Permafrost in a Global Warming Climate

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Abstract— As global temperatures rise, permafrost areas are also warming quickly. Permafrost collapse could lead to an acceleration in carbon dioxide release which will accelerate global warming. Aftermaths can already be seen in arctic environment. Scientists agree that global warming has a direct impact on permafrost thawing, however the fraction and speed of permafrost thaw is thornier to predict. Various model can be used to predict such trends. A time series prediction based on Mean Annual Air Temperature and permafrost interactions will be modeled to predict permafrost evolution.

Keywords— Permafrost, Global Warming, Climate Change, IPA, Carbon Dioxide, Prediction, Time Series, Deep Learning, LGTM, RNN

Introduction

An environmental vicious circle is taking place, as permafrost thaws. In fact, previously frozen organic in permafrost decomposes and generates carbon dioxide and methane which are released in the atmosphere, leading to an acceleration of global warming. In addition, Arctic areas are warming much faster than the rest of the globe, causing more and more hazards.

Fig. 1: Permafrost thaws at Batagaika, Russia [0].

Thanks to satellites data of Earth's surface, evolution of world's temperatures can be used to predict the evolution of permafrost. NASA's GISS Surface Temperature Analysis is also a great tool to see temperature anomalies from 1880. Then, mathematical model can be applied for this issue.

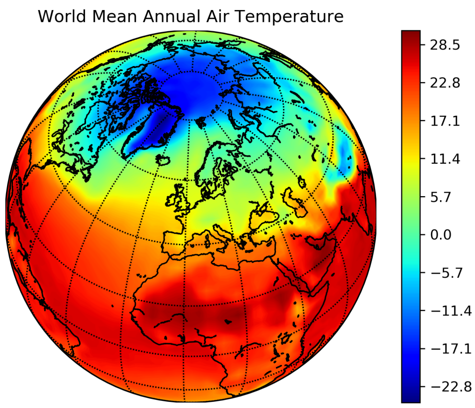

Fig. 2: World Mean Annual Air Temperature from 2018.

Model

This model is based on Mean Annual Air Temperatures (MAAT) and permafrost interactions. The model uses linear and non linear regression to estimate MAAT trends, and then predict the evolution of permafrost in these areas.

Definitions

A dataset from NCEP of daily temperatures from the past three years has been collected, and another one directly from NASA of monthly temperatures from 1880. These sets of data will be used to compute MAAT and temperature anomalies. In addition, a map of permafrost extends collected from the International Permafrost Association will be used to locate permafrost boundaries on the model [1]. The MAAT map has been computed from the NCEP daily data. The 0°C contour (figure 3, 4) highlights transitions between positive and negatives values. Thus, permafrost located in a positive

MAAT zone is more susceptible to thaw.

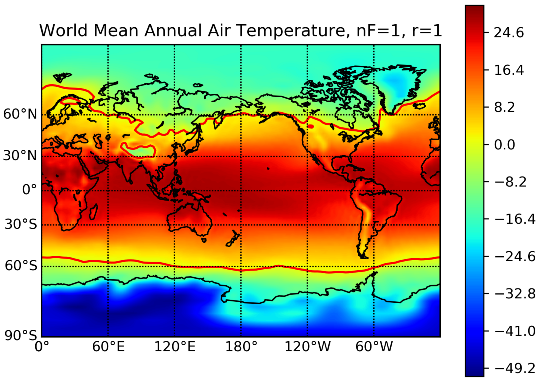

Fig. 3: Mean Annual Air Temperature. The contour in red represents the 0°C temperatures transition.

MAAT is calculated from Freezing Degree Days (FDD) and Thawing Degree Days (TDD). Let $\mathfrak{T}$ the set of all temperatures for one year.

$$\mathfrak{T}_{FDD} = \{T \in \mathfrak{T} | T < 0\} \tag{1}$$

$$\mathfrak{T}_{TDD} = \{T \in \mathfrak{T} | T \geq 0\} \tag{2}$$

Then, FDD and TDD are defined as:

$$FDD = \sum_{T \in \mathfrak{T}_{FDD}} T \tag{3}$$

$$TDD = \sum_{T \in \mathfrak{T}_{TDD}} T \tag{4}$$

FDD and TDD are temperatures in cold and warm period respectively, and the coefficients n_F and r enable to weight these periods and influence MAAT distribution:

$$MAAT = \frac{n_F FDD + rTDD}{time} \tag{5}$$

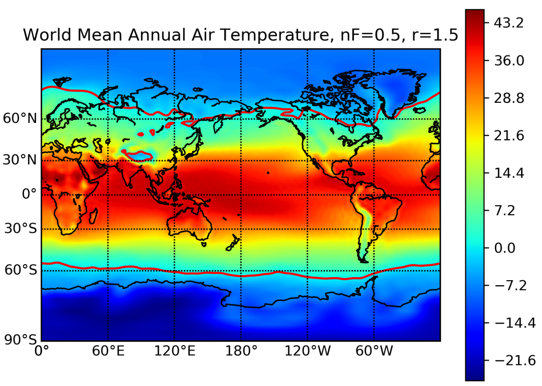

Fig. 4: Mean Annual Air Temperature with r=1.5 and nF=0.5. The contour in red represents the 0°C temperatures transition.

Then, the temperatures within permafrost areas has been mapped (figure 5).

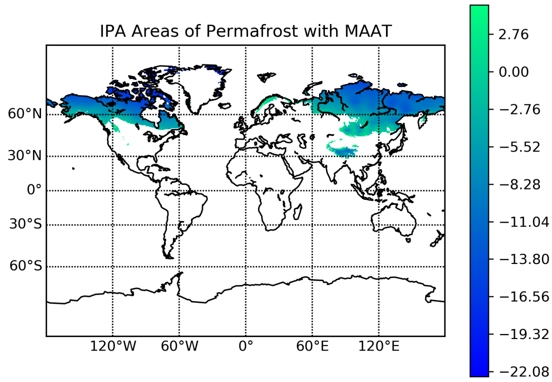

Fig. 5: MAAT in permafrost northern areas.

Global Temperature Anomalies Prediction

To predict the evolution of permafrost the NASA's dataset has been used. MAAT from both land and ocean have missing values, therefore they have been interpolated. Another way to fix these missing values would have been to crop the data to a specific location with no missing data over time or to predict what could have been the temperatures in the past from the global MAAT trend.

Temperature anomalies represents change in temperatures in a period of time. This change is measured in regards of the mean temperatures of this period. Let $\mathscr{T} : \Omega \longmapsto \mathfrak{T}$ the random variable of temperatures. Then, the temperature anomaly $T_{anomaly}$ for a specific event is:

$$\forall \omega \in \Omega, \quad T_{anomaly}(\omega) = \mathscr{T}(\omega) - \mathbb{E}(\mathscr{T}) \tag{6}$$

Temperature anomalies are well used to model and predict climate change. The following models will only use time-series temperature anomalies from 1880.

Then, linear and non-linear regressions are applied to fit best the temperature anomalies trend, curve, cycle and irregularities, using time t as regressor (figure 6). These functions can be decomposed into different categories, growth g, seasonal s, event e and errors ε. The regression function f is then:

$$\forall t \in \mathbb{R}, \quad f(t) = g(t) + s(t) + e(t) + \varepsilon(t) \tag{7}$$

To simplify the relations linked to temperature anomalies, a naive hypothesis is to suggests that temperatures only depends on time:

$$\forall t \in \mathbb{R}, \quad T_{anomaly}(t) = f(t) \tag{8}$$

The following models will rely on this hypothesis. A way to improve it could be to consider other parameters such as the rate of carbon dioxide release.

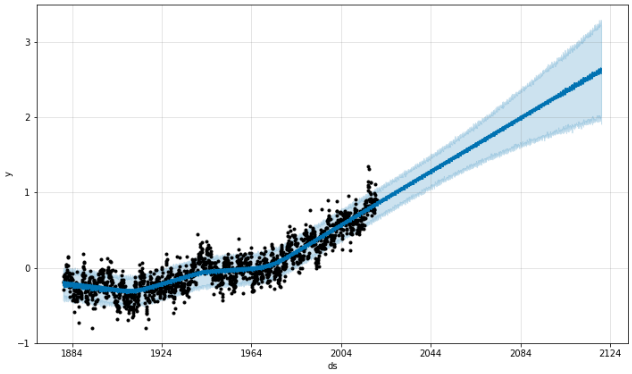

Fig. 6: Temperature anomalies prediction

Finally, this prediction can be used to model the global warmth over the world. For example, an increase of 2 °C may happen within the next 100 years (figure 8). Then, permafrost boundaries will change and fraction of permafrost will reduces (figure 9).

Local Temperature Anomalies Prediction

To have a more detailed prediction, the previous regression can be modelled locally. For each location, a MAAT time-series from 1880 has been extracted.

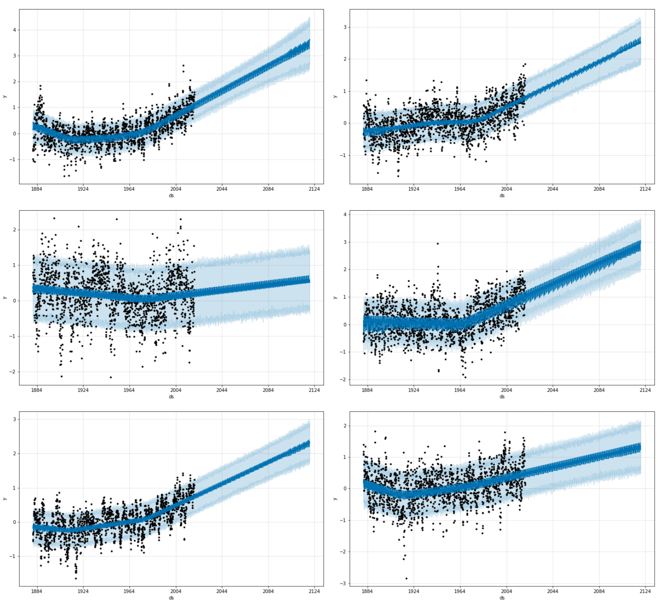

Fig. 7: Local anomalies temperature

Then, the predicted temperatures are merged together to create a global map of temperature anomalies. However, biases are introduced because local time-series are more prone to fluctuations.

Results

The regression model leads to different results depending on the inputs. The global MAAT time-series gives a more accurate prediction on temperature anomalies. The downside of this approach is that it considers that all locations will warm the same way. To take into account local variations, predictions based on local time-series highlight different evolution rate. However, this method is less accurate since the time-series are more noisy and clear patterns are harder to determine.

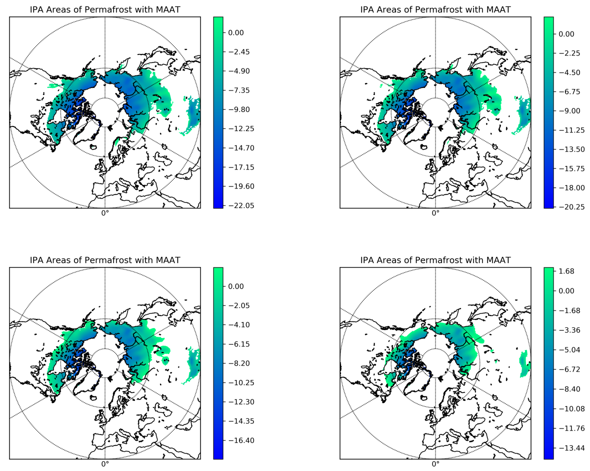

Fig. 8: Distribution of permafrost in function of MAAT. Prediction shows that Norwegian permafrost may disappear. From left to right, top to bottom: current situation, increase of +2°C, increase of +4°C, increase of +8°C.

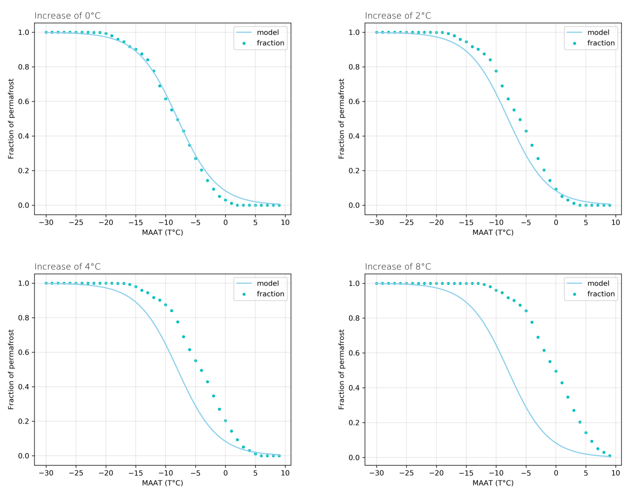

Fig. 9: The cyan dots represent the predicted fraction of permafrost. The sigmoid blue curve represents a modeled current fraction of permafrost. From left to right, top to bottom: current situation, increase of +2°C, increase of +4°C, increase of +8°C.

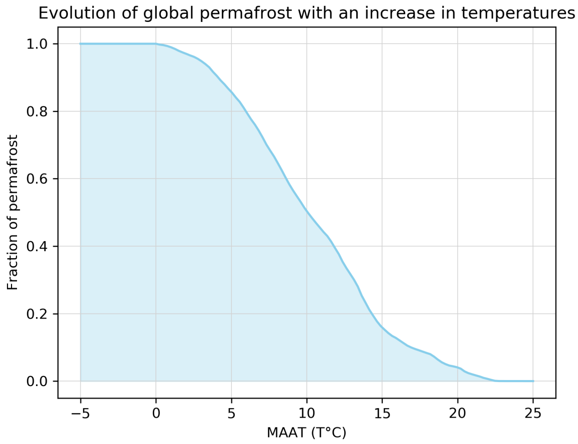

Fig. 10: Evolution of the fraction of permafrost with increasing temperatures. Above 25°C all permafrost areas thawed. This evolution is not totally linear. It depends on the previous permafrost distribution (figure 9).

As expected, with an increase of x°C, the fraction of permafrost is translated of x°C. To have a more realistic model, the local changes in temperatures has been predicted. As the regression model predicted (figure 6), an increase of 2°C may happens within the next 100 years.

Conclusion

Models show the same warming trend and permafrost will thaw at higher rate. This thaw will not be homogeneous all over the Earth, and northern hemisphere is prone to a huge increase in temperatures.

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