# Multiple linear regression example

October 6, 2020

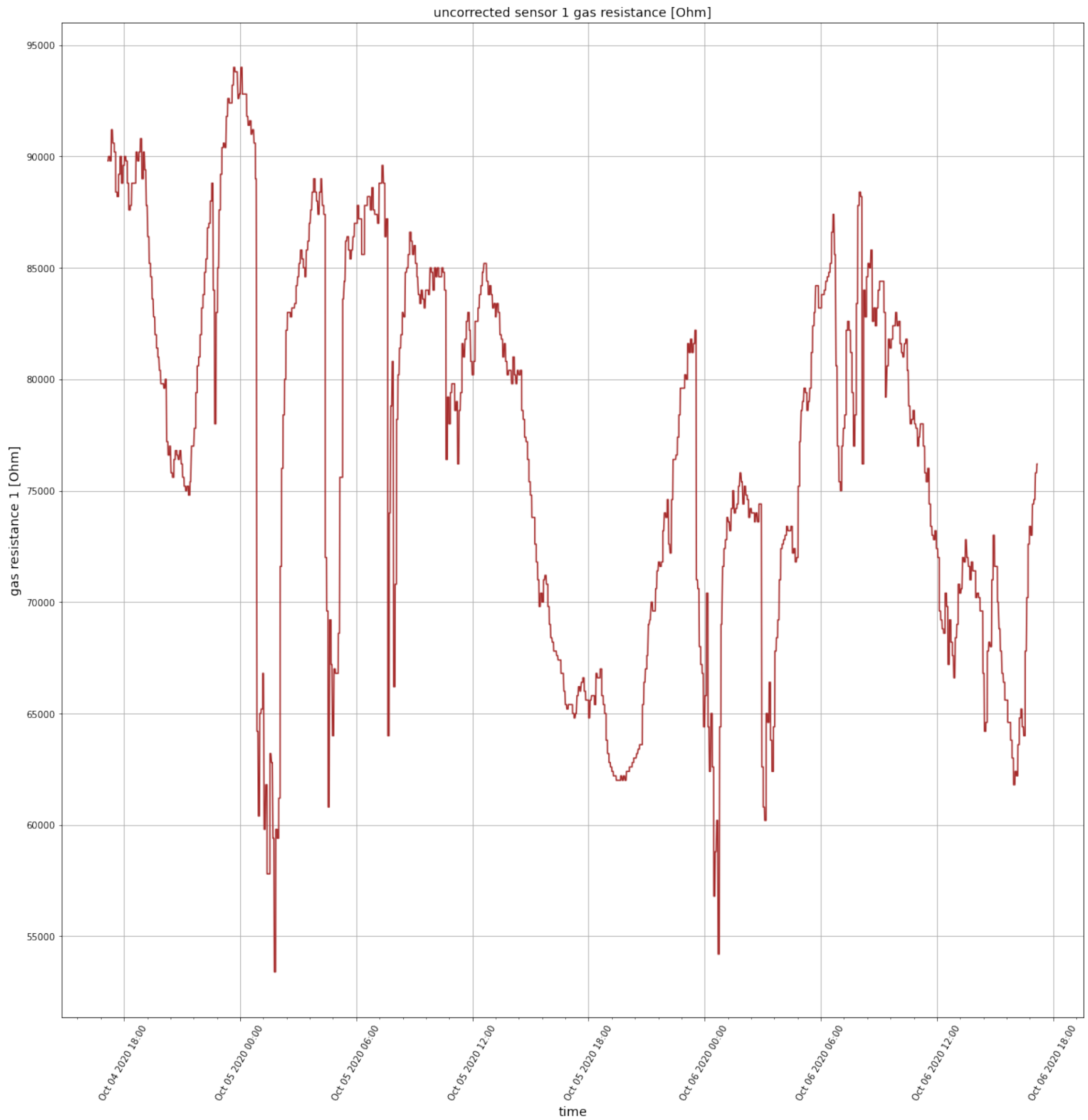
Read the CSV file created by the CCU Historian, ensure that field separator is ';' and decimal separator is '.', if necessary edit CSV file before reading it by the provided script 'csv_convert_historian.bsh' scale the sensor readings according the set conversion factors

[1]:
```
import warnings
warnings.simplefilter(action='ignore', category=FutureWarning)

import pandas as pd
from datetime import datetime

import numpy as np


dateparse = lambda x: pd.datetime.strptime(x, '%d.%m.%Y %H:%M:%S.%f')

scale1=2000    #sensor 1's gas readings arescaled by a factor of 2000 Ohms/deg C
scale2=2000    #sensor 2's gas readings arescaled by a factor of 2000 Ohms/deg C
scale3=4000    #sensor 3's gas readings arescaled by a factor of 4000 Ohms/deg C

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])

#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3
#df.shape
#df.columns
#df.dtypes

df.head()
#df['Datum']
#type(df['sensor 1'][0])
```

```
[1]:                      Datum  Mode  sensor 1  sensor 2  sensor 3  rLF außen  \
     0 2020-10-04 17:10:39.329     2   89800.0   77600.0  406000.0         66
     1 2020-10-04 17:11:02.903     2   89800.0   77600.0  406000.0         66
     2 2020-10-04 17:11:02.913     2   89800.0   77600.0  406000.0         66
     3 2020-10-04 17:11:52.502     2   90000.0   77600.0  406000.0         66
     4 2020-10-04 17:12:09.850     2   90000.0   77200.0  406000.0         66

        temperature  absolute humidity außen
     0         13.4                     7.667
     1         13.4                     7.667
     2         13.4                     7.667
     3         13.4                     7.667
     4         13.4                     7.667
```

Time series diagram of the raw gas resistance of sensor 1

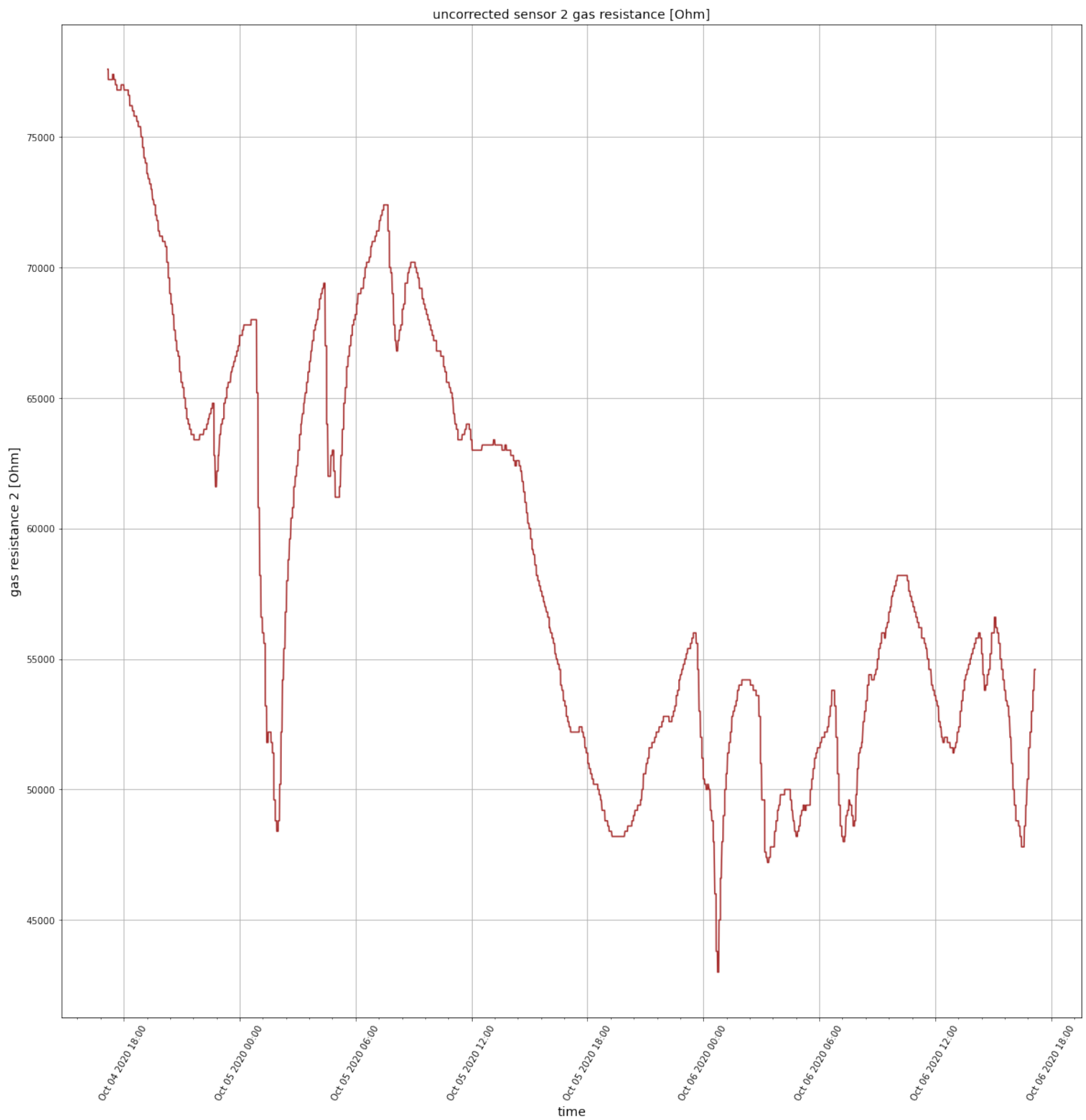
```
[2]: import matplotlib.pyplot as plt
     import matplotlib.dates as mdates
     from matplotlib.dates import DateFormatter
     from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                                    AutoMinorLocator)

     fig, ax = plt.subplots(figsize=(20, 20))
     plt.xticks(rotation=60)
     ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

     ax.xaxis.set_minor_locator(AutoMinorLocator())

     ax.plot_date(df['Datum'], df['sensor 1'], linestyle='solid', marker=" ",␣
      ↪color='brown')
     plt.title('uncorrected sensor 1 gas resistance [Ohm]', fontsize=14)
     plt.xlabel('time', fontsize=14)
     plt.ylabel('gas resistance 1 [Ohm]', fontsize=14)
     plt.grid(True)
     plt.show()
```




Time series diagram of the raw gas resistance of sensor 2

[3]:
```
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)

fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
```

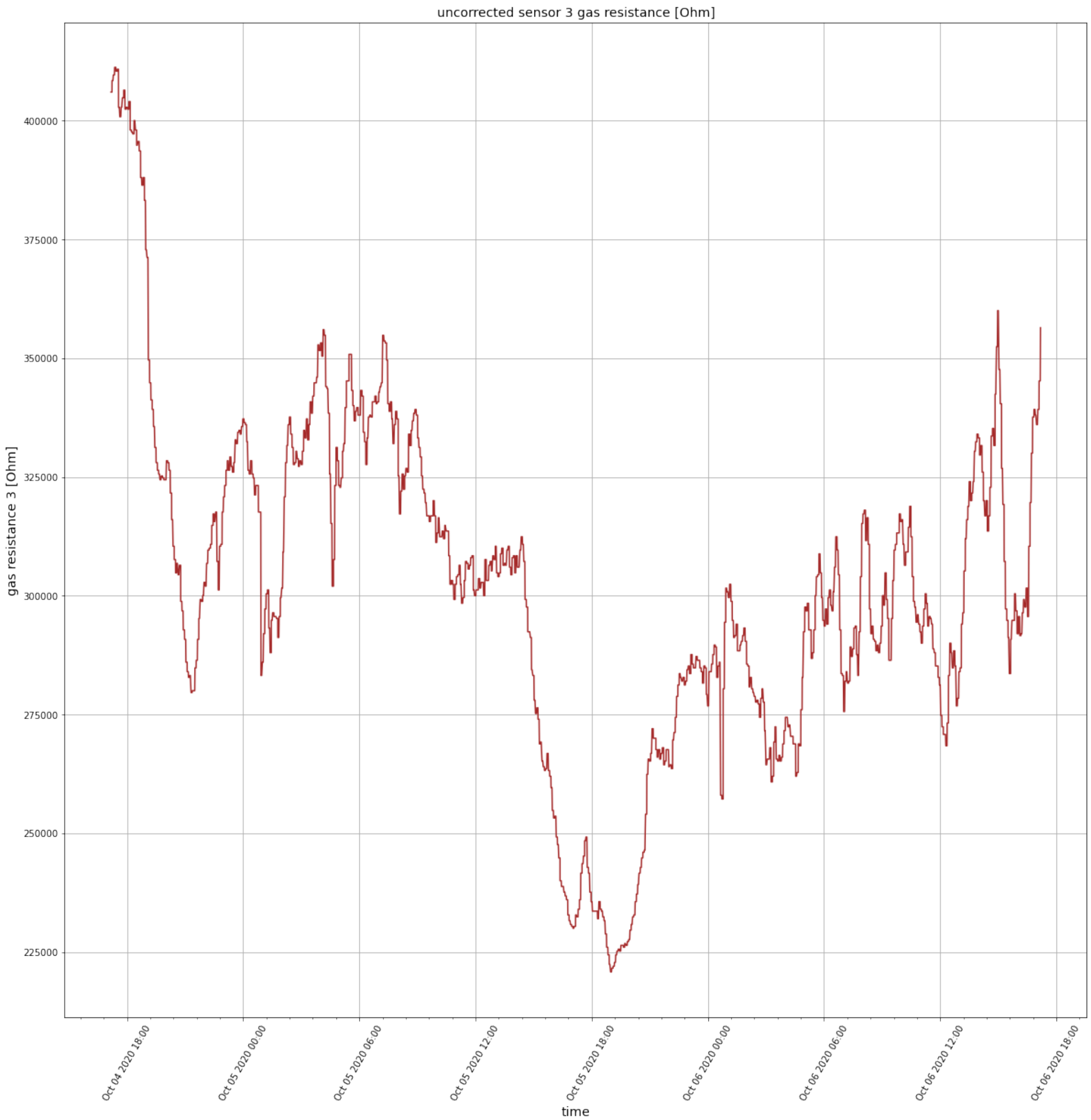
```
ax.xaxis.set_minor_locator(AutoMinorLocator())

plt.plot_date(df['Datum'], df['sensor 2'], linestyle='solid', marker=" ",␣
 ↪color='brown')
plt.title('uncorrected sensor 2 gas resistance [Ohm]', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('gas resistance 2 [Ohm]', fontsize=14)
plt.grid(True)
plt.show()
```




Time series diagram of the raw gas resistance of sensor 3

[4]:

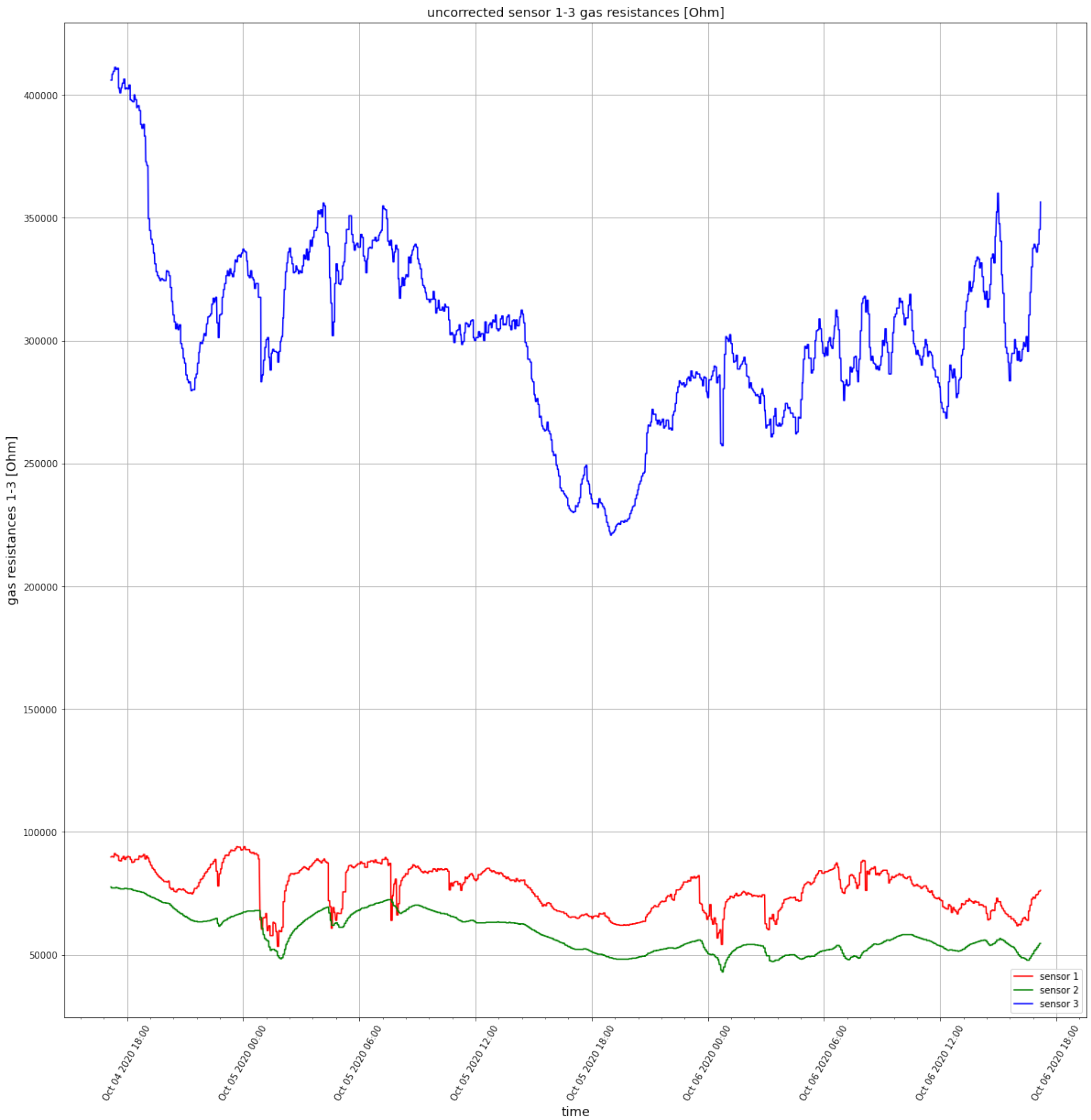
```
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)

fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax.xaxis.set_minor_locator(AutoMinorLocator())

scale3=4000

plt.plot_date(df['Datum'], df['sensor 3'], linestyle='solid', marker=" ",␣
 ↪color='brown')
plt.title('uncorrected sensor 3 gas resistance [Ohm]', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('gas resistance 3 [Ohm]', fontsize=14)
plt.grid(True)
plt.show()
```




Time series diagrams of the raw gas resistances of sensors 1-3

[5]:
```
import pandas as pd
from sklearn import linear_model
import matplotlib.pyplot as plt
from datetime import datetime
import matplotlib.dates as mdates
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

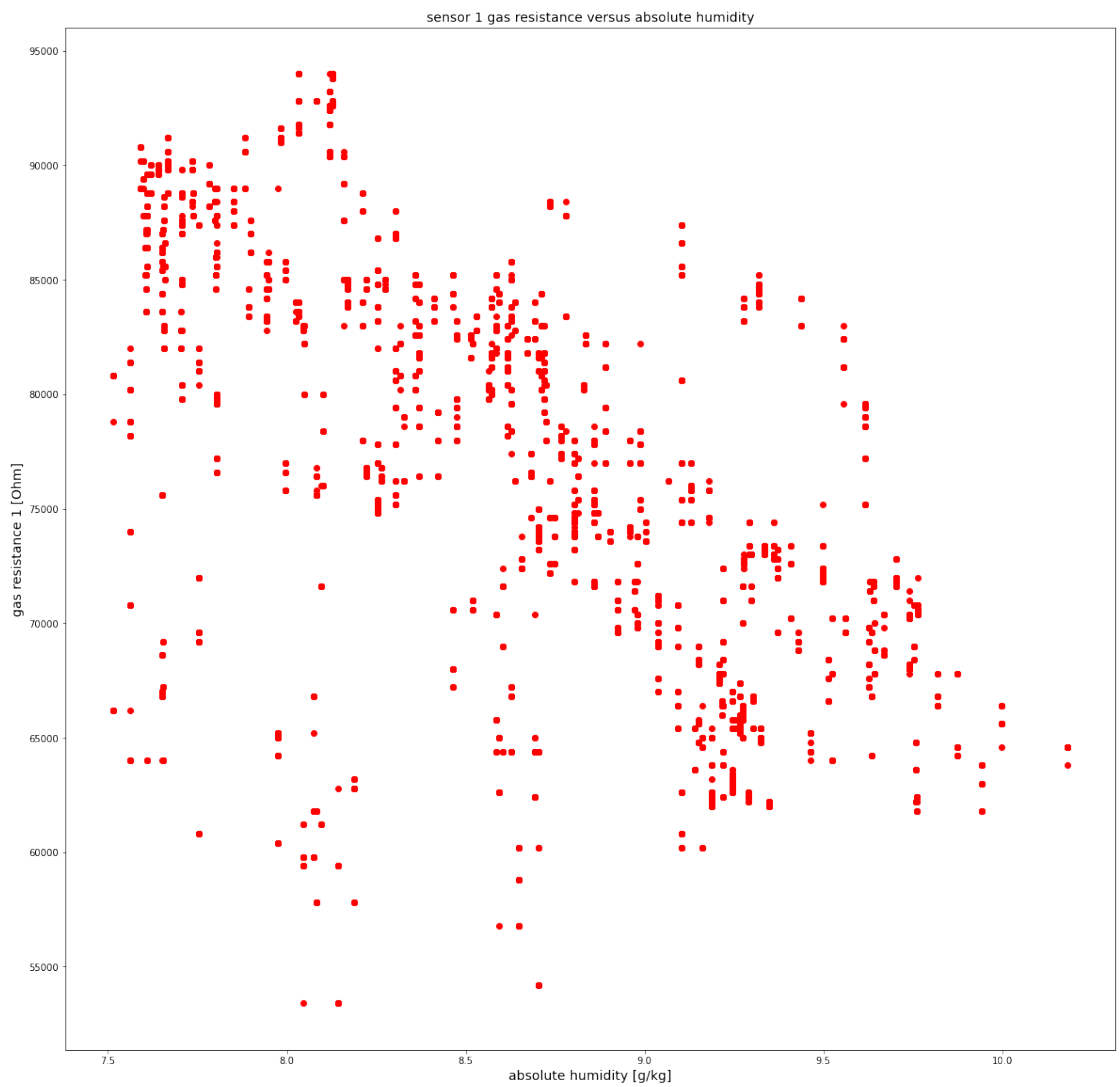
```
fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax.xaxis.set_minor_locator(AutoMinorLocator())

plt.plot_date(df['Datum'], df['sensor 1'], linestyle='solid', marker=" ",␣
 ↪color='red', label='sensor 1')
plt.plot_date(df['Datum'], df['sensor 2'], linestyle='solid', marker=" ",␣
 ↪color='green', label='sensor 2')
plt.plot_date(df['Datum'], df['sensor 3'], linestyle='solid', marker=" ",␣
 ↪color='blue', label='sensor 3')
plt.legend(loc ="lower right")
plt.title('uncorrected sensor 1-3 gas resistances [Ohm]', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('gas resistances 1-3 [Ohm]', fontsize=14)
plt.grid(True)
plt.show()
```




Scatter plot of raw gas resistance of sensor 1 versus the absolute humidity,

[6]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
```

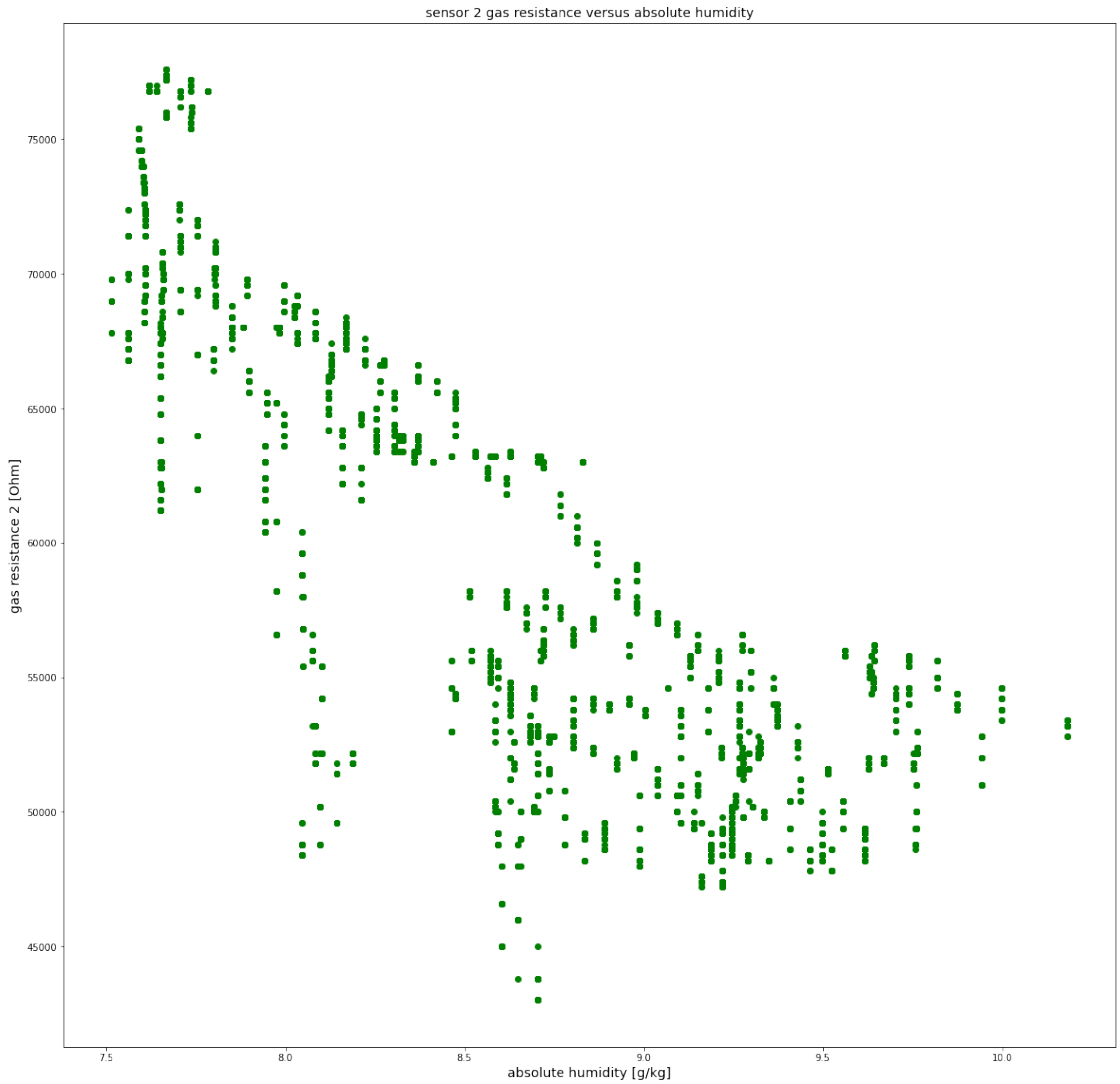
```python
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))

plt.scatter(df['absolute humidity außen'], df['sensor 1'], color='red')
plt.title('sensor 1 gas resistance versus absolute humidity', fontsize=14)
plt.xlabel('absolute humidity [g/kg]', fontsize=14)
plt.ylabel('gas resistance 1 [Ohm]', fontsize=14)
plt.show()
```




Scatter plot of raw gas resistance of sensor 2 versus the absolute humidity, is the dependency somehow linear?

[7]:

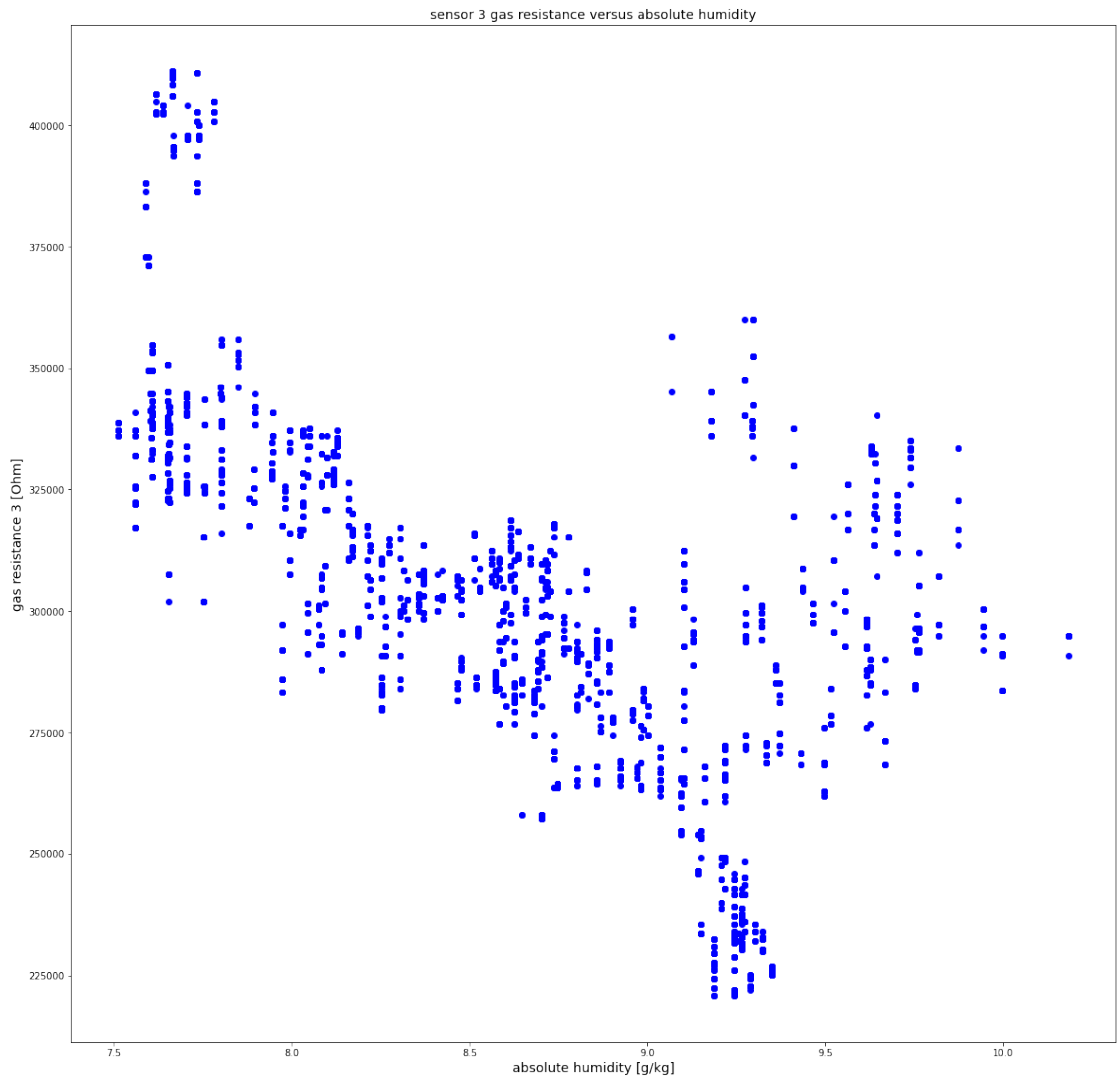
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['absolute humidity außen'], df['sensor 2'], color='green')
plt.title('sensor 2 gas resistance versus absolute humidity', fontsize=14)
plt.xlabel('absolute humidity [g/kg]', fontsize=14)
plt.ylabel('gas resistance 2 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




Scatter plot of raw gas resistance of sensor 3 versus the absolute humidity, is the dependency somehow linear?

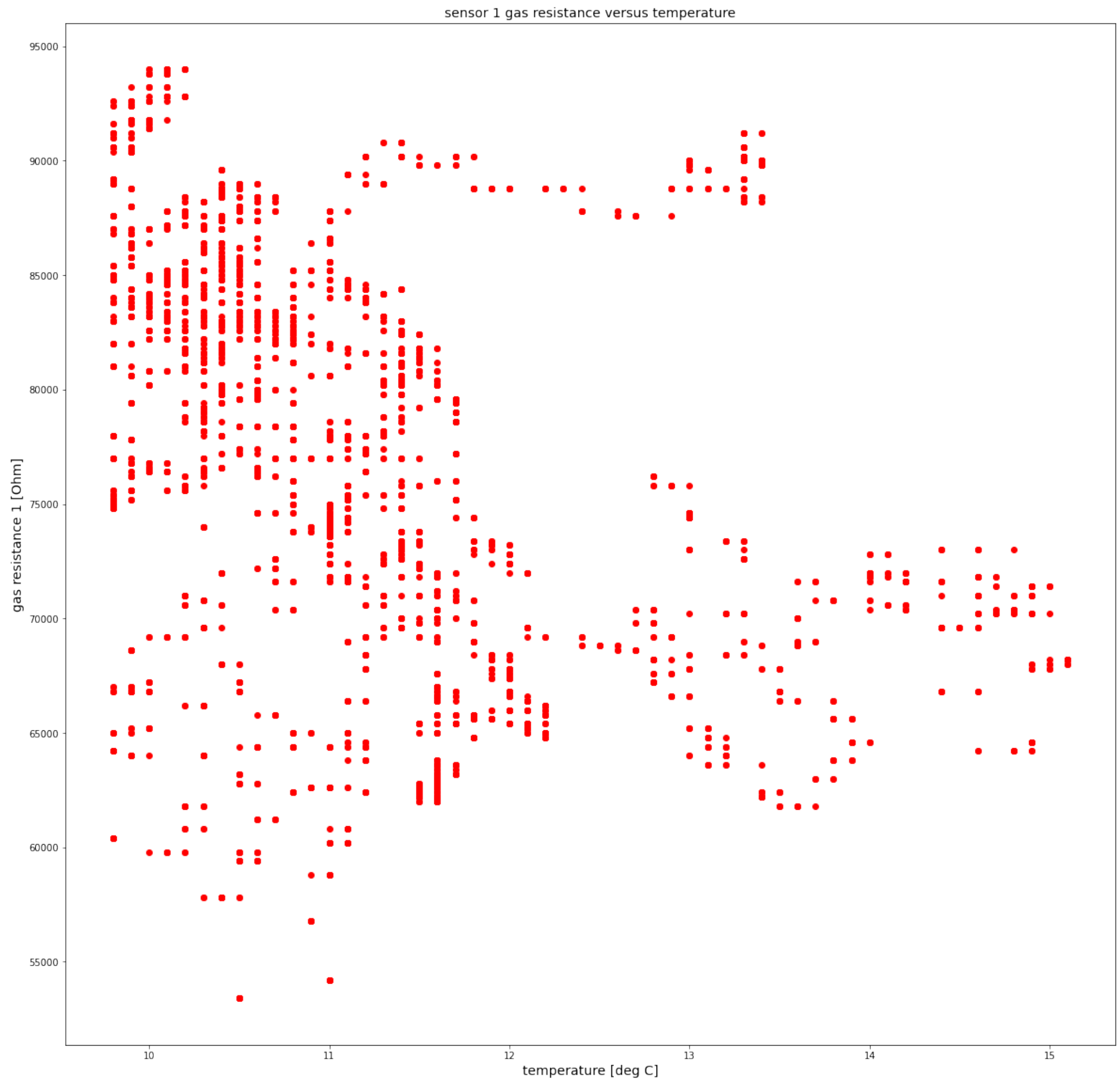
[8]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
```

```
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['absolute humidity außen'], df['sensor 3'], color='blue')
plt.title('sensor 3 gas resistance versus absolute humidity', fontsize=14)
plt.xlabel('absolute humidity [g/kg]', fontsize=14)
plt.ylabel('gas resistance 3 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




Scatter plot of raw gas resistance of sensor 1 versus the temperature, is the dependency somehow linear?

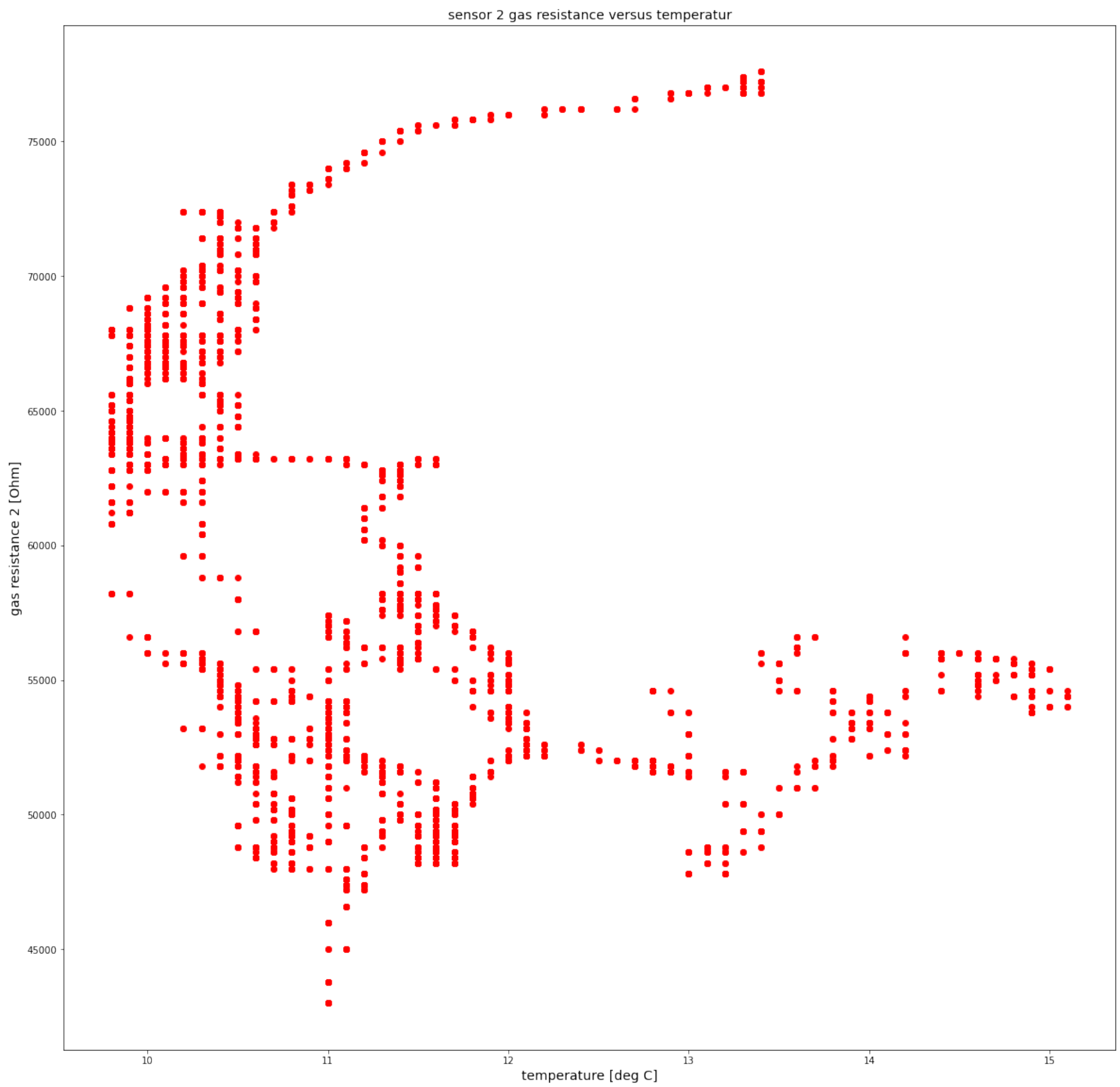
[9]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['temperature'], df['sensor 1'], color='red')
plt.title('sensor 1 gas resistance versus temperature', fontsize=14)
plt.xlabel('temperature [deg C]', fontsize=14)
plt.ylabel('gas resistance 1 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




Scatter plot of raw gas resistance of sensor 2 versus the temperature, is the dependency somehow linear?

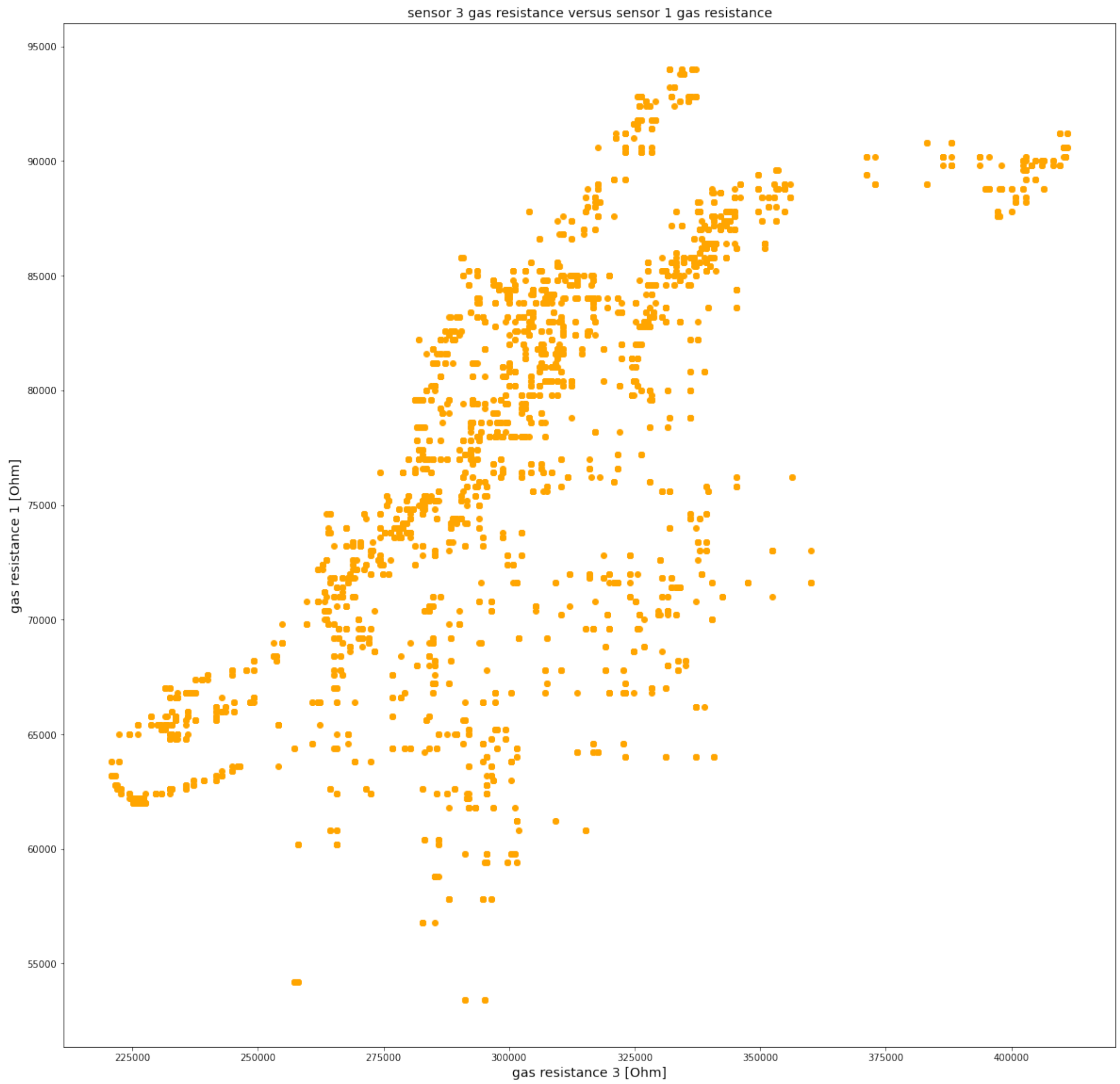
[10]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
```

```python
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['temperature'], df['sensor 2'], color='red')
plt.title('sensor 2 gas resistance versus temperatur', fontsize=14)
plt.xlabel('temperature [deg C]', fontsize=14)
plt.ylabel('gas resistance 2 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




Scatter plot of raw gas resistance of sensor 3 versus raw gas resistance of sensor 1, is the dependency somehow linear?

[11]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
 ↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
 ↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
 ↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
 ↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['sensor 3'], df['sensor 1'], color='orange')
plt.title('sensor 3 gas resistance versus sensor 1 gas resistance', fontsize=14)
plt.xlabel('gas resistance 3 [Ohm]', fontsize=14)
plt.ylabel('gas resistance 1 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




Scatter plot of raw gas resistance of sensor 2 versus raw gas resistance of sensor 1, is the dependency somehow linear?

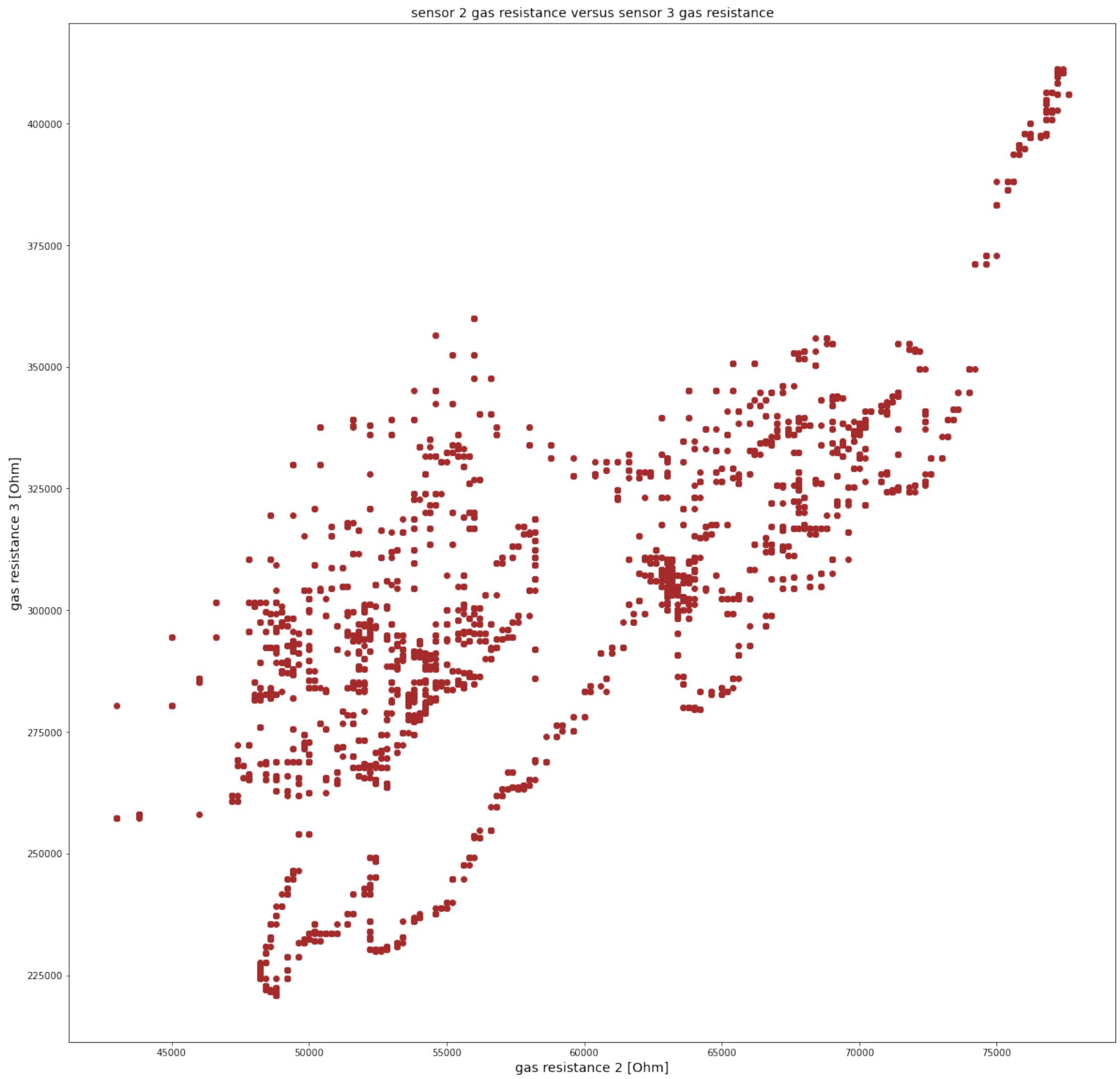
[12]:
```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
```

```
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['sensor 2'], df['sensor 1'], color='pink')
plt.title('sensor 2 gas resistance versus sensor 1 gas resistance', fontsize=14)
plt.xlabel('gas resistance 2 [Ohm]', fontsize=14)
plt.ylabel('gas resistance 1 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```


Scatter plot of raw gas resistance of sensor 2 versus raw gas resistance of sensor 3, is the dependency somehow linear?

[13]:

```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

plt.figure(figsize=(20,20))
plt.scatter(df['sensor 2'], df['sensor 3'], color='brown')
plt.title('sensor 2 gas resistance versus sensor 3 gas resistance', fontsize=14)
plt.xlabel('gas resistance 2 [Ohm]', fontsize=14)
plt.ylabel('gas resistance 3 [Ohm]', fontsize=14)
plt.grid(False)
plt.show()
```




multiple linear regression of raw gas resistance of sensor 1 in dependency of the absolute humidity and the temperature use the prediction 'predictions1' of the mutiple linear regression to create a corrected gas resistance 'residuals1' with eliminated influence of the absolute humidity and the temperature create a normalized scaled corrected gas resistance 'normalized_residuals1'

[14]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

```
dateparse = lambda x: pd.datetime.strptime(x, '%d.%m.%Y %H:%M:%S.%f')
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

X = df[['temperature','absolute humidity außen']] # here we have 2 variables␣
↪for multiple regression. If you just want to use one variable for simple␣
↪linear regression, then use X = df['Interest_Rate'] for example.
↪Alternatively, you may add additional variables within the brackets
Y = df['sensor 1']

# with sklearn
regr = linear_model.LinearRegression()
regr.fit(X, Y)

print('Intercept: \n', regr.intercept_)
print('Coefficients: \n', regr.coef_)

model = sm.OLS(Y, X).fit()
predictions1 = model.predict(X)

print_model = model.summary()
print(print_model)
print(model.rsquared)

residuals1=df['sensor 1']-predictions1
min_res=min(residuals1)
max_res=max(residuals1)

#clip min of residual1 to epsilon1 in order to avoid a log(0) trap
epsilon1=0.0001

normalized_residuals1=((residuals1-min_res)/(max_res-min_res)).
↪clip(epsilon1,None)*100


fig, ax1 = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
```

```
ax1.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax1.xaxis.set_minor_locator(AutoMinorLocator())

lns1=ax1.plot_date(df['Datum'], predictions1, linestyle='solid', marker=" ",␣
↪color='brown', label='linear regression prediction')
lns2=ax1.plot_date(df['Datum'], df['sensor 1'], linestyle='solid', marker=" ",␣
↪color='green', label='uncorrected input')
color = 'tab:red'
ax1.set_xlabel('time', fontsize=14)
ax1.set_ylabel('gas resistance 1 [Ohm]', color=color, fontsize=14)

ax2 = ax1.twinx()  # instantiate a second axes that shares the same x-axis
ax2.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax2.xaxis.set_minor_locator(AutoMinorLocator())

color = 'tab:blue'
ax2.set_ylabel('normalized gas resistance 1', color=color, fontsize=14)  # we␣
↪already handled the x-label with ax1
lns3=ax2.plot_date(df['Datum'], normalized_residuals1, linestyle='solid',␣
↪marker=" ", color='red', label='normalized scaled corrected')

plt.title('corrected sensor 1 gas resistance', fontsize=14)

ax1.grid(True)
lns = lns1+lns2+lns3
labs = [l.get_label() for l in lns]
ax1.legend(lns, labs, loc="lower left")

fig.tight_layout()  # otherwise the right y-label is slightly clipped
plt.show()
```

```
Intercept:
 146820.37610144832
Coefficients:
 [   72.584693   -8213.53828816]
                                 OLS Regression Results
================================================================================
=======
Dep. Variable:             sensor 1   R-squared (uncentered):
0.971
Model:                          OLS   Adj. R-squared (uncentered):
0.971
Method:               Least Squares   F-statistic:
7.596e+04
Date:              Tue, 06 Oct 2020   Prob (F-statistic):
```

```
0.00
Time:                        17:11:03   Log-Likelihood:
-49368.
No. Observations:                4528   AIC:
9.874e+04
Df Residuals:                    4526   BIC:
9.875e+04
Df Model:                           2
Covariance Type:            nonrobust
================================================================================
===========
                              coef    std err          t      P>|t|      [0.025
0.975]
--------------------------------------------------------------------------------
-----------
temperature              1328.1929    224.984      5.903      0.000     887.114
1769.272
absolute humidity außen  7085.0326    292.193     24.248      0.000    6512.191
7657.874
==============================================================================
Omnibus:                     2767.211   Durbin-Watson:                   0.005
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              262.882
Skew:                          -0.110   Prob(JB):                     8.24e-58
Kurtosis:                       1.840   Cond. No.                         26.7
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not
contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
0.9710706289546744
```


multiple linear regression of raw gas resistance of sensor 2 in dependency of the absolute humidity and the temperature use the prediction 'predictions2' of the mutiple linear regression to create a corrected gas resistance 'residuals2' with eliminated influence of the absolute humidity and the temperature create a normalized scaled corrected gas resistance 'normalized_residuals2'

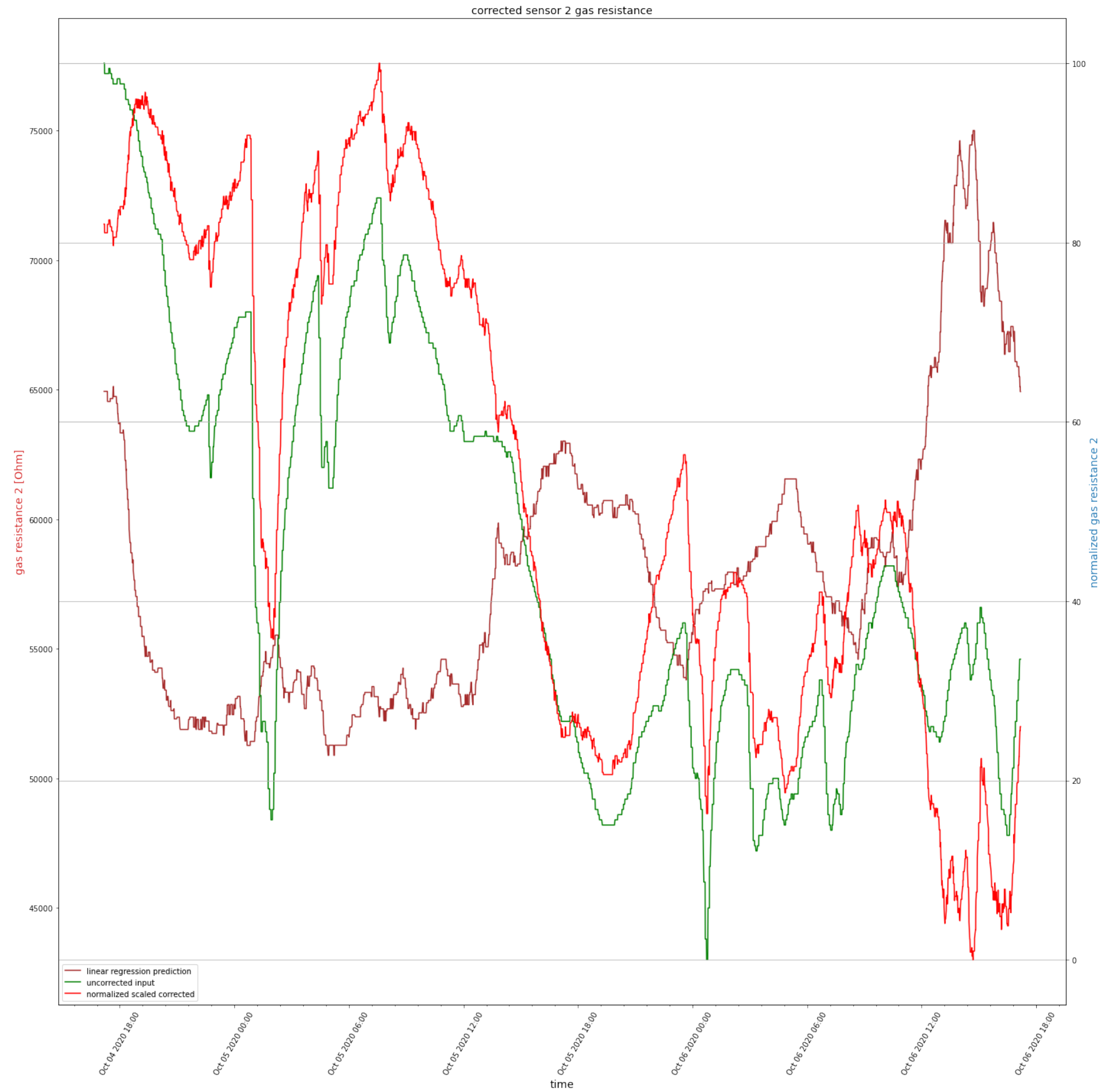
[15]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

```
dateparse = lambda x: pd.datetime.strptime(x, '%d.%m.%Y %H:%M:%S.%f')
import numpy as np

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

X = df[['temperature','absolute humidity außen']] # here we have 2 variables␣
↪for multiple regression. If you just want to use one variable for simple␣
↪linear regression, then use X = df['Interest_Rate'] for example.
↪Alternatively, you may add additional variables within the brackets
Y = df['sensor 2']

# with sklearn
regr = linear_model.LinearRegression()
regr.fit(X, Y)

print('Intercept: \n', regr.intercept_)
print('Coefficients: \n', regr.coef_)

model = sm.OLS(Y, X).fit()
predictions2 = model.predict(X)

print_model = model.summary()
print(print_model)
print(model.rsquared)

residuals2=df['sensor 2']-predictions2
min_res=min(residuals2)
max_res=max(residuals2)
#clip min of residual2 to epsilon2 in order to avoid a log(0) trap
epsilon2=0.0001

normalized_residuals2=((residuals2-min_res)/(max_res-min_res)).
↪clip(epsilon2,None)*100

fig, ax1 = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax1.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
```

```
ax1.xaxis.set_minor_locator(AutoMinorLocator())

lns1=plt.plot_date(df['Datum'], predictions2, linestyle='solid', marker=" ",␣
↪color='brown', label='linear regression prediction')
lns2=plt.plot_date(df['Datum'], df['sensor 2'], linestyle='solid', marker=" ",␣
↪color='green', label='uncorrected input')
color = 'tab:red'
ax1.set_xlabel('time', fontsize=14)
ax1.set_ylabel('gas resistance 2 [Ohm]', color=color, fontsize=14)

ax2 = ax1.twinx()  # instantiate a second axes that shares the same x-axis
ax2.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax2.xaxis.set_minor_locator(AutoMinorLocator())
color = 'tab:blue'
ax2.set_ylabel('normalized gas resistance 2', color=color, fontsize=14)  # we␣
↪already handled the x-label with ax1
lns3=plt.plot_date(df['Datum'], normalized_residuals2, linestyle='solid',␣
↪marker=" ", color='red', label='normalized scaled corrected')
plt.title('corrected sensor 2 gas resistance', fontsize=14)

plt.grid(True)
lns = lns1+lns2+lns3
labs = [l.get_label() for l in lns]
ax1.legend(lns, labs, loc="lower left")

fig.tight_layout()  # otherwise the right y-label is slightly clipped
plt.show()
```

```
Intercept:
 142914.5332752517
Coefficients:
 [  2672.33987407 -13228.82900672]
                                 OLS Regression Results
================================================================================
=======
Dep. Variable:               sensor 2   R-squared (uncentered):
0.962
Model:                            OLS   Adj. R-squared (uncentered):
0.962
Method:                 Least Squares   F-statistic:
5.746e+04
Date:                Tue, 06 Oct 2020   Prob (F-statistic):
0.00
Time:                        17:11:04   Log-Likelihood:
-48774.
```

```
No. Observations:                4528   AIC:
9.755e+04
Df Residuals:                    4526   BIC:
9.757e+04
Df Model:                           2
Covariance Type:            nonrobust
================================================================================
===========
                             coef    std err          t      P>|t|      [0.025
0.975]
--------------------------------------------------------------------------------
-----------
temperature             3894.5453    197.312     19.738      0.000    3507.717
4281.373
absolute humidity außen  1662.7561    256.255      6.489      0.000    1160.372
2165.140
==============================================================================
Omnibus:                    75200.429   Durbin-Watson:                   0.000
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              351.122
Skew:                           0.035   Prob(JB):                     5.69e-77
Kurtosis:                       1.638   Cond. No.                         26.7
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not
contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
0.9621111098444451
```




multiple linear regression of raw gas resistance of sensor 3 in dependency of the absolute humidity and the temperature use the prediction 'predictions3' of the mutiple linear regression to create a corrected gas resistance 'residuals3' with eliminated influence of the absolute humidity and the temperature create a normalized scaled corrected gas resistance 'normalized_residuals3'

[16]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

```
dateparse = lambda x: pd.datetime.strptime(x, '%d.%m.%Y %H:%M:%S.%f')

df = pd.read_csv("historian.csv", sep=';', decimal=".", skiprows =␣
↪[0,1,2],dtype={'High': np.float64, 'Low': np.float64}, header = None,␣
↪encoding= 'unicode_escape',  parse_dates=[0], date_parser=dateparse, names =␣
↪[ 'Datum', 'Mode', 'sensor 1', 'sensor 2','sensor 3', 'rLF außen',␣
↪'temperature', 'absolute humidity außen'])
#do the scaling for sensor 1-3 readings
df['sensor 1'] *= scale1
df['sensor 2'] *= scale2
df['sensor 3'] *= scale3

X = df[['temperature','absolute humidity außen']] # here we have 2 variables␣
↪for multiple regression. If you just want to use one variable for simple␣
↪linear regression, then use X = df['Interest_Rate'] for example.
↪Alternatively, you may add additional variables within the brackets
Y = df['sensor 3']

# with sklearn
regr = linear_model.LinearRegression()
regr.fit(X, Y)

print('Intercept: \n', regr.intercept_)
print('Coefficients: \n', regr.coef_)

model = sm.OLS(Y, X).fit()
predictions3 = model.predict(X)

print_model = model.summary()
print(print_model)
print(model.rsquared)

residuals3=df['sensor 3']-predictions3
min_res=min(residuals3)
max_res=max(residuals3)
#clip min of residual3 to epsilon3 in order to avoid a log(0) trap
epsilon3=0.0001

normalized_residuals3=((residuals3-min_res)/(max_res-min_res)).
↪clip(epsilon3,None)*100

fig, ax1 = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax1.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
```

```
ax1.xaxis.set_minor_locator(AutoMinorLocator())

lns1=plt.plot_date(df['Datum'], predictions3, linestyle='solid', marker=" ",␣
↪color='brown', label='linear regression prediction')
lns2=plt.plot_date(df['Datum'], df['sensor 3'], linestyle='solid', marker=" ",␣
↪color='green', label='uncorrected input')
color = 'tab:red'
ax1.set_xlabel('time', fontsize=14)
ax1.set_ylabel('gas resistance 1 [Ohm]', color=color, fontsize=14)

ax2 = ax1.twinx()  # instantiate a second axes that shares the same x-axis
ax2.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax2.xaxis.set_minor_locator(AutoMinorLocator())

color = 'tab:blue'
ax2.set_ylabel('normalized gas resistance 3', color=color, fontsize=14)  # we␣
↪already handled the x-label with ax1
lns3=plt.plot_date(df['Datum'], normalized_residuals3, linestyle='solid',␣
↪marker=" ", color='red', label='normalized scaled corrected')
plt.title('corrected sensor 3 gas resistance', fontsize=14)

plt.grid(True)
lns = lns1+lns2+lns3
labs = [l.get_label() for l in lns]
ax1.legend(lns, labs, loc="lower left")

fig.tight_layout()  # otherwise the right y-label is slightly clipped
plt.show()
```

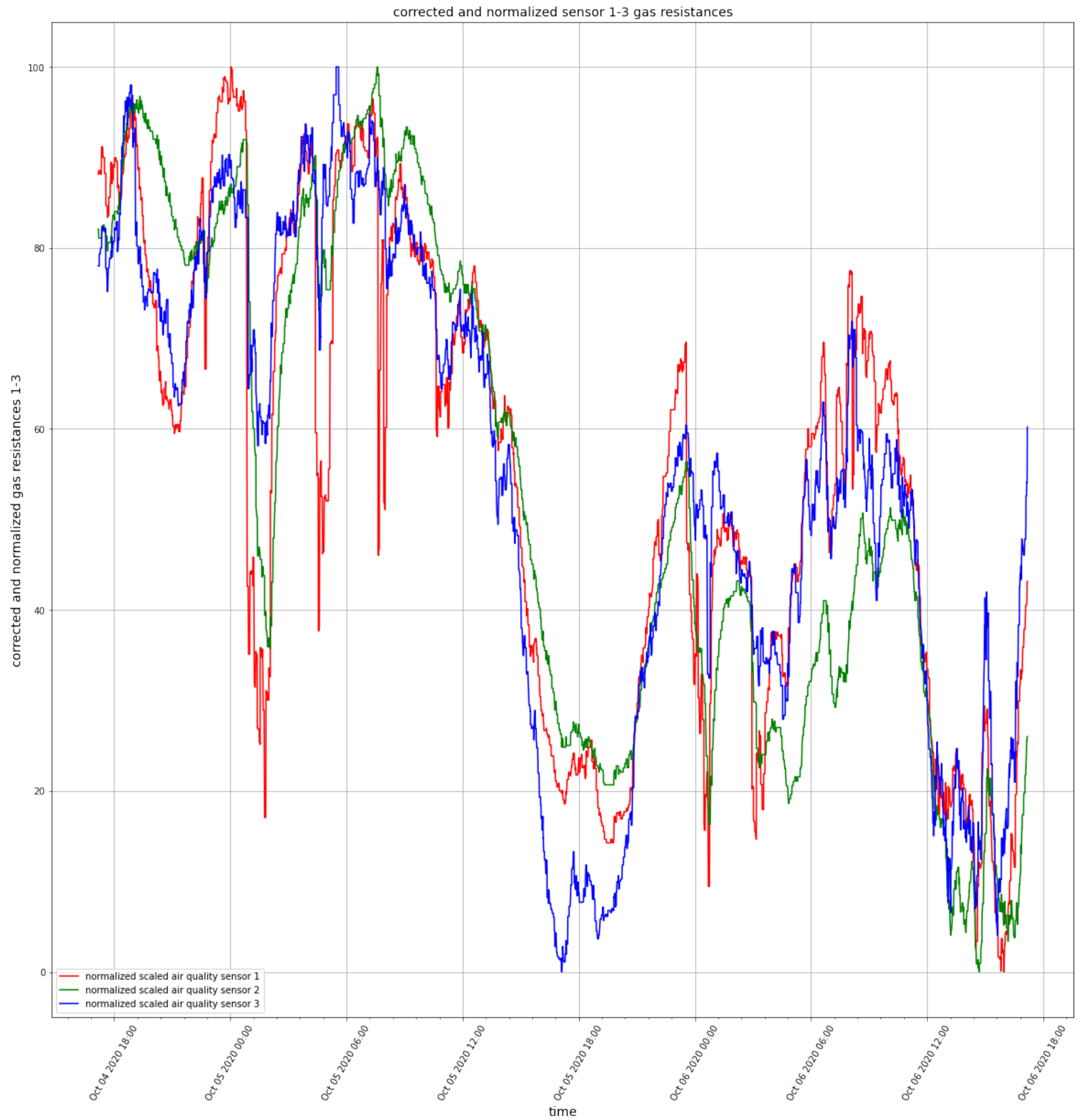
```
Intercept:
 579802.3242120288
Coefficients:
 [ 22246.06462549 -61085.37847776]
                                 OLS Regression Results
================================================================================
=======
Dep. Variable:               sensor 3   R-squared (uncentered):
0.975
Model:                            OLS   Adj. R-squared (uncentered):
0.975
Method:                 Least Squares   F-statistic:
8.733e+04
Date:                Tue, 06 Oct 2020   Prob (F-statistic):
0.00
Time:                        17:11:05   Log-Likelihood:
-55257.
```

```
No. Observations:                4528   AIC:
1.105e+05
Df Residuals:                    4526   BIC:
1.105e+05
Df Model:                           2
Covariance Type:            nonrobust
================================================================================
===========
                            coef    std err          t      P>|t|      [0.025
0.975]
--------------------------------------------------------------------------------
-----------
temperature             2.72e+04    825.968     32.937      0.000    2.56e+04
2.88e+04
absolute humidity außen  -670.4196   1072.708     -0.625      0.532   -2773.451
1432.612
==============================================================================
Omnibus:                     1080.405   Durbin-Watson:                   0.002
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              270.679
Skew:                          -0.333   Prob(JB):                     1.67e-59
Kurtosis:                       2.004   Cond. No.                         26.7
==============================================================================

Notes:
[1] R² is computed without centering (uncentered) since the model does not
contain a constant.
[2] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
0.9747412856706341
```


time series diagrams of normalized scaled gas resistances of sensors 1-3; y range is 0.0..100.0

[17]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)



fig, ax = plt.subplots(figsize=(20, 20))
```

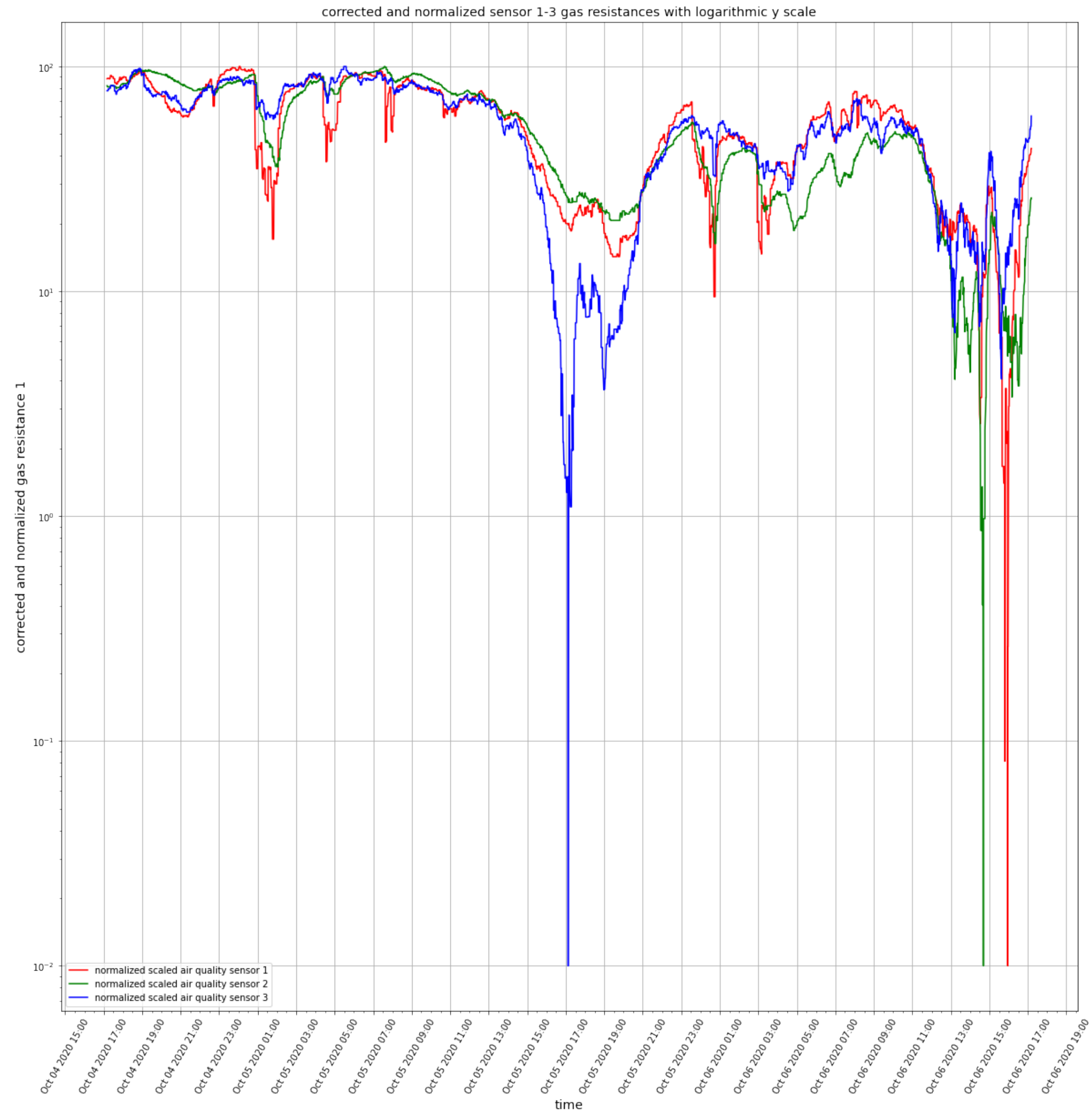
```
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))

ax.xaxis.set_minor_locator(AutoMinorLocator())

plt.plot_date(df['Datum'], normalized_residuals1, linestyle='solid', marker="␣
↪", color='red', label='normalized scaled air quality sensor 1')
plt.plot_date(df['Datum'], normalized_residuals2, linestyle='solid', marker="␣
↪", color='green', label='normalized scaled air quality sensor 2')
plt.plot_date(df['Datum'], normalized_residuals3, linestyle='solid', marker="␣
↪", color='blue', label='normalized scaled air quality sensor 3')
plt.title('corrected and normalized sensor 1-3 gas resistances', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('corrected and normalized gas resistances 1-3', fontsize=14)
plt.grid(True)
plt.legend(loc ="lower left")
plt.show()
```




time series diagrams of normalized scaled gas resistsnces of sensors 1-3 with logorithmic y scale

[18]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

```
fig, ax = plt.subplots(figsize=(20, 20))
plt.yscale('log')
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
hours = mdates.HourLocator(interval = 2)
ax.xaxis.set_major_locator(hours)
ax.xaxis.set_minor_locator(AutoMinorLocator())


plt.xticks(rotation=60)
plt.plot_date(df['Datum'], normalized_residuals1, linestyle='solid', marker="␣
↪", color='red', label='normalized scaled air quality sensor 1')
plt.plot_date(df['Datum'], normalized_residuals2, linestyle='solid', marker="␣
↪", color='green', label='normalized scaled air quality sensor 2')
plt.plot_date(df['Datum'], normalized_residuals3, linestyle='solid', marker="␣
↪", color='blue', label='normalized scaled air quality sensor 3')
plt.title('corrected and normalized sensor 1-3 gas resistances with logarithmic␣
↪y scale', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('corrected and normalized gas resistance 1', fontsize=14)
plt.grid(True)
plt.legend(loc ="lower left")
plt.show()
```

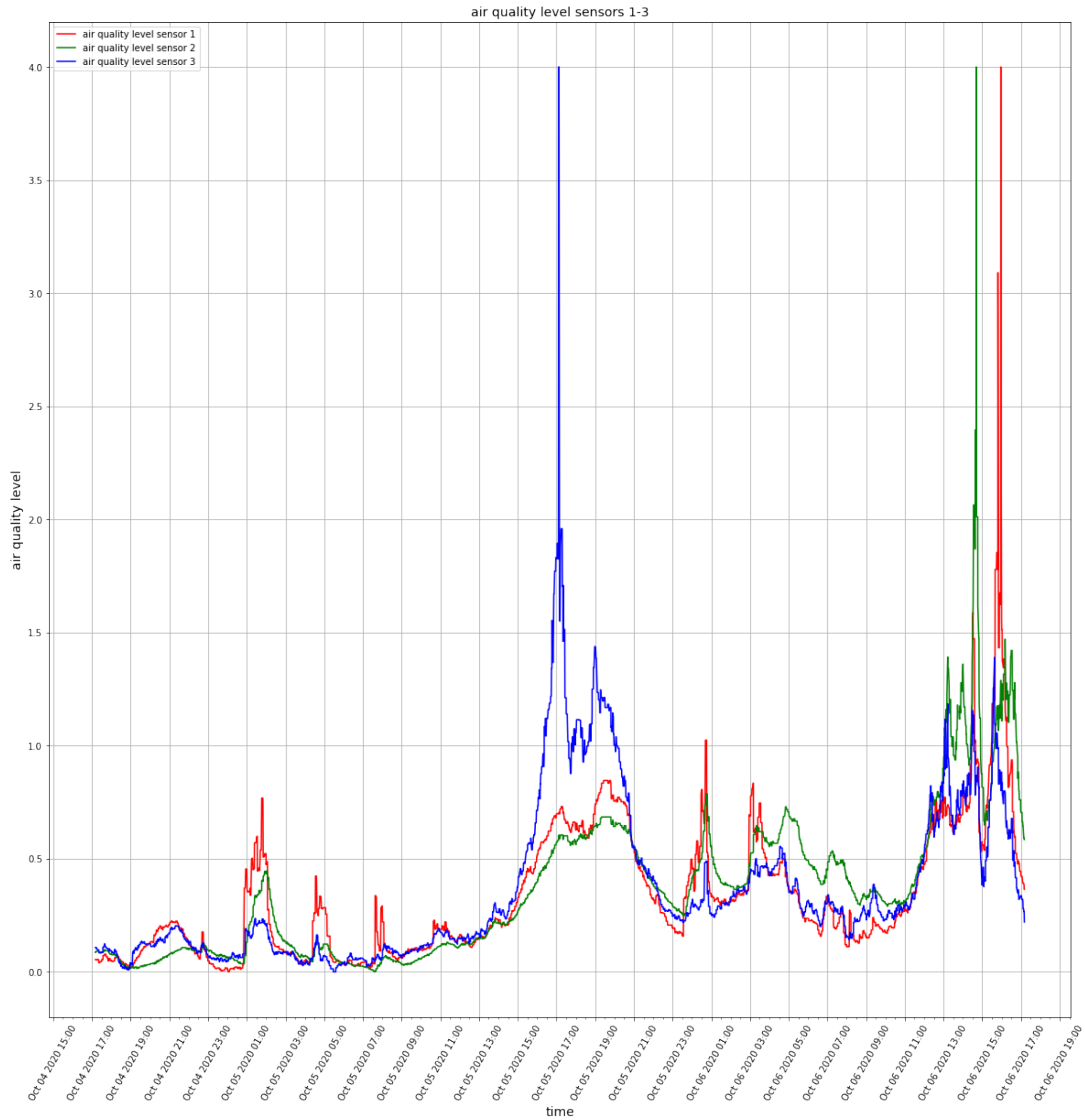



time series diagrams of logarithmic air quality levels of sensors 1-3 the air quality level can vary between 0 (fresh air) and 4 (very poor air quality)

[19]:

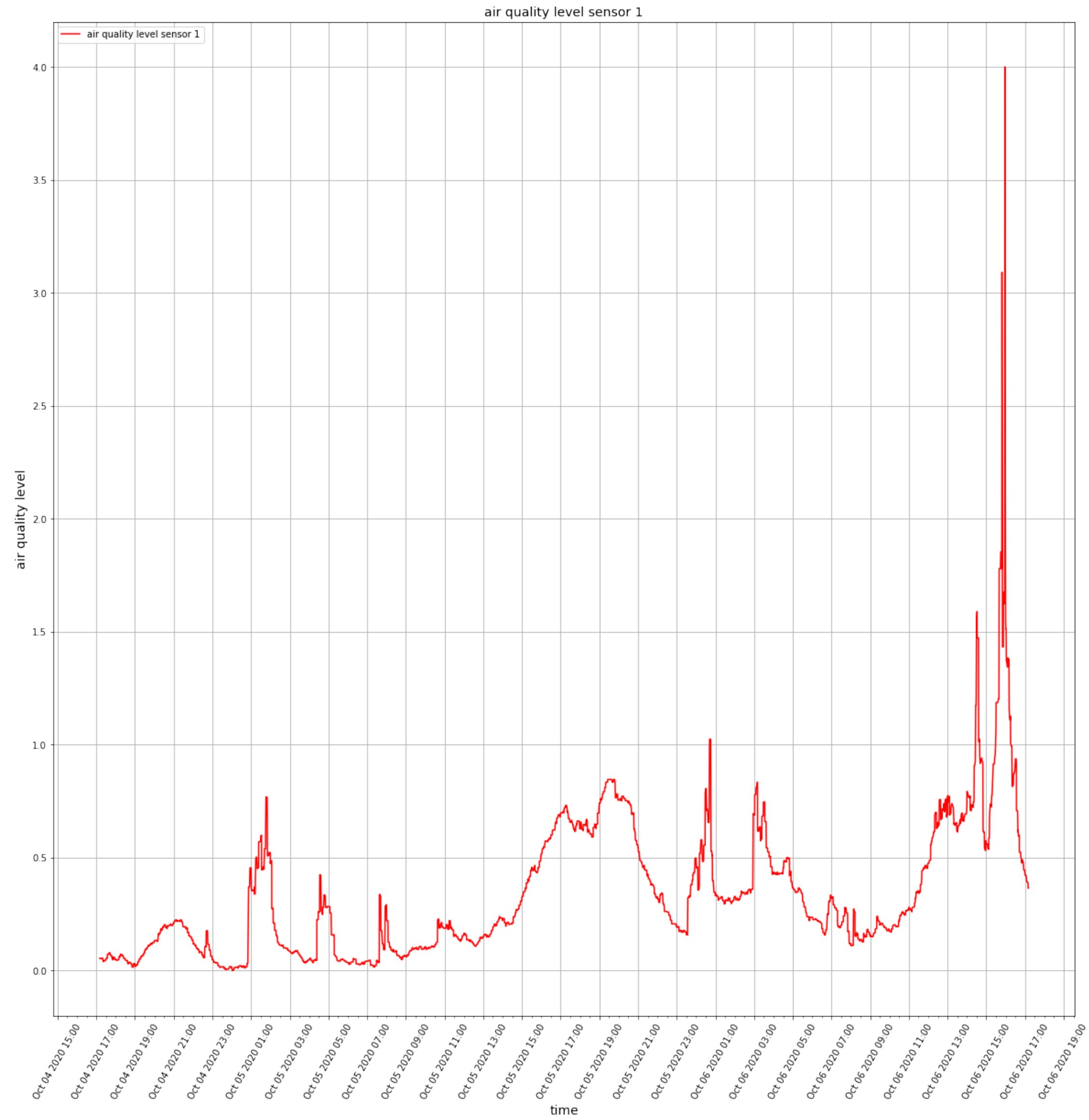
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)
```

```
log_normalized_residuals1 = -(np.log10(normalized_residuals1)-2)
log_normalized_residuals2 = -(np.log10(normalized_residuals2)-2)
log_normalized_residuals3 = -(np.log10(normalized_residuals3)-2)

fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
hours = mdates.HourLocator(interval = 2)
ax.xaxis.set_major_locator(hours)
ax.xaxis.set_minor_locator(AutoMinorLocator())


plt.xticks(rotation=60)
plt.plot_date(df['Datum'], log_normalized_residuals1, linestyle='solid',␣
 ↪marker=" ", color='red', label='air quality level sensor 1')
plt.plot_date(df['Datum'], log_normalized_residuals2, linestyle='solid',␣
 ↪marker=" ", color='green', label='air quality level sensor 2')
plt.plot_date(df['Datum'], log_normalized_residuals3, linestyle='solid',␣
 ↪marker=" ", color='blue', label='air quality level sensor 3')
plt.title('air quality level sensors 1-3', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('air quality level', fontsize=14)
plt.grid(True)
plt.legend(loc ="upper left")
plt.show()
```



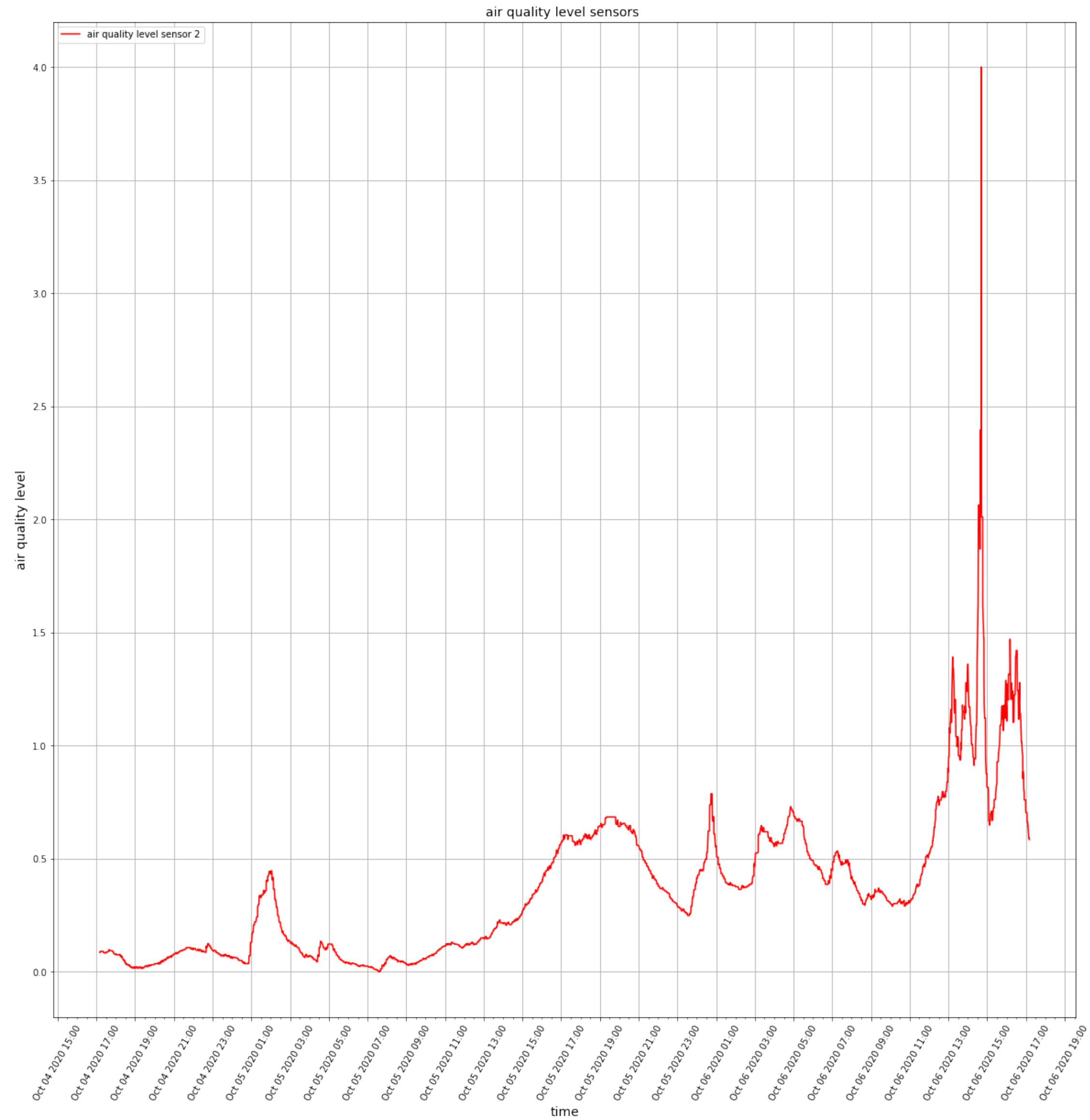

[20]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)

log_normalized_residuals1 = -(np.log10(normalized_residuals1)-2)
log_normalized_residuals2 = -(np.log10(normalized_residuals2)-2)
log_normalized_residuals3 = -(np.log10(normalized_residuals3)-2)
```

```
fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
hours = mdates.HourLocator(interval = 2)
ax.xaxis.set_major_locator(hours)
ax.xaxis.set_minor_locator(AutoMinorLocator())


plt.xticks(rotation=60)
plt.plot_date(df['Datum'], log_normalized_residuals1, linestyle='solid',␣
↪marker=" ", color='red', label='air quality level sensor 1')
plt.title('air quality level sensor 1', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('air quality level', fontsize=14)
plt.grid(True)
plt.legend(loc ="upper left")
plt.show()
```



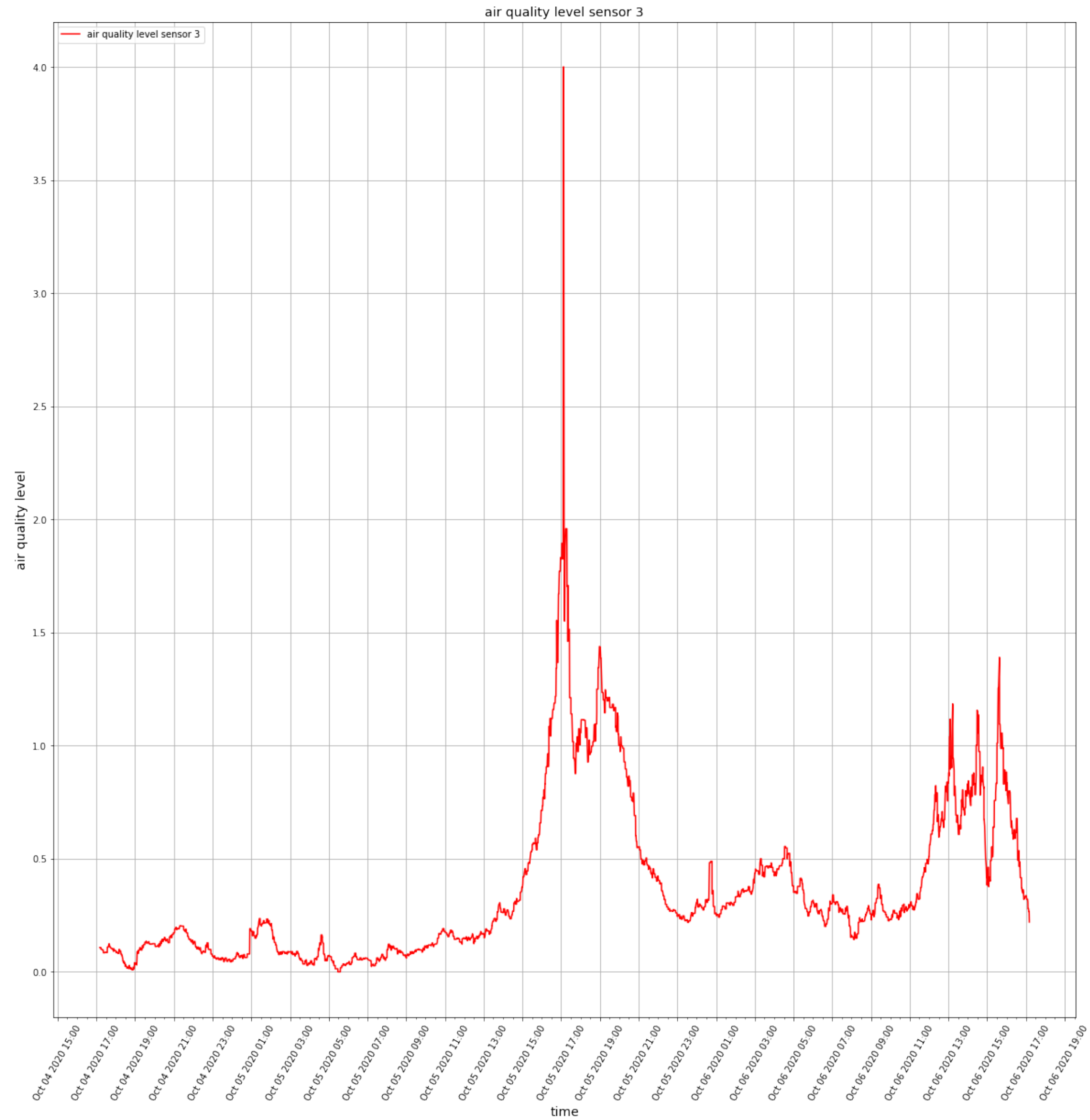

```
[21]: import pandas as pd
      from sklearn import linear_model
      import statsmodels.api as sm
      import matplotlib.pyplot as plt
      from datetime import datetime
      from matplotlib.dates import DateFormatter
      from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                                     AutoMinorLocator)

      log_normalized_residuals1 = -(np.log10(normalized_residuals1)-2)
      log_normalized_residuals2 = -(np.log10(normalized_residuals2)-2)
      log_normalized_residuals3 = -(np.log10(normalized_residuals3)-2)
```

```
fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
hours = mdates.HourLocator(interval = 2)
ax.xaxis.set_major_locator(hours)
ax.xaxis.set_minor_locator(AutoMinorLocator())


plt.xticks(rotation=60)
plt.plot_date(df['Datum'], log_normalized_residuals2, linestyle='solid',␣
↪marker=" ", color='red', label='air quality level sensor 2')
plt.title('air quality level sensors ', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('air quality level', fontsize=14)
plt.grid(True)
plt.legend(loc ="upper left")
plt.show()
```




[22]:
```
import pandas as pd
from sklearn import linear_model
import statsmodels.api as sm
import matplotlib.pyplot as plt
from datetime import datetime
from matplotlib.dates import DateFormatter
from matplotlib.ticker import (MultipleLocator, FormatStrFormatter,
                               AutoMinorLocator)

log_normalized_residuals1 = -(np.log10(normalized_residuals1)-2)
log_normalized_residuals2 = -(np.log10(normalized_residuals2)-2)
log_normalized_residuals3 = -(np.log10(normalized_residuals3)-2)
```

```
fig, ax = plt.subplots(figsize=(20, 20))
plt.xticks(rotation=60)
ax.xaxis.set_major_formatter(DateFormatter('%b %d %Y %H:%M'))
hours = mdates.HourLocator(interval = 2)
ax.xaxis.set_major_locator(hours)
ax.xaxis.set_minor_locator(AutoMinorLocator())


plt.xticks(rotation=60)
plt.plot_date(df['Datum'], log_normalized_residuals3, linestyle='solid',␣
 ↪marker=" ", color='red', label='air quality level sensor 3')
plt.title('air quality level sensor 3', fontsize=14)
plt.xlabel('time', fontsize=14)
plt.ylabel('air quality level', fontsize=14)
plt.grid(True)
plt.legend(loc ="upper left")
plt.show()
```


air quality level sensor 3
air quality level sensor 3
air quality level
time
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Oct 04 2020 15:00
Oct 04 2020 17:00
Oct 04 2020 19:00
Oct 04 2020 21:00
Oct 04 2020 23:00
Oct 05 2020 01:00
Oct 05 2020 03:00
Oct 05 2020 05:00
Oct 05 2020 07:00
Oct 05 2020 09:00
Oct 05 2020 11:00
Oct 05 2020 13:00
Oct 05 2020 15:00
Oct 05 2020 17:00
Oct 05 2020 19:00
Oct 05 2020 21:00
Oct 05 2020 23:00
Oct 06 2020 01:00
Oct 06 2020 03:00
Oct 06 2020 05:00
Oct 06 2020 07:00
Oct 06 2020 09:00
Oct 06 2020 11:00
Oct 06 2020 13:00
Oct 06 2020 15:00
Oct 06 2020 17:00
Oct 06 2020 19:00

```
[ ]:
```