Capstone Project 1 - Milestone Report:
Analyze Interdependency Between Global Sea Ice, CO2 levels and Forest Fires

Introduction

The chosen project aims to understand the worldwide connections between sea ice, CO2 levels and fire data. This is a topic that is included in the wider problem problem of global warming. The audience consists in educated, open-minded people, interested in global problems that will affect their own lives on the long term.

The data is accessed from public sources and consists mainly in satellite data available for different timeframes. The objective is to understand the relationships between different features and to make predictions on different dependent variables.

Overview of the Data Set

Linking the multiple sources for datasets is challenging, because of the following reasons:

- the data consists of time series, therefore there is a trend, a seasonality and auto-correlation
- some data is missing
- the data format is different: csv, xlsx with many tabs, JSON
- time sampling is different for different datasets, it can be days or months

Data Acquisition

The first step is Data acquisition. Details about datasources are available in the Annex but at a high level the datasources are:

1. For sea ice data: CSV files and xlsx file. The data is recorded daily and ranges from 1978 to 2019, The xls file has several tabs with data and needs to be converted to a flat file

2. For CO2, there is one csv file. It is recorded monthly. The data is available between 1958 and 2019.

3. For fires, there are daily recordings from satellite as described in data wrangling file. The data is available between 2000 and 2019, in JSON format.

Data Wrangling

Data Wrangling consists in transforming the data into tidy Python data frames and cleaning the data. The main challenge is the size of the forest fires data (hundreds of GB).

Fire data has several issues. There are missing data especially for the first years of recordings related to issues with satellite instruments. This data was linearly interpolated by using the values before and after the missing data. In the JSON files used as inputs, there are some missing quotas on a few fields and this issue had to be fixed before importing the data in the Pandas data frame. Furthermore, there are two datasets with data acquired from different satellites and there are some different field names and different units of measurement. The data was consolidated into two data frames, one for each satellite. The columns unrelated to direct measurements were dropped.

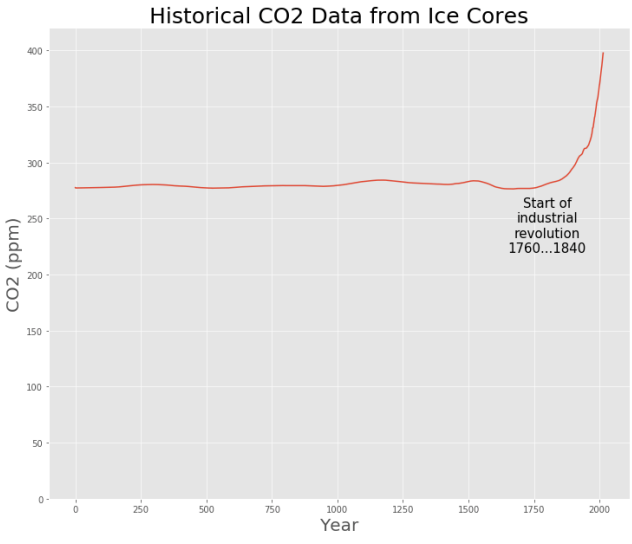
CO2 data is in a csv format and there were no issues while reading this file.

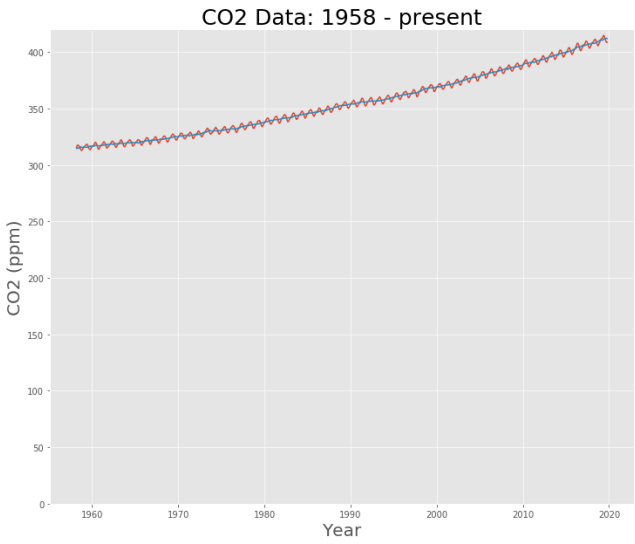
Ice data datasources are Excel files with North and South ice daily data and daily data for all the Northern Seas. This data was consolidated into one Pandas DataFrame in order to analyze the correlations between features and observations. As for fire data, there were several incomplete observations that had to be dealt with.

Exploratory Data Analysis - CO2

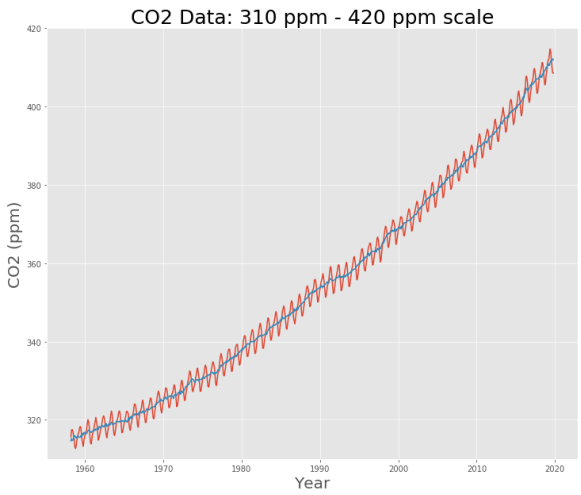
This stage is a preliminary analysis of the clean datasets for a better understanding of the features and the data trends and correlations.

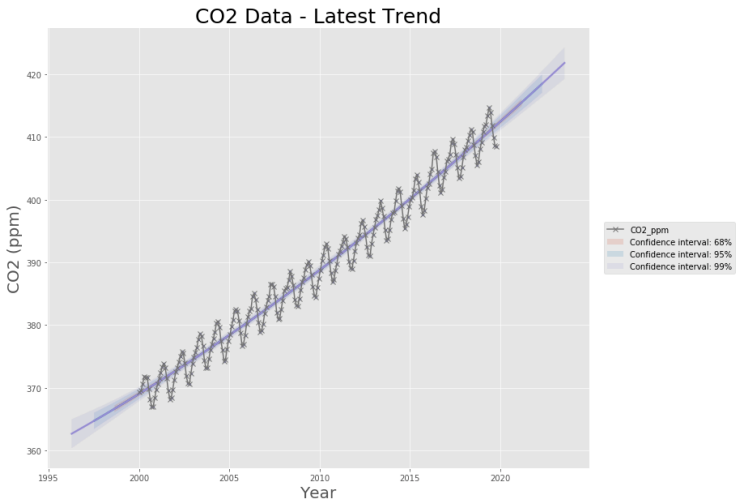
CO2 data is easier to analyze. As shown below, the CO2 concentration measured from ice cores was relatively constant until the industrial revolution. EDA will focus on the recent period (1958 - present).



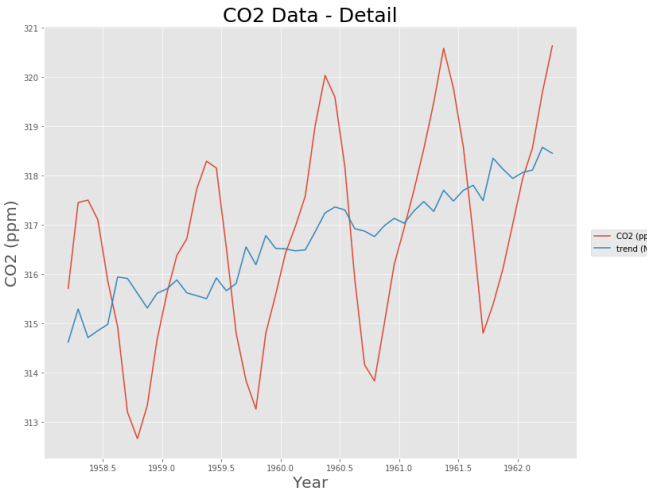


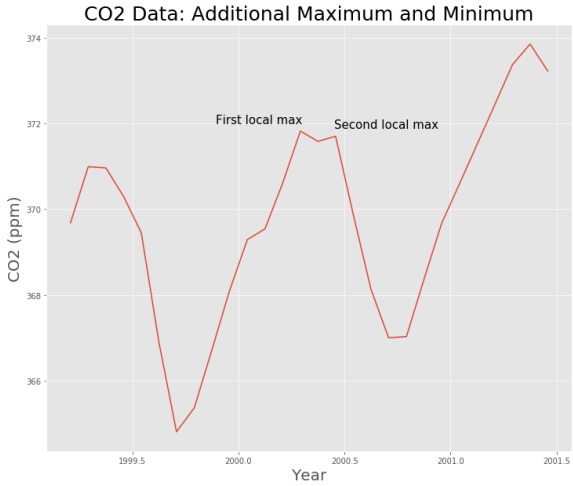
On a historic scale, the recent increase of CO2 concentration is almost a vertical line.



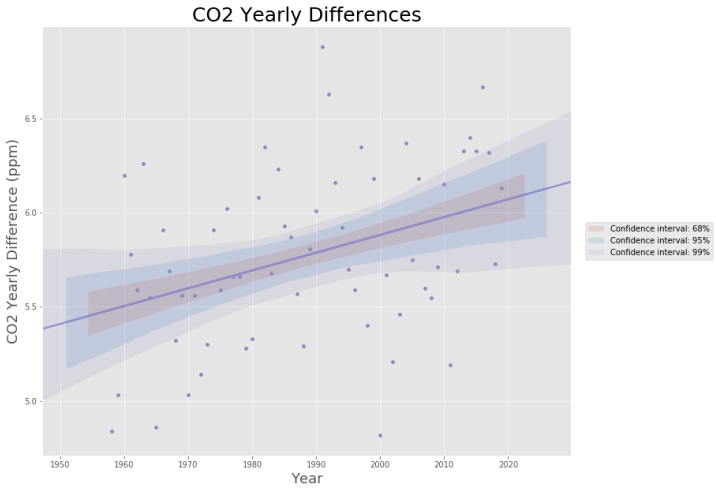


There is an upward trend and a seasonal variation as shown below. The seasonal variation is caused by the different land mass for the Northern and Southern Hemisphere. For a statistical analysis, I need to examine the seasonal component (annual min and max together with the overall trend).



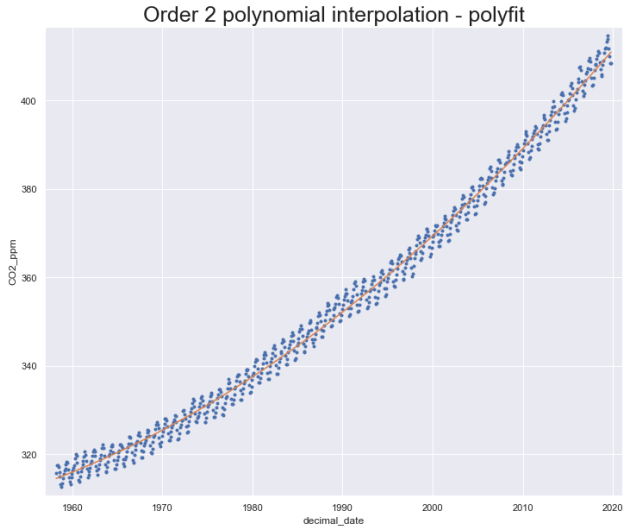


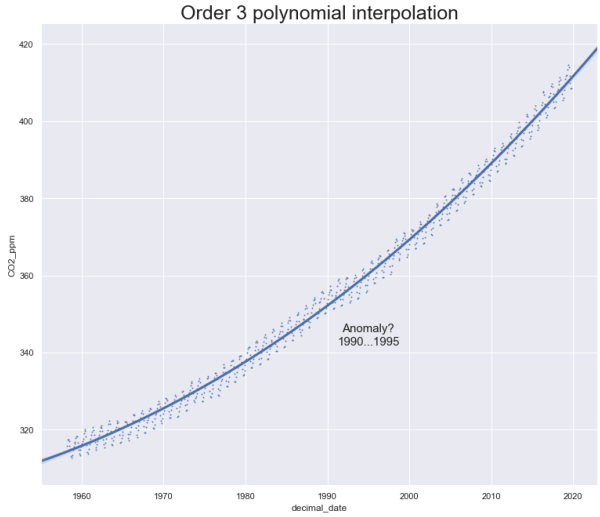
Data sampling and measurement errors may create false local maximums and minimums as shown above. These false extremes must be ignored. Using the correct minimums and maximums, it looks like the yearly difference between these local extremes is increasing:



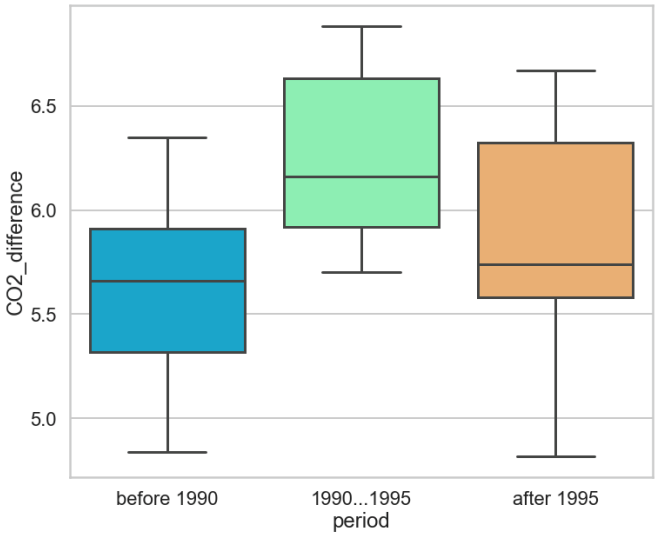
The positive trend for yearly CO2 differences is confirmed.

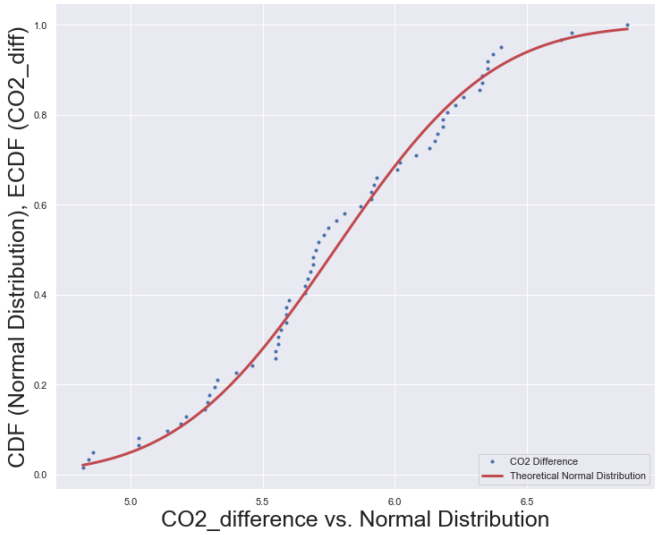
It is obvious that the upward trend has a positive second derivative so a polynomial fit should have at least order 2. I am checking the order 2 and order 3 polynomial fit:





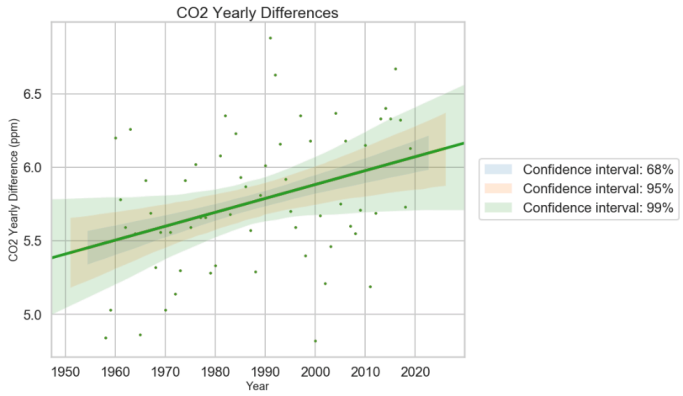
There is no visible difference between order 2 and order 3 interpolation and going to higher orders may end up in overfitting. There is a curious anomaly around 1990…1995 CO2 data, it looks like the CO2 emissions did not increase as fast as before. This anomaly must be investigated.

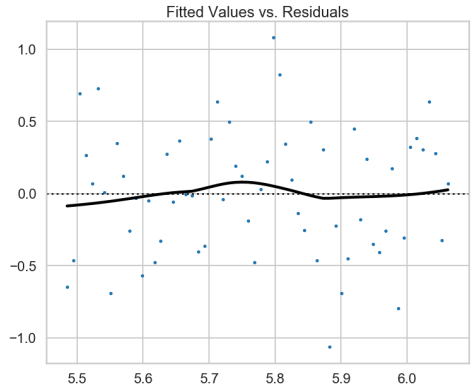




The box plots show a difference for the 1990…1995 period. It looks like the data is not symmetrical, the position for the median is close to the 3rd quartile before 1990 and close to the first quartile after 1995.

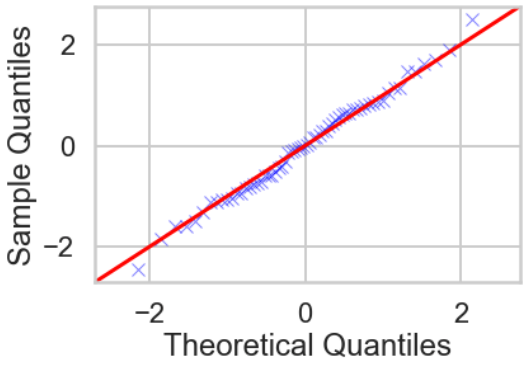
From the diagram on the right, the CO2 ECDF follows more or less the theoretical CDF for a normal distribution.



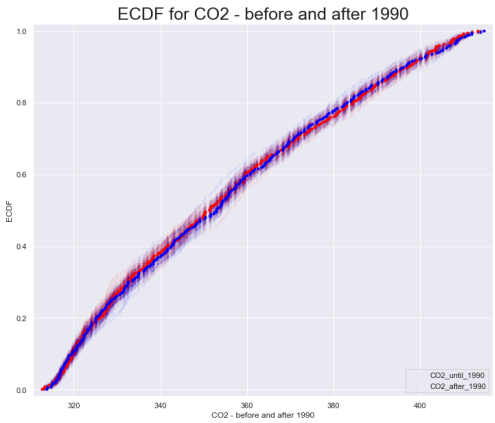


I am showing again the yearly CO2 difference in order to compare it with the fitted against residuals diagram. The residuals look good, with a slow increase between 5.5 and 6.3 and a slow decrease around 5.8. In the left diagram, the 5.8 value is exactly in the period 1990…1995 so the 1990…1995 anomaly is real.

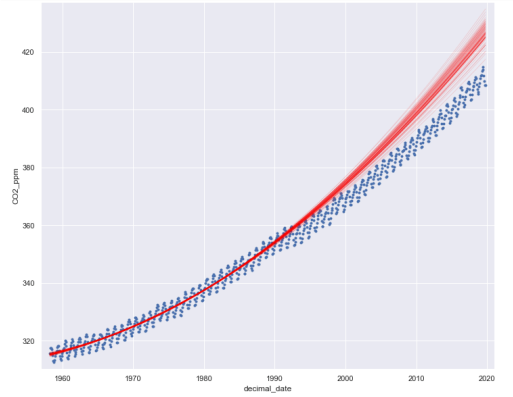
As shown on the right, the theoretical quantile align well with the sample quantiles so the CO2 yearly difference distribution is normal.



I am defining H0 by stating that the standard deviations of the two distributions before 1990 and after 1995 are identical. From the discussion above they might be different so H0 might be rejected but only by using statistical models. Using poly fit order 2 with the data until 1990 and extrapolating until 2020 shows that CO2 increase slowed down after 1990:



A better way to explore the variance inherent in the data is to use bootstrap replicates. I am showing 1000 bootstrap replicates calculated only with the data until 1990:

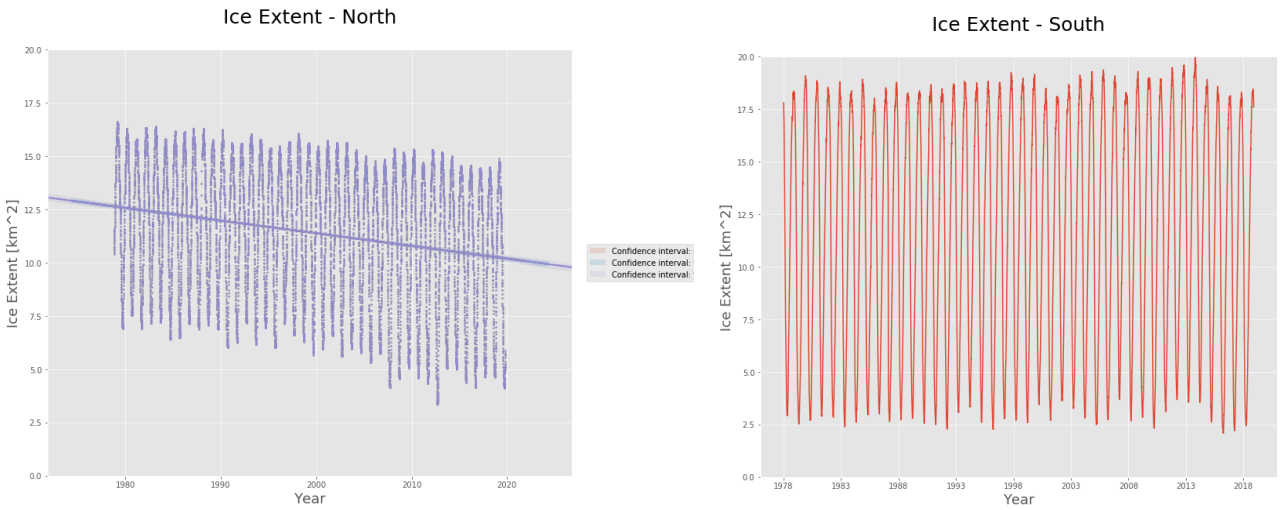


Even by choosing the lowest curve from the 1000 bootstrap replicates, the predicted CO2 value for 2020 (417.39 ppm) is higher than the maximum CO2 value measured so far (405.12 to 414.66 ppm in 2018 and 2019). This should make us believe that H0 can be rejected. However, for rejecting H0, ECDF must be calculated for the data before 1990 and after 1995:

There is no obvious difference between the two ECDF curves and the bootstrap replicas created from the full dataset. Furthermore, p-value is calculated as 1.0. Therefore, H0 cannot be rejected if the test consists of the standard deviation. Actually, the trend did not change, the 1990… 1995 period is just a delay in the long-term CO2 trend.

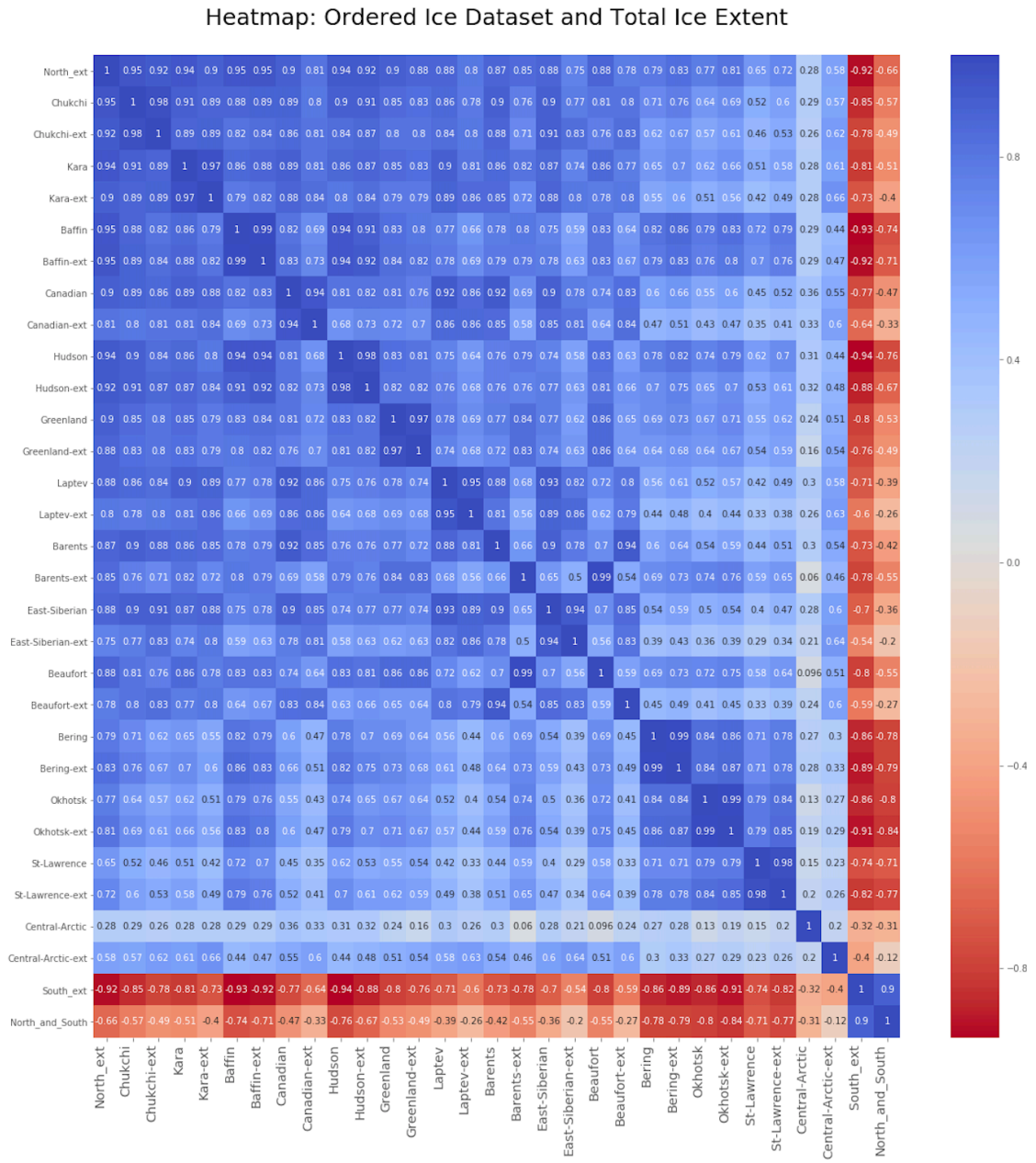
Exploratory Data Analysis - ice

The ice extent at the North is slowly decreasing while the ice extent at the South does not show any trend:



By adding all the Northern Seas to the North and South ice extent, I created a heat map ordered by Pearson correlation. As a metric I used the absolute value of L1. All the ice extents from the Northern Seas are positively correlated. Chukchi Sea is also highly correlated to the North extent, because it is just North of the Bering strait and there is a lot of ice movement around that area. At the other end, St. Lawrence and Central Arctic are less correlated because there are either no currents around (Central Arctic) or a very slow ice and water movement (St. Lawrence). As expected, North and South ice extents have the highest (negative) correlations.

The added feature “North and South” just adds up the data for North and for South. There is a strong correlation of 0.9 between South ice and North and South. This means that 90% of the variance of the total ice is explained by the variance of the ice on the South. This is to be expected, taking into account the huge ice sheet of Antarctica.

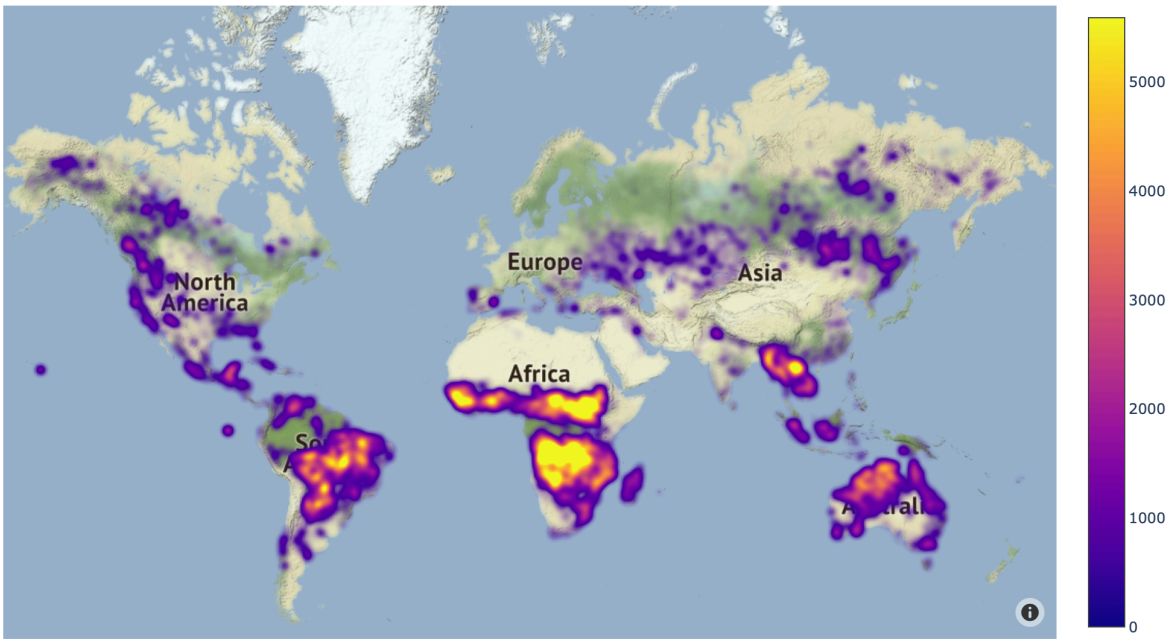


The project will continue to analyze the link between all these ice features, CO2 data and forest fires.

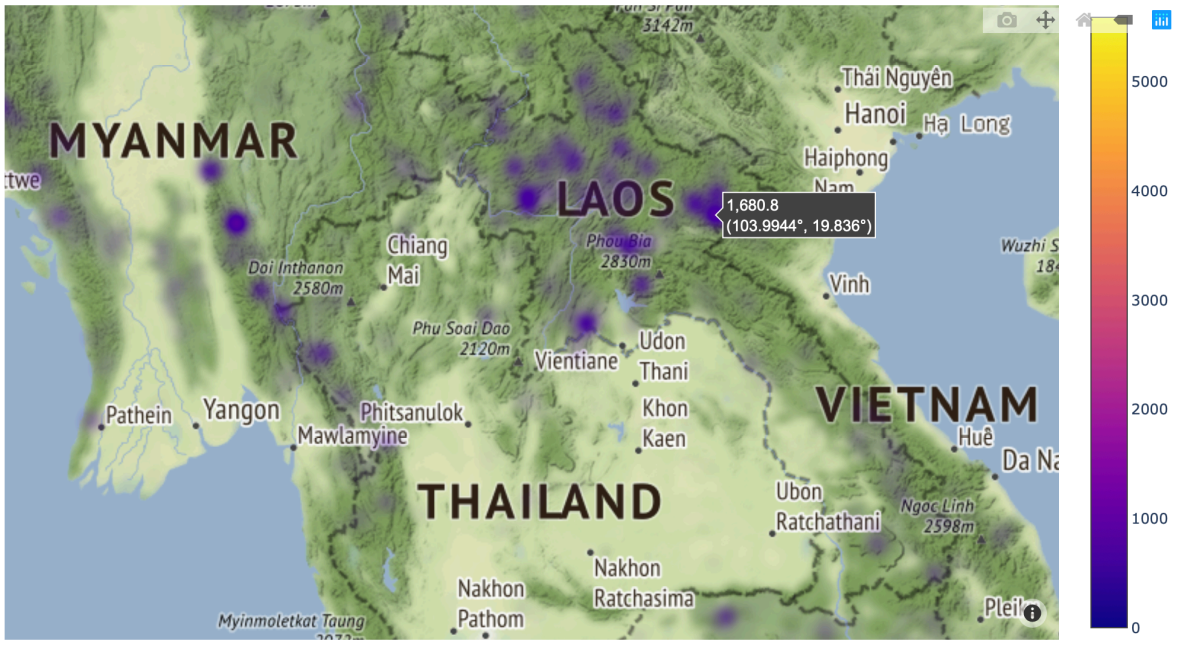
One of the tests will refer to sensitivity to CO2 data by trying to pinpoint if the 1990…1995 CO2 anomaly can be detected on ice data and for which seas.

Exploratory Data Analysis - fire

The last type of data are related to forest fires. A quick look on 20 years of forest fires data is shown above. It is interesting to see that the forest fires in Africa were much more intense than the fires in the Amazonian forest or the ones in Australia. The data does not include the Australian forest fires from December 2019 and January 2020. Data acquisition ended in October 2019.



Plotly allows showing on the map any features for observations that have a longitude and latitude. Zooming in can provide useful insights regarding the data, before statistical analysis. For example, this is a detail for South-East Asia:



The interactive plot shows that the highest radiative power (1680.8 W/m2) is located in a small area in the North-East of Laos. Future analysis will focus on trends of these forest fires and correlations to CO2 increase and ice loss worldwide.

Annex - References for Datasets

Sea Ice data (daily):

Fetterer, F., K. Knowles, W. N. Meier, M. Savoie, and A. K. Windnagel 2017, updated daily. Sea Ice Index, Version 3. [subset Sea_Ice_Index_Regional_Daily_Data_G02135_v3.0]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.7265/N5K072F8. [Date Accessed].
As specified in the User Guide for the data, “On monthly extent images, ice ends and water begins where the concentration estimates of grid cells for that month drop below 15 percent.”
Data downloaded from:
ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/data/
N_seaice_extent_daily_v3.0.csv
ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/data/
S_seaice_extent_daily_v3.0.csv
ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/seaice_analysis/
Sea_Ice_Index_Regional_Daily_Data_G02135_v3.0.xlsx

CO2 data (monthly):

C. D. Keeling, S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and H. A. Meijer, Exchanges of atmospheric CO2 and 13CO2 with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects, SIO Reference Series, No. 01-06, Scripps Institution of Oceanography, San Diego, 88 pages, 2001.
Data downloaded from: scrippsco2.ucsd.edu/assets/data/atmospheric/stations/in_situ_co2/monthly/monthly_in_situ_co2_mlo.csv

Forest Fires, satellite data (daily):

NRT VIIRS 375 m Active Fire product VNP14IMGT. Available on-line [https://earthdata.nasa.gov/firms]. doi: 10.5067/FIRMS/VIIRS/VNP14IMGT.NRT.001.
MODIS Collection 6 NRT Hotspot / Active Fire Detections MCD14DL. Available on-line [https://earthdata.nasa.gov/firms]. doi: 10.5067/FIRMS/MODIS/MCD14DL.NRT.006
Data downloaded from: https://firms.modaps.eosdis.nasa.gov/download/