Prediction of the daily mean level of PM10 in Italy in 2020

Github repository here.

General description

The aim of this work is to build machine learning models for predicting the daily mean level of PM10 in Italy in 2020.
Both air quality data and meteorological data will be taken into account.

The data will be processed several times, with different techniques, in order to find the best features and the best dataset. This search is performed with an incremental approach, effectuating a sequence of steps. At each step, several processing alternatives are built and evaluated: the best alternative is then selected and, if his addition on the current dataset does improve the performance, that new feature is added.

Practically speaking, each dataset is evaluated by building a machine learning model on it. For each dataset, four different models are taken into account: each of them is evaluated testing all the possible combinations of some hyperparameters in an exhaustive way. The following list is the list of the four models, with the associated grid of hyperparameters to test.

```
model_paramGrid_list = [
 ("kNN", KNeighborsRegressor(), {"n_neighbors":range(1,45),
                                 "weights":["uniform","distance"]}),
 ("DT", DecisionTreeRegressor(), {"max_leaf_nodes":range(2,51),
                                  "max_features":[None,"sqrt"]}),
 ("PR", PolynomialRegression(), {"degree":[1,2,3,4]}),
 ("RF", RandomForestRegressor(), {"n_estimators":range(1,51),
                                  "max_features":[None,"sqrt"]})
]
```

In the end, the best dataset and the best model are selected (i.e. the best couple dataset-model is selected).

The evaluating measure used during this incremental selection is the MSE cross validation score, which is an error measure: this means that the best couple dataset-model is the one which has associated the minimum validation score.

Prerequisites

The EEA-datasets-handler library will be used in order to acquire and handle the EEA air pollution datasets.

The ILMETEO-datasets-handler library will be used in order to acquire and handle the ILMETEO meteorological datasets.

The timeSeries-processing library will be used in order to process the time series datasets.

Finally, the model-selection library will be used in order to evaluate the machine learning models.

```
>>> import EEA_datasets_handler as eea
>>> import timeSeries_processing as tsp
>>> import model_selection as ms
```

Acquire the EEA air pollution datasets of PM10 in Italy in 2020

```
# Download the datasets
# IT'S NECESSARY ONLY IF THEY HAVEN'T BEEN DOWNLOADED YET
>>> dest_path = "C:\\Datasets"
>>> countries_cities_dict = {"IT": "all"}
>>> pollutants = ["PM10"]
>>> years = [2020]
>>> eea.download_datasets(dest_path, countries_cities_dict,
pollutants, years)

# Load the datasets
>>> source_path = "C:\\Datasets\\EEA"
>>> countries_cities_dict = {"IT":"all"}
>>> pollutants = ["PM10"]
>>> years = [2020]
>>> df = eea.load_datasets(source_path, countries_cities_dict,
pollutants, years)
```

`df` is a raw DataFrame, which simply contains the measurements: these are not grouped by day and are not cleaned properly.

Acquire the EEA air pollution datasets of PM10 in Italy in all the supported year (i.e. 2013-2020)

```
# Download the datasets
# IT'S NECESSARY ONLY IF THEY HAVEN'T BEEN DOWNLOADED YET
>>> dest_path = "C:\\Datasets"
>>> countries_cities_dict = {"IT": "all"}
>>> pollutants = ["PM10"]
>>> years = [2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020]
>>> eea.download_datasets(dest_path, countries_cities_dict,
pollutants, years)

# Load the datasets
>>> source_path = "C:\\Datasets\\EEA"
>>> countries_cities_dict = {"IT":"all"}
>>> pollutants = ["PM10"]
>>> years = [2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020]
>>> df = eea.load_datasets(source_path, countries_cities_dict,
pollutants, years)
```

`df_full` is a raw DataFrame, which simply contains the measurements: these are not grouped by day and are not cleaned properly.

Finally, also the meteorological datasets of ILMETEO will be used.
In particular,the meteorological data of the whole Italy are considered, with respect to 2020.
These data are loaded from the local storage ("meteorological_data_2020.csv") .
(See the appendix of the chapter about ILMETEO-datasets-handler).
These data will be loaded later on.

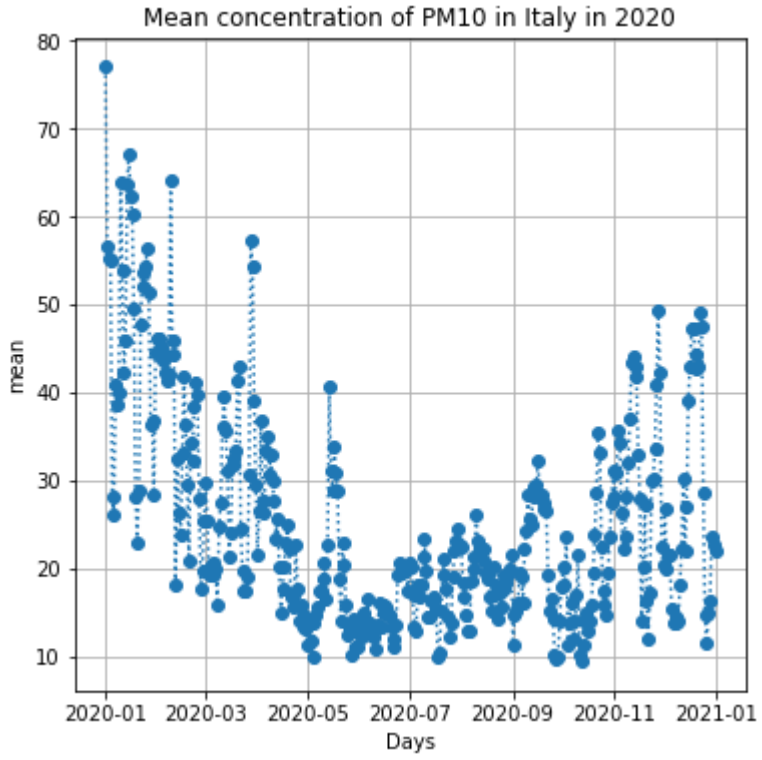
Plots

As the plots will show, the evolution over time of the PM10 concentration is strongly periodic.

Plot of the daily mean concentrations of PM10 in Italy in 2020.

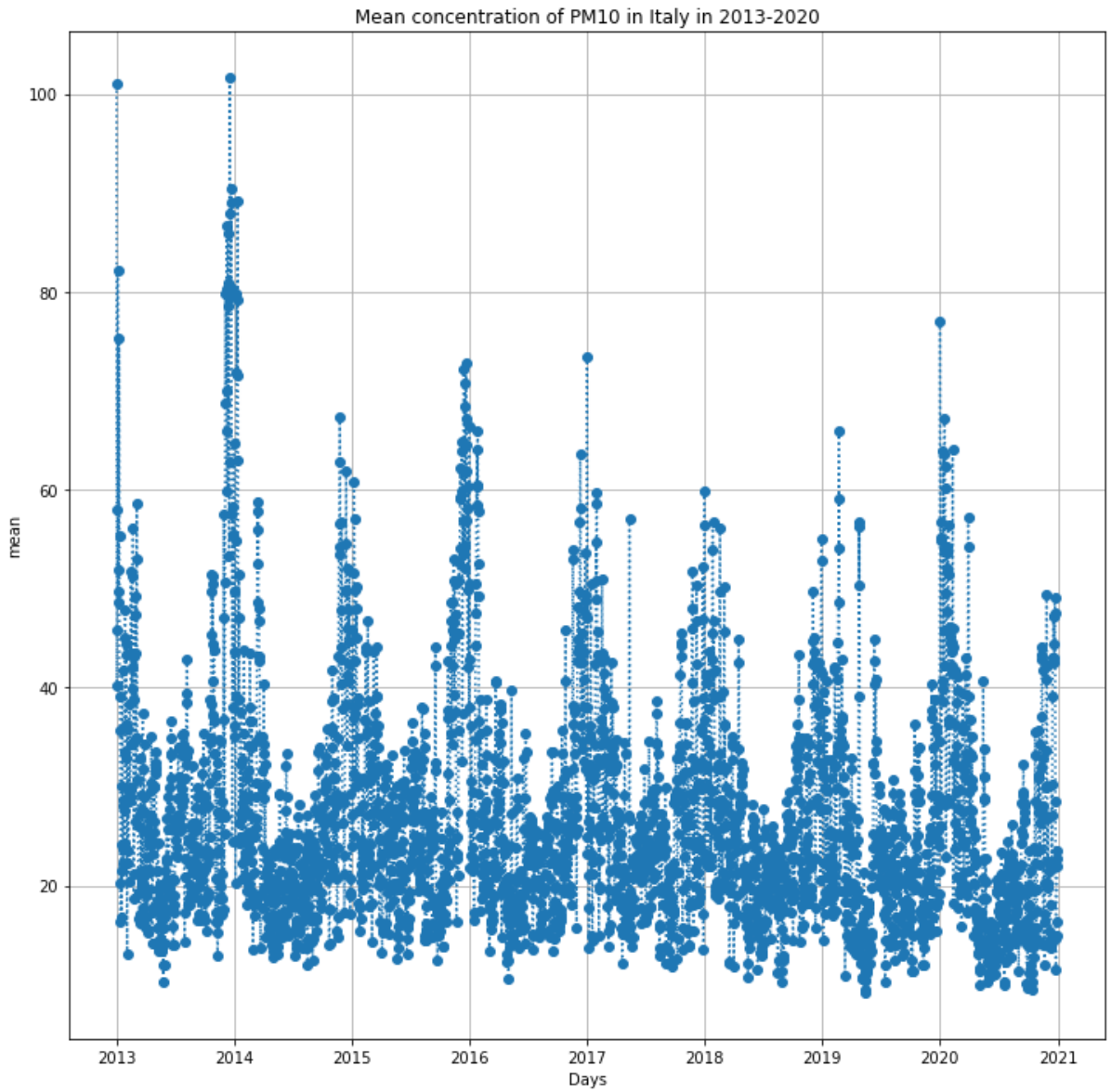
```
# Process the 2020 DataFrame (with an arbitrary `fill_n_days`)
>>> df_mean, _, _ = eea.preprocessing(df, fill=True,
fill_n_days=10 ,fill_aggr="mean")
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
```

```
'2020-02-11']

>>> df_mean
                mean
Datetime
2020-01-01  76.974569
2020-01-02  56.675791
2020-01-03  55.216906
2020-01-04  54.887035
2020-01-05  28.192059
...               ...
2020-12-27  14.997987
2020-12-28  16.317778
2020-12-29  23.536875
2020-12-30  22.759021
2020-12-31  22.005000

[366 rows x 1 columns]

>>> tsp.plot_timeSeries(df_mean, col_name="mean", title="Mean
concentration of PM10 in Italy in 2020", figsize=(6,6))
<AxesSubplot:title={'center':'Mean concentration of PM10 in Italy
in 2020'}, xlabel='Days', ylabel='mean'>
```

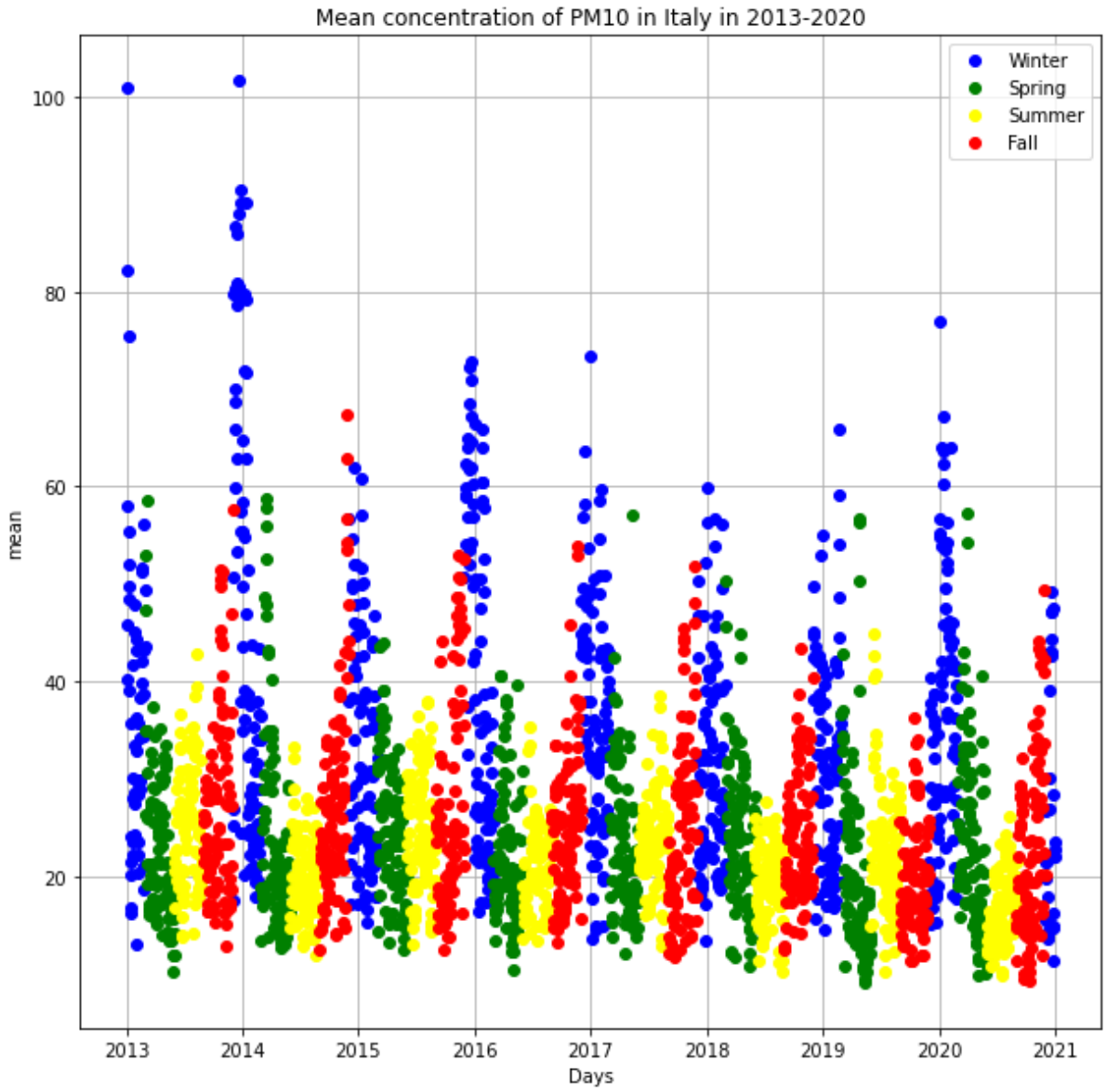


Plot of the daily mean concentrations of PM10 in Italy in all the supported years (2013-2020)

```
# Process the 2013-2020 DataFrame (with an arbitrary
`fill_n_days`)
>>> df_mean_full, _, _ = eea.preprocessing(df_full, fill=True,
fill_n_days=10 ,fill_aggr="mean")
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']

>>> df_mean_full
                mean
Datetime
2013-01-01  100.970568
2013-01-02  40.267997
2013-01-03  45.833017
2013-01-04  58.029136
2013-01-05  82.193141
...                ...
2020-12-27  14.997987
2020-12-28  16.317778
2020-12-29  23.536875
2020-12-30  22.759021
2020-12-31  22.005000

[2922 rows x 1 columns]

>>> tsp.plot_timeSeries(df_mean_full, col_name="mean", title="Mean
concentration of PM10 in Italy in 2013-2020", figsize=(12,12))
<AxesSubplot:title={'center':'Mean concentration of PM10 in Italy
in 2013-2020'}, xlabel='Days', ylabel='mean'>
```



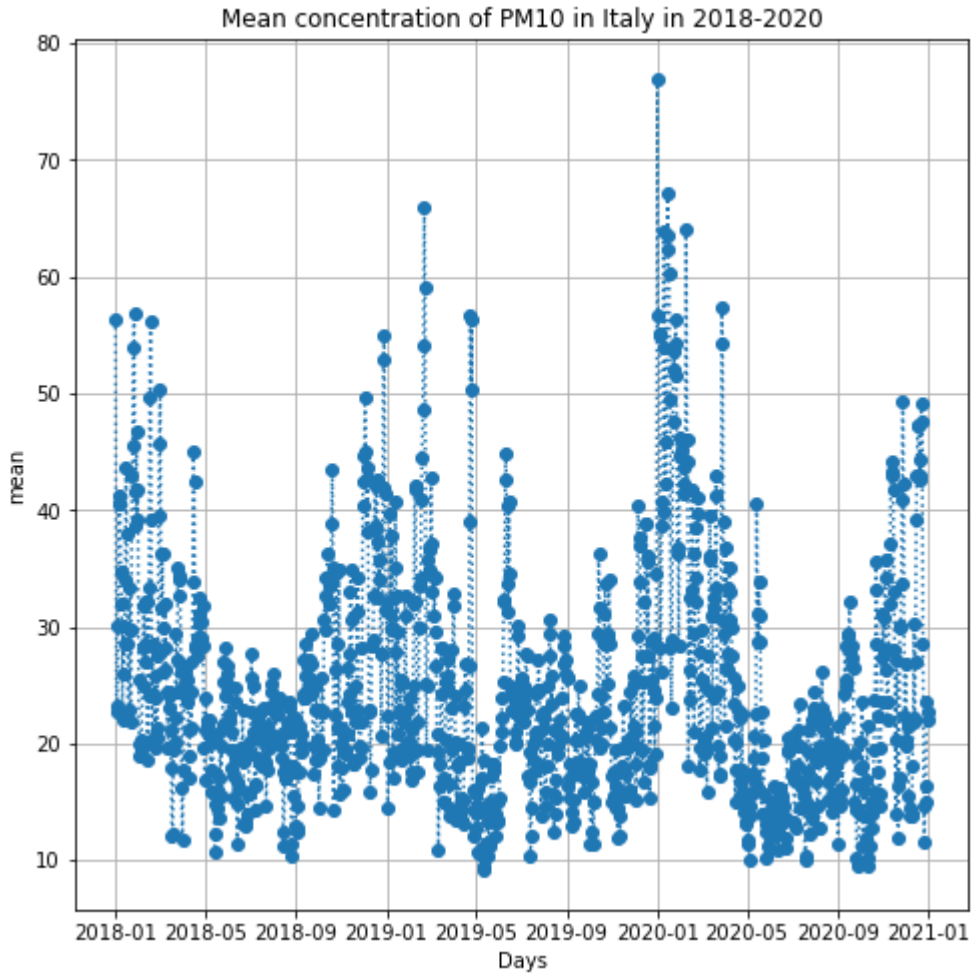

```
>>> tsp.plot_timeSeries(df_mean_full, col_name="mean",
divide="season", line=False, title="Mean concentration of PM10 in
Italy in 2013-2020", figsize=(10,10))
<AxesSubplot:title={'center':'Mean concentration of PM10 in Italy
in 2013-2020'}, xlabel='Days', ylabel='mean'>
```



Plot of the daily mean concentrations of PM10 in Italy during the years 2018-2020

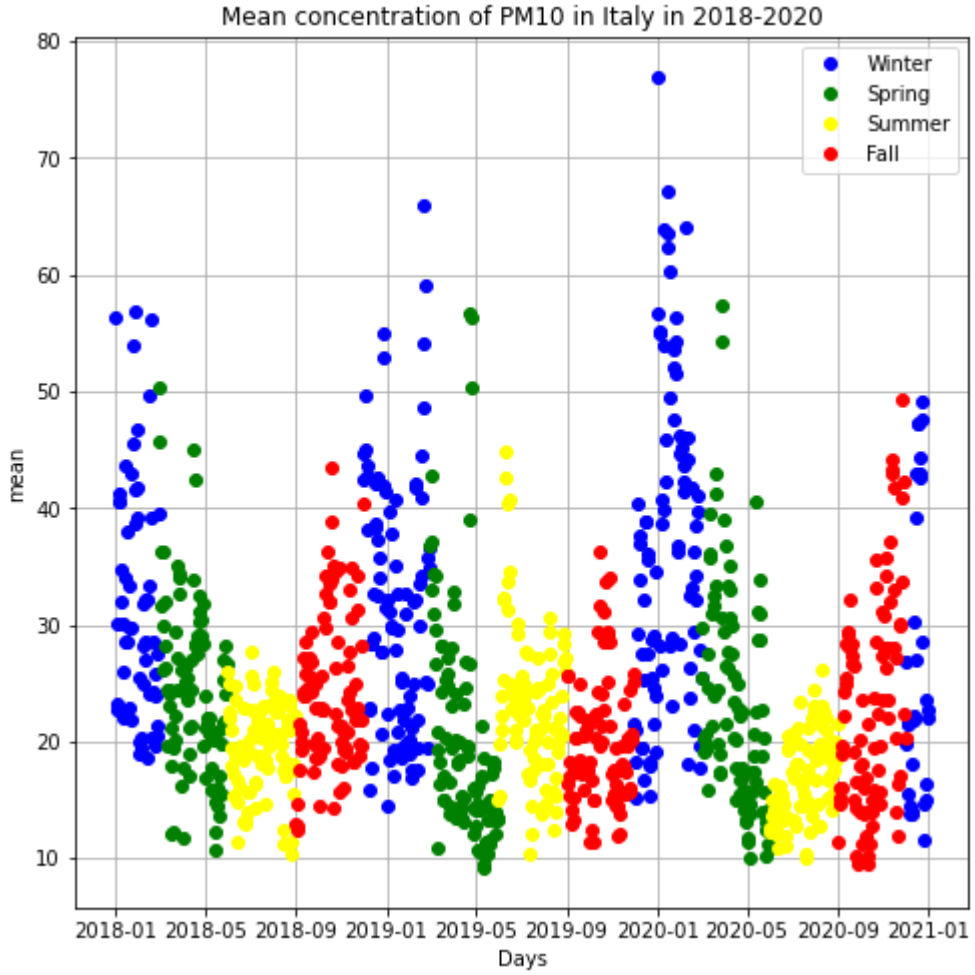
```
>>> df_mean_partial = df_mean_full[df_mean_full.index.map(lambda
day: day.year>=2018)]

>>> df_mean_partial
                mean
Datetime
2018-01-01  56.360286
2018-01-02  22.650771
2018-01-03  23.279466
```

```
2018-01-04  30.019436
2018-01-05  41.255582
...               ...
2020-12-27  14.997987
2020-12-28  16.317778
2020-12-29  23.536875
2020-12-30  22.759021
2020-12-31  22.005000

[2922 rows x 1 columns]

>>> tsp.plot_timeSeries(df_mean_partial, col_name="mean",
title="Mean concentration of PM10 in Italy in 2018-2020",
figsize=(8,8))
<AxesSubplot:title={'center':'Mean concentration of PM10 in Italy
in 2018-2020'}, xlabel='Days', ylabel='mean'>
```




```
>>> tsp.plot_timeSeries(df_mean_partial, col_name="mean",
```

```
divide="season", line=False, title="Mean concentration of PM10 in
Italy in 2018-2020", figsize=(8,8))
<AxesSubplot:title={'center':'Mean concentration of PM10 in Italy
in 2018-2020'}, xlabel='Days', ylabel='mean'>
```



Trivial model

Trivial model, which always predicts using the mean of all the daily mean concentrations of PM10 in all the supported years (2013-2020).

```
>>> from sklearn.metrics import mean_squared_error
>>> import numpy as np

# Process the 2013-2020 DataFrame (with an arbitrary
`fill_n_days`)
>>> df_mean_full,_,_ = eea.preprocessing(df_full, fill=True,
```

```
fill_n_days=10, fill_aggr="mean")
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']

# Split the DataFrame into X and y: the former contains only the
explanatory features, the latter only the response feature.
# To do that the function `tsp.split_X_y` is used.
>>> X,y = tsp.split_X_y(df_mean, y_col="mean",
                        scale_y=True) # Scale the y

# Splitting the dataset into training-validation-test sets, for
time series, with proportions 0.6-0.2-0.2
>>> train_len = int(X.shape[0]*(0.6))
>>> val_len = int(X.shape[0]*(0.2))
>>> y_val = y[train_len:train_len+val_len] # Validation set

# Trivial predictions
>>> y_pred = np.array([np.mean(y) for i in range(val_len)])

>>> val_score =  mean_squared_error(y_true=y_val, y_pred=y_pred)

>>> print("Validation score:", str(val_score))
Validation score: 0.015235327799312809
```

First models

Use k days ago to predict the current day

k new columns, which contain the daily mean level of PM10 in the k preceding days, are added into the 2020 DataFrame.

Two operations have to be made.

1. First of all, the 2020 raw DataFrame `df` needs to be processed and cleaned into a DataFrame containing the daily mean levels of PM10. The function `eea.processing` will be used. In order to do that, a value for the parameter

`fill_n_days` has to be chosen (i.e. the number of preceding days used to fill a missing day of the 2020 DataFrame).

2. After that, the function `tsp.add_k_previous_days` can be used, in order to create the k new features containing the daily mean level of PM10 in the k preceding days. To do so, a value for the parameter k has to be chosen.

To sum up, two choices have to be made at the same time: the choice for a specific value for `fill_n_days` and the choice for a specific value for k.

The value for `fill_n_days` is chosen among the values `[5, 10, 15, "all"]` (`"all"` means that all the previous days are used to fill a missing day); the value for k is chosen among the values `range(3,15)`. All the possible combinations of the couple `fill_n_days`-k are evaluated, i.e. an exhaustive selection is made. In the end, the best couple is selected.

```
>>> from sklearn.tree import DecisionTreeRegressor
>>> from sklearn.neighbors import KNeighborsRegressor
>>> from sklearn.ensemble import RandomForestRegressor

>>> range_fill_n_days = [5, 10, 15, "all"]
>>> range_k = range(3,15)
# All the datasets that have to be evaluated, one for each
possible combination of the couple `fill_n_days`-`k`
>>> dataset_list = [
    tsp.add_k_previous_days(eea.preprocessing(df, fill=True,
                                              fill_n_days=fill_n_days,
                                              fill_aggr="mean")[0],
                            col_name="mean", k=k, y_col="mean",
                            scale_y=True)[1:]
    for fill_n_days in range_fill_n_days for k in range_k
]
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
```

```
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
...

>>> model_paramGrid_list = [
 ("kNN", KNeighborsRegressor(), {"n_neighbors":range(1,45),
                                 "weights":["uniform","distance"]}),
 ("DT", DecisionTreeRegressor(), {"max_leaf_nodes":range(2,51),
                                  "max_features":[None,"sqrt"]}),
 ("PR", PolynomialRegression(), {"degree":[1,2,3,4]}),
 ("RF", RandomForestRegressor(), {"n_estimators":range(1,51),
                                  "max_features":[None,"sqrt"]})
]
>>> scale_list = [False,True,False,False]

>>> (datasets_train_val_score, datasets_best_model, best_index,
test_score, axes) = ms.datasets_models_validation(dataset_list,
model_paramGrid_list, scale_list=scale_list, time_series=True)
```

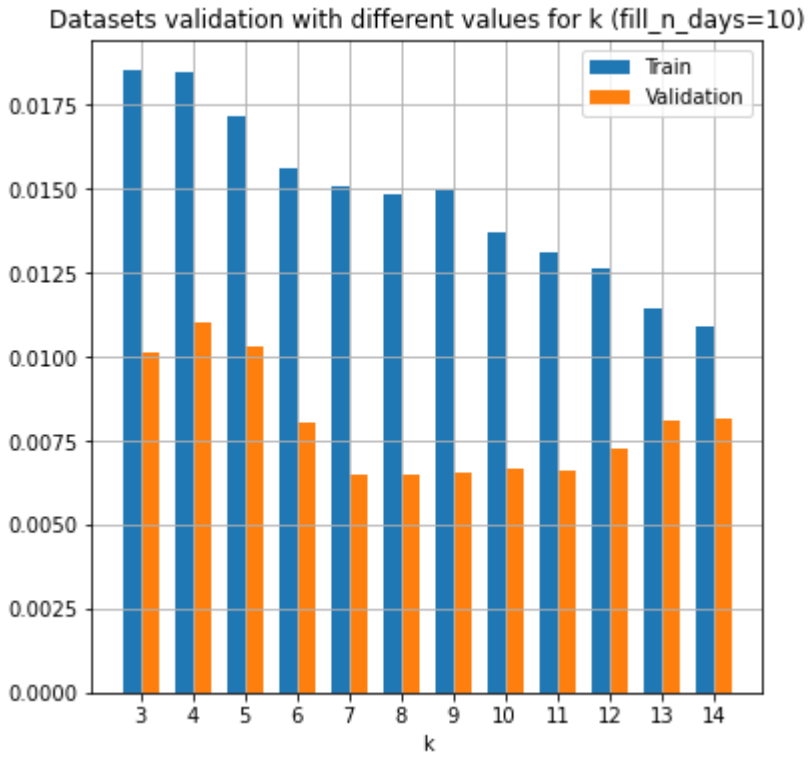
Here the results.

```
>>> print("Index best dataset:", str(best_index),
          "; fill_n_days-k:", xvalues[best_index])
Index best dataset: 16 ; fill_n_days-k: 10-7

>>> print("Best model:", datasets_best_model[best_index][1],
          " ; Hyperparameters values:",
          str(datasets_best_model[best_index][2]))
Best model: PR  ; Hyperparameters values: {'degree': 1}

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.00646793271790797

>>> print("Test score:", str(test_score))
Test score: 0.013199328929822 65
```

Now an example in which the value of `fill_n_days` has been fixed to `10`, in order to show the impact of different values for k on the performance.

```
# In this example only the Polynomial Regression model is used
```

```
>>> range_k = range(3,15)
>>> dataset_list = [
     tsp.add_k_previous_days(eea.preprocessing(df, fill=True,
                                               fill_n_days=10,
                                               fill_aggr="mean")[0],
                             col_name="mean", k=k, y_col="mean",
                             scale_y=True)[1:]
     for k in range_k]
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
...
>>> xvalues = [str(k) for k in range_k]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
best_index, test_score,
axes) = ms.datasets_hyperparameter_validation(dataset_list,
 model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="k",
 title="Datasets validation with different values for k
(fill_n_days=10)")
```



Best dataset: `fill_n_days=10` and k=7

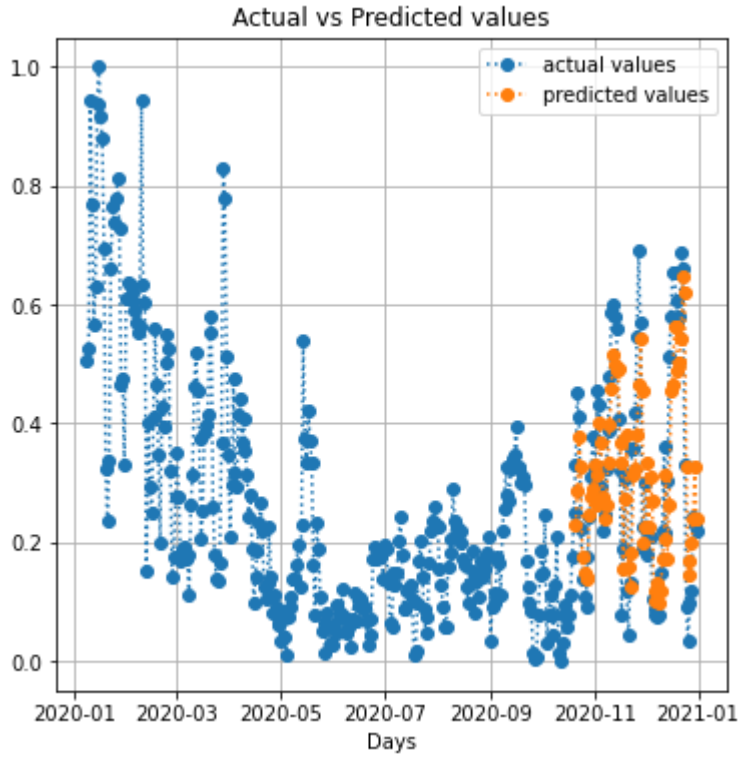
There has been an improvement as compared to the trivial model: the validation score has decreased from `0.01523` to `0.00647`

```
# Processing with `fill_n_days`=10
>>> df_mean, _, _ = eea.preprocessing(df, fill=True,
fill_n_days=10 ,fill_aggr="mean")
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']

# `k`=7
>>> df_mean_best, X, y = tsp.add_k_previous_days(df_mean,
col_name="mean", k=7, y_col="mean", scale_y=True)

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
```

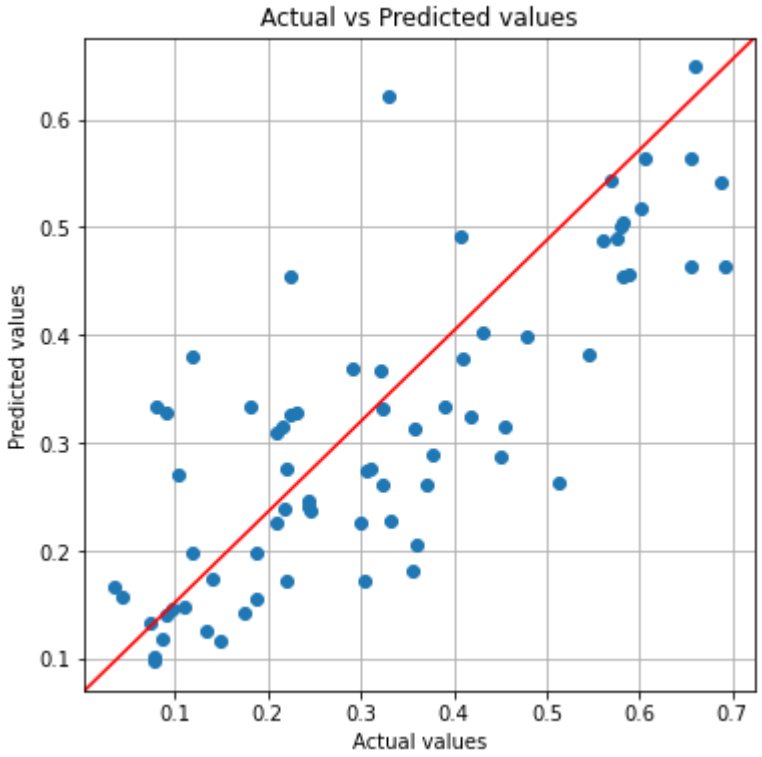
```
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7
Datetime
2020-01-08  55.216906   56.675791  76.974569
2020-01-09  54.887035   55.216906  56.675791
2020-01-10  28.192059   54.887035  55.216906
2020-01-11  26.099399   28.192059  54.887035
2020-01-12  40.759729   26.099399  28.192059
...               ...        ...        ...
2020-12-27  49.143828   43.004333  42.601218
2020-12-28  47.568209   49.143828  43.004333
2020-12-29  28.473515   47.568209  49.143828
2020-12-30  14.695619   28.473515  47.568209
2020-12-31  11.480358   14.695619  28.473515

[359 rows x 8 columns]
```

Plots which show the goodness of the predictions.

```
>>> model = ms.PolynomialRegression(degree=1) # Best model

>>> ms.plot_predictions(X ,y ,model, xvalues=df_mean_best.index,
xlabel="Days")
<AxesSubplot:title={'center':'Actual vs Predicted values'},
xlabel='Days'>
```




```
>>> ms.plot_predictions(X ,y ,model, plot_type=1,
xvalues=df_mean_best.index, xlabel="Days")
<AxesSubplot:title={'center':'Actual vs Predicted values'},
xlabel='Actual values', ylabel='Predicted values'>
```



Add statistical information about up to k years ago

Create the full DataFrame (i.e. years 2013-2020) processed and cleaned (using `fill_n_days=10`).

```
>>> df_full_mean, _, _ = eea.preprocessing(df_full, fill=True,
fill_n_days=10, fill_aggr="mean")
UserWarning: Missing days: ['2020-01-31', '2020-02-01',
'2020-02-02', '2020-02-03', '2020-02-04', '2020-02-05',
'2020-02-06', '2020-02-07', '2020-02-08', '2020-02-10',
'2020-02-11']
```

A new column is added, containing statistical information about the daily mean level of PM10 of up to k years ago. In order to do that, the function `tsp.add_upTo_k_years_ago_statistics` is applied.

In this step, two choices have to be made.

1. The specific value of k has to be chosen, among the values `[1, 2, 3, 4, 5, 6, 7]`. (The supported years available are 2013-2020, so up to 7 years ago).
2. The specific value of `days_to_select` has to be chosen, among the values `[1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]`. This parameter specifies, for each 2020 day, which days of the previous years have to be taken into account: if it's a number n, the n days centered on that day but in the previous years are selected; if it's `"month"`, the days of the same month but in the previous years are selected; if it's `"season"`, the days of the same season but in the previous years are selected.

To sum up, two choices have to be made at the same time: the choice for a specific value for k and the choice for a specific value for `days_to_select`. All the possible combinations of the couple `k-days_to_select` are evaluated, i.e. an exhaustive selection is made. In the end, the best couple is selected.

```
>>> from sklearn.tree import DecisionTreeRegressor
>>> from sklearn.neighbors import KNeighborsRegressor
>>> from sklearn.ensemble import RandomForestRegressor

>>> range_years = [1, 2, 3, 4, 5, 6, 7]
>>> range_n_days = [1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]
# All the datasets that have to be evaluated, one for each possible
combination of the couple `k`-`days_to_select`
>>> dataset_list = [
   tsp.add_upTo_k_years_ago_statistics(df=df_mean_best,
                       df_upTo_k_years_ago=df_full_mean, k=k,
```

```
                    current_year=False,
                    days_to_select=days_to_select, y_col="mean",
                    scale_y=True)[1:]
    for k in range_years for days_to_select in range_n_days
]
UserWarning: For the day 2020-01-08 only these 7 years ago days have
been found: ['2013-01-01', '2013-01-02', '2013-01-03', '2013-01-04',
'2013-01-05', '2013-01-06', '2013-01-07', '2013-01-08', '2013-01-09',
'2013-01-10', '2013-01-11', '2013-01-12', '2013-01-13', '2013-01-14',
'2013-01-15', '2013-01-16', '2013-01-17', '2013-01-18', '2013-01-19',
'2013-01-20', '2013-01-21', '2013-01-22', '2013-01-23', '2013-01-24',
'2013-01-25', '2013-01-26', '2013-01-27', '2013-01-28', '2013-01-29',
'2013-01-30', '2013-01-31', '2013-02-01', '2013-02-02', '2013-02-03',
'2013-02-04', '2013-02-05', '2013-02-06', '2013-02-07', '2013-02-08',
'2013-02-09', '2013-02-10', '2013-02-11', '2013-02-12', '2013-02-13',
'2013-02-14', '2013-02-15', '2013-02-16', '2013-02-17', '2013-02-18',
'2013-02-19', '2013-02-20', '2013-02-21', '2013-02-22', '2013-02-23',
'2013-02-24', '2013-02-25', '2013-02-26', '2013-02-27', '2013-02-28']
UserWarning: For the day 2020-01-09 only these 7 years ago days have
been found: ['2013-01-01', '2013-01-02', '2013-01-03', '2013-01-04',
'2013-01-05', '2013-01-06', '2013-01-07', '2013-01-08', '2013-01-09',
'2013-01-10', '2013-01-11', '2013-01-12', '2013-01-13', '2013-01-14',
'2013-01-15', '2013-01-16', '2013-01-17', '2013-01-18', '2013-01-19',
'2013-01-20', '2013-01-21', '2013-01-22', '2013-01-23', '2013-01-24',
'2013-01-25', '2013-01-26', '2013-01-27', '2013-01-28', '2013-01-29',
'2013-01-30', '2013-01-31', '2013-02-01', '2013-02-02', '2013-02-03',
'2013-02-04', '2013-02-05', '2013-02-06', '2013-02-07', '2013-02-08',
'2013-02-09', '2013-02-10', '2013-02-11', '2013-02-12', '2013-02-13',
'2013-02-14', '2013-02-15', '2013-02-16', '2013-02-17', '2013-02-18',
'2013-02-19', '2013-02-20', '2013-02-21', '2013-02-22', '2013-02-23',
'2013-02-24', '2013-02-25', '2013-02-26', '2013-02-27', '2013-02-28']
...

>>> model_paramGrid_list = [
 ("kNN", KNeighborsRegressor(), {"n_neighbors":range(1,45),
                                 "weights":["uniform","distance"]}),
 ("DT", DecisionTreeRegressor(), {"max_leaf_nodes":range(2,51),
                                  "max_features":[None,"sqrt"]}),
 ("PR", PolynomialRegression(), {"degree":[1,2,3,4]}),
 ("RF", RandomForestRegressor(), {"n_estimators":range(1,51),
                                  "max_features":[None,"sqrt"]})
]
```

```
>>> scale_list = [False,True,False,False]

>>> (datasets_train_val_score, datasets_best_model, best_index,
test_score, axes) = ms.datasets_models_validation(dataset_list,
model_paramGrid_list, scale_list=scale_list, time_series=True)
```

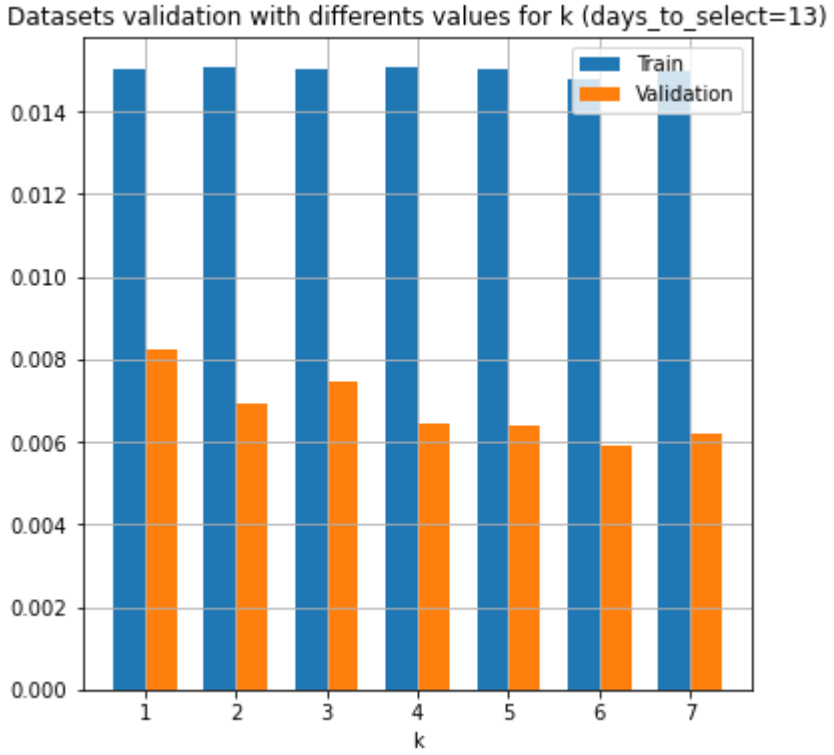
Here the results.

```
>>> print("Index best dataset:", str(best_index),
          "; k-days_to_select:", str(xvalues[best_index]))
Index best dataset: 56 ; k-days_to_select: 6-13

>>> print("Best model:", datasets_best_model[best_index][1],
          "; Hyperparameters values:",
          str(datasets_best_model[best_index][2]))
Best model: PR ; Hyperparameters values: {'degree': 1}

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005815045651242979

>>> print("Test score:", str(test_score))
Test score: 0.01505297702537988
```

Now an example in which the value of `days_to_select` has been fixed to 13, in order to show the impact of different values for k on the performance.

```
# In this example only the Polynomial Regression model is used
>>> range_years = [1, 2, 3, 4, 5, 6, 7]
>>> dataset_list = [
       tsp.add_upTo_k_years_ago_statistics(df=df_mean_best,
                         df_upTo_k_years_ago=df_full_mean, k=k,
                         current_year=False,
                         days_to_select=7, y_col="mean",
                         scale_y=True)[1:]
       for k in range_years
]
>>> xvalues = [str(k) for k in range_years]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
```

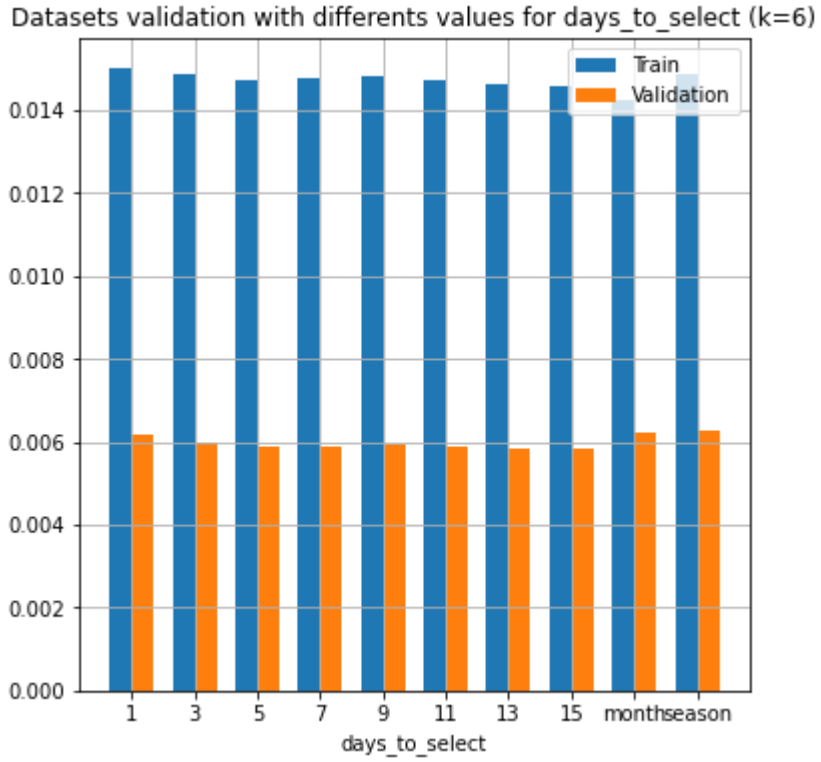
```
>>> hyperparameter_values=[1, 2, 3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="k",
title="Datasets validation with differents values for k
(days_to_select=13)")
```



Now an example in which the value of k has been fixed to 6, in order to show the impact of different values for `days_to_select` on the performance.

```
# In this example only the Polynomial Regression model is used
>>> range_n_days = [1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]
>>> dataset_list = [
        tsp.add_upTo_k_years_ago_statistics(df=df_mean_best,
                            df_upTo_k_years_ago=df_full_mean, k=6,
                            current_year=False,
                            days_to_select=days_to_select,
                            y_col="mean", scale_y=True)[1:]
        for days_to_select in range_n_days
]
```

```
>>> xvalues = [str(days_to_select) for days_to_select in
range_n_days]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues,
xlabel="days_to_select", title="Datasets validation with
differents values for days_to_select (k=6)")
```



Best dataset: k=6 and days_to_select=13

There has been an improvement as compared to the previous dataset: the validation score has decreased from `0.00647` to `0.00581`.

```
>>> (df_mean_best, _,
_) = tsp.add_upTo_k_years_ago_statistics(df=df_mean_best,
df_upTo_k_years_ago=df_full_mean, k=6, current_year=False,
```

```
days_to_select=13, y_col="mean", scale_y=True)

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...        ...        ...          ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

[359 rows x 9 columns]
```

Add statistical information about k years ago

The same full DataFrame prepared before is used, which is `df_mean_full`.

A new column is added, containing statistical information about the daily mean level of PM10 of k years ago. So, the difference with the previous step is that now only a single previous

year is considered. In order to do that, the function `tsp.add_k_years_ago_statistics` is applied.

In this step, two choices have to be made.

1. The specific value of k has to be chosen, among the values `[1, 2, 3, 4, 5, 6, 7]`. (The supported years available are 2013-2020, so up to 7 years ago).
2. The specific value of `days_to_select` has to be chosen, among the values `[1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]`. This parameter specifies, for each 2020 day, which days of k years ago have to be taken into account: if it's a number n, the n days centered on that day but k years ago are selected; if it's `"month"`, the days of the same month but k years ago are selected; if it's `"season"`, the days of the same season but k years ago are selected.

To sum up, two choices have to be made at the same time: the choice for a specific value for k and the choice for a specific value for `days_to_select`. All the possible combinations of the couple `k-days_to_select` are evaluated, i.e. an exhaustive selection is made. In the end, the best couple is selected.

```
>>> from sklearn.tree import DecisionTreeRegressor
>>> from sklearn.neighbors import KNeighborsRegressor
>>> from sklearn.ensemble import RandomForestRegressor

>>> range_years = [1, 2, 3, 4, 5, 6, 7]
>>> range_n_days = [1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]
# All the datasets that have to be evaluated, one for each
possible combination of the couple `k`-`days_to_select`
>>> dataset_list = [
     tsp.add_k_years_ago_statistics(df_mean_best,
                                    df_k_years_ago=df_full_mean,
                                    k=k,
                                    days_to_select=days_to_select,
                                    y_col="mean",
                                    scale_y=True)[1:]
     for k in range_years for days_to_select in range_n_days
]
UserWarning: For the day 2020-01-08 only these 7 years ago days have
been found: ['2013-01-01', '2013-01-02', '2013-01-03', '2013-01-04',
'2013-01-05', '2013-01-06', '2013-01-07', '2013-01-08', '2013-01-09',
'2013-01-10', '2013-01-11', '2013-01-12', '2013-01-13', '2013-01-14',
'2013-01-15', '2013-01-16', '2013-01-17', '2013-01-18', '2013-01-19',
'2013-01-20', '2013-01-21', '2013-01-22', '2013-01-23', '2013-01-24',
'2013-01-25', '2013-01-26', '2013-01-27', '2013-01-28', '2013-01-29',
```

```
'2013-01-30', '2013-01-31', '2013-02-01', '2013-02-02', '2013-02-03',
'2013-02-04', '2013-02-05', '2013-02-06', '2013-02-07', '2013-02-08',
'2013-02-09', '2013-02-10', '2013-02-11', '2013-02-12', '2013-02-13',
'2013-02-14', '2013-02-15', '2013-02-16', '2013-02-17', '2013-02-18',
'2013-02-19', '2013-02-20', '2013-02-21', '2013-02-22', '2013-02-23',
'2013-02-24', '2013-02-25', '2013-02-26', '2013-02-27', '2013-02-28']
UserWarning: For the day 2020-01-09 only these 7 years ago days have
been found: ['2013-01-01', '2013-01-02', '2013-01-03', '2013-01-04',
'2013-01-05', '2013-01-06', '2013-01-07', '2013-01-08', '2013-01-09',
'2013-01-10', '2013-01-11', '2013-01-12', '2013-01-13', '2013-01-14',
'2013-01-15', '2013-01-16', '2013-01-17', '2013-01-18', '2013-01-19',
'2013-01-20', '2013-01-21', '2013-01-22', '2013-01-23', '2013-01-24',
'2013-01-25', '2013-01-26', '2013-01-27', '2013-01-28', '2013-01-29',
'2013-01-30', '2013-01-31', '2013-02-01', '2013-02-02', '2013-02-03',
'2013-02-04', '2013-02-05', '2013-02-06', '2013-02-07', '2013-02-08',
'2013-02-09', '2013-02-10', '2013-02-11', '2013-02-12', '2013-02-13',
'2013-02-14', '2013-02-15', '2013-02-16', '2013-02-17', '2013-02-18',
'2013-02-19', '2013-02-20', '2013-02-21', '2013-02-22', '2013-02-23',
'2013-02-24', '2013-02-25', '2013-02-26', '2013-02-27', '2013-02-28']
...

>>> model_paramGrid_list = [
 ("kNN", KNeighborsRegressor(), {"n_neighbors":range(1,45),
                                 "weights":["uniform","distance"]}),
 ("DT", DecisionTreeRegressor(), {"max_leaf_nodes":range(2,51),
                                  "max_features":[None,"sqrt"]}),
 ("PR", PolynomialRegression(), {"degree":[1,2,3,4]}),
 ("RF", RandomForestRegressor(), {"n_estimators":range(1,51),
                                  "max_features":[None,"sqrt"]})
]
>>> scale_list = [False,True,False,False]

>>> (datasets_train_val_score, datasets_best_model, best_index,
test_score, axes) = ms.datasets_models_validation(dataset_list,
model_paramGrid_list, scale_list=scale_list, time_series=True)
```

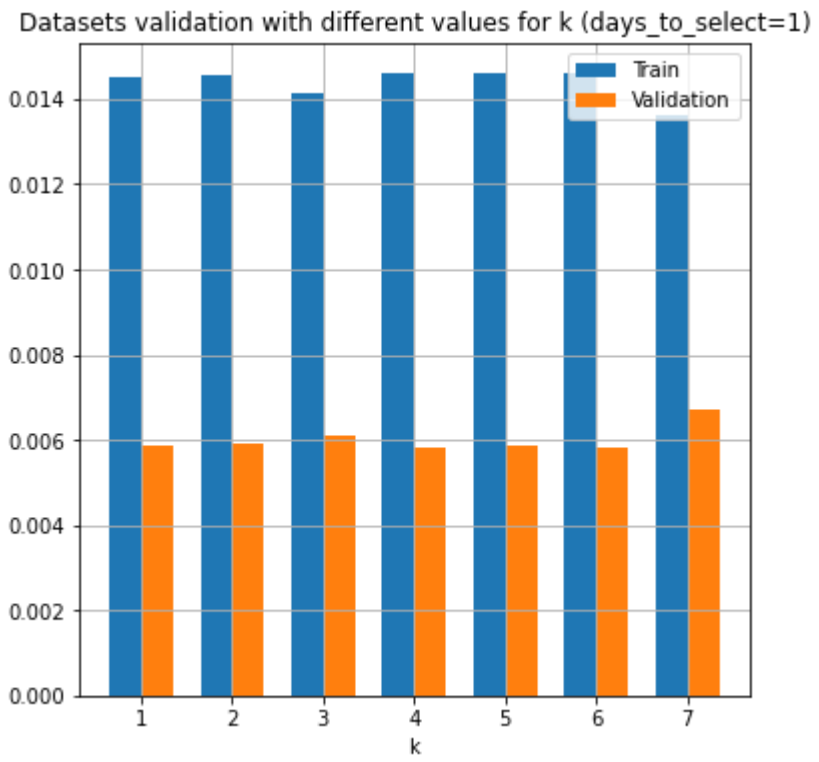
Here the results.

```
>>> print("Index best dataset:", str(best_index),
          "; k-days_to_select:", str(xvalues[best_index]))
Index best dataset: 50 ; k-days_to_select: 6-1
```

```
>>> print("Best model:", datasets_best_model[best_index][1],
          "; Hyperparameters values:",
          str(datasets_best_model[best_index][2]))
Best model: PR ; Hyperparameters values: {'degree': 1}

>>> print("Validation score:",
           str(datasets_train_val_score[best_index,1]))
Validation score: 0.005804228658914929

>>> print("Test score:", str(test_score))
Test score: 0.014628394398884796
```

Now an example in which the value of `days_to_select` has been fixed to 1, in order to show the impact of different values for k on the performance.

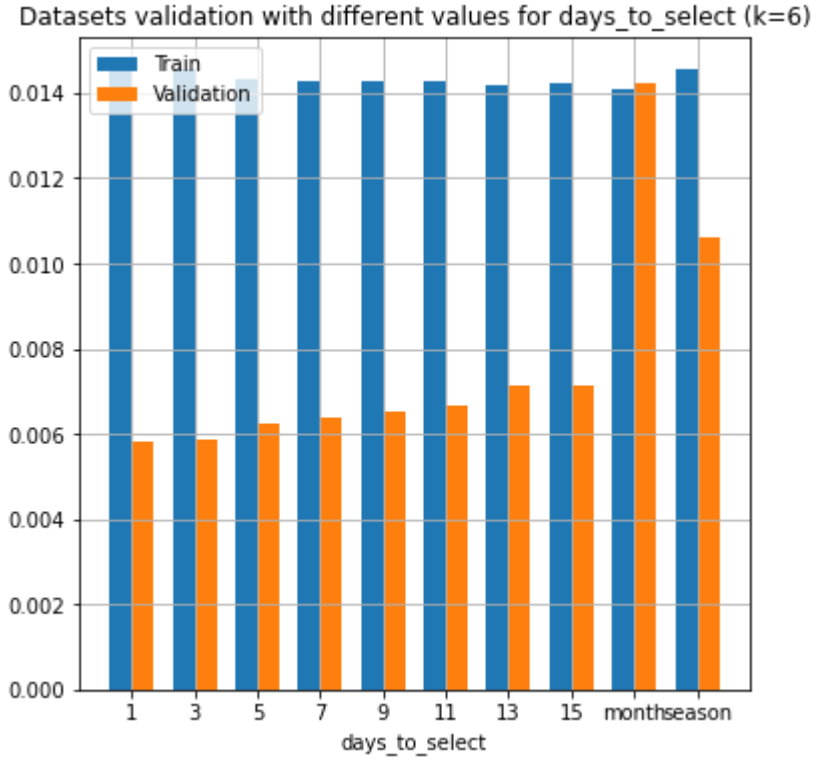
```
# In this example only the Polynomial Regression model is used
>>> range_years = [1, 2, 3, 4, 5, 6, 7]
>>> dataset_list = [
      tsp.add_k_years_ago_statistics(df_mean_best,
                                     df_k_years_ago=df_full_mean,
                                     k=k, days_to_select=1,
                                     y_col="mean",
                                     scale_y=True)[1:]
      for k in range_years]
>>> xvalues = [str(k) for k in range_years]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1, 2, 3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="k",
title="Datasets validation with different values for k
(days_to_select=1)")
```



Now an example in which the value of k has been fixed to 6, in order to show the impact of different values for `days_to_select` on the performance.

```
# In this example only the Polynomial Regression model is used
>>> range_n_days = [1, 3, 5, 7, 9, 11, 13, 15, "month", "season"]
>>> dataset_list = [
     tsp.add_k_years_ago_statistics(df_mean_best,
                                    df_k_years_ago=df_full_mean,
                                    k=6,
                                    days_to_select=days_to_select,
                                    y_col="mean",
                                    scale_y=True)[1:]
     for days_to_select in range_n_days]
>>> xvalues = [str(days_to_select) for days_to_select in
range_n_days]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
```

```
hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues,
xlabel="days_to_select", title="Datasets validation with different
values for days_to_select (k=6)")
```



Best dataset: k=6 and days_to_select=1

There has been an improvement as compared to the previous dataset: the validation score has decreased from `0.00581` to `0.00580`.

```
>>> (df_mean_best, _,
_) = tsp.add_k_years_ago_statistics(df_mean_best,
df_k_years_ago=df_full_mean, k=6, days_to_select=1, y_col="mean",
scale_y=True)

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
```

```
...              ...         ...         ...         ...         ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...         ...         ...          ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

               6_years_ago_mean
Datetime
2020-01-08          71.802620
2020-01-09          79.803419
2020-01-10          71.632078
2020-01-11          79.216124
2020-01-12          89.111978
...                       ...
2020-12-27          17.186082
2020-12-28          19.039899
2020-12-29          20.643419
2020-12-30          19.247014
2020-12-31          23.937203

[359 rows x 10 columns]
```

Add meteorological information

Load the meteorological dataset, which contains values for several climatic agents in Italy in 2020.

```
>>> import pandas as pd
>>> df_meteo = pd.read_csv("meteorological_data_2020.csv",
index_col=0)
>>> df_meteo = df_meteo.set_index(pd.DatetimeIndex(df_meteo.index))

>>> df_meteo
            TMEDIA °C   TMIN °C    TMAX °C  PUNTORUGIADA °C
2020-01-01   5.202196  0.173764  11.003131         2.534921
2020-01-02   4.774801  0.182640  10.325979         2.465371
2020-01-03   4.885063  0.531284   9.658314         3.231408
2020-01-04   6.162960  1.381113  11.354987         3.776887
2020-01-05   6.551925  1.686219  12.409042         3.172703
...               ...       ...        ...              ...
2020-12-27   3.366679  0.191966   6.335378         2.162273
2020-12-28   4.014919  1.075045   6.692360         3.125000
2020-12-29   4.921844  1.494424   8.174234         3.427775
2020-12-30   5.007944  2.084797   8.026350         3.539751
2020-12-31   3.614142 -0.334781   7.465027         2.430201

...
```

Add meteorological information about 2020

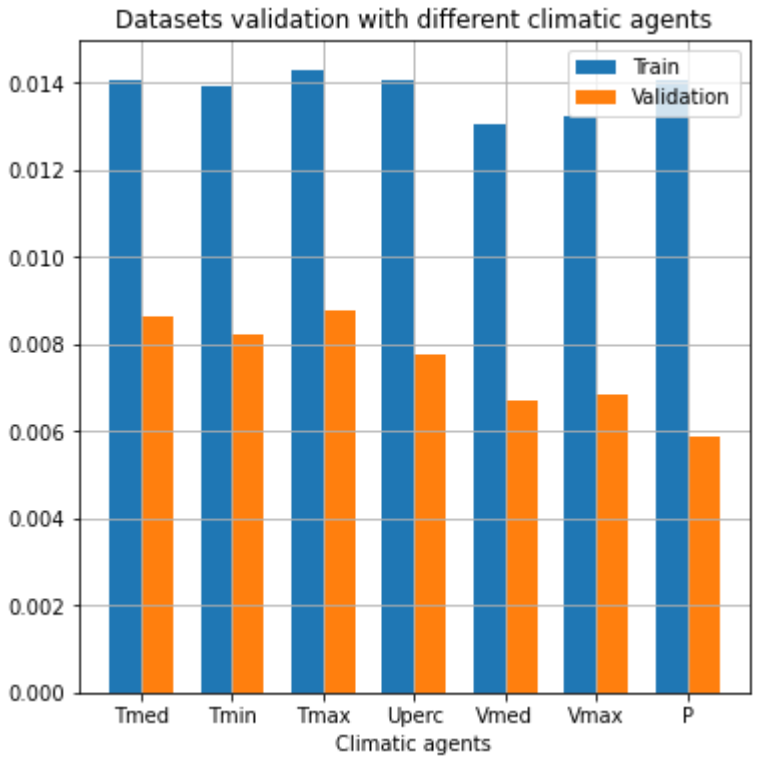
A new column is added, containing meteorological information about a specific climatic agent in Italy in 2020.

That specific climatic agent has to be chosen among the list `["TMEDIA °C", "TMIN °C", "TMAX °C", "UMIDITA %", "VENTOMEDIA km/h", "VENTOMAX km/h", "PRESSIONESLM mb"]`. All these possible agents are evaluated: in the end, the best one is selected.

In order to add a climatic agent, the function `tsp.add_timeSeries_dataframe` is used.

```
>>> from sklearn.tree import DecisionTreeRegressor
>>> from sklearn.neighbors import KNeighborsRegressor
```

```
>>> from sklearn.ensemble import RandomForestRegressor

>>> columns = ["TMEDIA °C", "TMIN °C", "TMAX °C", "UMIDITA %",
"VENTOMEDIA km/h", "VENTOMAX km/h", "PRESSIONESLM mb"]
# All the datasets that have to be evaluated, one for each
possible climatic agent
>>> dataset_list = [
      tsp.add_timeSeries_dataframe(df_mean_best,df_meteo[[agent]],
                                   y_col="mean", scale_y=True)[1:]
      for agent in columns]
>>> xvalues = ["Tmed", "Tmin", "Tmax", "Uperc", "Vmed", "Vmax",
"P"]

>>> model_paramGrid_list = [
 ("kNN", KNeighborsRegressor(), {"n_neighbors":range(1,45),
                                 "weights":["uniform","distance"]}),
 ("DT", DecisionTreeRegressor(), {"max_leaf_nodes":range(2,51),
                                  "max_features":[None,"sqrt"]}),
 ("PR", PolynomialRegression(), {"degree":[1,2,3,4]}),
 ("RF", RandomForestRegressor(), {"n_estimators":range(1,51),
                                  "max_features":[None,"sqrt"]})
]
>>> scale_list = [False,True,False,False]

>>> (datasets_train_val_score, datasets_best_model, best_index,
test_score, axes) = ms.datasets_models_validation(dataset_list,
model_paramGrid_list, scale_list=scale_list, time_series=True,
regr=True, plot=True, plot_train=True, xvalues=xvalues,
xlabel="Climatic agents",  title="Datasets validation with
different climatic agents")
```



Here the results.

```
>>> print("Index best dataset:", str(best_index),
          "; Climatic agent:", str(xvalues[best_index]))
Index best dataset: 6 ; Climatic agent: P

>>> print("Best model:", datasets_best_model[best_index][1],
          "; Hyperparameters values:",
          str(datasets_best_model[best_index][2]))
Best model: PR ; Hyperparameters values: {'degree': 1}

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005893619946527116

>>> print("Test score:", str(test_score))
Test score: 0.011106647607909125
```

There has been no improvement as compared to the previous dataset: no new feature is added.

The validation score associated with the best climatic agent has not decreased as compared to the previous dataset: the previous validation score was `0.00580` and the current is `0.00589`

In all the datasets that have been tested, the `PolynomialRegression` model was always the best one. For this reason, from this point on only this model will be used.

Add statistical information about 2020 days with similar meteorological conditions

The previous attempt to add meteorological features was a failure. For this reason, the technique and the point of view have to be changed.

First of all, a new DataFrame is created: this simply contains the daily mean levels of PM10 in Italy in 2020 and the climatic agents in Italy in 2020. This DataFrame is simply obtained by merging the DataFrames `df_mean` and `df_meteo`.

```
>>> df_mean_meteo, _, _ = tsp.add_timeSeries_dataframe(df_mean,
df_meteo, y_col="mean", scale_y=True)
>>> df_mean_meteo

                mean         TMEDIA °C     TMIN °C      TMAX °C
2020-01-01     76.974569       5.202196      0.173764    11.003131
2020-01-02     56.675791       4.774801      0.182640    10.325979
2020-01-03     55.216906       4.885063      0.531284    9.658314
2020-01-04     54.887035       6.162960      1.381113    11.354987
2020-01-05     28.192059       6.551925      1.686219    12.409042
...                              ...           ...          ...
2020-12-27     14.997987       3.366679      0.191966    6.335378
2020-12-28     16.317778       4.014919      1.075045    6.692360
2020-12-29     23.536875       4.921844      1.494424    8.174234
2020-12-30     22.759021       5.007944      2.084797    8.026350
2020-12-31     22.005000       3.614142     -0.334781    7.465027

...
```

A new column is added, containing statistical information about the daily mean level of PM10 of the preceding 2020 days with similar meteorological conditions. So, for each 2020 day the

preceding 2020 days with similar meteorological conditions are considered and then the mean of their daily level of PM10 is computed.

In order to do that, the function `tsp.add_current_year_statistics` is applied, specifying as `days_to_select` a predicate (i.e. a function which returns a boolean).

Now, the meaning of 'similar meteorological conditions' has to be defined. Two days have similar meteorological conditions if, for a certain specified climatic agent, their values differ by not more than a certain tolerance `t`. So, two choices have to be made:

- the climatic agent has to be chosen, among `["TMEDIA °C", "TMIN °C", "TMAX °C", "UMIDITA %", "VENTOMEDIA km/h", "VENTOMAX km/h", "PRESSIONESLM mb"]`
- the tolerance has to be chosen (the possible values depend on the climatic agent).

All the possible combinations of the couple `Climatic agent-t` are evaluated, i.e. an exhaustive selection is made. In the end, the best couple is selected. Unlike the dataset selections seen previously, now the dataset selection is divided by climatic agent, in order to simplify the visualization.

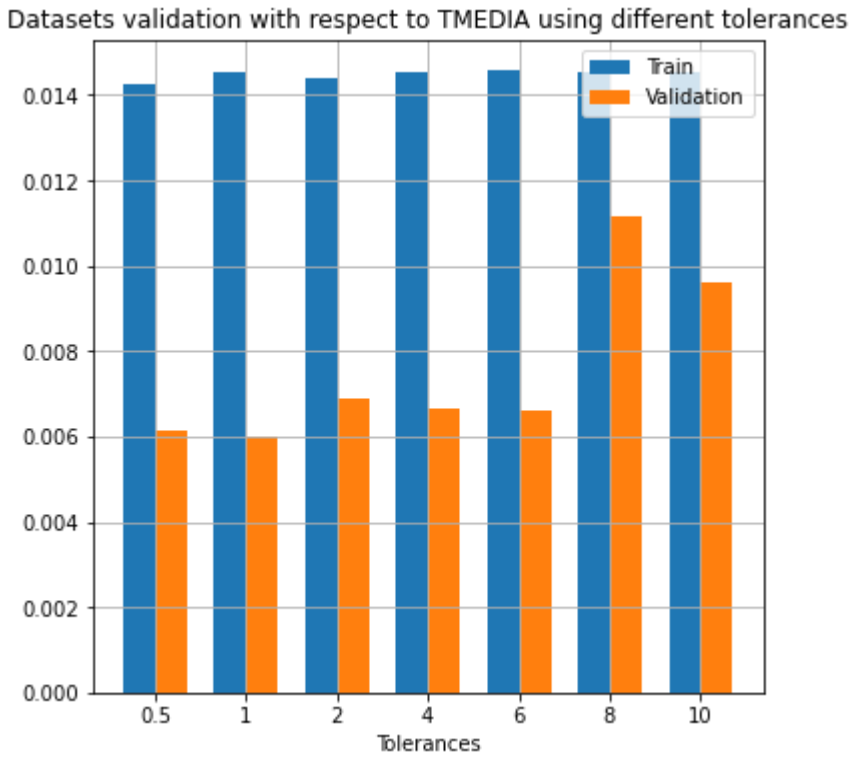
As it will be shown, the just described technique is effective. In fact, four new features will be added with this technique.

First addition

TMEDIA

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    #  to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar TMEDIA
    # with respect to `day` (i.e. the difference is less than `t`)
    return (
        lambda day, df, day_current_year, df_current_year :
            abs(df_current_year["TMEDIA °C"].loc[day] -
            df_current_year["TMEDIA °C"].loc[day_current_year])<t
    )

>>> tolerances = [0.5, 1, 2, 4, 6, 8, 10] # Possible tolerances
>>> dataset_list = [
```

```
   tsp.add_current_year_statistics(df=df_mean_best,
                  df_current_year=df_mean_meteo,
                  # Create `days_to_select`
                  days_to_select = create_daysToSelect_function(t),
                  # Only the "mean" column is of interest
                  columns_to_select=["mean"], y_col="mean",
                  scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-08
UserWarning: No current year days have been found for the day
2020-01-28
UserWarning: No current year days have been found for the day
2020-02-03
UserWarning: No current year days have been found for the day
2020-02-04
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to TMEDIA using different
tolerances")
```




```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 1 ; Tolerance: 1

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005973842073088957

>>> print("Test score:", str(test_score))
Test score: 0.014607561953069621
```

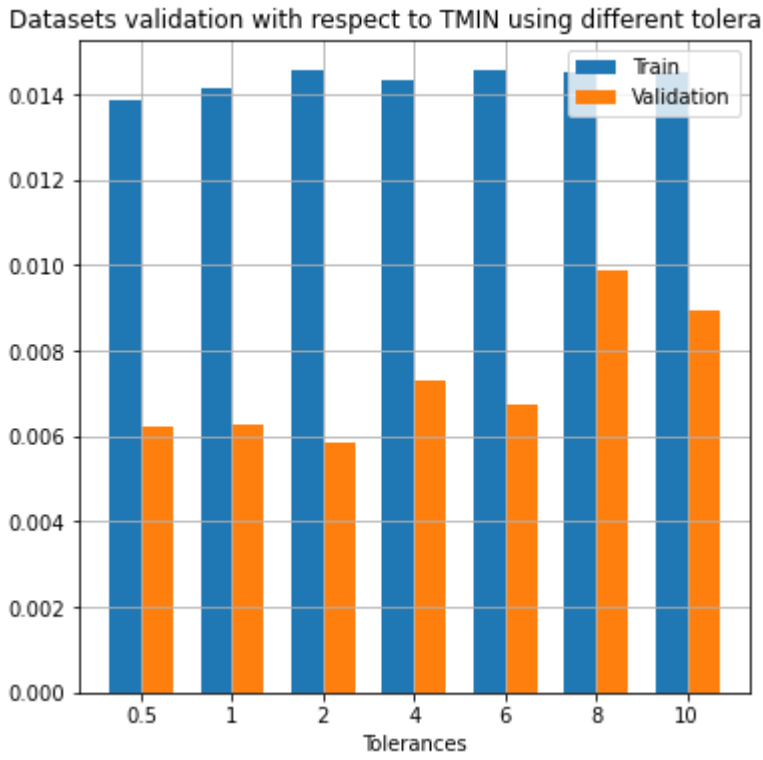
The validation score has not decreased.

TMIN

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
```

```
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar TMIN
    # with respect to `day` (i.e. the difference is less than `t`)
    return (
        lambda day, df, day_current_year, df_current_year :
            abs(df_current_year["TMIN °C"].loc[day] -
            df_current_year["TMIN °C"].loc[day_current_year])<t
    )

>>> tolerances = [0.5, 1, 2, 4, 6, 8, 10] # Possible tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-08
UserWarning: No current year days have been found for the day
2020-01-18
UserWarning: No current year days have been found for the day
2020-01-25
UserWarning: No current year days have been found for the day
2020-01-28
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
```

```
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to TMIN using different
tolerances")
```



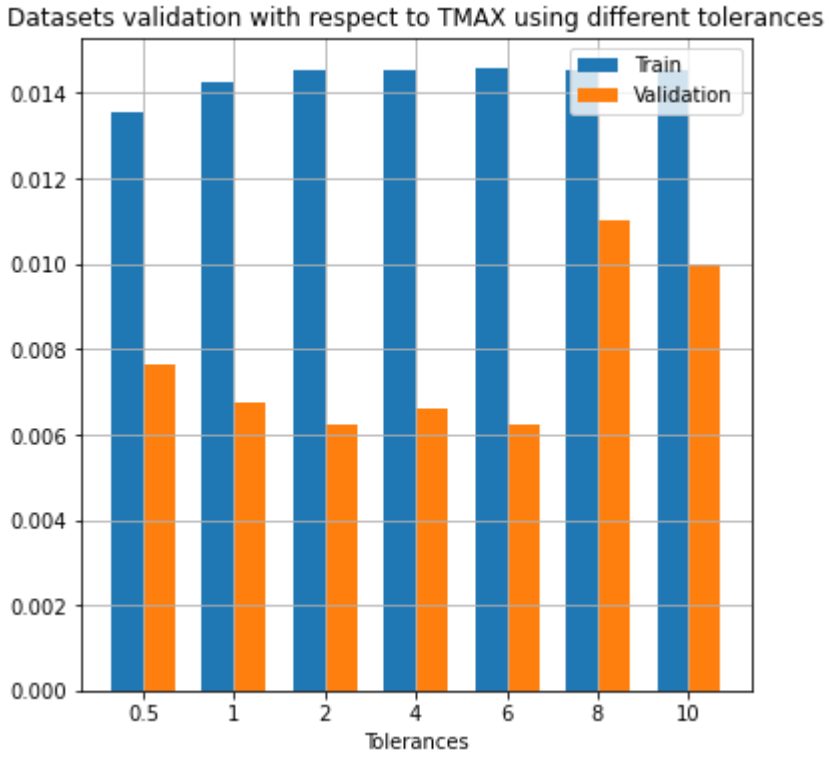

```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 2 ; Tolerance: 2

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.00585275308627106

>>> print("Test score:", str(test_score))
Test score: 0.013347518888114866
```

The validation score has not decreased.

TMAX

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar TMAX
    # with respect to `day` (i.e. the difference is less than `t`)
    return (
        lambda day, df, day_current_year, df_current_year :
            abs(df_current_year["TMAX °C"].loc[day] -
            df_current_year["TMAX °C"].loc[day_current_year])<t
    )

>>> tolerances = [0.5, 1, 2, 4, 6, 8, 10] # Possible tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-29
UserWarning: No current year days have been found for the day
2020-01-31
UserWarning: No current year days have been found for the day
2020-02-03
UserWarning: No current year days have been found for the day
2020-02-04
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]
```

```
>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to TMAX using different
tolerances")
```



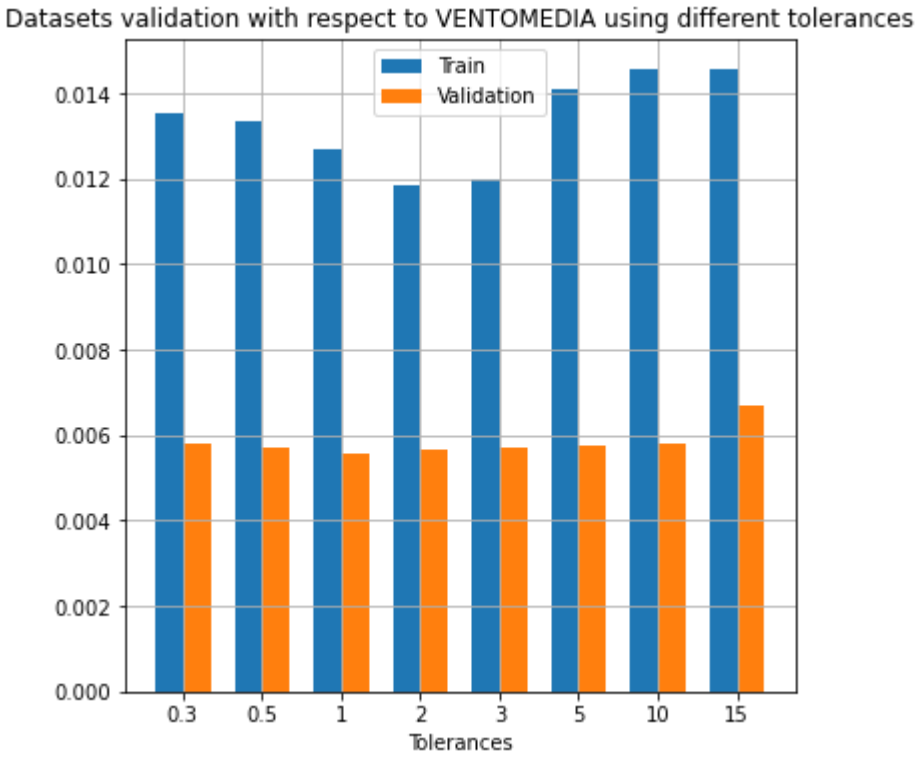

```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 2 ; Tolerance: 2

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.0062306936890401425

>>> print("Test score:", str(test_score))
Test score: 0.015206419159237023
```

The validation score has not decreased.

VENTOMEDIA

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # VENTOMEDIA with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
       df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<t
    )

>>> tolerances = [0.3, 0.5, 1, 2, 3, 5, 10, 15] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-09
UserWarning: No current year days have been found for the day
2020-01-18
UserWarning: No current year days have been found for the day
2020-01-19
UserWarning: No current year days have been found for the day
2020-01-20
...
>>> xvalues = [str(t) for t in tolerances]
```

```
>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to VENTOMEDIA using
different tolerances")
```




```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 2 ; Tolerance: 1

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
```

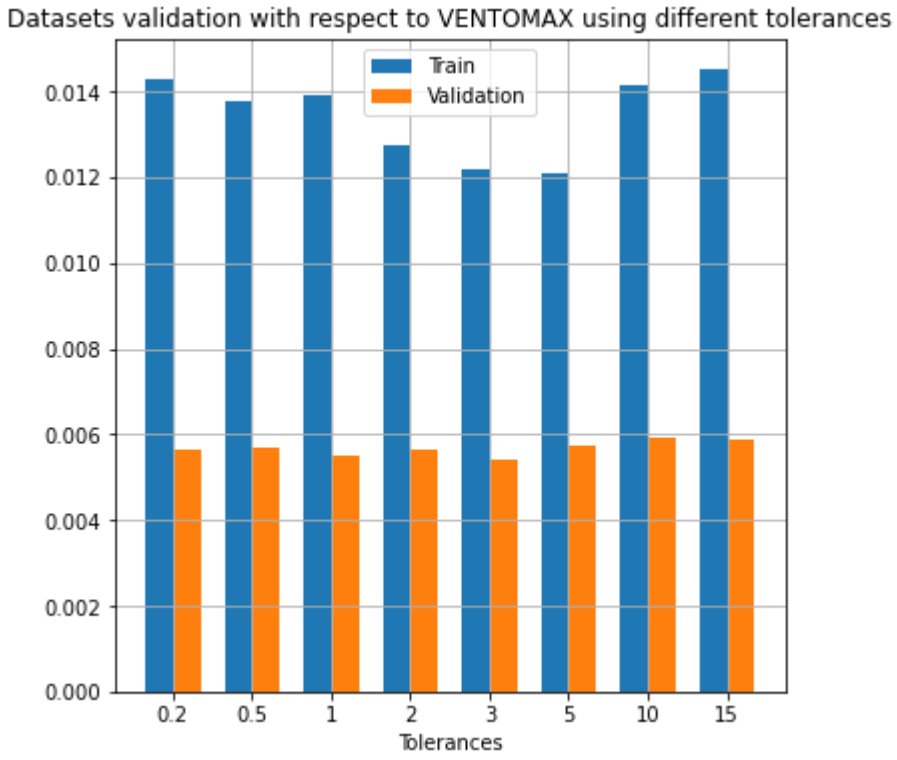
```
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005579159708244468

>>> print("Test score:", str(test_score))
Test score: 0.0070760470805857805
```

The validation score has decreased!

VENTOMAX

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # VENTOMAX with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["VENTOMAX km/h"].loc[day] -
       df_current_year["VENTOMAX km/h"].loc[day_current_year])<t
    )

>>> tolerances = [0.2, 0.5, 1, 2, 3, 5, 10, 15] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-09
UserWarning: No current year days have been found for the day
2020-01-13
UserWarning: No current year days have been found for the day
```

```
2020-01-18
UserWarning: No current year days have been found for the day
2020-01-19
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to VENTOMAX using
different tolerances")
```




```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 4 ; Tolerance: 3

>>> print("Best polynomial grade:",
```

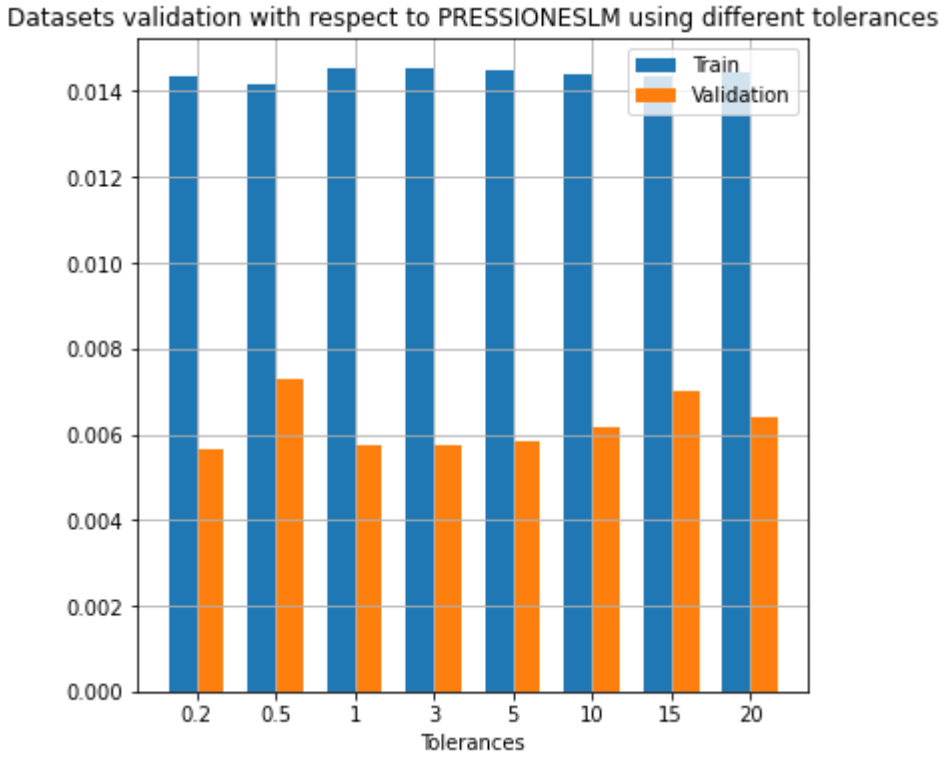
```
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005414068416456359

>>> print("Test score:", str(test_score))
Test score: 0.0071246954594039215
```

The validation score has decreased!

PRESSIONE

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # PRESSIONE with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["PRESSIONESLM mb"].loc[day] -
       df_current_year["PRESSIONESLM mb"].loc[day_current_year])<t
    )

>>> tolerances = [0.2, 0.5, 1, 3, 5, 10, 15, 20] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
```

```
UserWarning: No current year days have been found for the day
2020-01-09
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-11
UserWarning: No current year days have been found for the day
2020-01-13
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to PRESSIONESLM using
different tolerances")
```



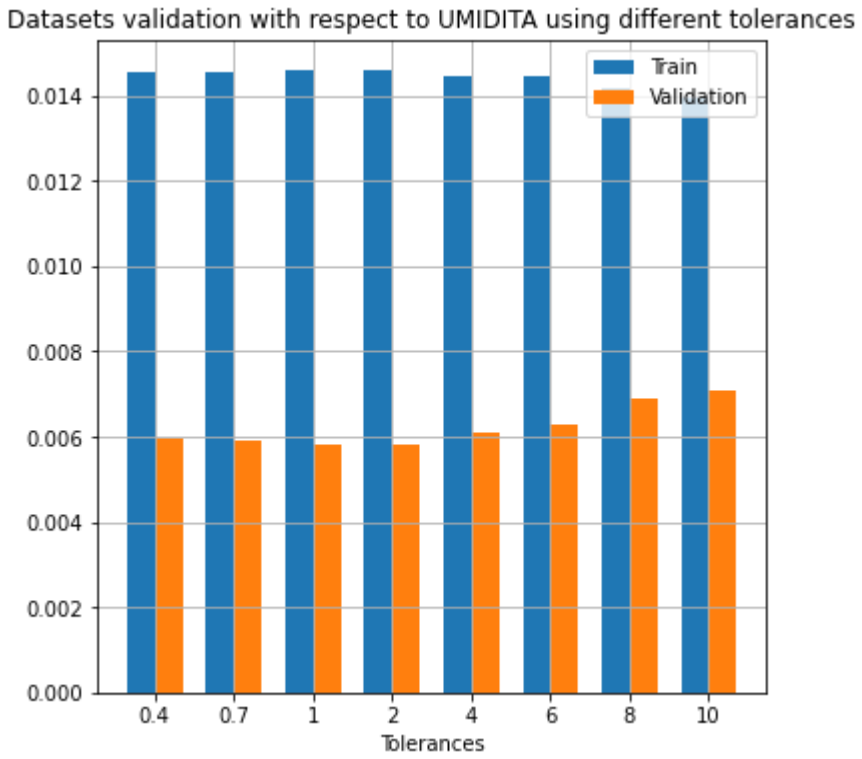
```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 0 ; Tolerance: 0.2

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005665634068097989

>>> print("Test score:", str(test_score))
Test score: 0.01260854713712688
```

The validation score has decreased!

UMIDITA

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # UMIDITA with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["UMIDITA %"].loc[day] -
       df_current_year["UMIDITA %"].loc[day_current_year])<t
    )

>>> tolerances = [0.4, 0.7, 1, 2, 4, 6, 8, 10] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
```

```
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-11
UserWarning: No current year days have been found for the day
2020-01-12
UserWarning: No current year days have been found for the day
2020-01-14
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True,
plot=True, plot_train=True, xvalues=xvalues, xlabel="Tolerances",
title="Datasets validation with respect to UMIDITA using different
tolerances")
```




```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 2 ; Tolerance: 1

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005827590144634284

>>> print("Test score:", str(test_score))
Test score: 0.014934800194941403
```

The validation score has not decreased

VMEDIA VMAX PRESSIONE

Trying to use more climatic agents together could be interesting. The three most effective climatic agents are considered, which are VMEDIA, VMAX, P. Each of them is tested with different tolerances: `t1` is the tolerance for VMEDIA, `t2` is the tolerance for VMAX, and `t3` is the tolerance for P. All the possible combinations of tolerances `t1-t2-t3` are evaluated.

```
# Higher-order function, which creates the `days_to_select` function.
# It takes in input three specific tolerances `t1-t2-t3` and it returns
the corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t1, t2, t3):
    return (
     lambda day, df, day_current_year, df_current_year :
     (abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
       df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<t1 and
      abs(df_current_year["VENTOMAX km/h"].loc[day] -
       df_current_year["VENTOMAX km/h"].loc[day_current_year])<t2 and
      abs(df_current_year["PRESSIONESLM mb"].loc[day] -
       df_current_year["PRESSIONESLM mb"].loc[day_current_year])<t3)
    )

>>> tolerances = [1, 5, 10, 15] # Possible tolerances
>>> dataset_list = [
       tsp.add_current_year_statistics(df=df_mean_best,
                 df_current_year=df_mean_meteo,
                 # Create `days_to_select`
                 days_to_select=create_daysToSelect_function(t1,t2,t3),
                 # Only the "mean" column is of interest
                 columns_to_select=["mean"], y_col="mean",
                 scale_y=True)[1:]
       for t1 in tolerances for t2 in tolerances for t3 in tolerances]
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-13
UserWarning: No current year days have been found for the day
2020-01-18
UserWarning: No current year days have been found for the day
2020-01-19
...

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
```

```
hyperparameter, hyperparameter_values, time_series=True)
```

```
>>> print("Index best dataset:", str(best_index), "; t1-t2-t3:",
          str(xvalues[best_index]))
Index best dataset: 18 ; t1-t2-t3: 5-1-10

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005454695745022879

>>> print("Test score:", str(test_score))
Test score: 0.007884025168365652
```

The validation score has decreased!

Best dataset: VENTO MAX with `tolerance=3`

The best alternative is the one with VENTOMAX and with `tolerance=3`. There is an improvement as compared to the previous dataset: the validation score has decreased from `0.00580` to `0.00541`

```
# `days_to_select` function
>>> days_to_select = lambda day, df, day_current_year,
      df_current_year :
         abs(df_current_year["VENTOMAX km/h"].loc[day] -
         df_current_year["VENTOMAX km/h"].loc[day_current_year])<3

>>> (df_mean_best, _,
_) = tsp.add_current_year_statistics(df=df_mean_best,
df_current_year=df_mean_meteo, days_to_select=days_to_select,
columns_to_select=["mean"], y_col="mean", scale_y=True)
UserWarning: No current year days have been found for the day
2020-02-04
UserWarning: No current year days have been found for the day
2020-02-11

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
```

```
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

                mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...        ...        ...          ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

            6_years_ago_mean  current_year_mean
Datetime
2020-01-08     71.802620         56.902806
2020-01-09     79.803419         53.860020
2020-01-10     71.632078         51.860875
2020-01-11     79.216124         53.371621
2020-01-12     89.111978         53.430592
...              ...              ...
2020-12-27     17.186082         21.778933
2020-12-28     19.039899         20.635976
2020-12-29     20.643419         20.311077
2020-12-30     19.247014         24.071164
2020-12-31     23.937203         26.838859
```

```
[359 rows x 11 columns]
```

Second addition

VENTOMEDIA

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # VENTOMEDIA with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
       df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<t
    )

>>> tolerances = [1, 3, 5, 10, 13, 15, 17, 20, 23] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-02-04
UserWarning: No current year days have been found for the day
2020-02-05
UserWarning: No current year days have been found for the day
2020-02-11
```

```
UserWarning: No current year days have been found for the day
2020-02-27
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True)
```

```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 4 ; Tolerance: 13

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005267587773141723

>>> print("Test score:", str(test_score))
Test score: 0.006624223754847354
```

The validation score has decreased!

PRESSIONE

```
# Higher-order function, which creates the `days_to_select`
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
```

```
    # PRESSIONE with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["PRESSIONESLM mb"].loc[day] -
       df_current_year["PRESSIONESLM mb"].loc[day_current_year])<t
    )

>>> tolerances = [0.2, 0.5, 1, 3, 5, 10, 15, 20] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-09
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-11
UserWarning: No current year days have been found for the day
2020-01-13
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True)
```

```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
```

```
          str(xvalues[best_index]))
Index best dataset: 3 ; Tolerance: 3

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005337474933219499

>>> print("Test score:", str(test_score))
Test score: 0.0069914173394748525
```

The validation score has decreased!

Best dataset : VENTO MED with `tolerance=13`

There is an improvement as compared to the previous dataset: the validation score has decreased from `0.00541` to `0.00527`.

```
# `days_to_select` function
>>> days_to_select = lambda day, df, day_current_year,
     df_current_year :
      abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
      df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<13

>>> (df_mean_best, _,
_) = tsp.add_current_year_statistics(df=df_mean_best,
df_current_year=df_mean_meteo, days_to_select=days_to_select,
columns_to_select=["mean"], y_col="mean", scale_y=True)

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
```

```
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...        ...        ...          ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

          6_years_ago_mean  current_year_mean  current_year_mean.1
Datetime
2020-01-08     71.802620          56.902806         48.400784
2020-01-09     79.803419          53.860020         47.181447
2020-01-10     71.632078          51.860875         46.368620
2020-01-11     79.216124          53.371621         48.126442
2020-01-12     89.111978          53.430592         48.651526
...              ...                ...               ...
2020-12-27     17.186082          21.778933         25.123485
2020-12-28     19.039899          20.635976         25.146538
2020-12-29     20.643419          20.311077         25.122216
2020-12-30     19.247014          24.071164         25.066962
2020-12-31     23.937203          26.838859         25.060622

[359 rows x 12 columns]
```

Third adding

PRESSIONE

```
# Higher-order function, which creates the `days_to_select`
```

```
function.
# It takes in input a specific tolerance `t` and it returns the
corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t):
    # `days_to_select` is a lambda function which decides whether
    # to select `day_current_year` for `day` or not.
    # It returns True if `day_current_year` has a similar
    # PRESSIONE with respect to `day` (i.e. the difference is
    # less than `t`)
    return (
     lambda day, df, day_current_year, df_current_year :
       abs(df_current_year["PRESSIONESLM mb"].loc[day] -
       df_current_year["PRESSIONESLM mb"].loc[day_current_year])<t
    )

>>> tolerances = [0.2, 0.5, 1, 3, 5, 10, 15, 20] # Possible
tolerances
>>> dataset_list = [
   tsp.add_current_year_statistics(df=df_mean_best,
                df_current_year=df_mean_meteo,
                # Create `days_to_select`
                days_to_select = create_daysToSelect_function(t),
                # Only the "mean" column is of interest
                columns_to_select=["mean"], y_col="mean",
                scale_y=True)[1:]
   for t in tolerances
]
UserWarning: No current year days have been found for the day
2020-01-09
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-11
UserWarning: No current year days have been found for the day
2020-01-13
...
>>> xvalues = [str(t) for t in tolerances]

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]
```

```
>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list,
model, hyperparameter, hyperparameter_values, time_series=True)
```

```
>>> print("Index best dataset:", str(best_index), "; Tolerance:",
          str(xvalues[best_index]))
Index best dataset: 0 ; Tolerance: 0.2

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.005221659150174389

>>> print("Test score:", str(test_score))
Test score: 0.006919093386128838
```

The validation score has decreased!

Best dataset: PRESSIONE with `tolerance=0.2`

There is an improvement as compared to the previous dataset: the validation score has decreased from `0.00527` to `0.00522`.

```
# `days_to_select` function
>>>days_to_select = lambda day, df, day_current_year,
    df_current_year :
     abs(df_current_year["PRESSIONESLM mb"].loc[day] -
     df_current_year["PRESSIONESLM mb"].loc[day_current_year])<0.2

>>> (df_mean_best, _,
_) = tsp.add_current_year_statistics(df=df_mean_best,
df_current_year=df_mean_meteo, days_to_select=days_to_select,
columns_to_select=["mean"], y_col="mean", scale_y=True)
No current year days have been found for the day 2020-01-09
No current year days have been found for the day 2020-01-10
No current year days have been found for the day 2020-01-11
No current year days have been found for the day 2020-01-13
```

```
...

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906  56.675791  76.974569              36.287863
2020-01-09  54.887035  55.216906  56.675791              35.814008
2020-01-10  28.192059  54.887035  55.216906              36.143744
2020-01-11  26.099399  28.192059  54.887035              35.806540
2020-01-12  40.759729  26.099399  28.192059              35.522678
...               ...        ...        ...                    ...
2020-12-27  49.143828  43.004333  42.601218              38.902204
2020-12-28  47.568209  49.143828  43.004333              38.423588
2020-12-29  28.473515  47.568209  49.143828              37.817480
2020-12-30  14.695619  28.473515  47.568209              36.864552
2020-12-31  11.480358  14.695619  28.473515              35.864452

          6_years_ago_mean  current_year_mean  current_year_mean.1
Datetime
2020-01-08         71.802620          56.902806            48.400784
2020-01-09         79.803419          53.860020            47.181447
2020-01-10         71.632078          51.860875            46.368620
2020-01-11         79.216124          53.371621            48.126442
2020-01-12         89.111978          53.430592            48.651526
...                      ...                ...                  ...
2020-12-27         17.186082          21.778933            25.123485
2020-12-28         19.039899          20.635976            25.146538
```

```
2020-12-29     20.643419          20.311077          25.122216
2020-12-30     19.247014          24.071164          25.066962
2020-12-31     23.937203          26.838859          25.060622

          current_year_mean.2
Datetime
2020-01-08    76.974569
2020-01-09    47.181447
2020-01-10    46.368620
2020-01-11    48.126442
2020-01-12    53.902359
...                ...
2020-12-27    14.463473
2020-12-28    25.146538
2020-12-29    25.122216
2020-12-30    25.117861
2020-12-31    16.131590


[359 rows x 13 columns]
```

Fourth adding

VMEDIA VMAX PRESSIONE

```
# Higher-order function, which creates the `days_to_select` function.
# It takes in input three specific tolerances `t1-t2-t3` and it returns
the corresponding `days_to_select` function.
>>> def create_daysToSelect_function(t1, t2, t3):
    return (
     lambda day, df, day_current_year, df_current_year :
     (abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
       df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<t1 and
      abs(df_current_year["VENTOMAX km/h"].loc[day] -
       df_current_year["VENTOMAX km/h"].loc[day_current_year])<t2 and
      abs(df_current_year["PRESSIONESLM mb"].loc[day] -
       df_current_year["PRESSIONESLM mb"].loc[day_current_year])<t3)
    )

>>> tolerances = [1, 5, 10, 15] # Possible tolerances
```

```
>>> dataset_list = [
       tsp.add_current_year_statistics(df=df_mean_best,
                 df_current_year=df_mean_meteo,
                 # Create `days_to_select`
                 days_to_select=create_daysToSelect_function(t1,t2,t3),
                 # Only the "mean" column is of interest
                 columns_to_select=["mean"], y_col="mean",
                 scale_y=True)[1:]
       for t1 in tolerances for t2 in tolerances for t3 in tolerances]
UserWarning: No current year days have been found for the day
2020-01-10
UserWarning: No current year days have been found for the day
2020-01-13
UserWarning: No current year days have been found for the day
2020-01-18
UserWarning: No current year days have been found for the day
2020-01-19
...

>>> model = ms.PolynomialRegression()
>>> hyperparameter="degree"
>>> hyperparameter_values=[1,2,3]

>>> (datasets_train_val_score, datasets_best_hyperparameter_value,
 best_index, test_score,
 axes) = ms.datasets_hyperparameter_validation(dataset_list, model,
hyperparameter, hyperparameter_values, time_series=True)
```

```
>>> print("Index best dataset:", str(best_index), "; t1-t2-t3:",
          str(xvalues[best_index]))
Index best dataset: 23 ; t1-t2-t3: 5-5-15

>>> print("Best polynomial grade:",
          str(datasets_best_hyperparameter_value[best_index]))
Best polynomial grade: 1

>>> print("Validation score:",
          str(datasets_train_val_score[best_index,1]))
Validation score: 0.00518555388716895
```

```
>>> print("Test score:", str(test_score))
Test score: 0.00724853609009831
```

The validation score has decreased!

Best dataset: `tolerances 5-5-1`

There is an improvement as compared to the previous dataset: the validation score has decreased from `0.00522` to `0.00518`.

```
>>> days_to_select = lambda day, df, day_current_year, df_current_year :
      (abs(df_current_year["VENTOMEDIA km/h"].loc[day] -
        df_current_year["VENTOMEDIA km/h"].loc[day_current_year])<5 and
       abs(df_current_year["VENTOMAX km/h"].loc[day] -
        df_current_year["VENTOMAX km/h"].loc[day_current_year])<5 and
       abs(df_current_year["PRESSIONESLM mb"].loc[day] -
        df_current_year["PRESSIONESLM mb"].loc[day_current_year])<15)

>>> (df_mean_best, X,
 y) = tsp.add_current_year_statistics(df=df_mean_best,
df_current_year=df_mean_meteo, days_to_select=days_to_select,
columns_to_select=["mean"], y_col="mean", scale_y=True)

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
...               ...        ...        ...        ...        ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
```

```
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...         ...        ...          ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

          6_years_ago_mean  current_year_mean  current_year_mean.1
Datetime
2020-01-08     71.802620          56.902806          48.400784
2020-01-09     79.803419          53.860020          47.181447
2020-01-10     71.632078          51.860875          46.368620
2020-01-11     79.216124          53.371621          48.126442
2020-01-12     89.111978          53.430592          48.651526
...                  ...                ...                ...
2020-12-27     17.186082          21.778933          25.123485
2020-12-28     19.039899          20.635976          25.146538
2020-12-29     20.643419          20.311077          25.122216
2020-12-30     19.247014          24.071164          25.066962
2020-12-31     23.937203          26.838859          25.060622

        current_year_mean.2   current_year_mean.3
Datetime
2020-01-08   76.974569             51.768905
2020-01-09   47.181447             53.860020
2020-01-10   46.368620             51.860875
2020-01-11   48.126442             50.341374
2020-01-12   53.902359             50.697472
...               ...                   ...
2020-12-27   14.463473             19.177966
2020-12-28   25.146538             17.899923
2020-12-29   25.122216             18.574172
2020-12-30   25.117861             20.902818
2020-12-31   16.131590             24.139165


[359 rows x 14 columns]
```

Conclusion

Now the results of the previous case study are discussed.

On the whole, the validation score has dramatically decreased. It has decreased from `0.01523` of the trivial model to `0.00518`.
The final test score is `0.00725`.

The best dataset which has been selected contains 14 features. More specifically, it contains the response feature "`mean`" and 13 explanatory features.

```
>>> df_mean_best.info()
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 359 entries, 2020-01-08 to 2020-12-31
Data columns (total 14 columns):
 #   Column                 Non-Null Count  Dtype
---  ------                 --------------  -----
 0   mean                   359 non-null    float64
 1   mean_1                 359 non-null    float64
 2   mean_2                 359 non-null    float64
 3   mean_3                 359 non-null    float64
 4   mean_4                 359 non-null    float64
 5   mean_5                 359 non-null    float64
 6   mean_6                 359 non-null    float64
 7   mean_7                 359 non-null    float64
 8   upTo_6_years_ago_mean  359 non-null    float64
 9   6_years_ago_mean       359 non-null    float64
 10  current_year_mean      359 non-null    float64
 11  current_year_mean.1    359 non-null    float64
 12  current_year_mean.2    359 non-null    float64
 13  current_year_mean.3    359 non-null    float64
dtypes: float64(14)
memory usage: 50.2 KB

>>> df_mean_best
                mean     mean_1     mean_2     mean_3     mean_4
Datetime
2020-01-08  38.646087  40.759729  26.099399  28.192059  54.887035
2020-01-09  39.866008  38.646087  40.759729  26.099399  28.192059
2020-01-10  63.946840  39.866008  38.646087  40.759729  26.099399
2020-01-11  53.902359  63.946840  39.866008  38.646087  40.759729
2020-01-12  42.199734  53.902359  63.946840  39.866008  38.646087
```

```
...              ...         ...         ...         ...         ...
2020-12-27  14.997987  11.480358  14.695619  28.473515  47.568209
2020-12-28  16.317778  14.997987  11.480358  14.695619  28.473515
2020-12-29  23.536875  16.317778  14.997987  11.480358  14.695619
2020-12-30  22.759021  23.536875  16.317778  14.997987  11.480358
2020-12-31  22.005000  22.759021  23.536875  16.317778  14.997987

               mean_5     mean_6     mean_7  upTo_6_years_ago_mean
Datetime
2020-01-08  55.216906   56.675791  76.974569    36.287863
2020-01-09  54.887035   55.216906  56.675791    35.814008
2020-01-10  28.192059   54.887035  55.216906    36.143744
2020-01-11  26.099399   28.192059  54.887035    35.806540
2020-01-12  40.759729   26.099399  28.192059    35.522678
...               ...         ...         ...         ...
2020-12-27  49.143828   43.004333  42.601218    38.902204
2020-12-28  47.568209   49.143828  43.004333    38.423588
2020-12-29  28.473515   47.568209  49.143828    37.817480
2020-12-30  14.695619   28.473515  47.568209    36.864552
2020-12-31  11.480358   14.695619  28.473515    35.864452

          6_years_ago_mean  current_year_mean  current_year_mean.1
Datetime
2020-01-08     71.802620          56.902806         48.400784
2020-01-09     79.803419          53.860020         47.181447
2020-01-10     71.632078          51.860875         46.368620
2020-01-11     79.216124          53.371621         48.126442
2020-01-12     89.111978          53.430592         48.651526
...              ...                ...               ...
2020-12-27     17.186082          21.778933         25.123485
2020-12-28     19.039899          20.635976         25.146538
2020-12-29     20.643419          20.311077         25.122216
2020-12-30     19.247014          24.071164         25.066962
2020-12-31     23.937203          26.838859         25.060622

        current_year_mean.2   current_year_mean.3
Datetime
2020-01-08   76.974569            51.768905
2020-01-09   47.181447            53.860020
2020-01-10   46.368620            51.860875
2020-01-11   48.126442            50.341374
```

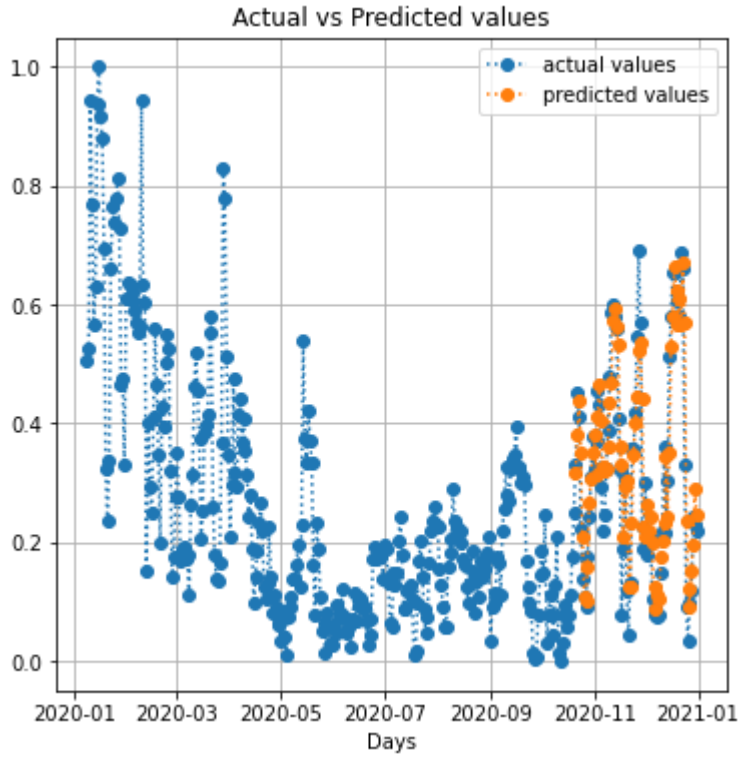
```
2020-01-12   53.902359            50.697472
...             ...                  ...
2020-12-27   14.463473            19.177966
2020-12-28   25.146538            17.899923
2020-12-29   25.122216            18.574172
2020-12-30   25.117861            20.902818
2020-12-31   16.131590            24.139165


[359 rows x 14 columns]
```

The best model which has been selected is `PolynomialRegression` with `degree=1`, i.e. the linear regression model.

```
>>> model = ms.PolynomialRegression(degree=1)
```

To conclude, the plots which describe the goodness of the predictions are shown. The improvement of the goodness of predictions as compared to the first model is graphically visible.

```
>>> ms.plot_predictions(X ,y ,model, xvalues=df_mean_best.index,
xlabel="Days")
<AxesSubplot:title={'center':'Actual vs Predicted values'},
xlabel='Days'>
```




```
>>> ms.plot_predictions(X ,y ,model, plot_type=1,
xvalues=df_mean_best.index, xlabel="Days")
<AxesSubplot:title={'center':'Actual vs Predicted values'},
xlabel='Actual values', ylabel='Predicted values'>
```