detailed_ellipticity

August 24, 2025

Dark-Fiber Charakterisierung

für entanglement polarisierter QKD

Verhalten der Winkelparameter: Schwerpunkt Ellipticity [°]

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Datensatz: Erfurt - Sundhausen

1 Aufbereitung der Messdaten

1.1 Ressourcen und Literatur

- Messdaten
- Messgerät
- Open-Meteo: Wetterdaten & Dokumentation
- Sonnenauf- und untergang
- Plotting Tool für Poincaré-Kugel

1.2 Verwendete Libraries / Softwaretools

[1]:
```
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
import numpy as np
import pandas as pd

import io
import datetime
import requests
from mpl_toolkits.mplot3d import Axes3D
from scipy.stats import norm
from scipy.signal import butter, filtfilt

from py_pol.jones_vector import Jones_vector, degrees
from py_pol.stokes import Stokes
```

1.3 Eigene Hilfsfunktionen

[2]:
```
def format_time(x, pos):
    h = int(x) // 3600
    m = (int(x) % 3600) // 60
    return f"{h:02d}:{m:02d}"
```

[3]:
```
def lowpass(data, box = 100):
    box = box
    LP_filter = np.full(int(box), 1/box)
    lps = np.convolve(ydata, LP_filter)
    lps = lps[ int((box-1) / 2) :len(lps) - int((box - 1) / 2)]
    return lps

def highpass(data, box = 100):
    lps = lowpass(data, box)
    hps = data - lps[:-1]
    return hps
```

[4]:
```
def butter_filter(data, cutoff, fs=4, order=4, btype='low'):
    nyq = 0.5 * fs
    normal_cutoff = cutoff / nyq
    b, a = butter(order, normal_cutoff, btype=btype, analog=False)
    y = filtfilt(b, a, data)
    return y
```

[5]:
```
def convert_angel(az, el):
    az = np.array(az) * degrees
    el = np.array(el) * degrees

    x = np.cos(2*el) * np.cos(2*az)
    y = np.cos(2*el) * np.sin(2*az)
    z = np.sin(2*el)
    return x, y, z
```

[6]:
```
def calculate_freq(x, y, z):
    bins = 50
    coords = np.vstack((x, y, z)).T
    hist, edges = np.histogramdd(coords, bins=bins)

    # Indices for each coordinate pair (with clipping)
    bin_indices = [
        np.clip(np.digitize(x, edges[0]) - 1, 0, bins - 1),
        np.clip(np.digitize(y, edges[1]) - 1, 0, bins - 1),
        np.clip(np.digitize(z, edges[2]) - 1, 0, bins - 1)
    ]
    freq = hist[bin_indices[0], bin_indices[1], bin_indices[2]]
```

```
    return freq
```

```
[7]: def plot_poincare(x, y, z, freq, elev=15, azim=45, title="Not given"):
    fig = plt.figure(figsize=(6, 6))
    ax = fig.add_subplot(111, projection='3d')

    # Poincaré-Sphere
    u = np.linspace(0, 2 * np.pi, 50)
    v = np.linspace(0, np.pi, 50)
    X = np.outer(np.cos(u), np.sin(v))
    Y = np.outer(np.sin(u), np.sin(v))
    Z = np.outer(np.ones(np.size(u)), np.cos(v))

    ax.plot_surface(X, Y, Z, color='lightgray', alpha=0.1, edgecolor='k',␣
 ↪linewidth=0.5)

    # Axes
    ax.plot([0, 1.6], [0, 0], [0, 0], color='red')     # +S1
    ax.plot([0, -1.6], [0, 0], [0, 0], color='red')    # -S1
    ax.plot([0, 0], [0, 1.6], [0, 0], color='green')   # +S2
    ax.plot([0, 0], [0, -1.6], [0, 0], color='green')  # -S2
    ax.plot([0, 0], [0, 0], [0, 1.4], color='blue')    # +S3
    ax.plot([0, 0], [0, 0], [0, -1.4], color='blue')   # -S3

    # Labeling Axes
    ax.text( 2.0, 0, 0,  'S1',  color='red', fontsize=10)
    ax.text(-1.8, 0, 0, '-S1',  color='red', fontsize=10)
    ax.text( 0, 1.8, 0,  'S2',  color='green', fontsize=10)
    ax.text( 0, -2.0, 0, '-S2',  color='green', fontsize=10)
    ax.text( 0, 0, 1.6, 'S3',   color='blue', fontsize=10)
    ax.text( 0, 0, -1.6, '-S3',  color='blue', fontsize=10)

    # Measurement
    sc = ax.scatter(x, y, z, c=freq, cmap='hot', s=15)
    plt.colorbar(sc, label='density')

    # Scaling
    ax.set_box_aspect([1, 1, 1])
    ax.set_xticks([]); ax.set_yticks([]); ax.set_zticks([])

    # Aligning Poincaré-Sphere
    ax.view_init(elev=elev, azim=azim)

    ax.set_title(title)

    plt.show()
```

1.4 Aufbereitung der Messdaten

[8]:
```
filename ='20_02_to_26_02_Sundhausen to FZE port 2.csv'
skip = 8
sep = ";"
```

[9]:
```
columns = ['Time[date hh:mm:ss] ', ' Elapsed Time [hh:mm:ss:ms]', ' Normalized␣
↪s 1 ', ' Normalized s 2 ', ' Normalized s 3 ', ' S 0 [mW]', ' S 1 [mW]', ' S␣
↪2 [mW]', ' S 3 [mW]', ' Azimuth[°] ', ' Ellipticity[°] ', ' DOP[%] ', '␣
↪DOCP[%] ', ' DOLP[%] ', ' Power[mW] ', ' Pol Power[mW] ', ' Unpol Power[mW]␣
↪', ' Power[dBm] ', ' Pol Power[dBm] ', ' Unpol Power[dBm] ', '␣
↪Power-Split-Ratio ', ' Phase Difference[°] ', ' Warning']
for c in range(len(columns)):
    print(c, ': ', columns[c])

colors = ["tab:blue", "tab:orange", "tab:green", "tab:red", "tab:purple", "tab:
↪brown", "tab:pink", "tab:gray"]
```

```
0 :  Time[date hh:mm:ss]
1 :   Elapsed Time [hh:mm:ss:ms]
2 :   Normalized s 1
3 :   Normalized s 2
4 :   Normalized s 3
5 :   S 0 [mW]
6 :   S 1 [mW]
7 :   S 2 [mW]
8 :   S 3 [mW]
9 :   Azimuth[°]
10 :   Ellipticity[°]
11 :   DOP[%]
12 :   DOCP[%]
13 :   DOLP[%]
14 :   Power[mW]
15 :   Pol Power[mW]
16 :   Unpol Power[mW]
17 :   Power[dBm]
18 :   Pol Power[dBm]
19 :   Unpol Power[dBm]
20 :   Power-Split-Ratio
21 :   Phase Difference[°]
22 :   Warning
```

[10]:
```
angle = pd.read_csv(filename,skiprows=skip, sep=sep, usecols=[columns[0],␣
↪columns[9], columns[10]])
```

[11]:
```
angle[columns[0]] = pd.to_datetime(angle[columns[0]])
angle.set_index(columns[0], inplace=True)
```

[12]:
```
angle_daily = angle.groupby(angle.index.date)
angle_daily_list = list(angle_daily)
```

1.5 Aufbereitung der Wetterdaten

[13]:
```
# Erfurt - Latitude: 51.0 & Longitude: 11.0

url = (
    "https://archive-api.open-meteo.com/v1/archive?"
    "latitude=51.0&longitude=11.0&"
    "start_date=2025-02-20&end_date=2025-02-27&"
   ␣
 ↪"hourly=temperature_2m,relative_humidity_2m,cloud_cover,wind_speed_10m,wind_direction_10m,r
    "timezone=Europe/Berlin"
)

response = requests.get(url)

if response.status_code == 200:
    data = response.json()
    weather = pd.DataFrame(data["hourly"])
    print(weather.head())
else:
    print("Fehler beim Abrufen:", response.status_code)
    print(response.text)
```

```
               time  temperature_2m  relative_humidity_2m  cloud_cover  \
0  2025-02-20T00:00            -2.9                    54            0
1  2025-02-20T01:00            -2.7                    50            0
2  2025-02-20T02:00            -2.5                    47            0
3  2025-02-20T03:00            -2.0                    50            0
4  2025-02-20T04:00            -2.4                    52           11

   wind_speed_10m  wind_direction_10m  rain
0             9.5                 143   0.0
1             9.8                 144   0.0
2             9.5                 148   0.0
3            11.6                 159   0.0
4            11.1                 166   0.0
```

[14]:
```
units = data['hourly_units']
weather_columns = []
for key, value in units.items():
    weather_columns.append(f'{key} [{value}]')

weather.columns = weather_columns
weather.to_csv("open-meteo_erfurt.csv", index=False)
```

[15]:
```
sunrise = [
    datetime.datetime.strptime('2025-02-20 07:18:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-21 07:16:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-22 07:14:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-23 07:12:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-24 07:10:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-25 07:08:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-26 07:06:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-27 07:04:00', '%Y-%m-%d %H:%M:%S')
]

sunset =  [
    datetime.datetime.strptime('2025-02-20 17:41:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-21 17:43:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-22 17:44:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-23 17:46:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-24 17:48:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-25 17:50:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-26 17:51:00', '%Y-%m-%d %H:%M:%S'),
    datetime.datetime.strptime('2025-02-27 17:53:00', '%Y-%m-%d %H:%M:%S')
]
```

[16]:
```
w_data = [
    {"header": "temperature_2m [°C]", "color" : "tab:red", "unit": "°C",␣
 ↪"label": "Temperature"},
    {"header": "relative_humidity_2m [%]", "color" : "tab:purple", "unit": "%",␣
 ↪"label": "Humidity"},
    {"header": "cloud_cover [%]", "color" : "tab:gray", "unit": "%", "label":␣
 ↪"Cloud Cover"},
    {"header": "wind_speed_10m [km/h]", "color" : "tab:green", "unit": "km/h",␣
 ↪"label": "Windspeed"},
    {"header": "wind_direction_10m [°]", "color" : "tab:orange", "unit": "°",␣
 ↪"label": "Winddirection"},
    {"header": "rain [mm]", "color" : "tab:cyan", "unit": "mm", "label": "Rain"}
]

for i in range(len(w_data)):
    print(f'{i}: {w_data[i]["label"]}')
```

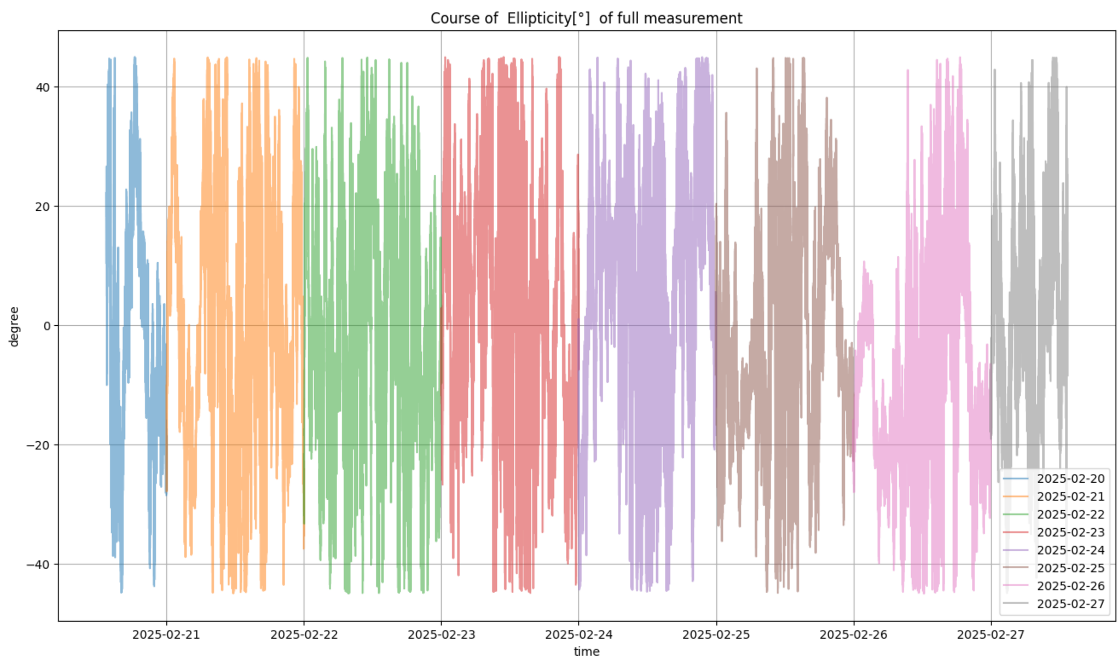
```
0: Temperature
1: Humidity
2: Cloud Cover
3: Windspeed
4: Winddirection
5: Rain
```

[17]:
```
weather[weather_columns[0]] = pd.to_datetime(weather[weather_columns[0]])
weather.set_index(weather_columns[0], inplace=True)
```

2 Analyse der Mess- und Wetterdaten

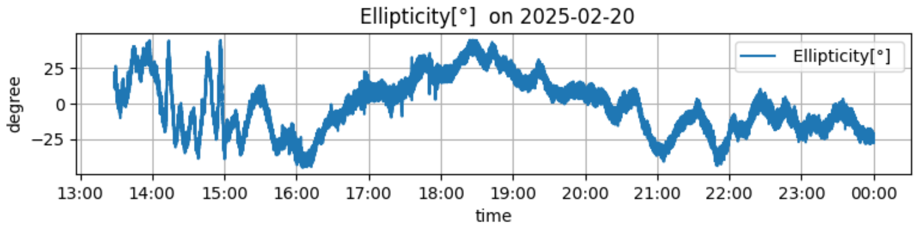
2.1 Tägliche Aufteilung der Messdaten

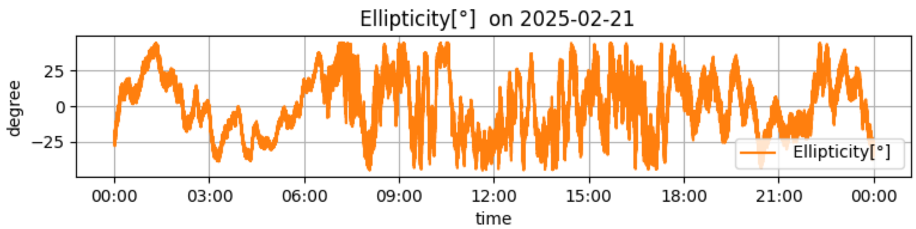
[19]:
```
plt.figure(figsize = (16,9))
for date, df_day in angle_daily_list:
    values = df_day[columns[10]]
    plt.plot(values, label=str(date), alpha=0.5)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Course of {columns[10]} of full measurement')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

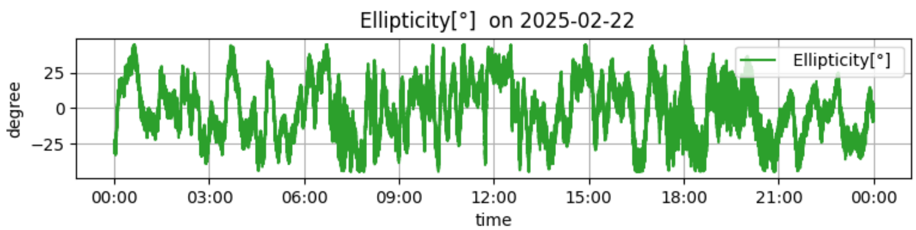


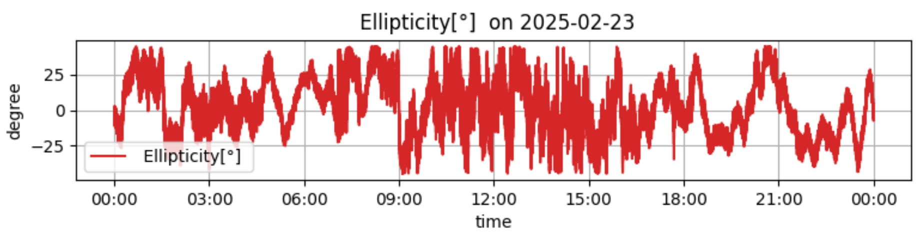
[21]:
```
fig, axs = plt.subplots(len(angle_daily_list), 1, figsize=(8, 16), sharex=False)

for i in range(len(angle_daily_list)):
    ax = axs[i] if len(angle_daily_list) > 1 else axs
    df_day = angle_daily_list[i][1][columns[10]]

    ax.plot(df_day.index, df_day, label=columns[10], color=colors[i])
```

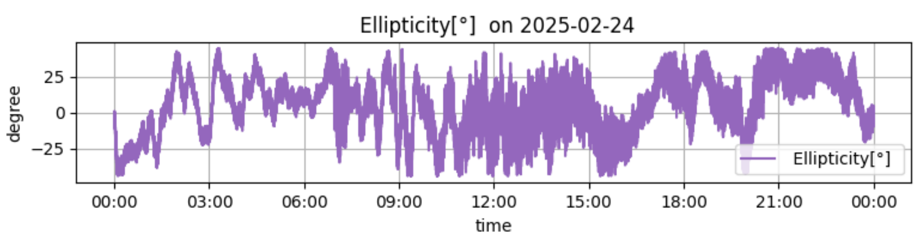
```
    ax.grid()
    ax.legend(loc='best')
    ax.set_title(f'{columns[10]} on {angle_daily_list[i][0]}')
    ax.set_xlabel('time')
    ax.set_ylabel('degree')

    ax.xaxis.set_major_formatter(mdates.DateFormatter('%H:%M'))

plt.tight_layout()
plt.show()
```

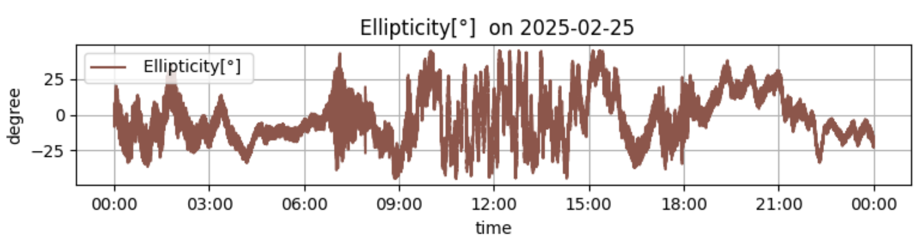

Ellipticity[°] on 2025-02-20
Ellipticity[°]
degree
25
0
−25
13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 00:00
time

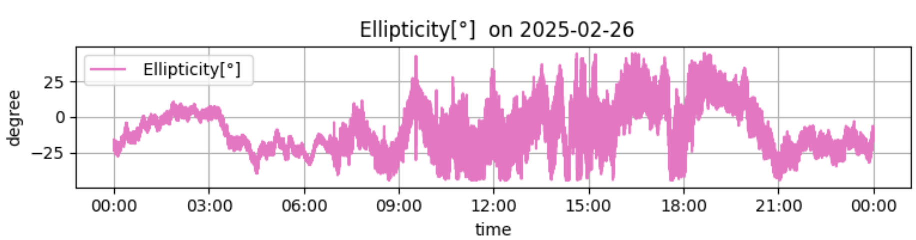

Ellipticity[°] on 2025-02-21
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time

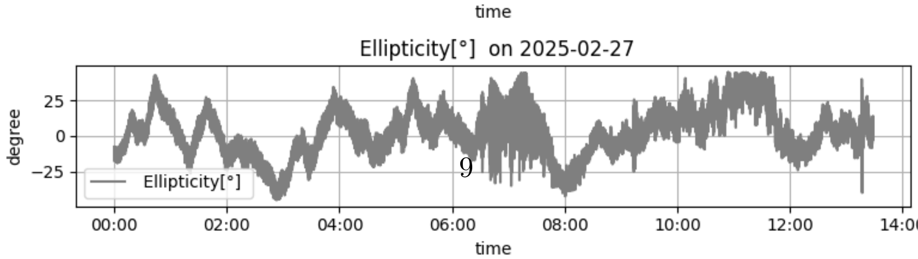

Ellipticity[°] on 2025-02-22
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time


Ellipticity[°] on 2025-02-23
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time

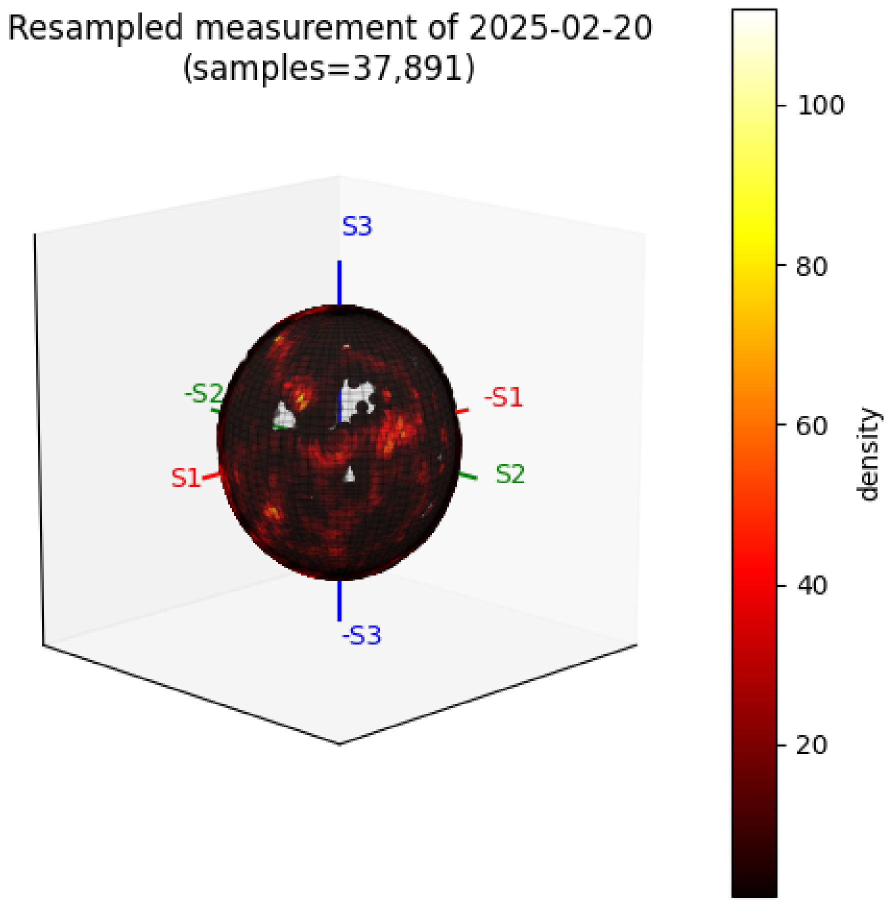

Ellipticity[°] on 2025-02-24
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time

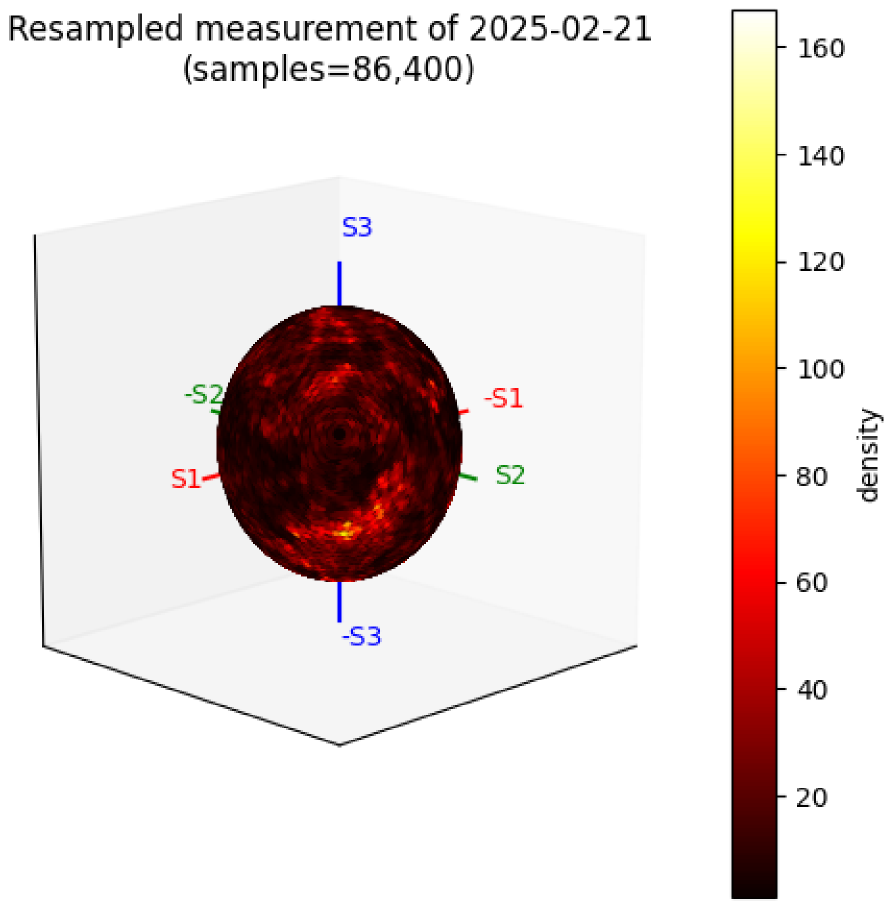

Ellipticity[°] on 2025-02-25
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time


Ellipticity[°] on 2025-02-26
Ellipticity[°]
degree
25
0
−25
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
time

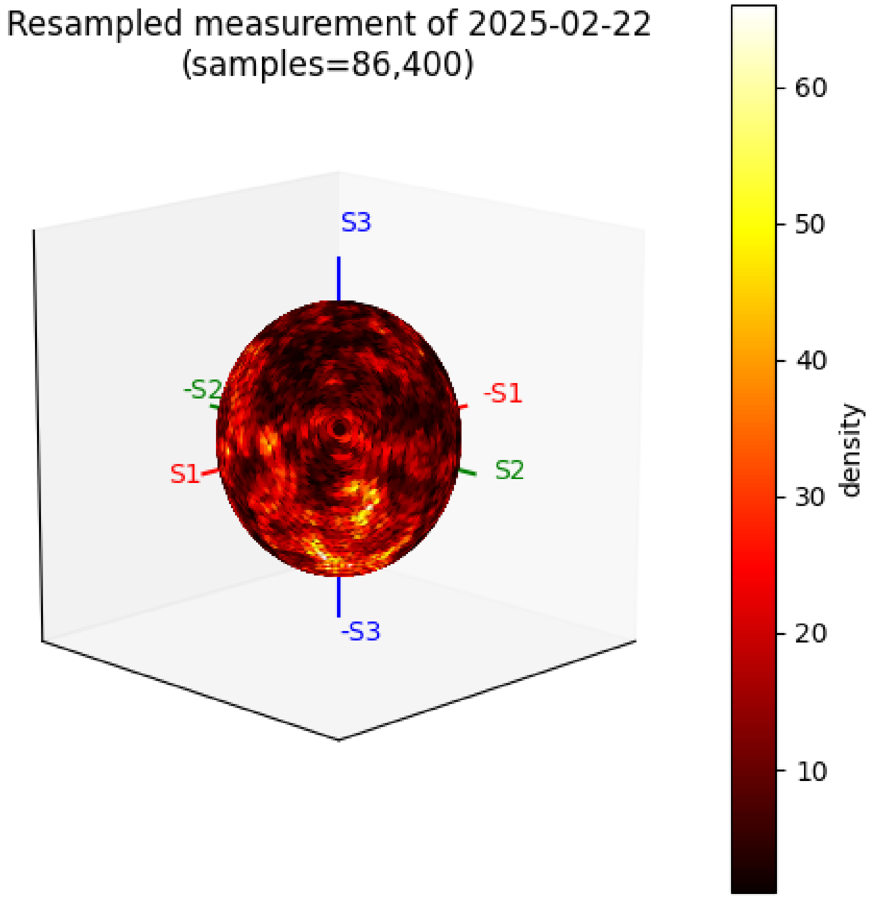

Ellipticity[°] on 2025-02-27
Ellipticity[°]
degree
25
0
−25
00:00 02:00 04:00 06:00 08:00 10:00 12:00 14:00
time

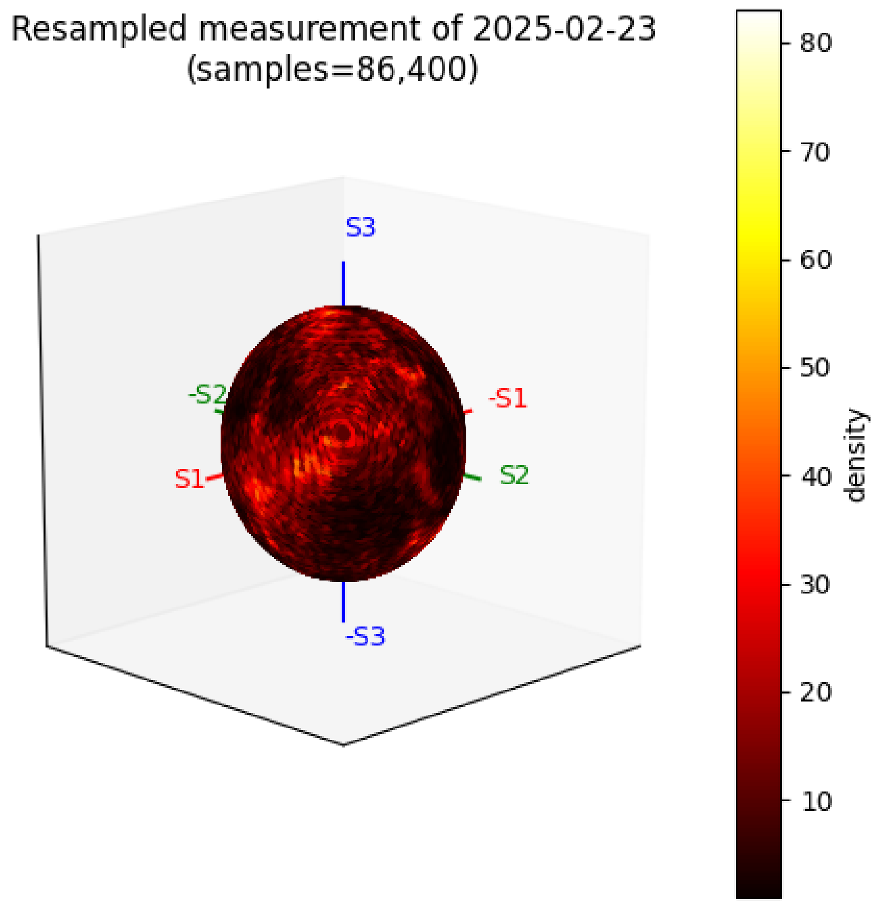
```
[22]: for i in range(len(angle_daily_list)):
          df_day = angle_daily_list[i][1]
          resample = df_day.resample('s').mean().ffill()
          title = f'Resampled measurement of␣
       ↪{angle_daily_list[i][0]}\n(samples={len(resample):,})'

          x,y,z = convert_angel(resample[columns[9]], resample[columns[10]])
          freq = calculate_freq(x, y, z)
          plot_poincare(x, y, z, freq, title=title)
```



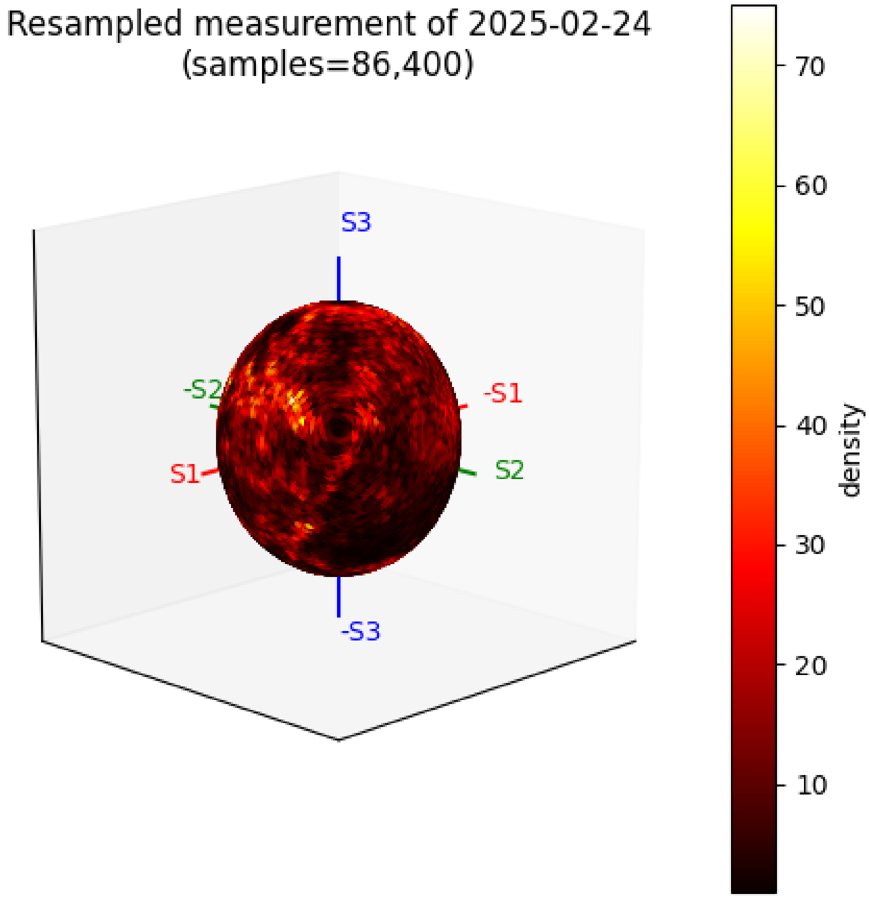


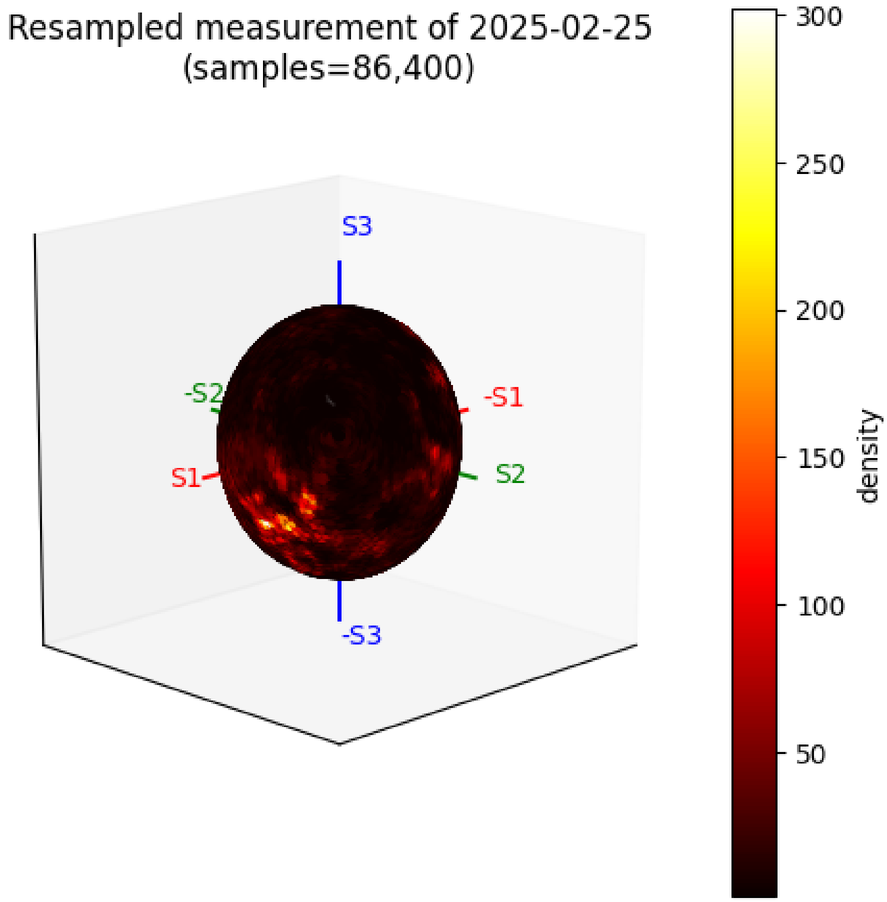
Resampled measurement of 2025-02-21
(samples=86,400)
S3
-S3
S1
-S1
S2
-S2
density
160
140
120
100
80
60
40
20

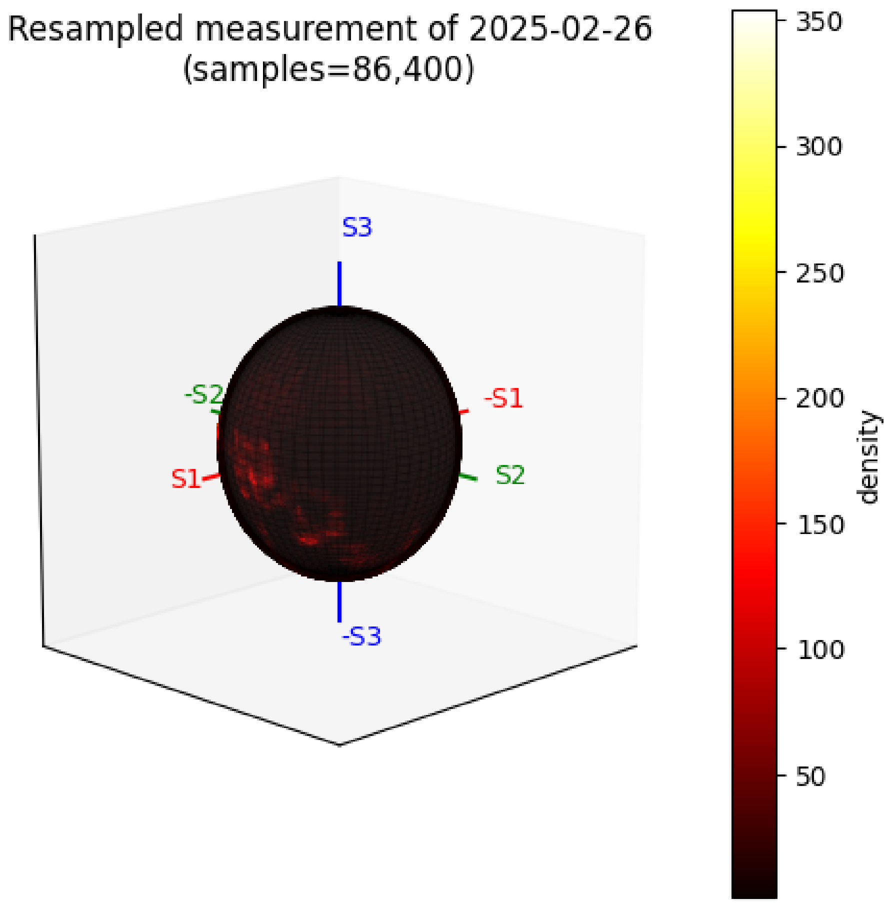

Resampled measurement of 2025-02-22
(samples=86,400)
S3
-S2
-S1
S1
S2
-S3
60
50
40
30
20
10
density

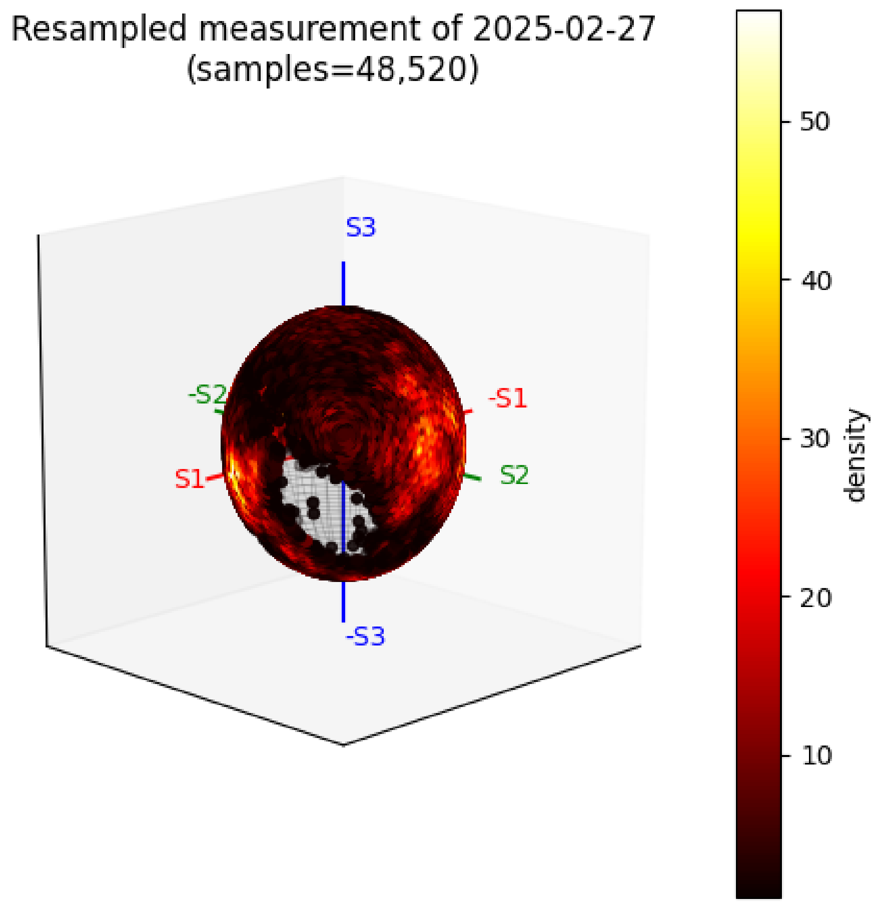


Resampled measurement of 2025-02-23
(samples=86,400)
S3
-S3
S1
-S1
S2
-S2
density
80
70
60
50
40
30
20
10


Resampled measurement of 2025-02-24
(samples=86,400)
S3
-S3
S1
-S1
S2
-S2
density
10
20
30
40
50
60
70

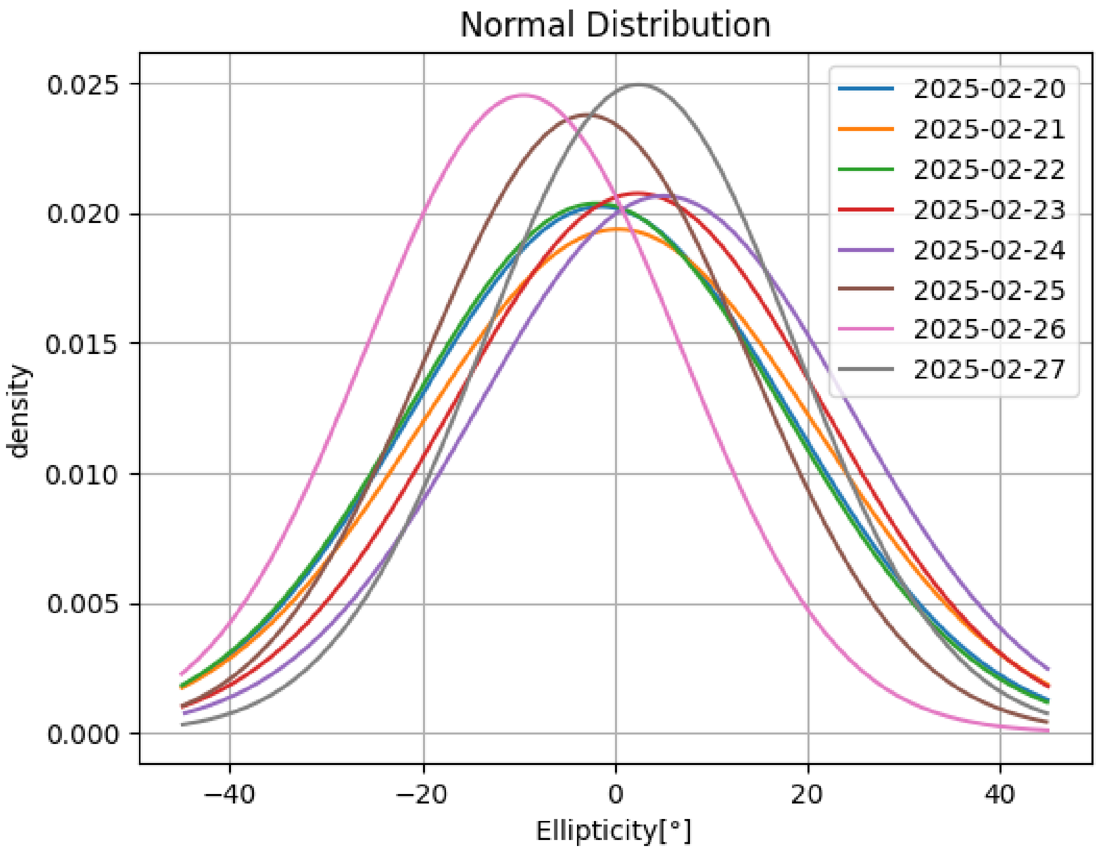

Resampled measurement of 2025-02-25
(samples=86,400)
S3
-S2
-S1
S1
S2
-S3
300
250
200
150
100
50
density


Resampled measurement of 2025-02-26
(samples=86,400)
S3
-S2
-S1
S1
S2
-S3
350
300
250
200
150
100
50
density



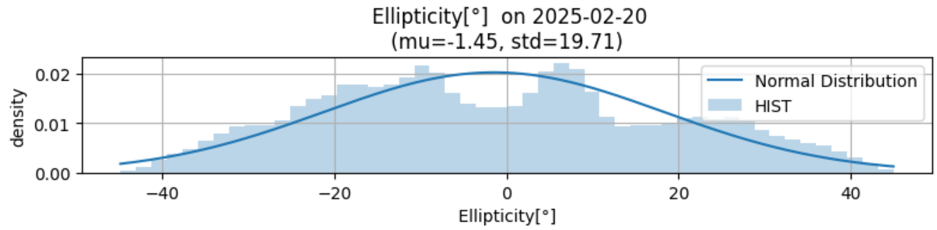
2.2 Normalverteilung

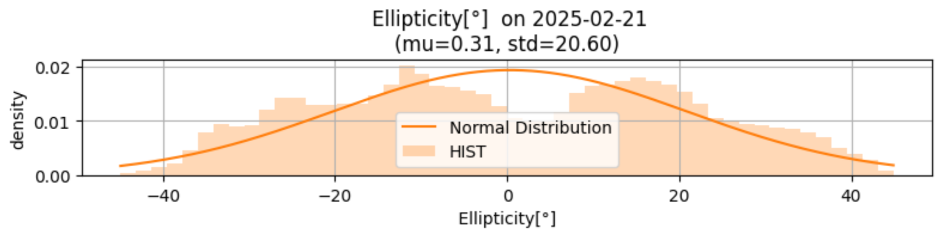
[23]:
```
for i in range(len(angle_daily_list)):
    ydata1 = np.array(angle_daily_list[i][1][columns[10]])
    mu1 = np.mean(ydata1)
    sigma1 = np.std(ydata1)
    x1 = np.linspace(ydata1.min(),ydata1.max(),len(ydata1))
    y1 = norm.pdf(x1, mu1, sigma1)

    plt.plot(x1, y1, label = angle_daily_list[i][0])

plt.title(f'Normal Distribution')
plt.legend(loc = 'best')
plt.xlabel(columns[10])
plt.ylabel('density')
plt.grid()
plt.show()
```

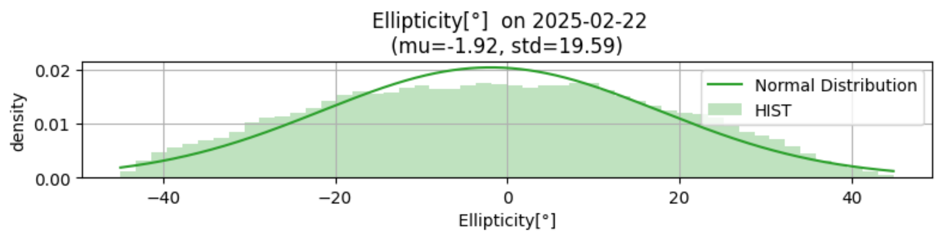


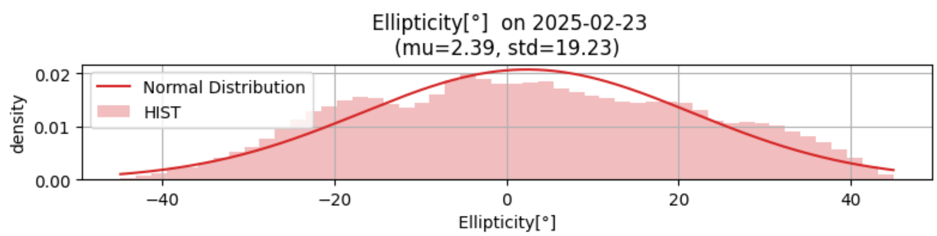
[24]:
```
fig, axs = plt.subplots(len(angle_daily_list), 1, figsize=(8, 16), sharex=False)

for i in range(len(angle_daily_list)):
    ax = axs[i] if len(angle_daily_list) > 1 else axs
    ydata1 = np.array(angle_daily_list[i][1][columns[10]])
    mu1 = np.mean(ydata1)
    sigma1 = np.std(ydata1)
    x1 = np.linspace(ydata1.min(),ydata1.max(),len(ydata1))
    y1 = norm.pdf(x1, mu1, sigma1)

    ax.plot(x1, y1, label = 'Normal Distribution', color=colors[i])
    ax.hist(ydata1, bins = 50, density = True, color=colors[i], alpha = 0.3,␣
 ↪label = "HIST")

    ax.grid()
    ax.legend(loc='best')
    ax.set_title(f'{columns[10]} on {angle_daily_list[i][0]}\n(mu={mu1:.2f},␣
 ↪std={sigma1:.2f})')
    ax.set_xlabel(columns[10])
```

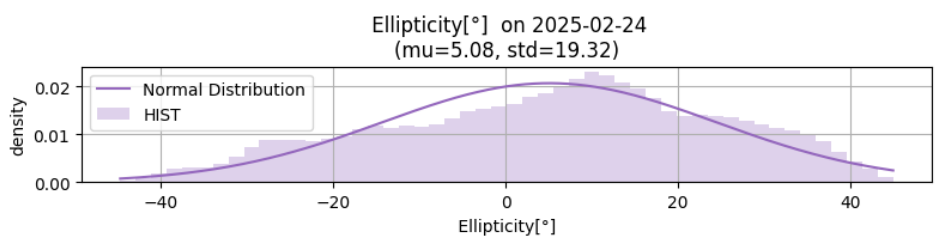
```
    ax.set_ylabel('density')

plt.tight_layout()
plt.show()
```

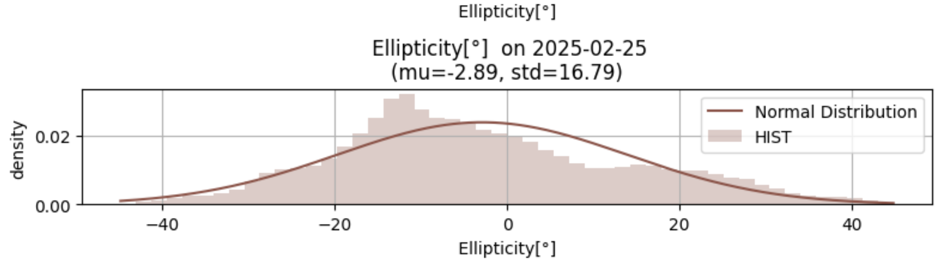

Ellipticity[°] on 2025-02-20
(mu=-1.45, std=19.71)
density
Normal Distribution
HIST
Ellipticity[°]

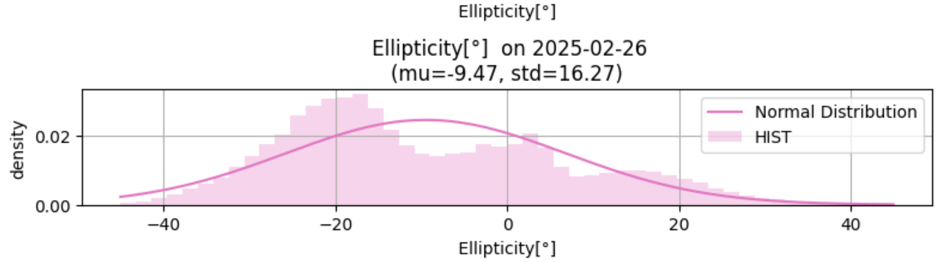

Ellipticity[°] on 2025-02-21
(mu=0.31, std=20.60)
density
Normal Distribution
HIST
Ellipticity[°]

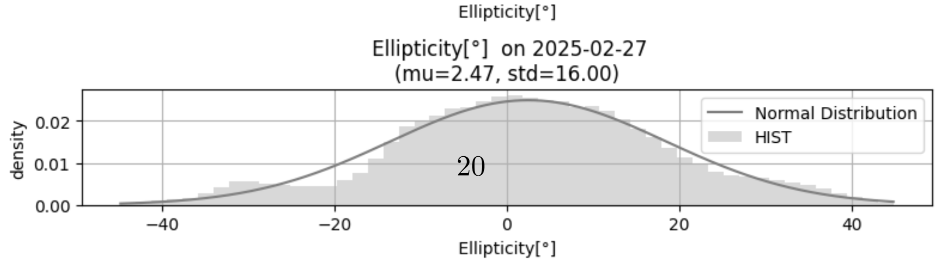

Ellipticity[°] on 2025-02-22
(mu=-1.92, std=19.59)
density
Normal Distribution
HIST
Ellipticity[°]


Ellipticity[°] on 2025-02-23
(mu=2.39, std=19.23)
density
Normal Distribution
HIST
Ellipticity[°]


Ellipticity[°] on 2025-02-24
(mu=5.08, std=19.32)
density
Normal Distribution
HIST
Ellipticity[°]

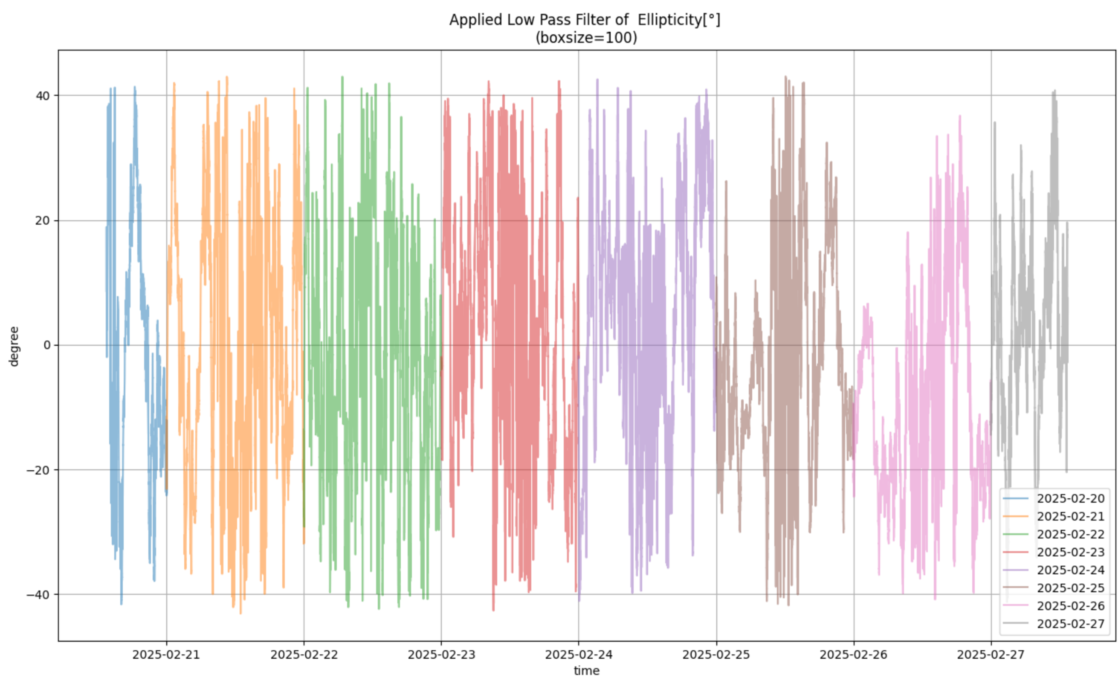

Ellipticity[°] on 2025-02-25
(mu=-2.89, std=16.79)
density
Normal Distribution
HIST
Ellipticity[°]


Ellipticity[°] on 2025-02-26
(mu=-9.47, std=16.27)
density
Normal Distribution
HIST
Ellipticity[°]


Ellipticity[°] on 2025-02-27
(mu=2.47, std=16.00)
density
Normal Distribution
HIST
Ellipticity[°]

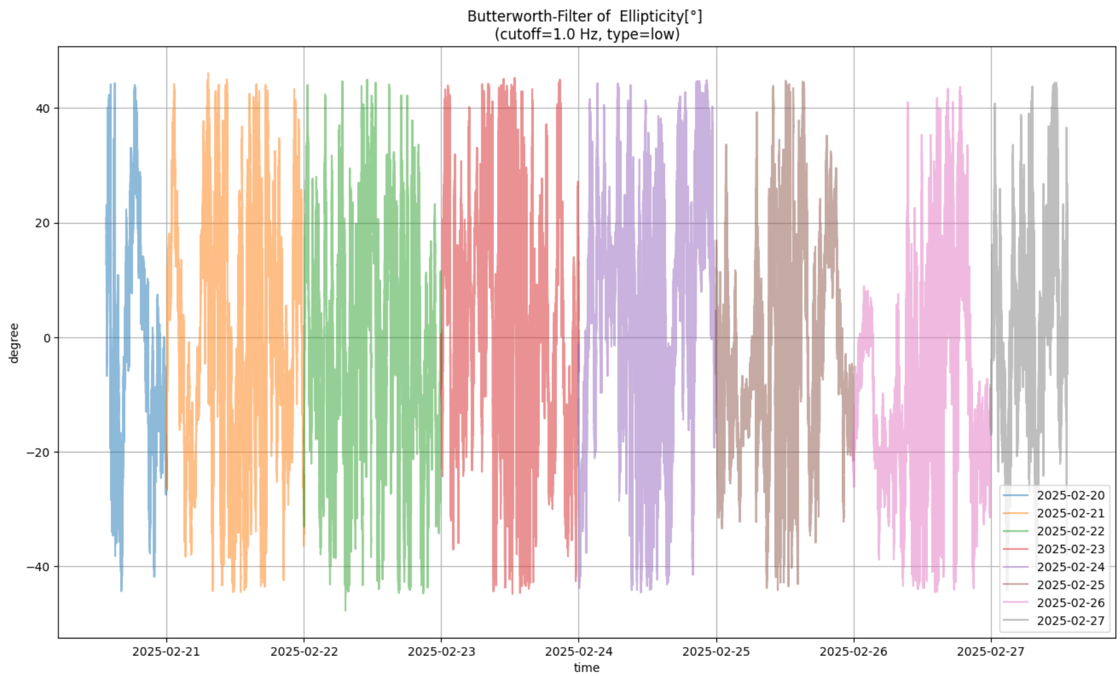
2.3 Filterung mittels Tief- und Hochpass

[25]:
```
box = 100

plt.figure(figsize = (16,9))
for date, df_day in angle_daily_list:
    ydata = np.array(df_day[columns[10]])
    lps = lowpass(ydata, box)
    plt.plot(df_day.index, lps[:-1], label=str(date) , alpha=0.5)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Applied Low Pass Filter of {columns[10]}\n(boxsize={box})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```



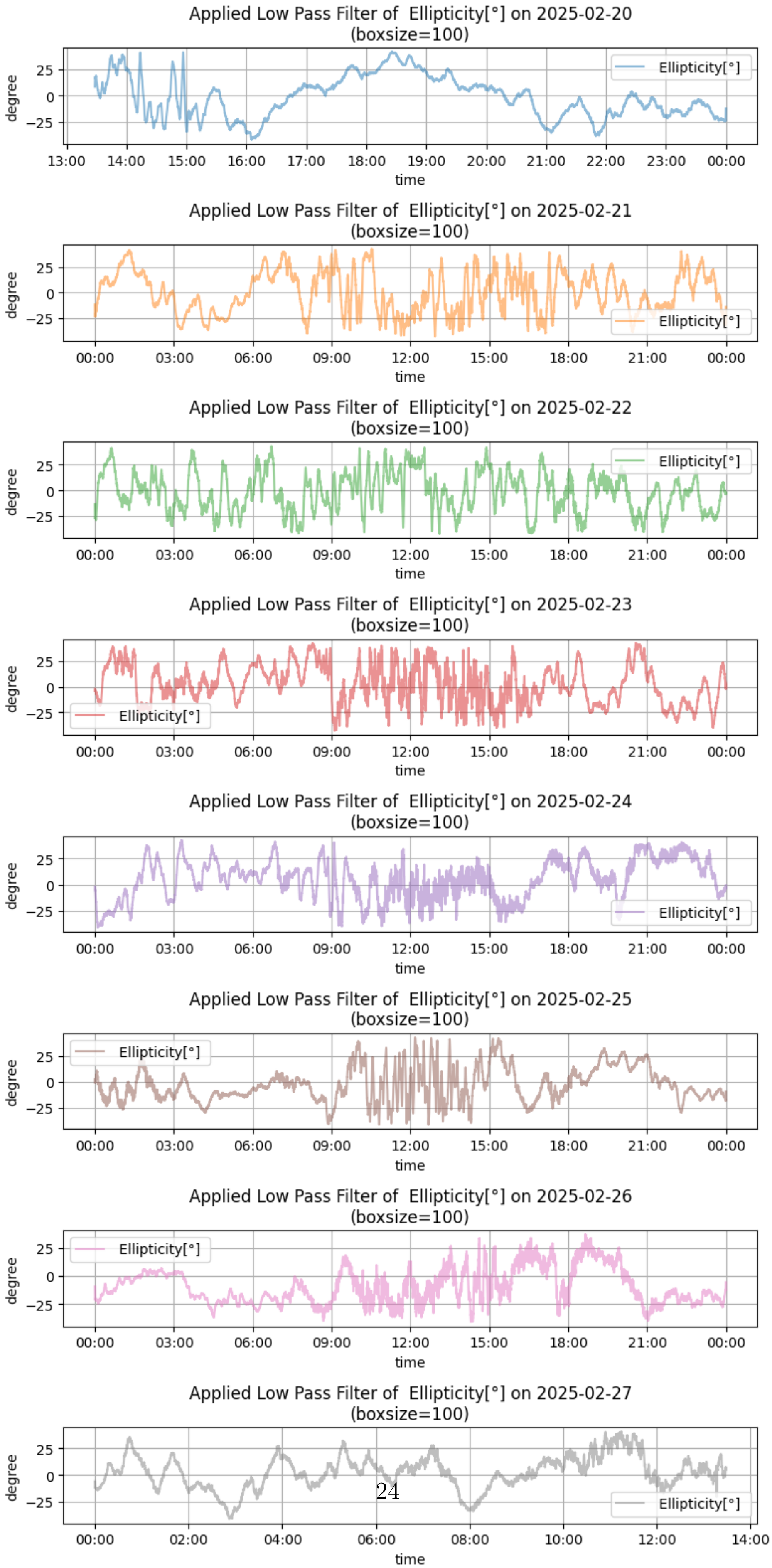
[26]:
```
cutoff = 1.0
pass_type = 'low'

plt.figure(figsize = (16,9))
for date, df_day in angle_daily_list:
    ydata = np.array(df_day[columns[10]])
```

```
    lps = butter_filter(ydata, cutoff=cutoff, btype=pass_type)
    plt.plot(df_day.index, lps, label=str(date) , alpha=0.5)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Butterworth-Filter of {columns[10]}\n(cutoff={cutoff} Hz,␣
 ↪type={pass_type})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

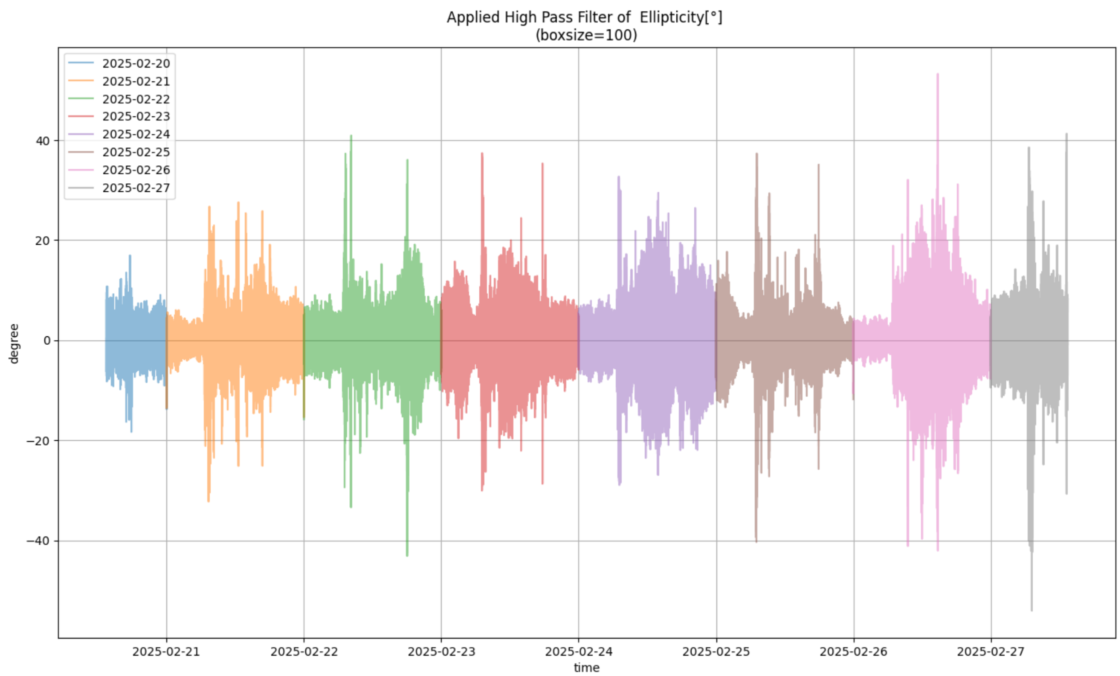


[27]:
```
box = 100

fig, axs = plt.subplots(len(angle_daily_list), 1, figsize=(8, 16), sharex=False)

for i in range(len(angle_daily_list)):
    ax = axs[i] if len(angle_daily_list) > 1 else axs
    df_day = angle_daily_list[i][1][columns[10]]
    ydata = np.array(df_day)
    lps = lowpass(ydata, box)

    ax.plot(df_day.index, lps[:-1], label=columns[10], color=colors[i], alpha=0.
 ↪5)

    ax.grid()
    ax.legend(loc='best')
```

```
    ax.set_title(f'Applied Low Pass Filter of {columns[10]}on␣
↪{angle_daily_list[i][0]}\n(boxsize={box})')
    ax.set_xlabel('time')
    ax.set_ylabel('degree')

    ax.xaxis.set_major_formatter(mdates.DateFormatter('%H:%M'))

plt.tight_layout()
plt.show()
```

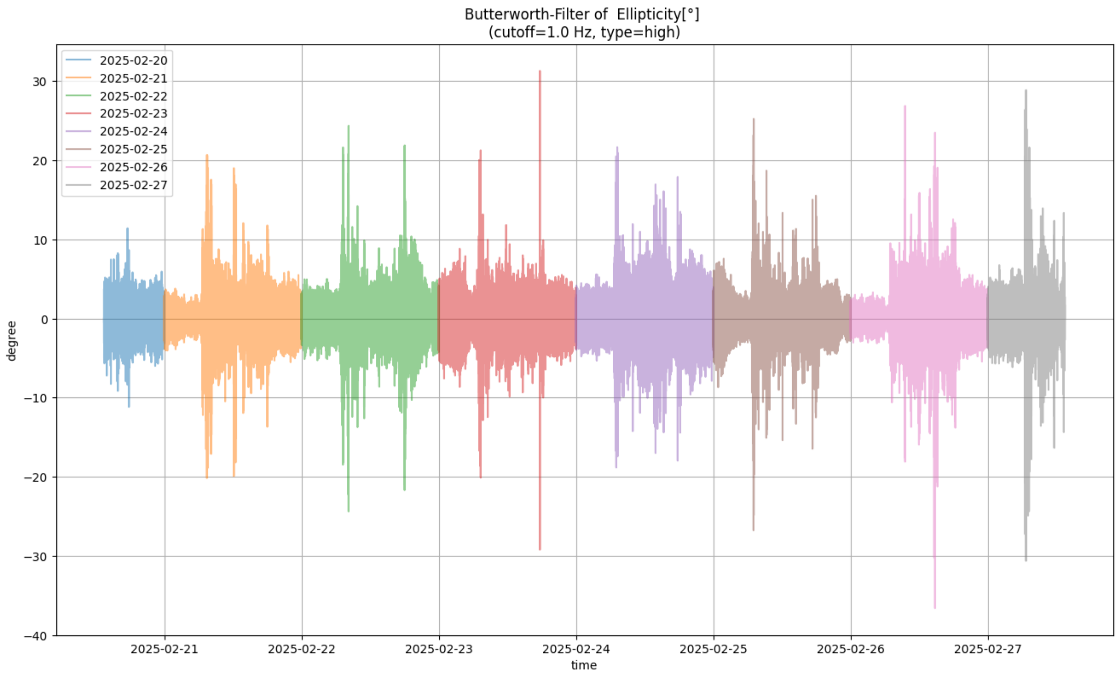

Applied Low Pass Filter of Ellipticity[°] on 2025-02-20
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-21
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-22
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-23
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-24
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-25
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-26
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
time
Applied Low Pass Filter of Ellipticity[°] on 2025-02-27
(boxsize=100)
Ellipticity[°]
degree
25
0
−25
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
time

[28]:
```
box = 100

plt.figure(figsize = (16,9))
for date, df_day in angle_daily_list:
    ydata = np.array(df_day[columns[10]])
    hps = highpass(ydata, box)
    plt.plot(df_day.index, hps, label=str(date) , alpha=0.5)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Applied High Pass Filter of {columns[10]}\n(boxsize={box})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```



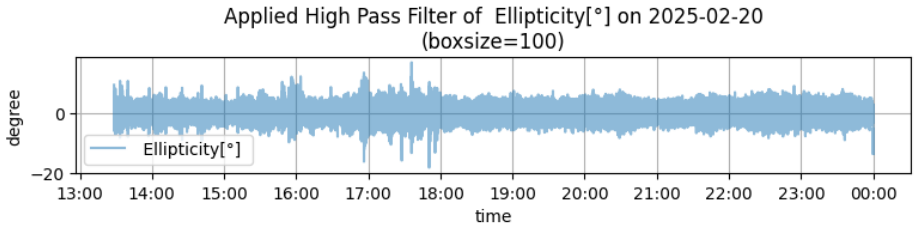
[29]:
```
cutoff = 1.0
pass_type = 'high'

plt.figure(figsize = (16,9))
for date, df_day in angle_daily_list:
    ydata = np.array(df_day[columns[10]])
    lps = butter_filter(ydata, cutoff=cutoff, btype=pass_type)
    plt.plot(df_day.index, lps, label=str(date) , alpha=0.5)
```

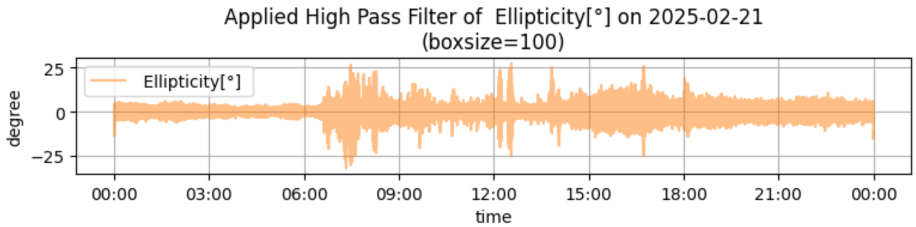
```
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Butterworth-Filter of {columns[10]}\n(cutoff={cutoff} Hz,␣
↪type={pass_type})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

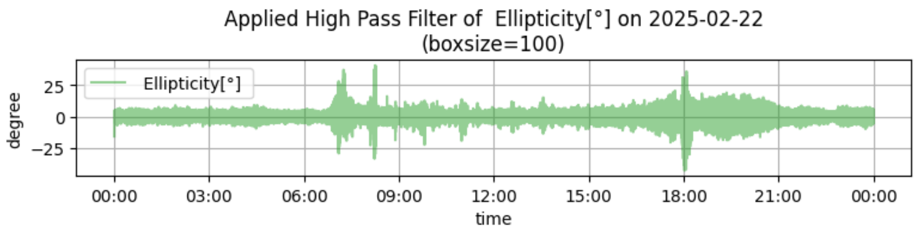


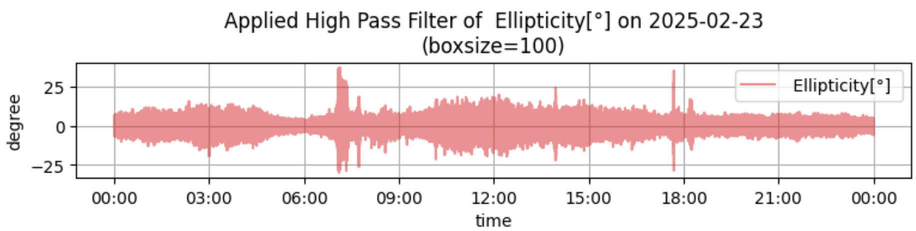
[31]:
```
box = 100

fig, axs = plt.subplots(len(angle_daily_list), 1, figsize=(8, 16), sharex=False)

for i in range(len(angle_daily_list)):
    ax = axs[i] if len(angle_daily_list) > 1 else axs
    df_day = angle_daily_list[i][1][columns[10]]
    ydata = np.array(df_day)
    hps = highpass(ydata, box)

    ax.plot(df_day.index, hps, label=columns[10], color=colors[i], alpha=0.5)

    ax.grid()
    ax.legend(loc='best')
    ax.set_title(f'Applied High Pass Filter of {columns[10]}on␣
↪{angle_daily_list[i][0]}\n(boxsize={box})')
    ax.set_xlabel('time')
```

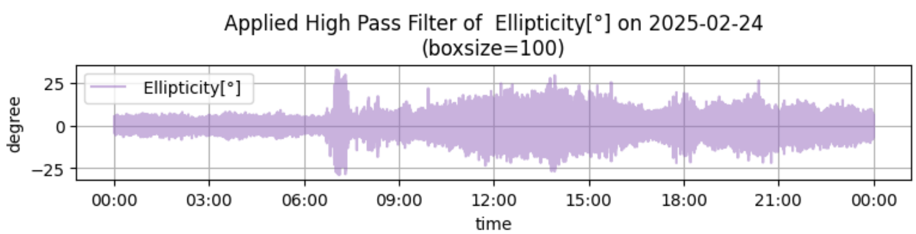
```
    ax.set_ylabel('degree')

    ax.xaxis.set_major_formatter(mdates.DateFormatter('%H:%M'))

plt.tight_layout()
plt.show()
```

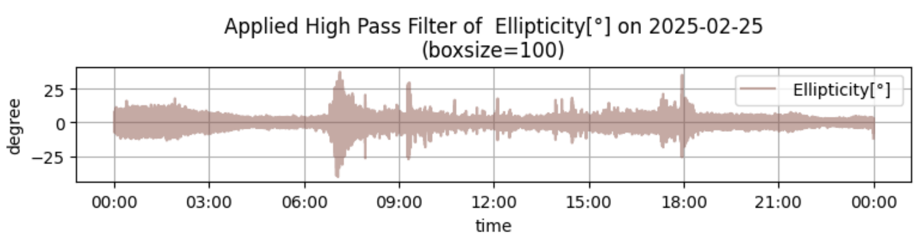

Applied High Pass Filter of Ellipticity[°] on 2025-02-20
(boxsize=100)
Ellipticity[°]
degree
time

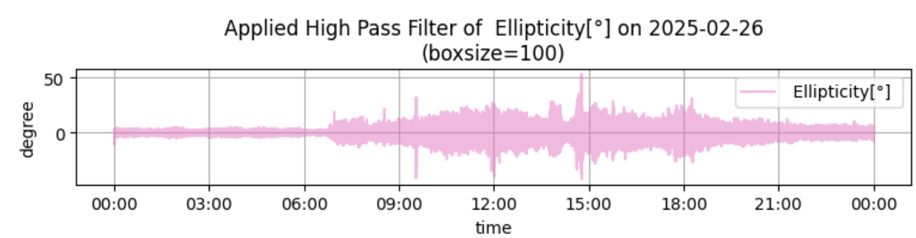

Applied High Pass Filter of Ellipticity[°] on 2025-02-21
(boxsize=100)
Ellipticity[°]
degree
time

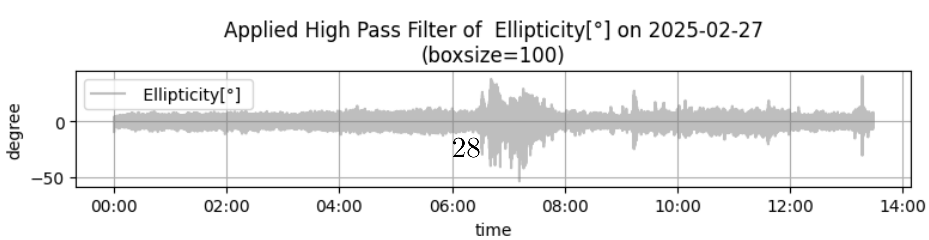

Applied High Pass Filter of Ellipticity[°] on 2025-02-22
(boxsize=100)
Ellipticity[°]
degree
time


Applied High Pass Filter of Ellipticity[°] on 2025-02-23
(boxsize=100)
Ellipticity[°]
degree
time


Applied High Pass Filter of Ellipticity[°] on 2025-02-24
(boxsize=100)
Ellipticity[°]
degree
time


Applied High Pass Filter of Ellipticity[°] on 2025-02-25
(boxsize=100)
Ellipticity[°]
degree
time

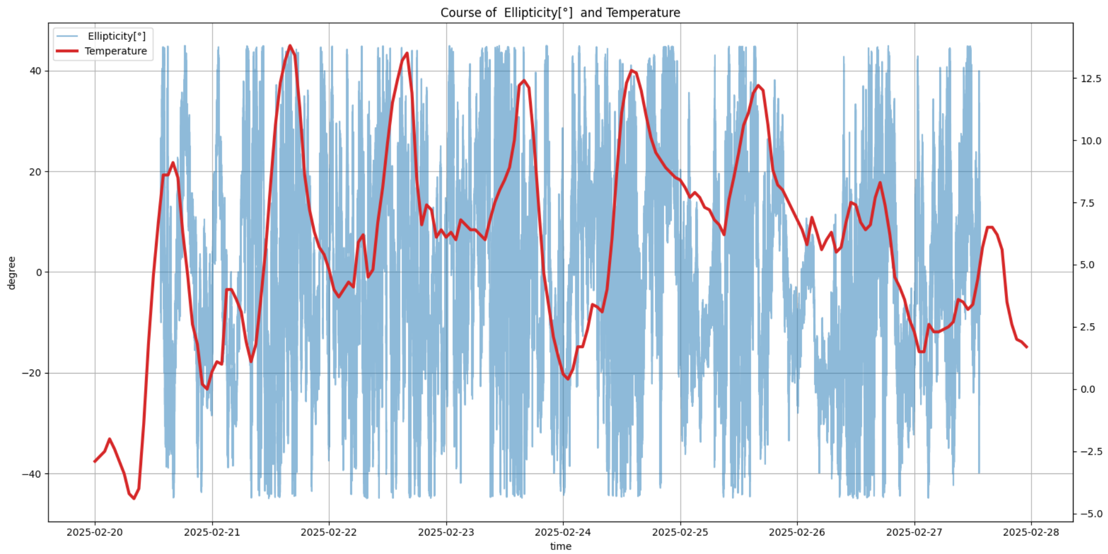

Applied High Pass Filter of Ellipticity[°] on 2025-02-26
(boxsize=100)
Ellipticity[°]
degree
time

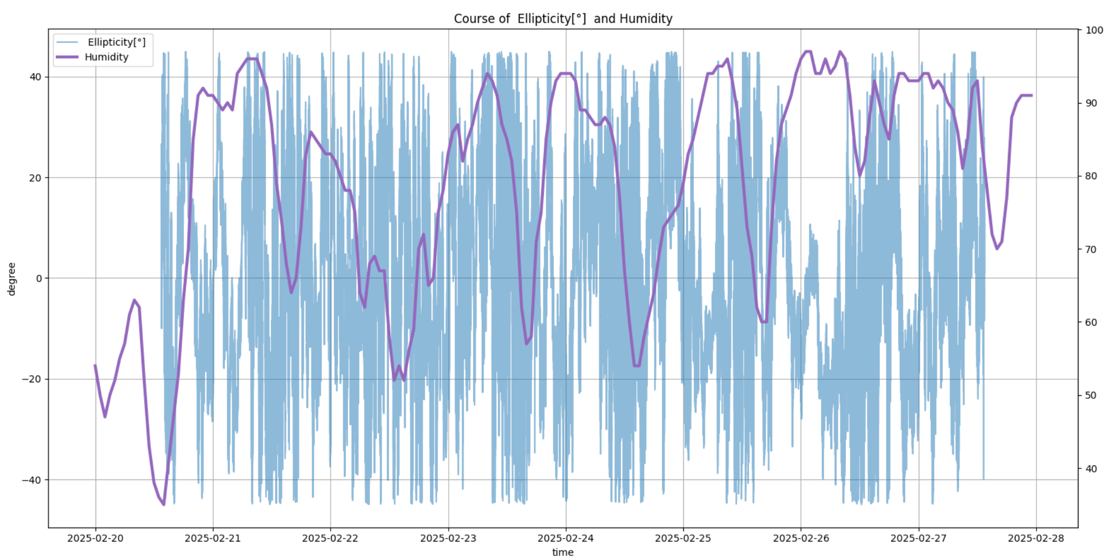

Applied High Pass Filter of Ellipticity[°] on 2025-02-27
(boxsize=100)
Ellipticity[°]
degree
time

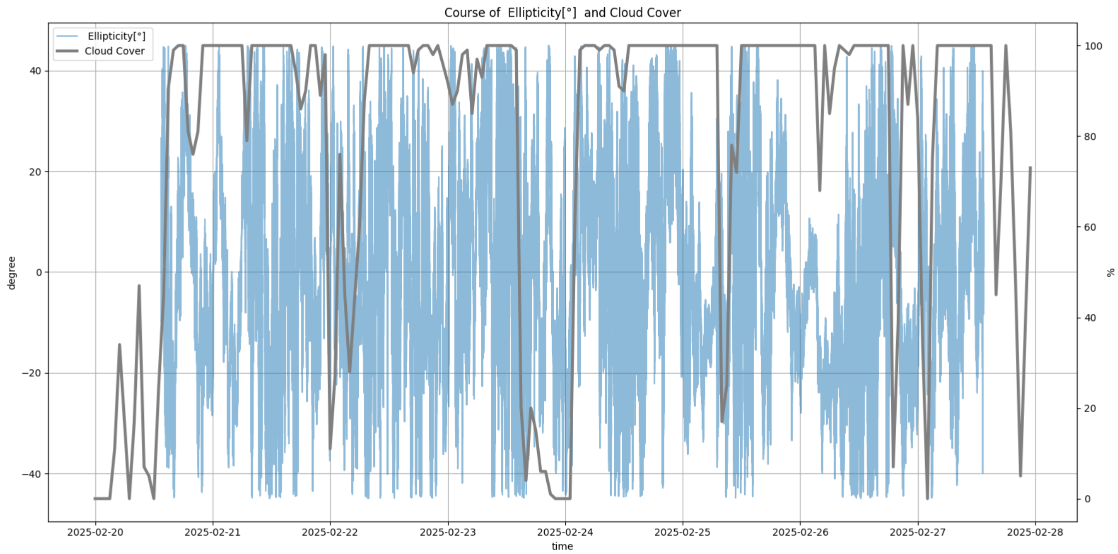
2.4 Analyse potenzieller Zusammenhänge

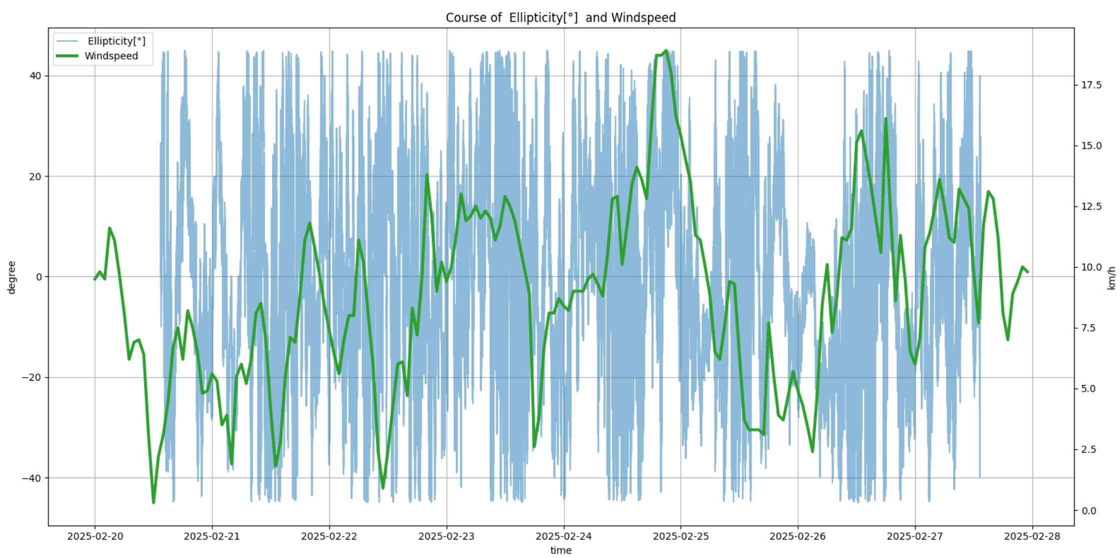
2.4.1 Originaldaten und Wetterparameter

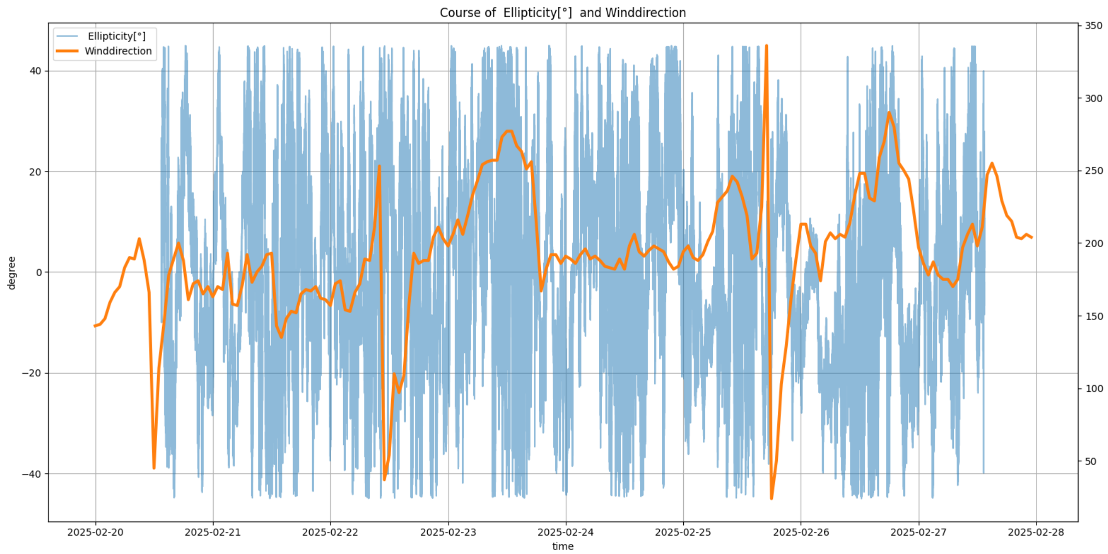
[32]:
```
for current in range(len(w_data)):
    fig, ax1 = plt.subplots(figsize=(16, 8))

    ax1.plot(angle[columns[10]], label=columns[10], alpha= 0.5)
    ax1.set_xlabel('time')
    ax1.set_ylabel('degree')
    h1, l1 = ax1.get_legend_handles_labels()

    ax2 = ax1.twinx()

    ax2.plot(weather.index, weather[w_data[current]["header"]],␣
 ↪label=w_data[current]["label"], color = w_data[current]["color"],␣
 ↪linewidth=3)
    ax2.set_ylabel(w_data[current]["unit"])
    h2, l2 = ax2.get_legend_handles_labels()

    ax1.grid()
    ax1.legend(h1+h2, l1+l2, loc="best")
    ax1.set_title(f'Course of {columns[10]} and {w_data[current]["label"]}')

    plt.tight_layout()
    plt.show()

# Sunlight (day-night context)

plt.figure(figsize = (16,8))
plt.plot(angle.index, angle[columns[10]], label=columns[10], alpha= 0.5)
for i in range(len(sunrise)):
    plt.axvline(x = sunrise[i], color = 'y', linewidth=3)
    if i == 0: plt.axvline(x = sunset[i], color = 'y',label = 'Sunrise &␣
 ↪Sunset', linewidth=3)
    else: plt.axvline(x = sunset[i], color = 'y', linewidth=3)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Course of {columns[10]} with Sunrise & Sunset')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

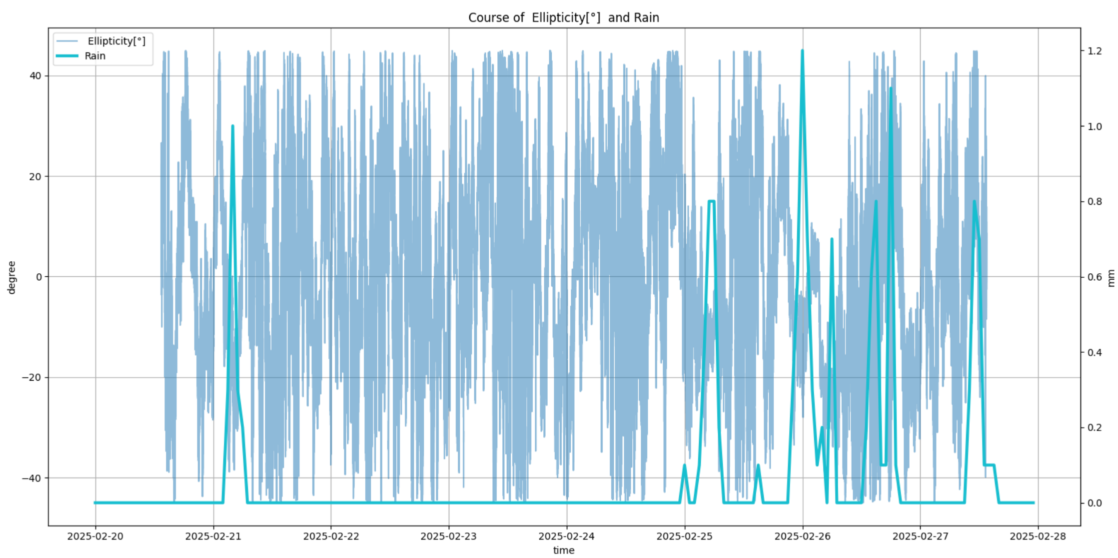

Course of Ellipticity[°] and Temperature
Ellipticity[°]
Temperature
degree
°C
time
40
20
0
−20
−40
12.5
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28

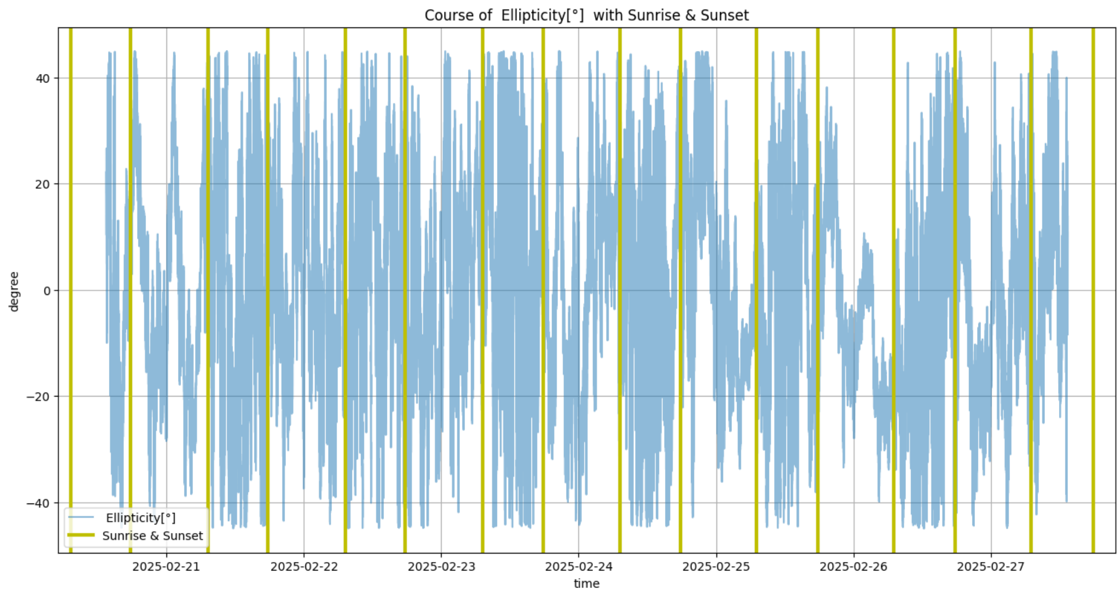

Course of Ellipticity[°] and Humidity
Ellipticity[°]
Humidity
degree
%
time
40
20
0
−20
−40
100
90
80
70
60
50
40
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Course of Ellipticity[°] and Cloud Cover
Ellipticity[°]
Cloud Cover
degree
%
time
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Course of Ellipticity[°] and Windspeed
Ellipticity[°]
Windspeed
degree
km/h
time
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Course of Ellipticity[°] and Winddirection
Ellipticity[°]
Winddirection
degree
time
40
20
0
−20
−40
350
300
250
200
150
100
50
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28

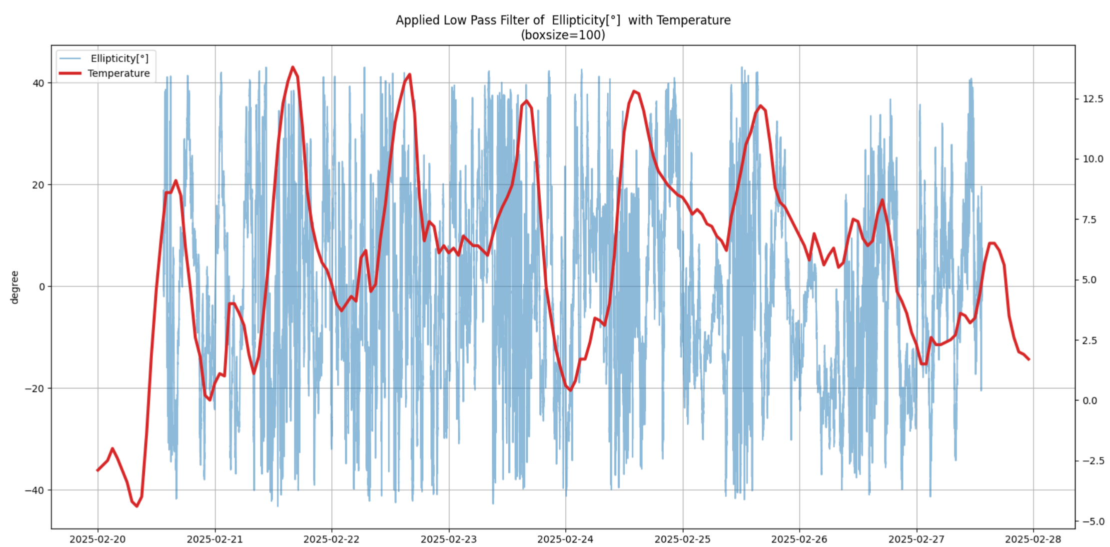

Course of Ellipticity[°] and Rain
Ellipticity[°]
Rain
degree
mm
time
40
20
0
−20
−40
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28

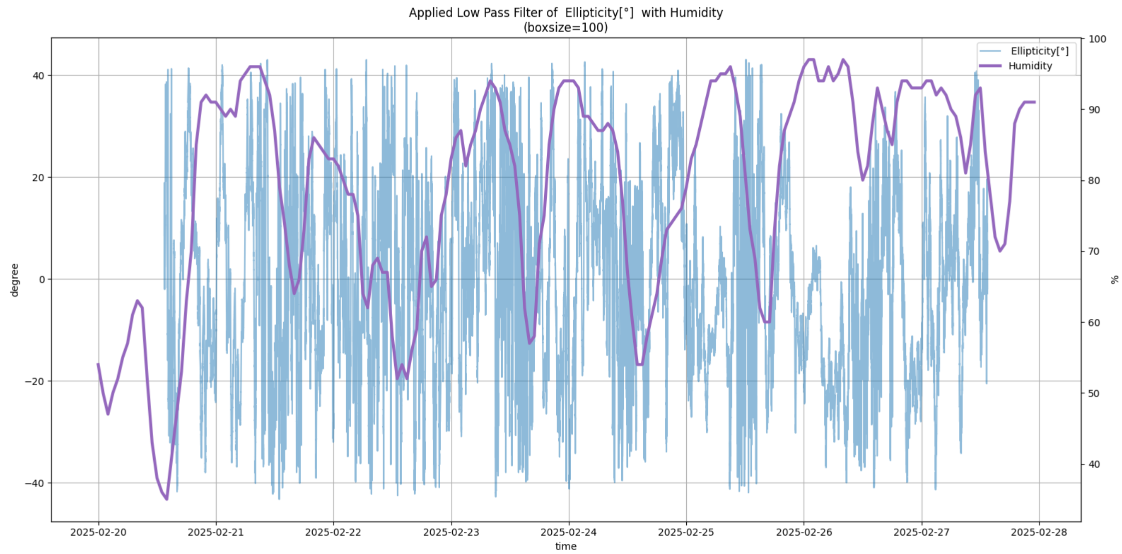


2.4.2 Tiefpass-gefilterte Daten und Wetterparameter

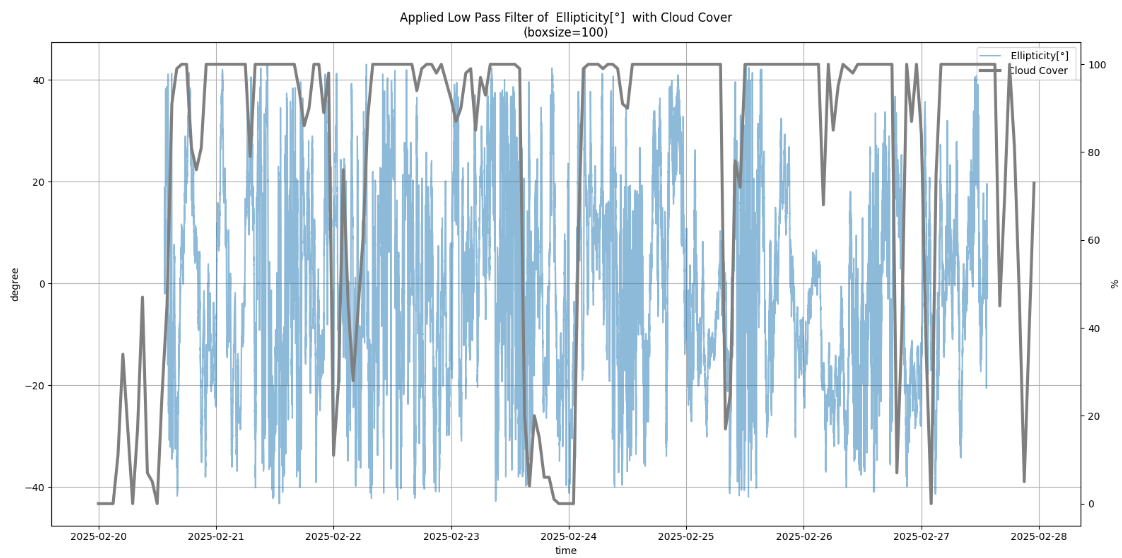
[33]:
```
box = 100

for current in range(len(w_data)):
    fig, ax1 = plt.subplots(figsize=(16, 8))

    ydata = np.array(angle[columns[10]])
    lps = lowpass(ydata, box)

    ax1.plot(angle.index, lps[:-1], label=columns[10], color= "tab:blue",␣
 ↪alpha= 0.5)

    ax1.set_xlabel('time')
    ax1.set_ylabel('degree')
    h1, l1 = ax1.get_legend_handles_labels()

    ax2 = ax1.twinx()

    ax2.plot(weather.index, weather[w_data[current]["header"]],␣
 ↪label=w_data[current]["label"], color = w_data[current]["color"],␣
 ↪linewidth=3)
    ax2.set_ylabel(w_data[current]["unit"])
    h2, l2 = ax2.get_legend_handles_labels()

    ax1.grid()
    ax1.legend(h1+h2, l1+l2, loc="best")
```

```
    ax1.set_title(f'Applied Low Pass Filter of {columns[10]} with␣
↪{w_data[current]["label"]}\n(boxsize={box})')

    plt.tight_layout()
    plt.show()

# Sunlight (day-night context)

plt.figure(figsize = (16,8))

ydata = np.array(angle[columns[9]])
lps = lowpass(ydata, box)

plt.plot(angle.index, lps[:-1], label=columns[10], color= "tab:blue", alpha= 0.
↪5)
for i in range(len(sunrise)):
    plt.axvline(x = sunrise[i], color = 'y', linewidth=3)
    if i == 0: plt.axvline(x = sunset[i], color = 'y',label = 'Sunrise &␣
↪Sunset', linewidth=3)
    else: plt.axvline(x = sunset[i], color = 'y', linewidth=3)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Applied Low Pass Filter of {columns[10]} with Sunrise &␣
↪Sunset\n(boxsize={box})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

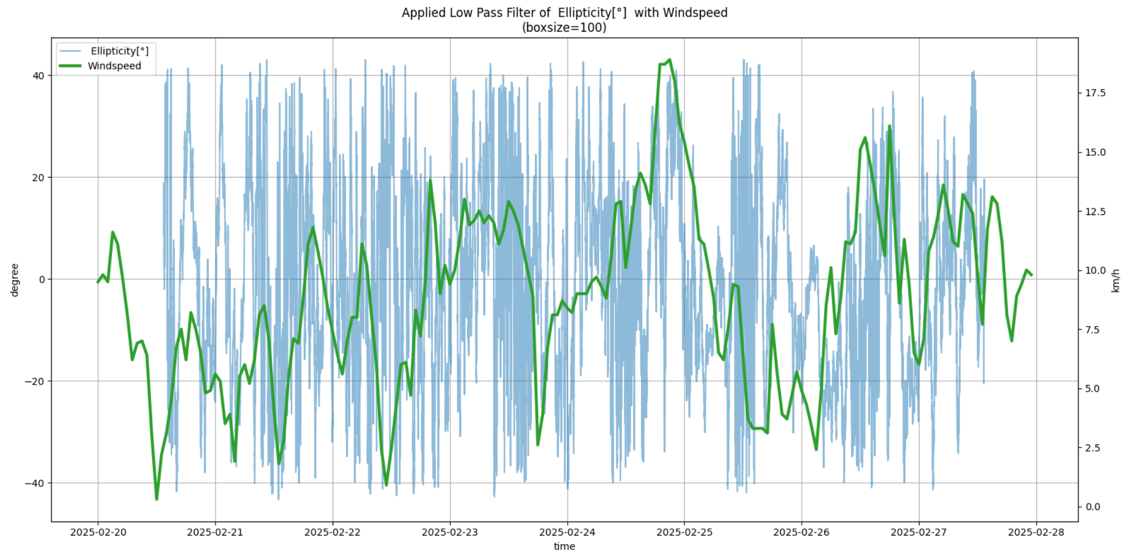




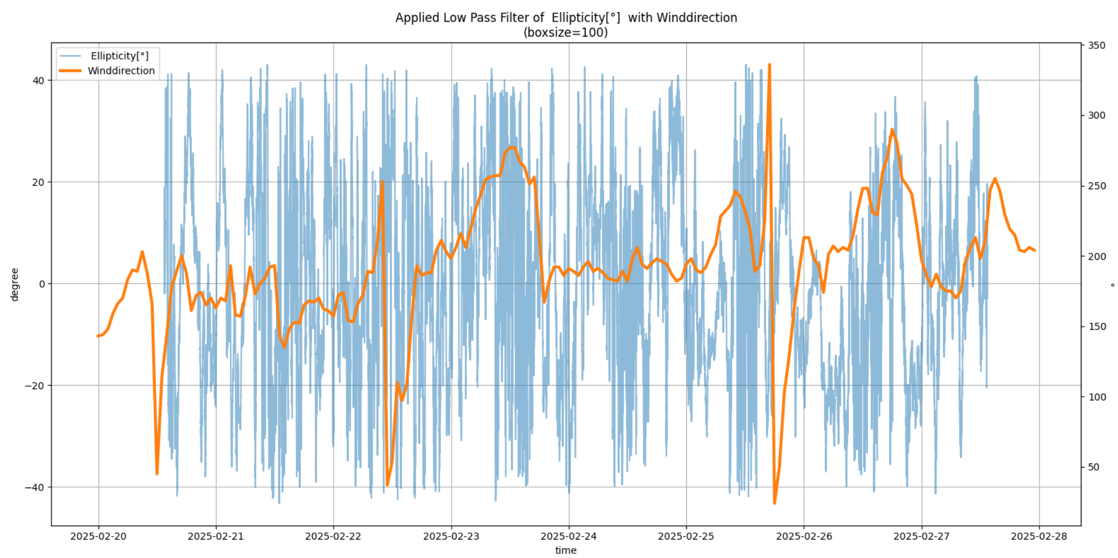
Applied Low Pass Filter of Ellipticity[°] with Humidity
(boxsize=100)
Ellipticity[°]
Humidity
degree
%
time
40
20
0
−20
−40
100
90
80
70
60
50
40
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28



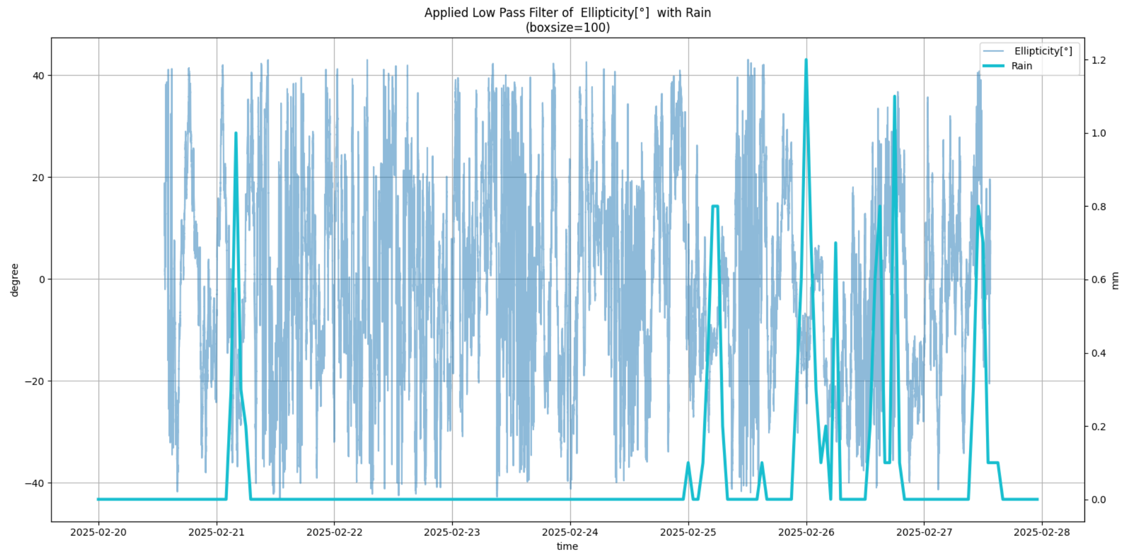
Applied Low Pass Filter of Ellipticity[°] with Cloud Cover
(boxsize=100)
Ellipticity[°]
Cloud Cover
degree
%
time
40
20
0
−20
−40
100
80
60
40
20
0
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28

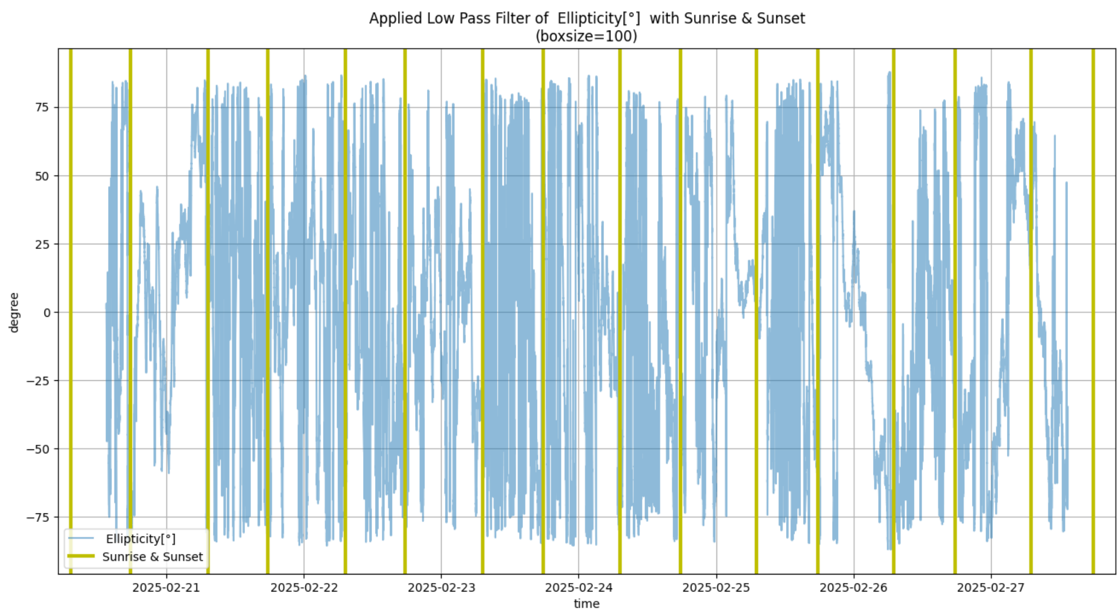


Applied Low Pass Filter of Ellipticity[°] with Windspeed
(boxsize=100)
Ellipticity[°]
Windspeed
degree
km/h
time



Applied Low Pass Filter of Ellipticity[°] with Winddirection
(boxsize=100)
Ellipticity[°]
Winddirection
degree
time

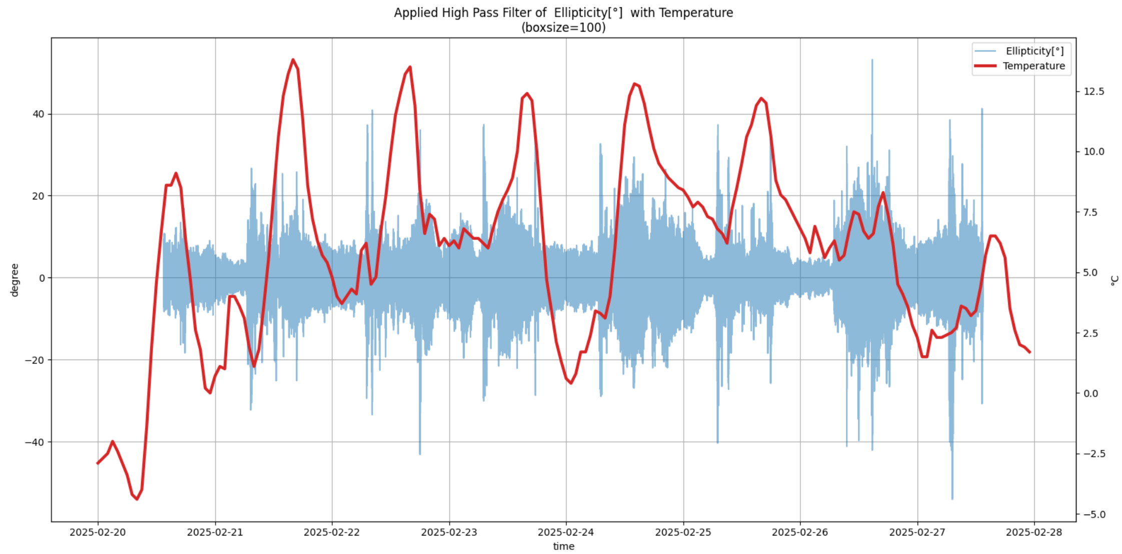


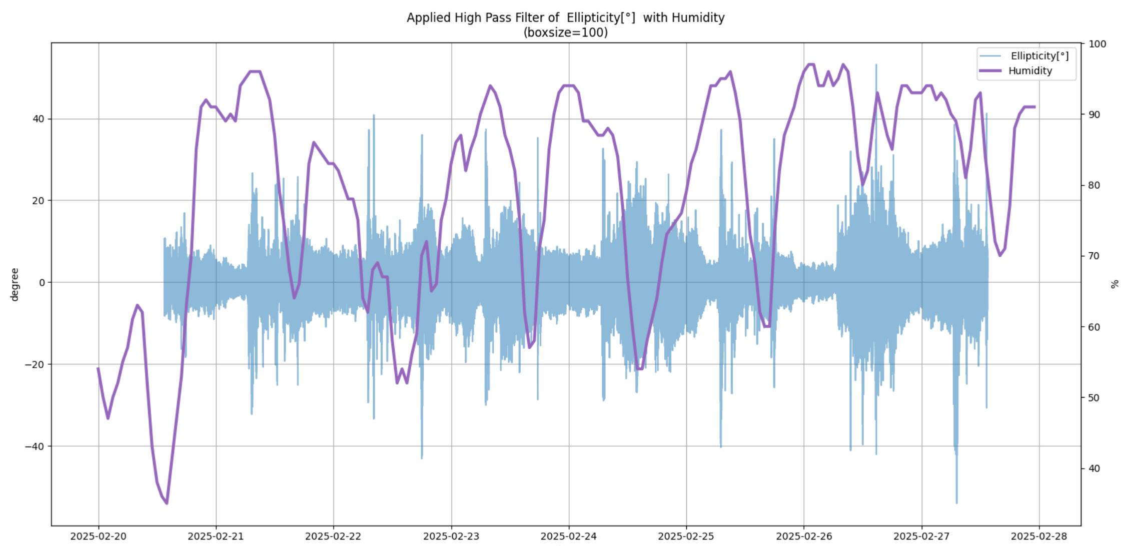


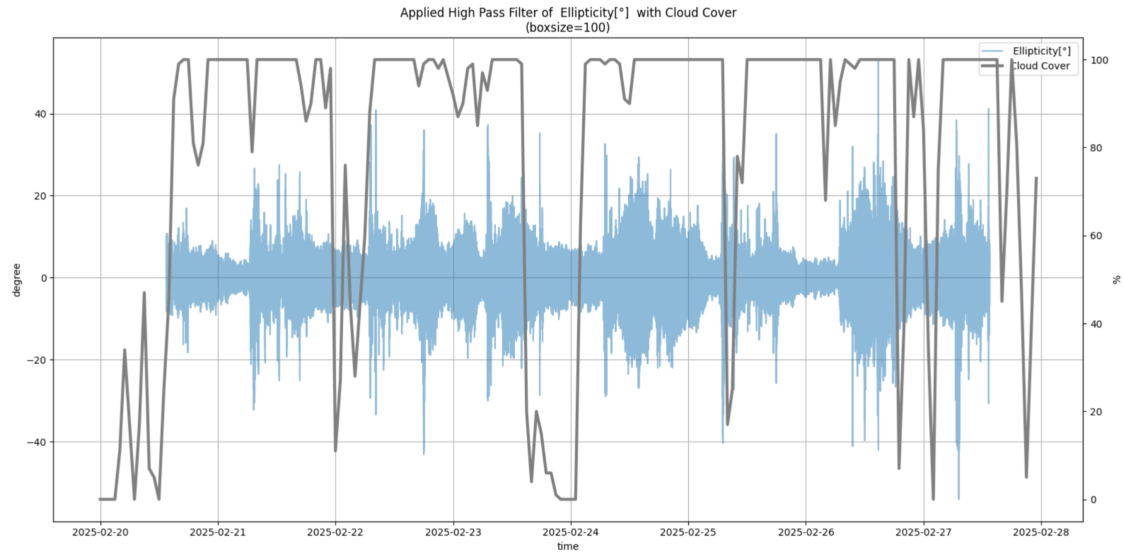
2.4.3 Hochpass-gefilterte Daten und Wetterparameter

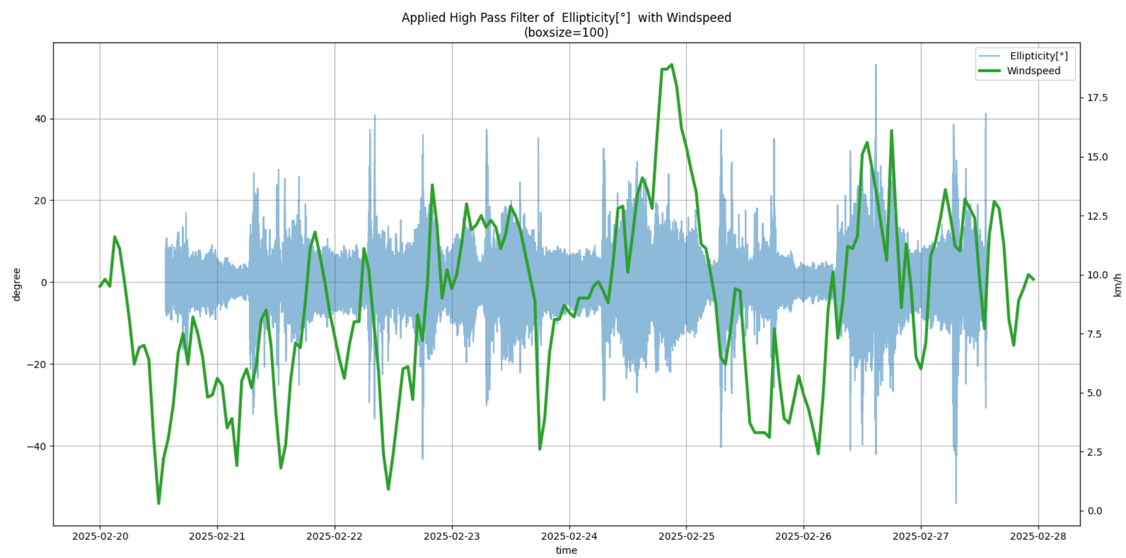
[34]:
```
box = 100

for current in range(len(w_data)):
    fig, ax1 = plt.subplots(figsize=(16, 8))

    ydata = np.array(angle[columns[10]])
```

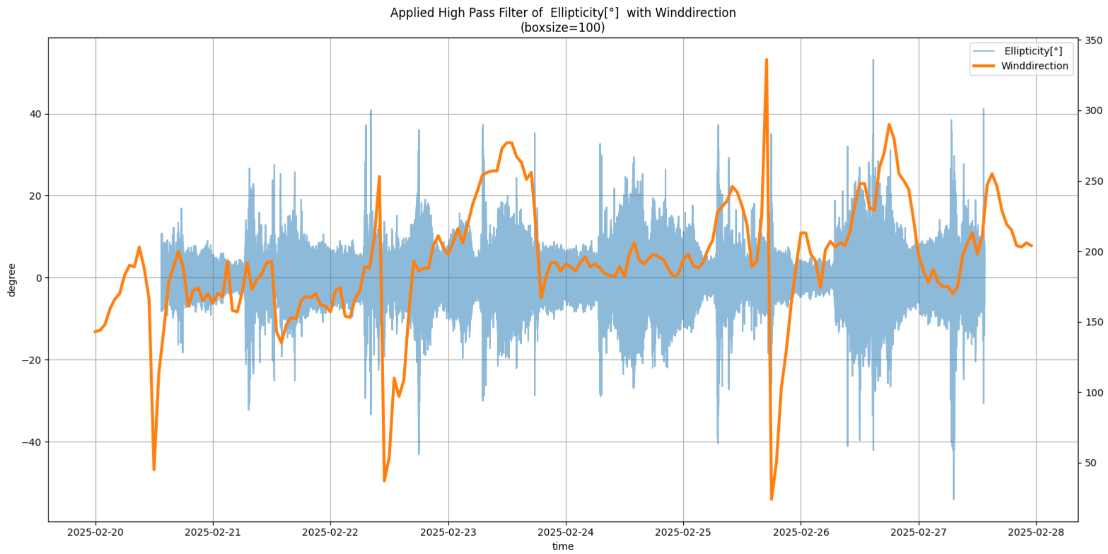
```
    hps = highpass(ydata, box)

    ax1.plot(angle.index, hps, label=columns[10], color= "tab:blue", alpha= 0.5)

    ax1.set_xlabel('time')
    ax1.set_ylabel('degree')
    h1, l1 = ax1.get_legend_handles_labels()

    ax2 = ax1.twinx()

    ax2.plot(weather.index, weather[w_data[current]["header"]],␣
 ↪label=w_data[current]["label"], color = w_data[current]["color"],␣
 ↪linewidth=3)
    ax2.set_ylabel(w_data[current]["unit"])
    h2, l2 = ax2.get_legend_handles_labels()

    ax1.grid()
    ax1.legend(h1+h2, l1+l2, loc="best")
    ax1.set_title(f'Applied High Pass Filter of {columns[10]} with␣
 ↪{w_data[current]["label"]}\n(boxsize={box})')

    plt.tight_layout()
    plt.show()

# Sunlight (day-night context)

plt.figure(figsize = (16,8))

ydata = np.array(angle[columns[9]])
hps = highpass(ydata, box)

plt.plot(angle.index, hps, label=columns[10], color= "tab:blue", alpha= 0.5)
for i in range(len(sunrise)):
    plt.axvline(x = sunrise[i], color = 'y', linewidth=3)
    if i == 0: plt.axvline(x = sunset[i], color = 'y',label = 'Sunrise &␣
 ↪Sunset', linewidth=3)
    else: plt.axvline(x = sunset[i], color = 'y', linewidth=3)
plt.grid()
plt.legend(loc = 'best')
plt.title(f'Applied High Pass Filter of {columns[10]} with Sunrise &␣
 ↪Sunset\n(boxsize={box})')
plt.xlabel('time')
plt.ylabel('degree')
plt.show()
```

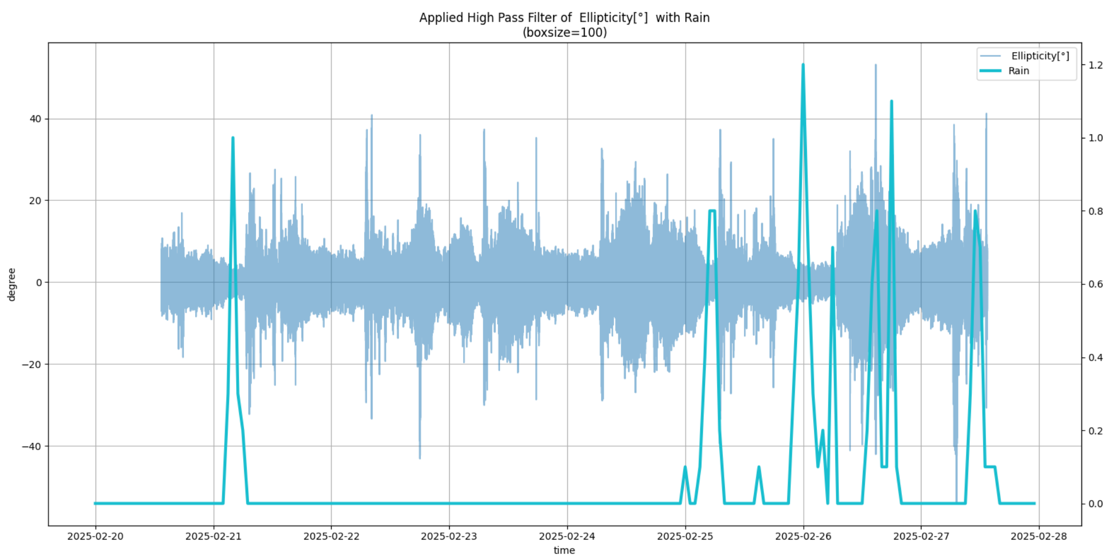

Applied High Pass Filter of Ellipticity[°] with Temperature
(boxsize=100)
Ellipticity[°]
Temperature
degree
°C
time
40
20
0
−20
−40
12.5
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28

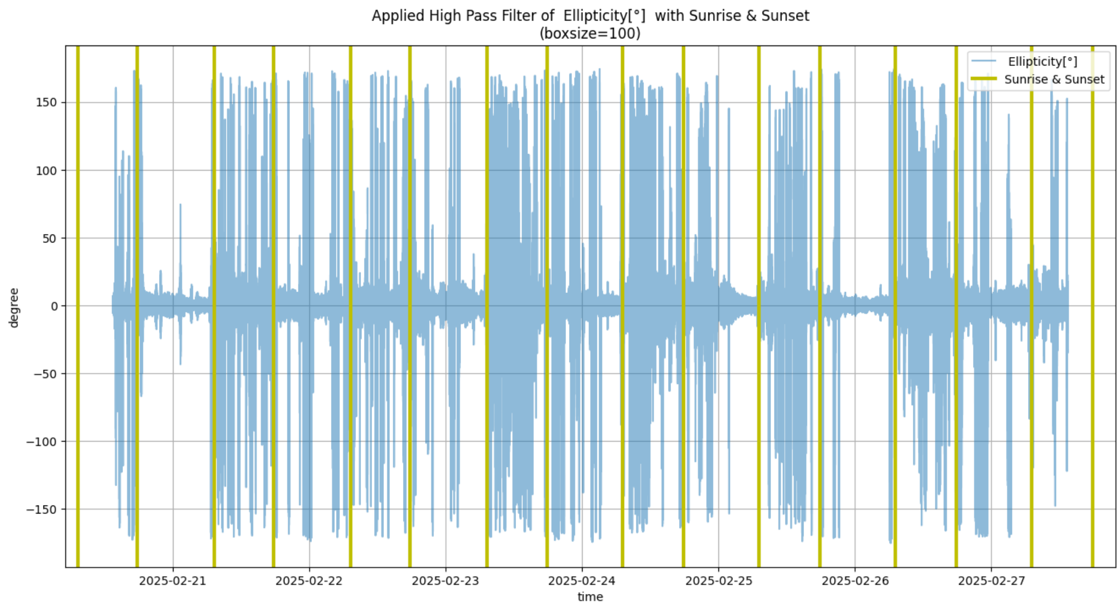

Applied High Pass Filter of Ellipticity[°] with Humidity
(boxsize=100)
Ellipticity[°]
Humidity
degree
%
time
40
20
0
−20
−40
100
90
80
70
60
50
40
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Applied High Pass Filter of Ellipticity[°] with Cloud Cover
(boxsize=100)
Ellipticity[°]
Cloud Cover
degree
%
time
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Applied High Pass Filter of Ellipticity[°] with Windspeed
(boxsize=100)
Ellipticity[°]
Windspeed
degree
km/h
time
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28


Applied High Pass Filter of Ellipticity[°] with Winddirection
(boxsize=100)
Ellipticity[°]
Winddirection
degree
time
°


Applied High Pass Filter of Ellipticity[°] with Rain
(boxsize=100)
Ellipticity[°]
Rain
degree
mm
time

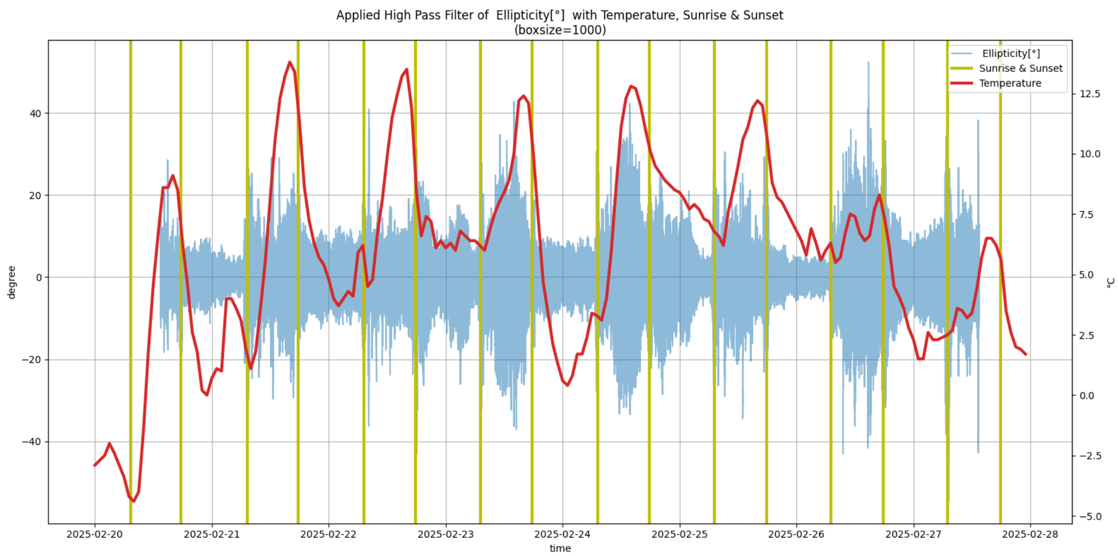


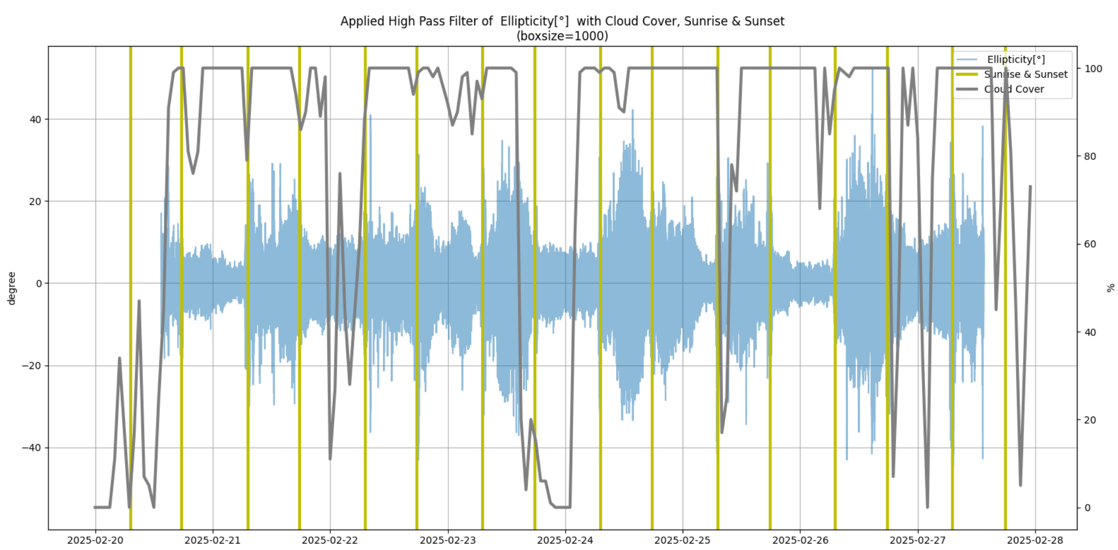
2.4.4 Spezielle Auffälligkeiten

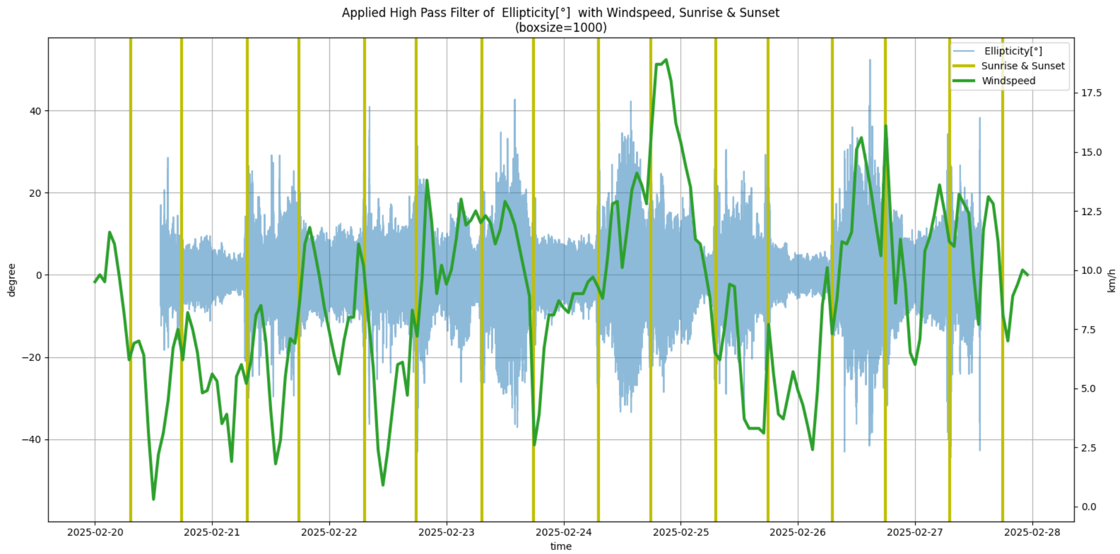
[35]:

```
box = 1000

for current in [0,2,3]:
    fig, ax1 = plt.subplots(figsize=(16, 8))

    ydata = np.array(angle[columns[10]])
    hps = highpass(ydata, 1000)
    ax1.plot(angle.index, hps, label=columns[10], alpha= 0.5)

    for i in range(len(sunrise)):
        ax1.axvline(x = sunrise[i], color = 'y', linewidth=3)
        if i == 0: ax1.axvline(x = sunset[i], color = 'y',label = 'Sunrise &␣
↪Sunset', linewidth=3)
        else: ax1.axvline(x = sunset[i], color = 'y', linewidth=3)

    ax1.set_xlabel('time')
    ax1.set_ylabel('degree')
    h1, l1 = ax1.get_legend_handles_labels()

    ax2 = ax1.twinx()

    ax2.plot(weather.index, weather[w_data[current]["header"]],␣
↪label=w_data[current]["label"], color = w_data[current]["color"],␣
↪linewidth=3)
    ax2.set_ylabel(w_data[current]["unit"])
```

```
    h2, l2 = ax2.get_legend_handles_labels()

    ax1.grid()
    ax1.legend(h1+h2, l1+l2, loc="best")
    ax1.set_title(f'Applied High Pass Filter of {columns[10]} with {w_data[current]["label"]}, Sunrise & Sunset\n(boxsize={box})')

    plt.tight_layout()
    plt.show()
```






Applied High Pass Filter of Ellipticity[°] with Windspeed, Sunrise & Sunset
(boxsize=1000)
Ellipticity[°]
Sunrise & Sunset
Windspeed
degree
km/h
time
40
20
0
−20
−40
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
2025-02-20
2025-02-21
2025-02-22
2025-02-23
2025-02-24
2025-02-25
2025-02-26
2025-02-27
2025-02-28