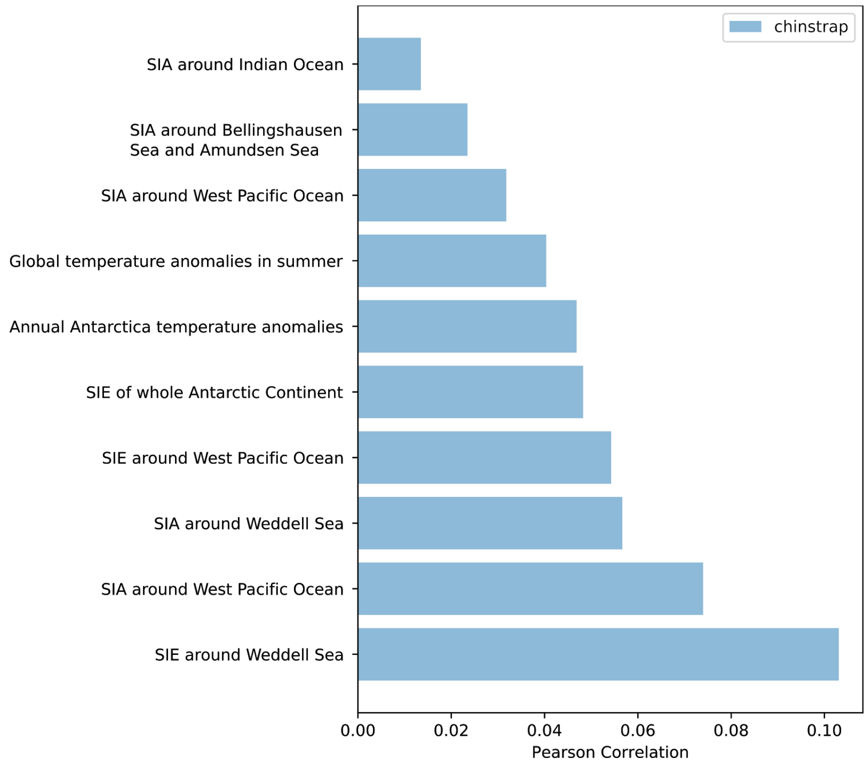

Figure 4. The stressor rank of Pearson Correlation of Chinstrap penguins.

In the following table, we collected 3 stressors with highest $R^2_{Pearson}$ and fit into the linear regression (LR). Here is the summary for generating the linear regression. The larger the $R^2_{Pearson}$, the more related the stressor is to the penguin population.

Species	Stressor selected			$R_{Pearson}$ of model
	name	Square of $R_{Pearson}$	$R_{Pearson}$	
Adelie Penguin	Huamn Krill Catch	0.233041053	0.482743258	0.491645965
	SIA of Antactica	0.077912927	-0.279128872	
	SIE of Antactica	0.062090457	-0.249179567	
Emperor Penguin	SIA around Ross Sea	0.200081304	-0.447304487	0.478597913
	SIE around Ross Sea	0.187283876	-0.432763071	
	Huamn Krill Catch	0.097636563	0.3124685	
Gentoo Penguin	Global temperature in winter	0.083197804	-0.288440295	0.432463287
	Huamn Krill Catch	0.047323692	-0.217540093	
	SIA around Ross Sea	0.028715179	-0.169455538	
Chinstrap Penguin	SIE around Weddell Sea	0.10307984	0.321060493	0.380312966
	SIA West Pacific Ocean	0.073989306	-0.272009753	
	SIA around Weddell Sea	0.056669794	0.238054182	

Table 1. The stressors selected for the model and the evaluation result of the model.

The $R_{Pearson}$ of model with 3 stressors are better than that of any single stressor. For Adélie penguins, the SIA and SIE of whole Antarctic region is consistent with the distribution of this species. Based on our penguin distribution in Figure 5, the Adélie is living circumpolar on Antarctic continent within limits of pack ice. It is worth to emphasize here that sea ice extent refers to edge of the sea ice. Slightly different from SIE, SIA refers to the real size of sea ice surface without the hole and suitable for living on. Even though the two concepts are both related to the size of habitat, they are also the index to estimate the traveling distance of penguin for foraging. For Chinstrap penguins, the SIE and SIA for their habitat near the Weddell Sea are also two index of the top 3 stressors. However, the size of sea ice showing by SIE and SIA exert different influence on the penguin population. The $R_{Pearseon}$ for Chinstrap is positive, meaning more sea ice benefits the population. It is clear to see from figure 5 all the Antarctic resident penguin live on the Antarctic Peninsula. The positive $R_{Pearseon}$ could possibly explained by competition for habitat among the species. In terms of Adélie who wide distribute on the whole Antarctic continent especially near the Ross Sea and Indian Ocean, increasing SIE and SIA may results in the longer distance for foraging in winter. This brings more threat to the survival of individuals.

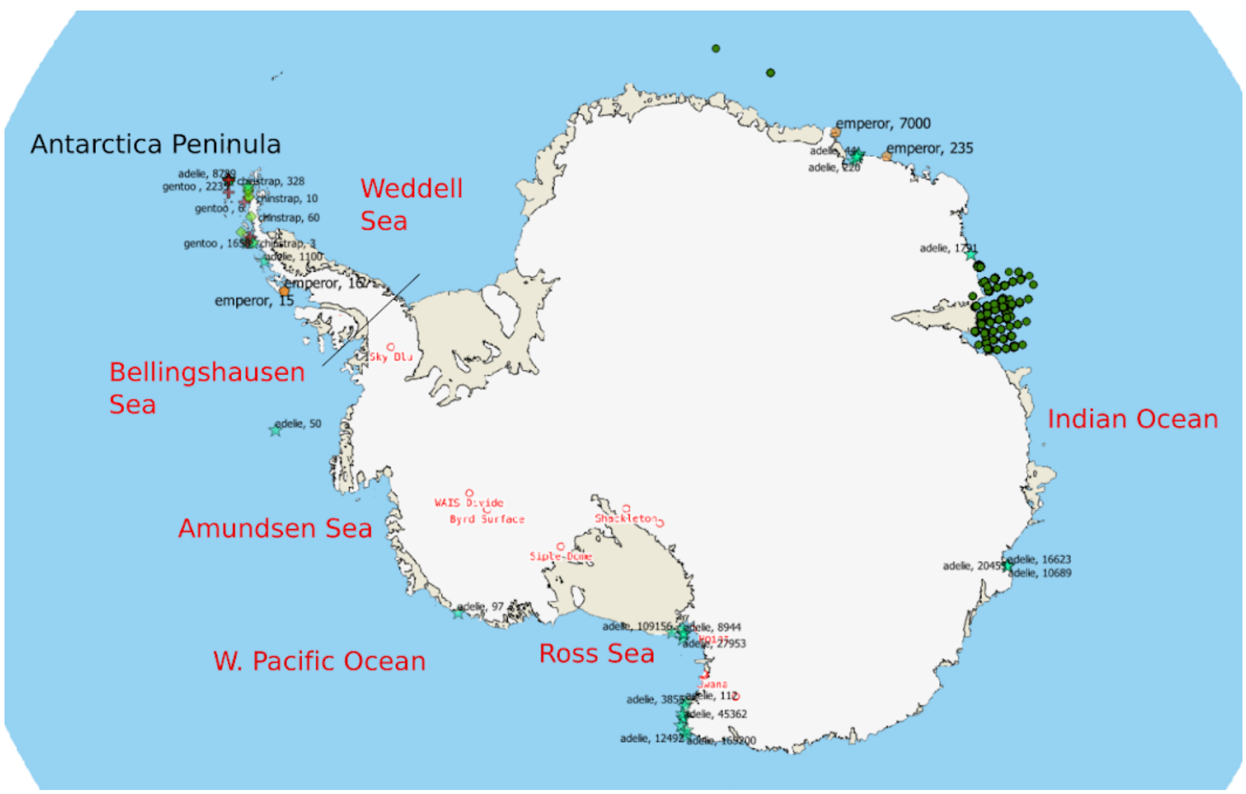

Figure 5. The visualization of Adélie, Gentoo, Chinstrap, and Emperor Penguin distribution on the Antarctic Continent.

Interestingly, for Gentoo and Emperor, SIE and SIA around Ross Sea stands out as one of the most related stressors for the population. From the visualization, the SIE and SIA we cares about now is not directly nearby the Gentoo habitat on west side of Antarctic Peninsula and one of the main Emperor habitat near Northeast of continent. However, some similar unknown geographical relationship between their habitat and Ross Sea Area gives the hint for predicting Emperor and Gentoo population with sea ice around Ross Sea.

In terms of the influence of human activities, we focused on the catching of Antarctica Krill. And this stressor was the top one for Adélie, Emperor and Gentoo. The $R_{Pearson}$ of fishery on the Adélie and Emperor are positive 0.48274325820009317 and 0.31246849965198442. On the contrary, the value of $R_{Pearson}$ of fishery on the Gentoo is -0.21754009319715659. Antarctic Krill is main prey of penguins and the influence Krill catch is always in controversy. According to the Fishery of report from Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Atkinson et al. 2009), the allowed catching weight of Krill are carefully calculated based on the various environmental factors and assigned to countries before the calendar year. The positive $R_{Pearson}$ does not mean Krill fishing itself benefiting penguins. Actually, it is possible that in conditions that benefit penguins, the allowed quota is increased. Looking at the catching area, the main area for human activities is limited to the Weddell Sea and vertex of the Antarctic Peninsula. It may have the least influence on widely distributed Adélie and Emperor, but be harmful for the Gentoo which only resides on the Antarctic Peninsula.

To our surprise, except for Gentoo, which Global Temperature in winter is the most important stressor, the top 3 stressors for the other three species did not contain temperature. In order to discover the relationship between temperature and SIE or SIA, the $R_{Pearson}$ was calculated after shifting the value of Annual Antarctic Temperature for 0~4 years. Table 2 shows the temperature has 1~2 years lag effect on the SIA and SIA. The global warming influence the penguin population through the change of SIE and SIA of Antarctica.

Target	# of shifting year	$R_{Pearson}$
SIA of Antarctica	0	-0.098779514
	1	0.250615463
	2	0.282867306
	3	-0.094267507
	4	-0.036746477
SIE of Antarctica	0	-0.161542336
	1	0.197672011
	2	0.348179163
	3	-0.166481131
	4	-0.055913137

Table 2. The $R_{Pearson}$ between shifted Annual Antarctica Temperature and SIE or SIA.

User Interface:

The user is provided a map of Antarctica provided a map of Antarctica with the ability to choose between the 4 different Antarctic penguins, and then overlay this with the different stressors. This was completed with a desktop application QGIS. Population is displayed on the map at the longitude and latitude coordinates and transformed to the Antarctic Polar Stereographic coordinates (standard EPSG:3031). The user can use the layer panel to select the species. To choose the year of interest, the user can edit the filter by right clicking on the filter name in the filter dialog box as shown in Figure 6. The filter is edited as shown in Figure 7. The filter can be set to a single year or a range using the syntax “Year” > XXXX AND “Year” < XXXX.

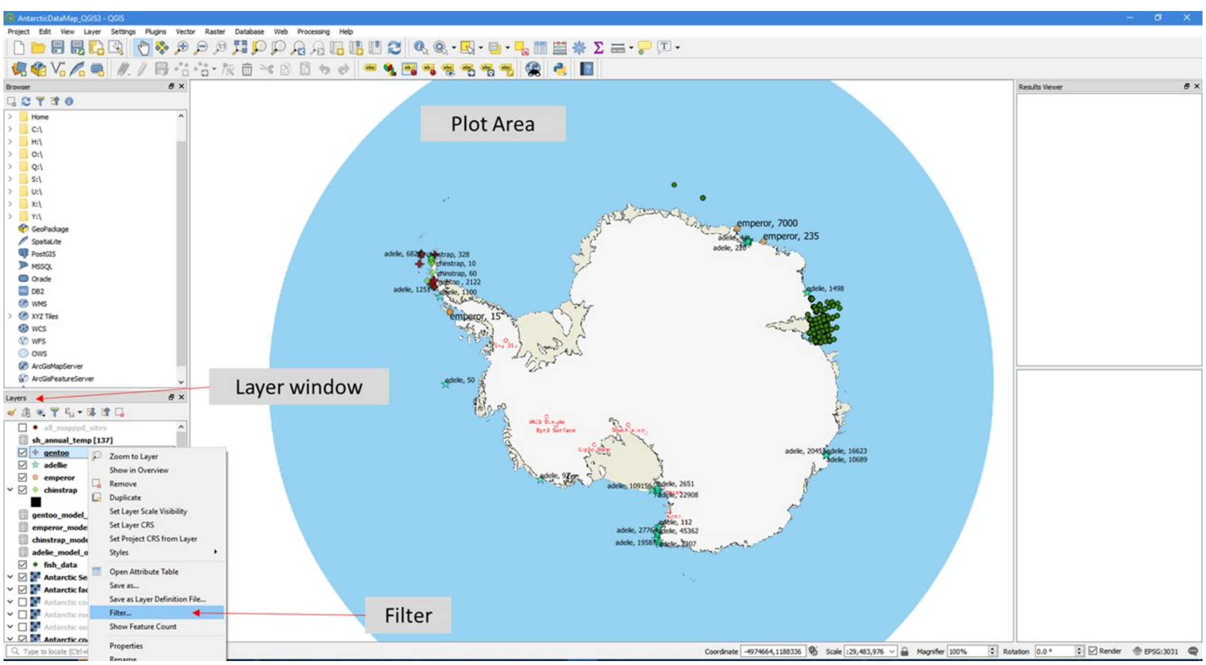

Figure 6. The visualization window using QGIS.

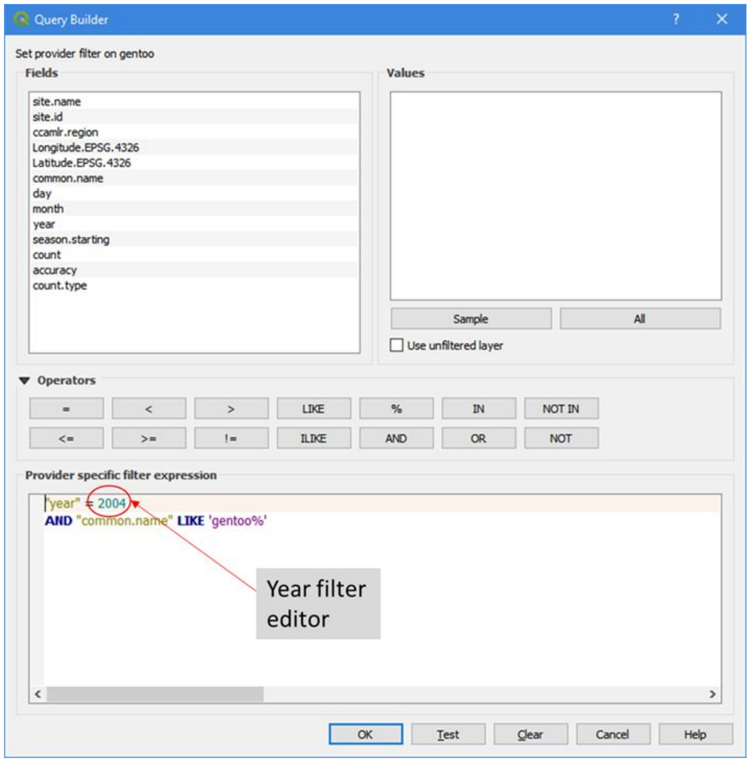

Figure 7. Layer filter dialog box.

Evaluation:

Instead of 10 laymen reviewing the visualization and software ease of use, we asked select members of the scientific community for their view of the data visualization. These are some comments about the interface:

1. The interface and year selection is difficult to use
2. The data visualization is easy to look at, and informative of where the penguin species are.
3. Average rating: 7/10.

List of Innovations

- Dynamic visualization of Antarctic penguin population
- Combination of multiple stressors on penguin population
- Machine learning for future penguin population prediction

Conclusion

The changes in the temperature of Antarctica due to global warming do not directly influence penguin population. Based on our experiment's results, the annual temperature of Antarctica is positively related to the size of sea ice area and sea ice extent in the following 1~2 years, and the influence on the penguin population is through this change in sea ice.

For all the observed penguins living on Antarctica, sea ice area and/or extent are always within the top 3 stressors to the population. In traditional "sea ice hypothesis" guiding ecological interpretations of changes in penguin populations, the population of "ice loving" species such as Adélie, would decline with the sea ice reduction, while the population of "ice avoiding" species such as Chinstrap would increase. Our observation contradicts with this hypothesis as Adélie penguins are negatively related to ice area and extent, whereas Chinstrap is positively related to ice area and extent. This result is consistent with other observations for the relationship with penguins living on West Antarctic Peninsula, (Trivelpiece et al. 2011) meaning other unknown factors such as the density of competitors and geographical distribution of species needs to be involved.

In order to protect the ecosystem of the Antarctic region, Antarctic fishing is well controlled within the waters of Weddell Sea and limited to 120,000 tons each year. Though it may lead to a slight decline of Gentoo penguin who are specifically populous in the nearby region, the influence on the other widely distributed penguin such as Adélie or Emperor penguins are almost invisible.

Distribution of Effort

All team members have contributed a similar amount of effort between data collection/scrubbing, model building/evaluation, and writing proposal/progress reports.

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Appendix A: Plan of Activities

Original

Activity	Duration	Owner	Week Starting							
			3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
Building Database	2 weeks	Everybody								
Data Scrubbing										
Sourcing Data										
Model	6 weeks	Team 1								
Model Evaluation										
Model Building										
Final Model										
Visualization	6 weeks	Team A								
Visualization Building										
Evaluation of vis										
Final visualization										
Checkpoint/Midterm	1 week	Everybody					9-Apr			
Final Proj Write-up	1 week	Everybody								27-Apr
Final Proj Presentation	1 week	Everybody								27-Apr

Updated

Activity	Duration	Owner	Week Starting							
			3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23
Building Database	2 weeks	Everybody								
Data Scrubbing										
Sourcing Data										
Model	6 weeks	Team 1								
Model Evaluation										
Model Building										
Final Model										
Visualization	6 weeks	Team A								
Visualization Building										
Evaluation of vis										
Final visualization										
Checkpoint/Midterm	1 week	Everybody					9-Apr			
Final Proj Write-up	1 week	Everybody								27-Apr
Final Proj Presentation	1 week	Everybody								27-Apr

Appendix B: SQL Database Schema

```
.open C:/docs/spring2018/cse6242/project_work/project.db;

CREATE TABLE krill_catch (
    id integer,
    year integer,
    month integer,
      group_ssmu_code text,
      ssmu_code text,
      scaled text,
    weight integer
    );

CREATE TABLE ice_area (
    year integer,
      month integer,
    Weddell_Sea integer,
    Indian_Ocean integer,
    W_Pacific_Ocean integer,
    Ross_Sea integer,
    Bellingshausen_Amundsen integer,
    Antarctic integer
    );

CREATE TABLE ice_extent (
    year integer,
      month integer,
    Weddell_Sea integer,
    Indian_Ocean integer,
    W_Pacific_Ocean integer,
    Ross_Sea integer,
    Bellingshausen_Amundsen integer,
    Antarctic integer
    );

CREATE TABLE global_annual_temp (
      year integer,
      Jan   float,
      Feb float,
      Mar float,
      Apr float,
      May float,
      Jun float,
      Jul float,
      Aug float,
      Sep float,
      Oct float,
      Nov float,
      Dec float,
```

```
      JD float,
      DN float,
      DJF float,
      MAM float,
      JJA float,
      SON float
      );

CREATE TABLE zone_temp(
      Year integer,
      Glob float,
      NHem float,
      SHem float,
      z_24N_90N float,
      z_24S_24N float,
      z_90S_24S float,
      z_64N_90N  float,
      z_44N_64N  float,
      z_24N_44N  float,
      EQU_24N    float,
      z_24S_EQU  float,
      z_44S_24S  float,
      z_64S_44S  float,
      z_90S_64S float
      );


CREATE TABLE all_mapppd_sites (
      site_id text,
      site_name text,
      ccamlr_region float,
      longitude_EPSG float,
      latitude_EPSG float
      );


CREATE TABLE penguin_population(
      site_name text,
      site_id    text,
      ccamlr_region float,
      Longitude_EPSG float,
      Latitude_EPSG float,
      common_name text,
      day integer,
      month integer,
      year integer,
      season_starting integer,
      count integer,
      accuracy integer,
      count_type text
```

```
      );

CREATE TABLE sh_annual_temp (
      Year integer,
      Jan   float,
      Feb float,
      Mar float,
      Apr float,
      May float,
      Jun float,
      Jul float,
      Aug float,
      Sep float,
      Oct float,
      Nov float,
      Dec float,
      JD float,
      DN float,
      DJF float,
      MAM float,
      JJA float,
      SON float
      );

.separator ","
.import            C:/docs/spring2018/cse6242/project_work/krill_catch.csv
krill_catch
.import C:/docs/spring2018/cse6242/project_work/ice_area.csv ice_area
.import C:/docs/spring2018/cse6242/project_work/ice_extent.csv ice_extent
.import     C:/docs/spring2018/cse6242/project_work/global_annual_temp.csv
global_annual_temp
.import C:/docs/spring2018/cse6242/project_work/zone_temp.csv zone_temp
.import       C:/docs/spring2018/cse6242/project_work/all_mapppd_sites.csv
all_mapppd_sites
.import     C:/docs/spring2018/cse6242/project_work/penguin_population.csv
penguin_population
.import        C:/docs/spring2018/cse6242/project_work/sh_annual_temp.csv
SH_Annual_Temp
```

Appendix C: Raw Data

Climate Change:
Temperature estimates based on Land-Surface Air Temperature and Sea-Surface Water Temperature Anomalies. According to the policy of World Meteorological Organization (WMO), the reference value of temperature anomalies is relative to the 1981-2010 period.[22, 23] The data is from the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA).

- Monthly Global temperature, 1880-2017
- Monthly South Hemisphere temperature, 1880-2017
- Annually gridded temperature (S90-S64), 1903-2017

Antarctic Sea Ice:
The data is from National snow and ice data center and collected in the following area of antarctica region: Weddell Sea, Indian Ocean, W. Pacific Ocean, Ross Sea, Bellingshausen Sea, and Amundsen Sea with total of whole Antarctic region.[24]

- Sea ice extent daily, 1978-2012
- Sea ice area daily, 1978-2012
- Sea ice extent monthly, 1978-2012
- Sea ice area monthly, 1978-2012

Human Activity :

- Monthly Fisheries of Antarctic Krill, fishing place with ccamlr region code, and amount.[25] The data is from Commission for the Conservation of Antarctic Marine Living Resources.

Krill Population Statistics:

- Data from 1992 to 2003 with location data of the growth rate, uropod size, and standard length.[26] The data is from the Australian Government public datasets.

Antarctic Silverfish (Pleuragramma antarctica) Population Statistics

- The data for silverfish is 21k observations from 1981 to 1993 over the breeding area of Emperor penguins.[27] The data is from Australian fishing boats and include statistics of location, weight, and standard length.