Time Series Analisys on Geoespatial Data with Python

Author: João Otavio Nascimento Firigato

email: joaootavionf007@gmail.com

LinkedIn: https://www.linkedin.com/in/jo%C3%A3o-otavio-firigato-4876b3aa/

First instructions:

✅ Access the link to join our private WhatsApp community for students: https://chat.whatsapp.com/EPn27ZgR07lF3e1vnj8FiI

❗ It is important to access the Whatsapp Group to get the Colab Notebooks, as the PDF files are protected from text copying.

Chapter 4 - Working with image time series with GEE

Let's start by importing the libraries

In [ ]:
```
import ee
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import geemap
import geopandas as gpd
import warnings
warnings.filterwarnings('ignore')
```

Let's authenticate and initialize the GEE library

In [ ]:
```
ee.Authenticate()
ee.Initialize(project='my-project-1527255156007')
```

In [ ]:
```
from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

We select our analysis area and convert it to a FeatureCollection:

Link to Dataset: https://drive.google.com/drive/folders/1B2O_kfc_Ntfu2eeNVFBHdPPhH8iI_VDy?usp=sharing

In [ ]:
```python
path_aoi_soja = '/content/drive/MyDrive/Datasets_TS/AOI_cana/cana_lotes.shp'
```

In [ ]:
```python
gdf_soja = gpd.read_file(path_aoi_soja)
```

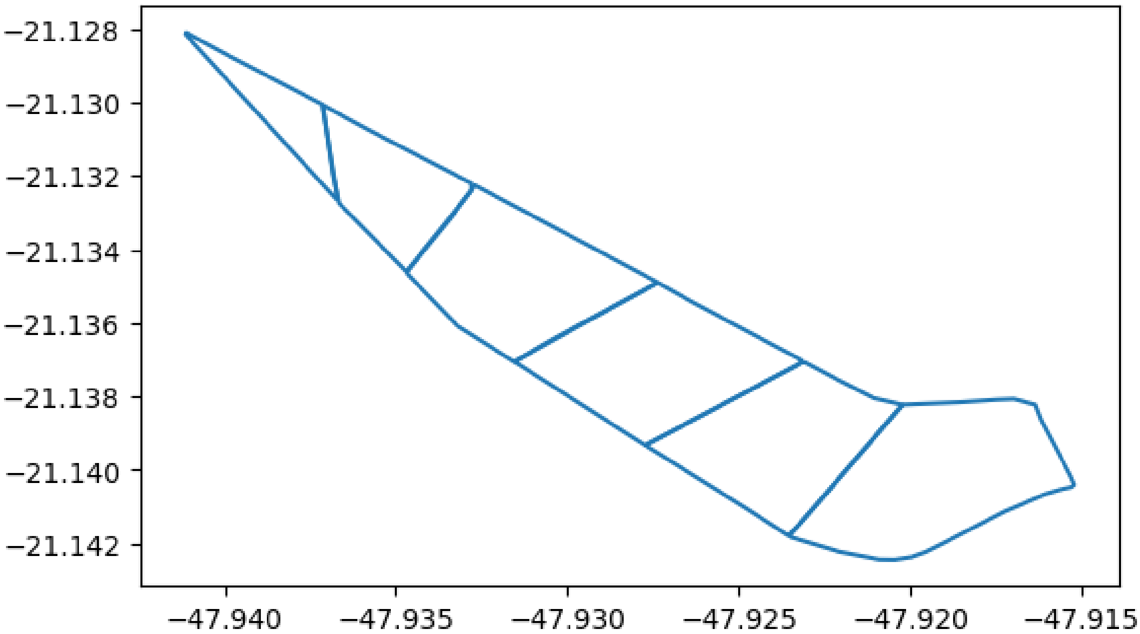
In [ ]:
```python
gdf_soja
```

Out[ ]:

	id	geometry
0	NaN	POLYGON ((-47.93468 -21.13461, -47.9334 -21.13...
1	NaN	POLYGON ((-47.93154 -21.13705, -47.92954 -21.1...
2	NaN	POLYGON ((-47.9231 -21.13705, -47.92215 -21.13...
3	NaN	POLYGON ((-47.93712 -21.13007, -47.93579 -21.1...
4	NaN	POLYGON ((-47.94116 -21.12812, -47.94111 -21.1...
5	NaN	POLYGON ((-47.92352 -21.14178, -47.92319 -21.1...

In [ ]:
```python
gdf_soja.boundary.plot()
```

Out[ ]: <Axes: >



In [ ]:
```python
fc = geemap.geopandas_to_ee(gdf_soja)
```

In [ ]:
```python
fc
```

Out[ ]:

▶ FeatureCollection (6 elements, 1 column)

Let's get an ImageCollection of Sentinel 2 from 2017 to 2024:

In [ ]:
```python
S2_coll = ee.ImageCollection("COPERNICUS/S2_SR_HARMONIZED").filter(ee.Filter.lt(
```

In [ ]:
```
print('Total number of images :', S2_coll.size().getInfo())
```

```
Total number of images : 162
```

We will create a folder to store the images:

In [ ]:
```
!mkdir sentinel_2_by_year
```

First we define a function to generate an image for each year:

In [ ]:
```
def create_image_collection_by_year(image_collection, fc, start_year, end_year):
  years = ee.List.sequence(start_year, end_year)

  def create_yearly_composite(year):
    start_date = ee.Date.fromYMD(year, 1, 1)
    end_date = ee.Date.fromYMD(year, 12, 31)

    year_image = image_collection \
        .filterDate(start_date, end_date) \
        .reduce(ee.Reducer.median()) \
        .set({'year': year})

    return year_image.clip(fc)

  yearly_composites = ee.ImageCollection.fromImages(
      years.map(create_yearly_composite))

  return yearly_composites
```

Then we apply it to our ImageCollection:

In [ ]:
```
start_year = 2019
end_year = 2023

yearly_s2_collection = create_image_collection_by_year(S2_coll, fc, start_year,
print('Total number of images :', yearly_s2_collection.size().getInfo())
```

```
Total number of images : 5
```

Let's visualize the results:

In [ ]:
```
Map = geemap.Map()
Map.centerObject(fc)

# Function to display an image on the map
def display_image(image):
  vis_params = {
      'bands': ['B4_median', 'B3_median', 'B2_median'],
      'min': 0,
      'max': 3000,
      'gamma': 1.4
  }
  Map.addLayer(image, vis_params, str(image.get('year').getInfo()))

# Iterate through the yearly image collection and display each image
for i in range(yearly_s2_collection.size().getInfo()):
    image = ee.Image(yearly_s2_collection.toList(yearly_s2_collection.size()).ge
    display_image(image)
```

```
Map
```

In [ ]:
```
start_year = 2019
end_year = 2023
```

This way we can export the images:

In [ ]:
```
geemap.ee_export_image_collection(
    yearly_s2_collection,
    out_dir="./sentinel_2_by_year",
    scale=20,
    crs='EPSG:4326',
    region=fc.geometry(),
    filenames= yearly_s2_collection.aggregate_array("year").getInfo(),
    file_per_band=False,
    timeout=300,
    proxies=None
)
```

Now we install rasterio to open the downloaded images and display them:

In [ ]:
```
!pip install rasterio
```

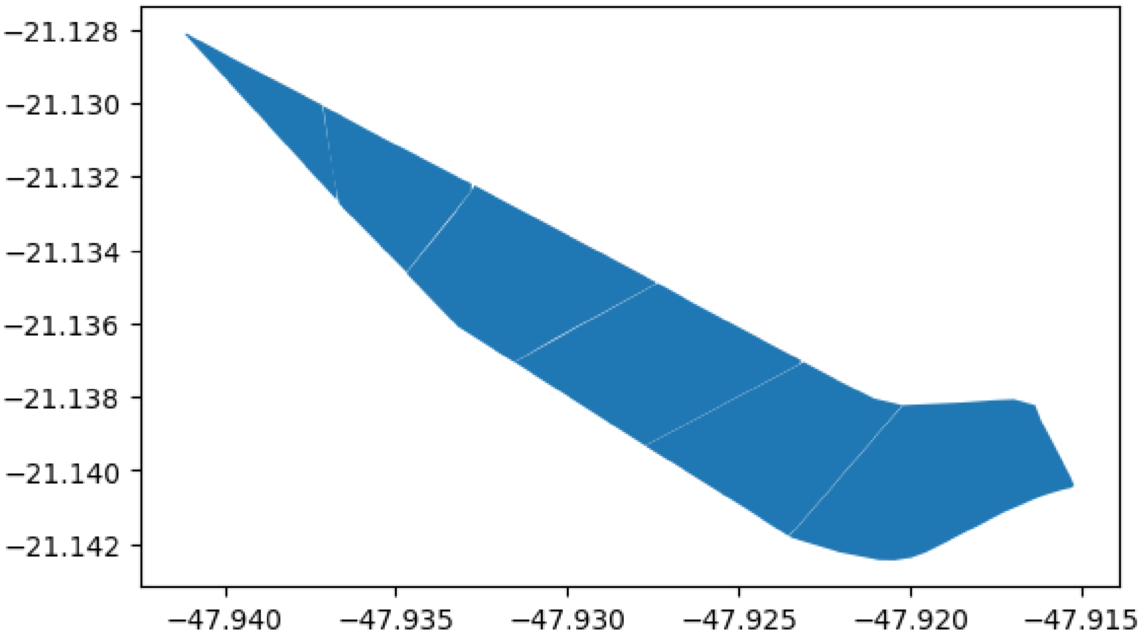
```
Collecting rasterio
  Downloading rasterio-1.4.3-cp311-cp311-manylinux_2_17_x86_64.manylinux2014_x86_
64.whl.metadata (9.1 kB)
Collecting affine (from rasterio)
  Downloading affine-2.4.0-py3-none-any.whl.metadata (4.0 kB)
Requirement already satisfied: attrs in /usr/local/lib/python3.11/dist-packages
(from rasterio) (25.3.0)
Requirement already satisfied: certifi in /usr/local/lib/python3.11/dist-packages
(from rasterio) (2025.4.26)
Requirement already satisfied: click>=4.0 in /usr/local/lib/python3.11/dist-packa
ges (from rasterio) (8.2.0)
Collecting cligj>=0.5 (from rasterio)
  Downloading cligj-0.7.2-py3-none-any.whl.metadata (5.0 kB)
Requirement already satisfied: numpy>=1.24 in /usr/local/lib/python3.11/dist-pack
ages (from rasterio) (2.0.2)
Collecting click-plugins (from rasterio)
  Downloading click_plugins-1.1.1-py2.py3-none-any.whl.metadata (6.4 kB)
Requirement already satisfied: pyparsing in /usr/local/lib/python3.11/dist-packag
es (from rasterio) (3.2.3)
Downloading rasterio-1.4.3-cp311-cp311-manylinux_2_17_x86_64.manylinux2014_x86_6
4.whl (22.2 MB)
   ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 22.2/22.2 MB 53.6 MB/s eta 0:00:00
Downloading cligj-0.7.2-py3-none-any.whl (7.1 kB)
Downloading affine-2.4.0-py3-none-any.whl (15 kB)
Downloading click_plugins-1.1.1-py2.py3-none-any.whl (7.5 kB)
Installing collected packages: cligj, click-plugins, affine, rasterio
Successfully installed affine-2.4.0 click-plugins-1.1.1 cligj-0.7.2 rasterio-1.4.
3
```

In [ ]:
```
import rasterio
import matplotlib.pyplot as plt
import os

image_dir = './sentinel_2_by_year'
```

```
for filename in os.listdir(image_dir):
    if filename.endswith('.tif'):
        filepath = os.path.join(image_dir, filename)

        with rasterio.open(filepath) as src:
            R = src.read(4)  # Band 4 (Red)
            G = src.read(3)  # Band 3 (Green)
            B = src.read(2)  # Band 2 (Blue)

            rgb = np.dstack((R, G, B))
            rgb = (rgb / 4000)


            plt.figure(figsize=(10, 10))
            plt.imshow(rgb)
            plt.title(filename)
            plt.axis('off')
            plt.show()
```

In [ ]:
```
gdf_soja.plot()
```

Out[ ]: <Axes: >



Let's now extract information from the polygons and images:

In [ ]:
```
import json
import rasterio
from rasterio.mask import mask
```

In [ ]:
```
total_gdf = gdf_soja.dissolve()
```

We start with NDVI information by year and for the entire area:

In [ ]:
```
ndvi_data = []
for year in range(start_year, end_year + 1):
  src_img = rasterio.open(f'./sentinel_2_by_year/{year}.tif')
  for feat in json.loads(total_gdf.to_json())['features']:
```

```
    out_img, _ = mask(dataset=src_img, shapes=[feat['geometry']], crop=True, nod

    nir = out_img[8, :, :]
    red = out_img[4, :, :]

    #Calculate NDVI, handling potential division by zero
    ndvi = np.where(red != 0, (nir - red) / (nir + red), np.nan)

    # Exclude nodata values (-9999) and NaN values when calculating mean
    valid_pixels = ndvi[ndvi != -9999]
    valid_pixels = valid_pixels[~np.isnan(valid_pixels)]
    mean_ndvi = np.nanmean(valid_pixels)

    print(f"Mean NDVI for year {year}: {mean_ndvi}")
    ndvi_data.append({'year': year, 'mean_ndvi': mean_ndvi})
ndvi_df = pd.DataFrame(ndvi_data)
```

```
WARNING:rasterio._env:CPLE_AppDefined in 2019.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2020.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2021.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2022.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
Mean NDVI for year 2019: 0.11235534825508786
Mean NDVI for year 2020: 0.12091211683305336
Mean NDVI for year 2021: 0.10815726939512024
WARNING:rasterio._env:CPLE_AppDefined in 2023.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
Mean NDVI for year 2022: 0.09125206936978875
Mean NDVI for year 2023: 0.10601139752554287
```

In [ ]:

```
ndvi_df
```

Out[ ]:

	year	mean_ndvi
0	2019	0.112355
1	2020	0.120912
2	2021	0.108157
3	2022	0.091252
4	2023	0.106011

We can also generate information by year and by polygon:

In [ ]:

```
ndvi_by_polygon = []
for year in range(start_year, end_year + 1):
  src_img = rasterio.open(f'./sentinel_2_by_year/{year}.tif')
  for feat in json.loads(gdf_soja.to_json())['features']:
    out_img, _ = mask(dataset=src_img, shapes=[feat['geometry']], crop=True, nod
```

```
    nir = out_img[8, :, :]
    red = out_img[4, :, :]

    #Calculate NDVI, handling potential division by zero
    ndvi = np.where(red != 0, (nir - red) / (nir + red), np.nan)

    # Exclude nodata values (-9999) and NaN values when calculating mean
    valid_pixels = ndvi[ndvi != -9999]
    valid_pixels = valid_pixels[~np.isnan(valid_pixels)]
    mean_ndvi = np.nanmean(valid_pixels)
    ndvi_by_polygon.append({'year': year, 'mean_ndvi': mean_ndvi, 'id_polygon':
ndvi_polygon_df = pd.DataFrame(ndvi_by_polygon)
```

```
WARNING:rasterio._env:CPLE_AppDefined in 2019.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2020.tif: TIFFReadDirectory:Sum of Photo
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l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2021.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2022.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2023.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
```

In [ ]:

```
ndvi_polygon_df
```

Out[ ]:

	year	mean_ndvi	id_polygon
0	2019	0.211833	0
1	2019	0.222753	1
2	2019	0.215872	2
3	2019	0.243543	3
4	2019	0.102792	4
5	2019	0.271991	5
6	2020	0.243169	0
7	2020	0.253338	1
8	2020	0.248999	2
9	2020	0.227691	3
10	2020	0.089343	4
11	2020	0.279476	5
12	2021	0.222637	0
13	2021	0.229863	1
14	2021	0.221499	2
15	2021	0.218580	3
16	2021	0.083739	4
17	2021	0.233424	5
18	2022	0.199790	0
19	2022	0.211180	1
20	2022	0.200020	2
21	2022	0.164285	3
22	2022	0.061607	4
23	2022	0.172599	5
24	2023	0.210022	0
25	2023	0.217239	1
26	2023	0.207668	2
27	2023	0.197545	3
28	2023	0.085981	4
29	2023	0.259470	5

And finally we will create some spectral indices and obtain the information by year and by plot:

In [ ]:

```
ndvi_ndre_ndwi_by_polygon = []
for year in range(start_year, end_year + 1):
  src_img = rasterio.open(f'./sentinel_2_by_year/{year}.tif')
  for feat in json.loads(gdf_soja.to_json())['features']:
    out_img, _ = mask(dataset=src_img, shapes=[feat['geometry']], crop=True, nod

    nir = out_img[8, :, :]
    red = out_img[4, :, :]
    re = out_img[5, :, :]
    green = out_img[3, :, :]

    #Calculate NDVI
    ndvi = np.where(red != 0, (nir - red) / (nir + red), np.nan)
    #Calculate NDRE
    ndre = np.where(nir != 0, (nir - re) / (nir + re), np.nan)
    #Calculate NDWI
    ndwi = np.where((green + nir) != 0, (green - nir) / (green + nir), np.nan)

    # Exclude nodata values (-9999) and NaN values when calculating mean
    valid_pixels_ndvi = ndvi[ndvi != -9999]
    valid_pixels_ndvi = valid_pixels_ndvi[~np.isnan(valid_pixels_ndvi)]
    mean_ndvi = np.nanmean(valid_pixels_ndvi)

    valid_pixels_ndre = ndre[ndre != -9999]
    valid_pixels_ndre = valid_pixels_ndre[~np.isnan(valid_pixels_ndre)]
    mean_ndre = np.nanmean(valid_pixels_ndre)

    valid_pixels_ndwi = ndwi[ndwi != -9999]
    valid_pixels_ndwi = valid_pixels_ndwi[~np.isnan(valid_pixels_ndwi)]
    mean_ndwi = np.nanmean(valid_pixels_ndwi)


    ndvi_ndre_ndwi_by_polygon.append({'year': year, 'mean_ndvi': mean_ndvi, 'mea
ndvi_ndre_ndwi_polygon_df = pd.DataFrame(ndvi_ndre_ndwi_by_polygon)
```

```
WARNING:rasterio._env:CPLE_AppDefined in 2019.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2020.tif: TIFFReadDirectory:Sum of Photo
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l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2021.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2022.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
WARNING:rasterio._env:CPLE_AppDefined in 2023.tif: TIFFReadDirectory:Sum of Photo
metric type-related color channels and ExtraSamples doesn't match SamplesPerPixe
l. Defining non-color channels as ExtraSamples.
```

In [ ]:

```
ndvi_ndre_ndwi_polygon_df
```

Out[ ]:

	year	mean_ndvi	mean_ndre	mean_ndwi	id_polygon
0	2019	0.211833	0.071175	-0.292873	0
1	2019	0.222753	0.074579	-0.308874	1
2	2019	0.215872	0.071267	-0.296813	2
3	2019	0.243543	0.058453	-0.335602	3
4	2019	0.102792	0.024878	-0.147474	4
5	2019	0.271991	0.078054	-0.351619	5
6	2020	0.243169	0.056209	-0.339234	0
7	2020	0.253338	0.059032	-0.354262	1
8	2020	0.248999	0.060208	-0.341119	2
9	2020	0.227691	0.058162	-0.314856	3
10	2020	0.089343	0.025259	-0.130339	4
11	2020	0.279476	0.065116	-0.401848	5
12	2021	0.222637	0.060281	-0.320042	0
13	2021	0.229863	0.065044	-0.331048	1
14	2021	0.221499	0.058338	-0.318446	2
15	2021	0.218580	0.050339	-0.307804	3
16	2021	0.083739	0.020576	-0.121875	4
17	2021	0.233424	0.061486	-0.350738	5
18	2022	0.199790	0.056870	-0.295521	0
19	2022	0.211180	0.060725	-0.310015	1
20	2022	0.200020	0.057007	-0.290526	2
21	2022	0.164285	0.051227	-0.237701	3
22	2022	0.061607	0.021142	-0.091213	4
23	2022	0.172599	0.059635	-0.269935	5
24	2023	0.210022	0.062079	-0.296140	0
25	2023	0.217239	0.064826	-0.306923	1
26	2023	0.207668	0.061425	-0.292091	2
27	2023	0.197545	0.052667	-0.228555	3
28	2023	0.085981	0.022509	-0.108081	4
29	2023	0.259470	0.071183	-0.368327	5

Timelapses

One feature of the geemap library is the creation of timelapses. Let's create some:

In [ ]:
```
Map = geemap.Map()
```

In [ ]:
```
roi = Map.user_roi
if roi is None:
    roi = ee.Geometry.BBox(-18.6983, -36.1630, 52.2293, 38.1446)
    Map.addLayer(roi)
    Map.centerObject(roi)
```

First one using NDVI from the MODIS satellite

In [ ]:
```
timelapse = geemap.modis_ndvi_timelapse(
    roi,
    out_gif='ndvi.gif',
    data='Terra',
    band='NDVI',
    start_date='2000-01-01',
    end_date='2022-12-31',
    frames_per_second=3,
    title='MODIS NDVI Timelapse',
    overlay_data='countries',
)
geemap.show_image(timelapse)
```

In [ ]:
```
roi = ee.Geometry.BBox(-171.21, -57.13, 177.53, 79.99)
Map.addLayer(roi)
Map.centerObject(roi)
```

Then the temperature of the oceans:

In [ ]:
```
timelapse = geemap.modis_ocean_color_timelapse(
    satellite='Aqua',
    start_date='2018-01-01',
    end_date='2020-12-31',
    roi=roi,
    frequency='month',
    out_gif='temperature.gif',
    overlay_data='continents',
    overlay_color='yellow',
    overlay_opacity=0.5,
)
geemap.show_image(timelapse)
```

In [ ]:
```
from IPython.display import Image

Image(filename='temperature.gif')
```

Thank you! See you in the next Chapter!