Author: Md Fahim Hasan

The model has contributions from `Thornton-Dunwoody, Alex (@ atdunwoody)`. The entire code can be found at this github link - https://github.com/mdfahimhasan/SVAT_EcoHydro

---

In [1]:
```python
import pandas as pd
import matplotlib.pyplot as plt
```

Plot functions

In [2]:
```python
def make_single_line_plot(x, y, x_label, y_label, title, x_lim=None, y_lim=None):
    """
    Plot single line plot.

    :param x (list / df series): x-axis name.
    :param y (list / df series): y-axis name.
    :param x_label (str): x_label.
    :param y_label (str): y_label.
    :param title (str): title.
    :param x_lim / y_lim: List of x_lim/y_lim. Default set to None.

    :return: Line plot.
    """
    # Plot gR wide layout with y min of 0
    fig, ax = plt.subplots(figsize=(15, 3))
    ax.plot(x, y)
    ax.set_title(title)
    ax.set_xlabel(x_label)
    ax.set_ylabel(y_label)

    if x_lim is not None:
        ax.set_xlim(x_lim)
    if y_lim is not None:
        ax.set_ylim(y_lim)

    plt.show()

def make_multiline_plot(x1, y1, label1,
                        x2, y2, label2,
                        x_label, y_label,title,
                        x3=None, y3=None, label3=None,
                        x_lim=None, y_lim=None):
    """
    Plot multiline plot. Can at max plot 3 series.

    :param x (list / df series): x-axis name.  x3 set to None by default.
    :param y (list / df series): y-axis name. y3 set to None by default.
    :param x_label (str): x_label.
    :param y_label (str): y_label.
    :param title (str): title.
    :param x_lim / y_lim: List of x_lim/y_lim. Default set to None.

    :return: Multi-line plot.
    """
    # Plot gR wide layout with y min of 0
    fig, ax = plt.subplots(figsize=(15, 3))
    ax.plot(x1, y1, label=label1)
    ax.plot(x2, y2, label=label2)
    if x3 is not None:
        ax.plot(x3, y3, label=label3)

    ax.set_title(title)
    ax.set_xlabel(x_label)
    ax.set_ylabel(y_label)

    if x_lim is not None:
        ax.set_xlim(x_lim)
    if y_lim is not None:
        ax.set_ylim(y_lim)

    plt.legend()
    plt.show()
```

`Canopy:` Grass

In [3]:
```python
grass_df = pd.read_csv('../results/grass.csv')
print(grass_df.columns)
grass_df.head()
```

```
Index(['Total Hour', 'Hour', 'SR_down', 'LW_down', 'Ta', 'wind_speed', 'q',
       'precip', 'ra', 'e', 'e_sat', 'VPD', 'gR', 'gD', 'gT', 'Lambda',
       'delta', 'psy_const', 'gSM', 'gS', 'rs', 'LW_up', 'Rn', 'Cinterim',
       'Cactual', 'Dcanopy', 'lambdaEi', 'Cfinal', 'lambdaEt', 'lambdaET', 'H',
       'Ts', 'SMlast', 'SMnew'],
      dtype='object')
```

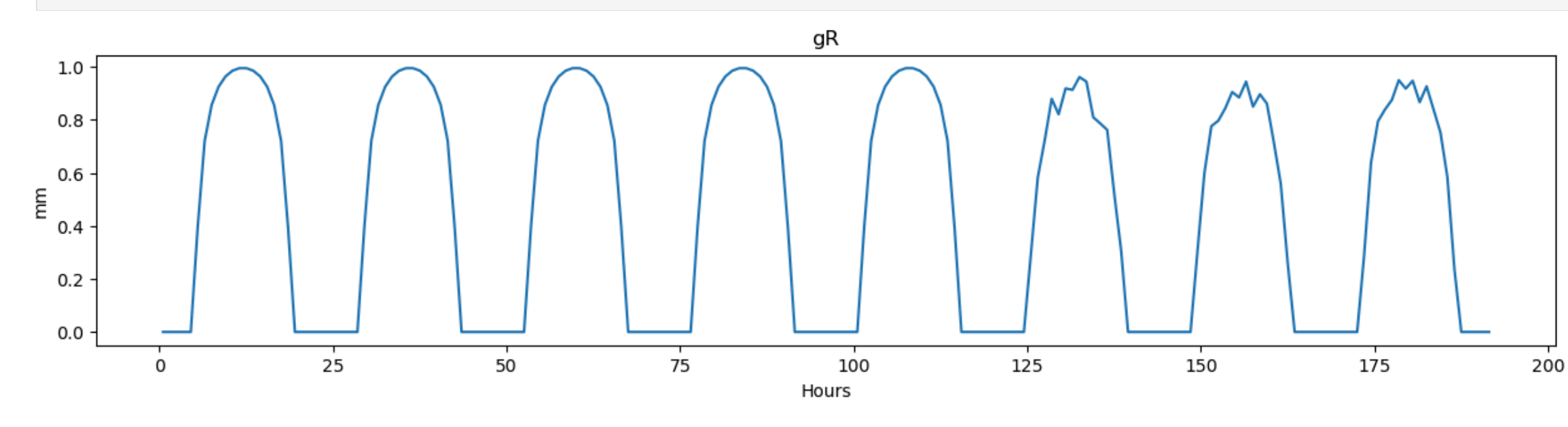
Out[3]:

	Total Hour	Hour	SR_down	LW_down	Ta	wind_speed	q	precip	ra	e	...	Cactual	Dcanopy	lambdaEi	Cfinal	lambdaEt	lambdaET	H	
0	0.5	0.5	0	269.131	12.697	2.429	2.444	0	94.264140	0.397641	...	0.0	0.0	0.0	0.0	0.013213	0.013213	-49.882213	282.0
1	1.5	1.5	0	271.000	13.160	2.390	2.030	0	95.802341	0.330283	...	0.0	0.0	0.0	0.0	0.015276	0.015276	-48.015276	282.6
2	2.5	2.5	0	265.400	11.770	2.330	2.360	0	98.269354	0.383974	...	0.0	0.0	0.0	0.0	0.008284	0.008284	-77.026460	278.8
3	3.5	3.5	0	265.100	11.700	2.310	2.190	0	99.120171	0.356315	...	0.0	0.0	0.0	0.0	0.009631	0.009631	-69.654029	279.3
4	4.5	4.5	0	265.200	11.720	2.210	2.140	0	103.605247	0.348180	...	0.0	0.0	0.0	0.0	0.010513	0.010513	-61.645873	279.7

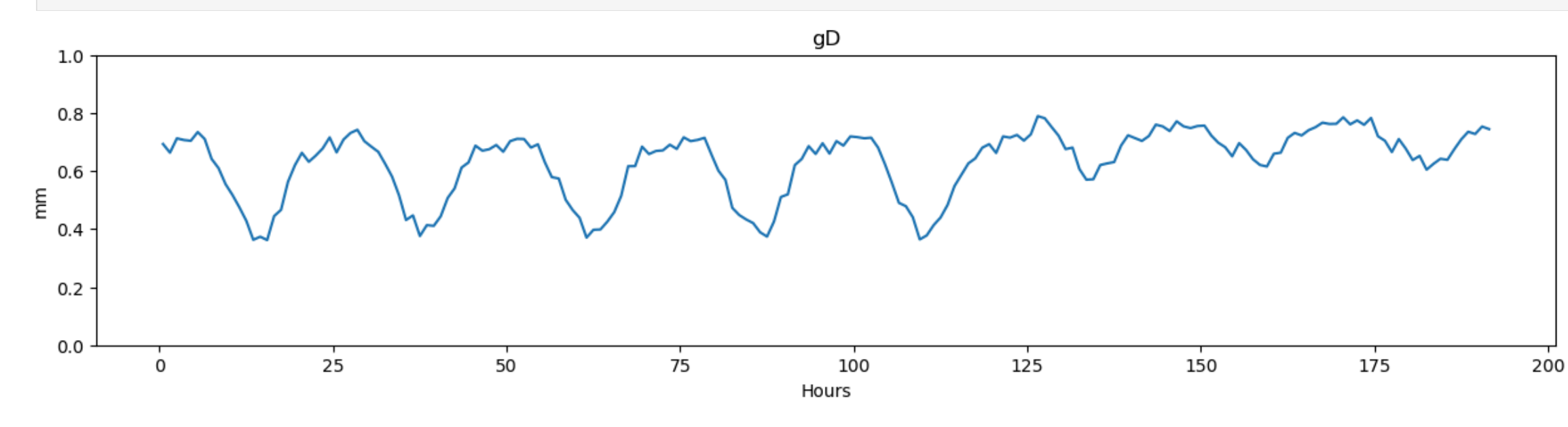
5 rows × 34 columns

gR, gD, gT

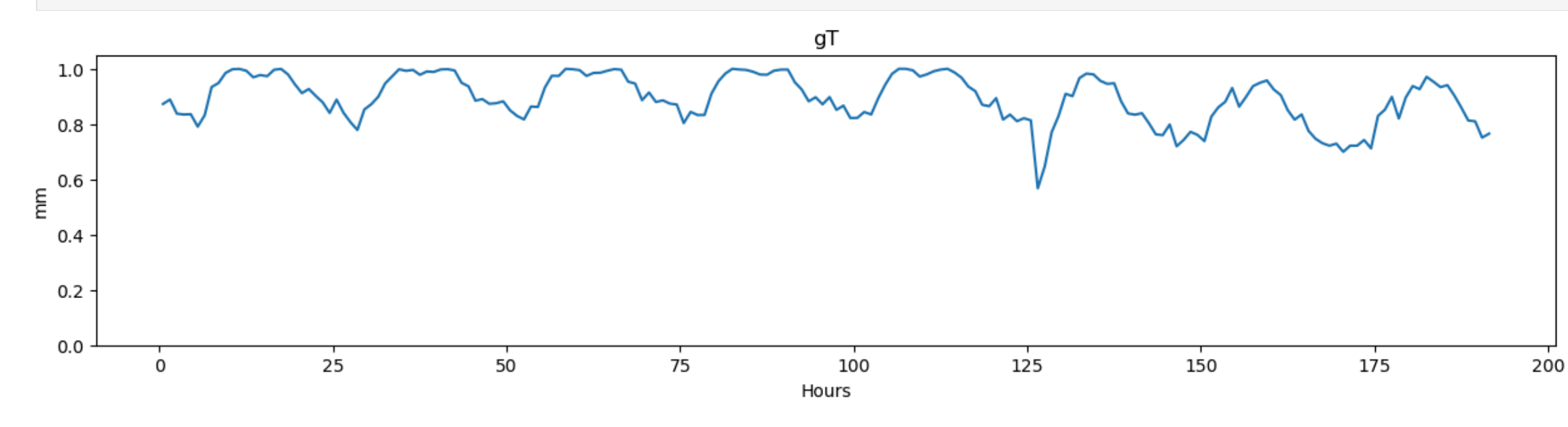
In [4]:
```python
make_single_line_plot(x=grass_df['Total Hour'], y = grass_df['gR'],
                      x_label='Hours', y_label='mm', title='gR')
```



In [5]:
```python
make_single_line_plot(x=grass_df['Total Hour'], y = grass_df['gD'],
                      x_label='Hours', y_label='mm', title='gD', y_lim=[0, 1])
```

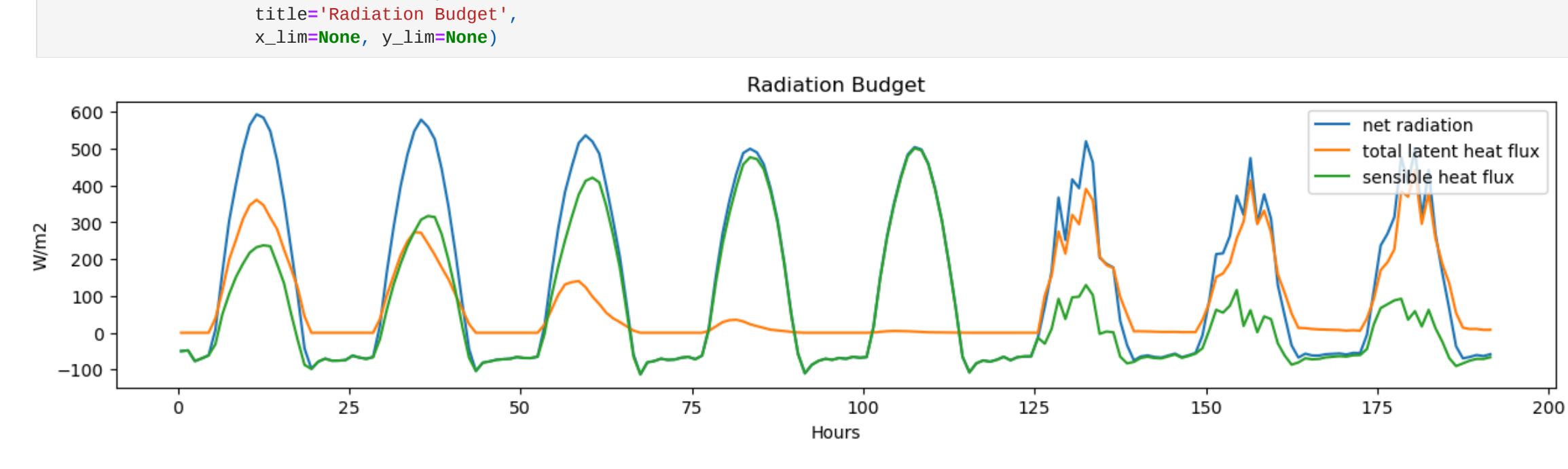


In [6]:
```python
make_single_line_plot(x=grass_df['Total Hour'], y = grass_df['gT'],
                      x_label='Hours', y_label='mm', title='gT', y_lim=[0, 1.05])
```



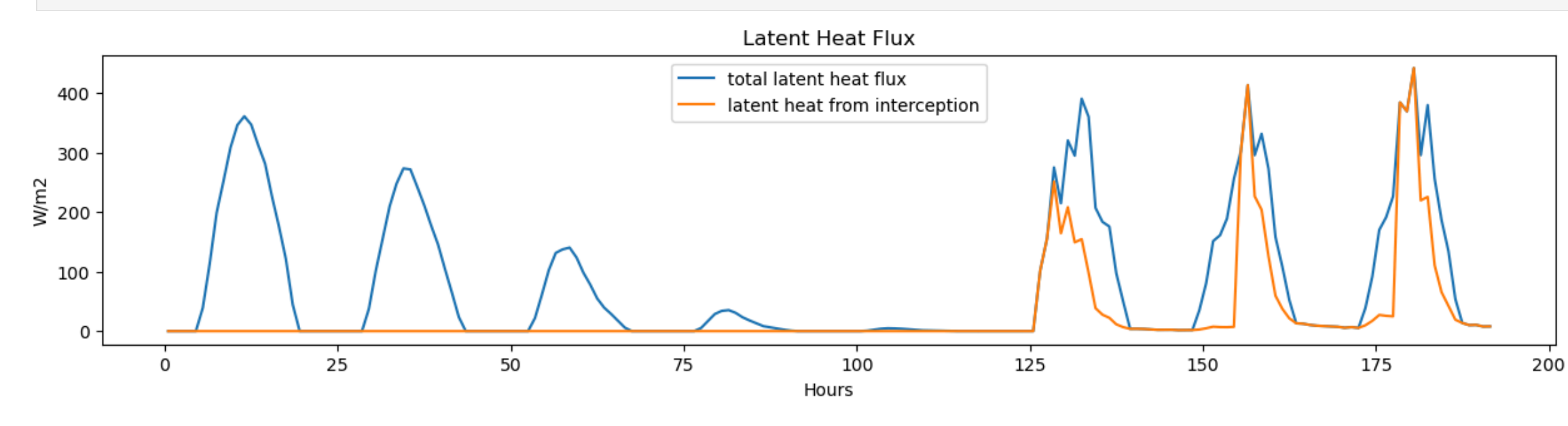
(I) Rn, labmdaET, and H

In [7]:
```python
make_multiline_plot(x1=grass_df['Total Hour'], y1=grass_df['Rn'], label1='net radiation',
                    x2=grass_df['Total Hour'], y2=grass_df['lambdaET'], label2='total latent heat flux',
                    x3=grass_df['Total Hour'], y3=grass_df['H'], label3='sensible heat flux',
                    x_label='Hours', y_label='W/m2',
                    title='Radiation Budget',
                    x_lim=None, y_lim=None)
```



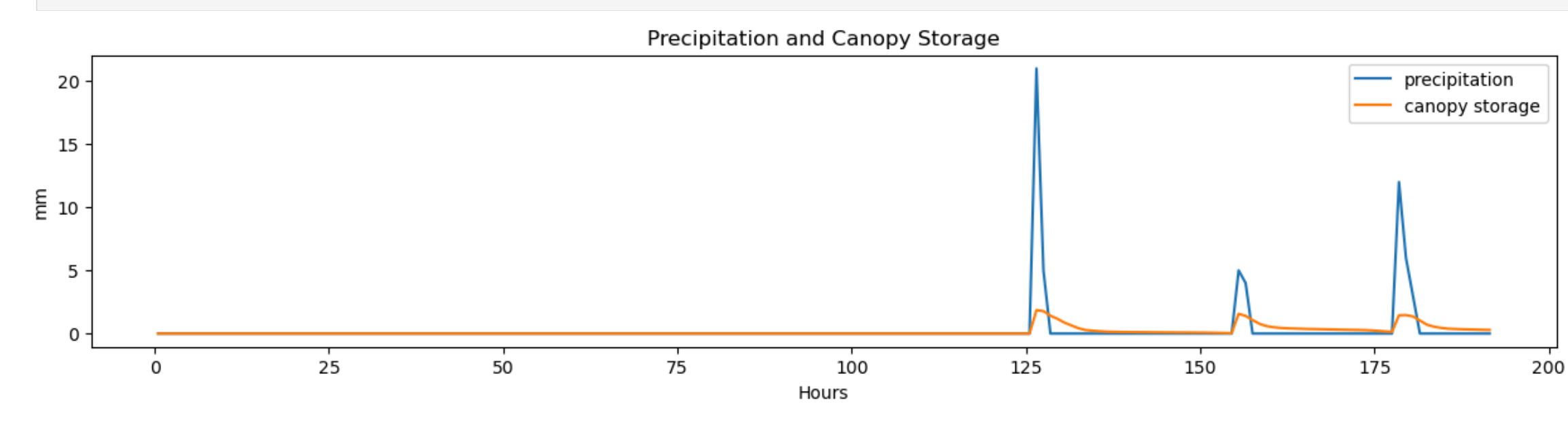
(II) labmdaET and labmdaEi

In [8]:
```python
make_multiline_plot(x1=grass_df['Total Hour'], y1=grass_df['lambdaET'], label1='total latent heat flux',
                    x2=grass_df['Total Hour'], y2=grass_df['lambdaEi'], label2='latent heat from interception',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='W/m2',
                    title='Latent Heat Flux',
                    x_lim=None, y_lim=None)
```



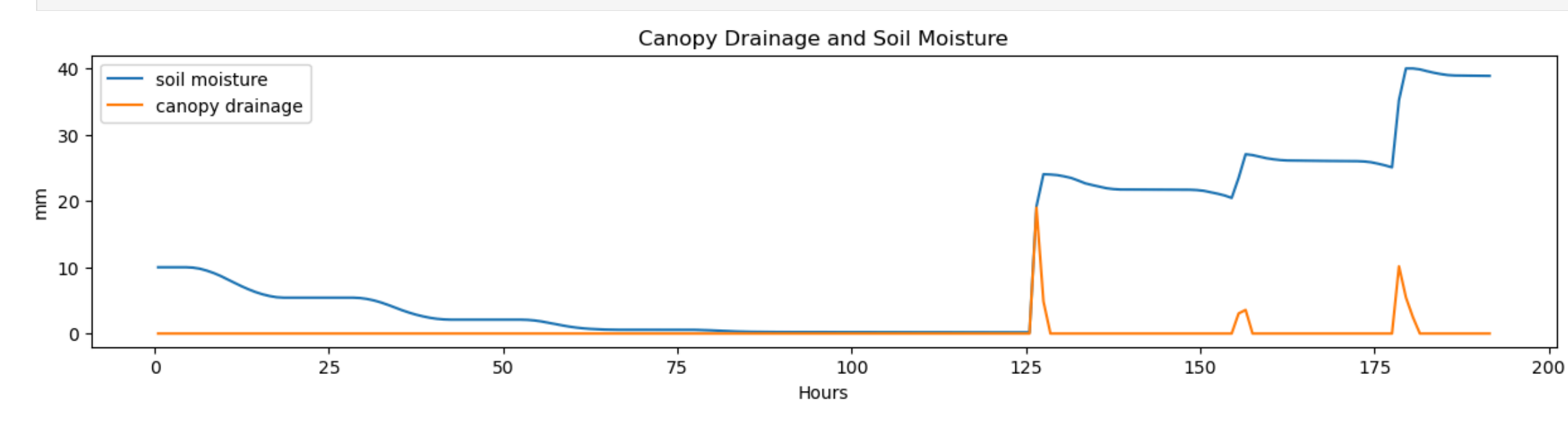
(III) Precip and Canopy Storage

In [9]:
```python
make_multiline_plot(x1=grass_df['Total Hour'], y1=grass_df['precip'], label1='precipitation',
                    x2=grass_df['Total Hour'], y2=grass_df['Cfinal'], label2='canopy storage',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='mm',
                    title='Precipitation and Canopy Storage',
                    x_lim=None, y_lim=None)
```



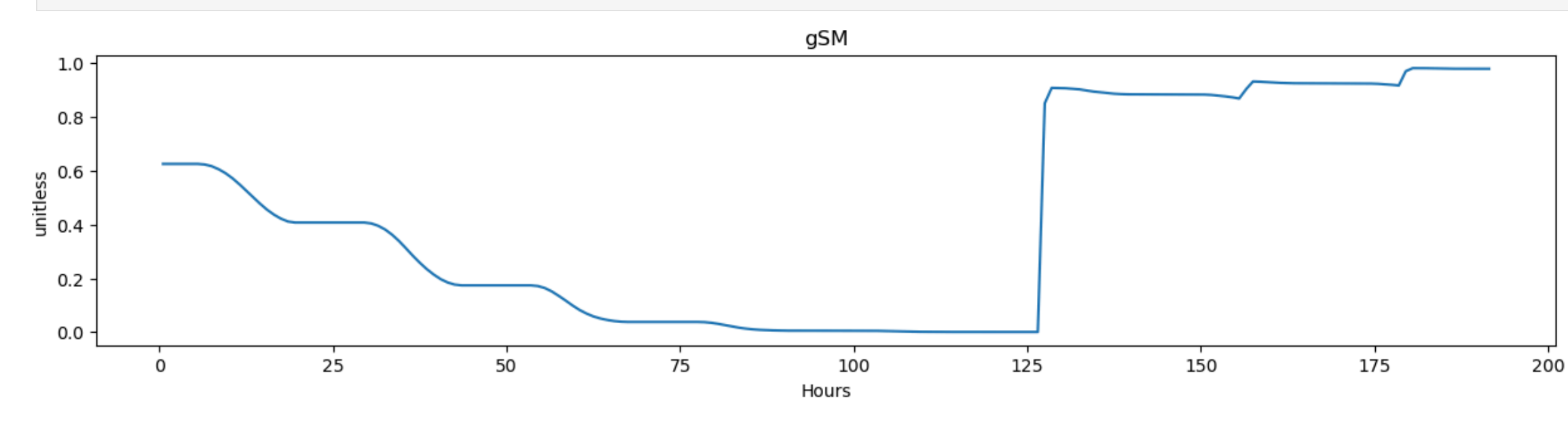
(IV) Canopy Drainage and Soil Moisture

In [10]:
```python
make_multiline_plot(x1=grass_df['Total Hour'], y1=grass_df['SMnew'], label1='soil moisture',
                    x2=grass_df['Total Hour'], y2=grass_df['Dcanopy'], label2='canopy drainage',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='mm',
                    title='Canopy Drainage and Soil Moisture',
                    x_lim=None, y_lim=None)
```



(V) gSM

In [11]:
```python
make_single_line_plot(x=grass_df['Total Hour'], y = grass_df['gSM'],
                      x_label='Hours', y_label='unitless', title='gSM', y_lim=None)
```



(VI) Daily average fluxes

In [15]:
```python
# setting day number in the dataset
grass_df['day'] = (grass_df['Total Hour'] // 24)  + 1
```

In [20]:
```python
daily_df_grass = grass_df.groupby('day')[['precip', 'Rn', 'lambdaET', 'H', 'lambdaEi']].mean()
daily_df_grass = daily_df_grass.reset_index()
daily_df_grass['Bowen Ratio'] = daily_df_grass['H'] / daily_df_grass['lambdaET']
daily_df_grass['Fractional contribution of intercepted water'] = daily_df_grass['lambdaEi'] / daily_df_grass['lambdaET']
daily_df_grass
```

Out[20]:

	day	precip	Rn	lambdaET	H	lambdaEi	Bowen Ratio	Fractional contribution of intercepted water
0	1.0	0.000000	169.840927	130.338033	39.502894	0.000000	0.303080	0.000000
1	2.0	0.000000	160.759236	94.419193	66.340043	0.000000	0.702612	0.000000
2	3.0	0.000000	146.827766	43.379202	103.448564	0.000000	2.384750	0.000000
3	4.0	0.000000	137.002807	9.488904	127.513902	0.000000	13.438212	0.000000
4	5.0	0.000000	136.832765	1.285243	135.547522	0.000000	105.464502	0.000000
5	6.0	1.083333	105.550592	118.434627	-12.884034	58.589294	-0.108786	0.494697
6	7.0	0.375000	102.329511	119.606651	-17.277140	62.033500	-0.144450	0.518646
7	8.0	0.875000	121.896169	137.659095	-15.762926	86.121669	-0.114507	0.625616

At the beginning of simulation, soil water storage is maximum, and ET is maximum. The 1st 5 days of simulation has no rainfall, so all ET is sourced from available soil moisture. As soil moisture is the only source of water during the first 5 days, ET depletes with time during this period. Therefore, most of the net radiation becomes SH and SH increases in the first 5 days along with Bowen ratio. The 5th day of simulation has rainfall that replenishes soil moisture. This makes the soil wet and more of the net radiation goes toward latent heat, making SH negative. That's why during the last 3 days of the simulation, SH is negative and so is the bowen ratio.

During the first 5 days of simulation, there was no rainfall. So, the contribution of intercepted water by canopy to ET is zero. As the last 3 days of simulation, rainfall occurs and canopy intercepts some of it. This intercepted water contributes toward ET and fraction contribution of intercepted water toward ET increases and comprises nearly half of ET

`Canopy:` Forest

In [16]:
```python
forest_df = pd.read_csv('../results/forest.csv')
print(forest_df.columns)
forest_df.head()
```

```
Index(['Total Hour', 'Hour', 'SR_down', 'LW_down', 'Ta', 'wind_speed', 'q',
       'precip', 'ra', 'e', 'e_sat', 'VPD', 'gR', 'gD', 'gT', 'Lambda',
       'delta', 'psy_const', 'gSM', 'gS', 'rs', 'LW_up', 'Rn', 'Cinterim',
       'Cactual', 'Dcanopy', 'lambdaEi', 'Cfinal', 'lambdaEt', 'lambdaET', 'H',
       'Ts', 'SMlast', 'SMnew'],
      dtype='object')
```

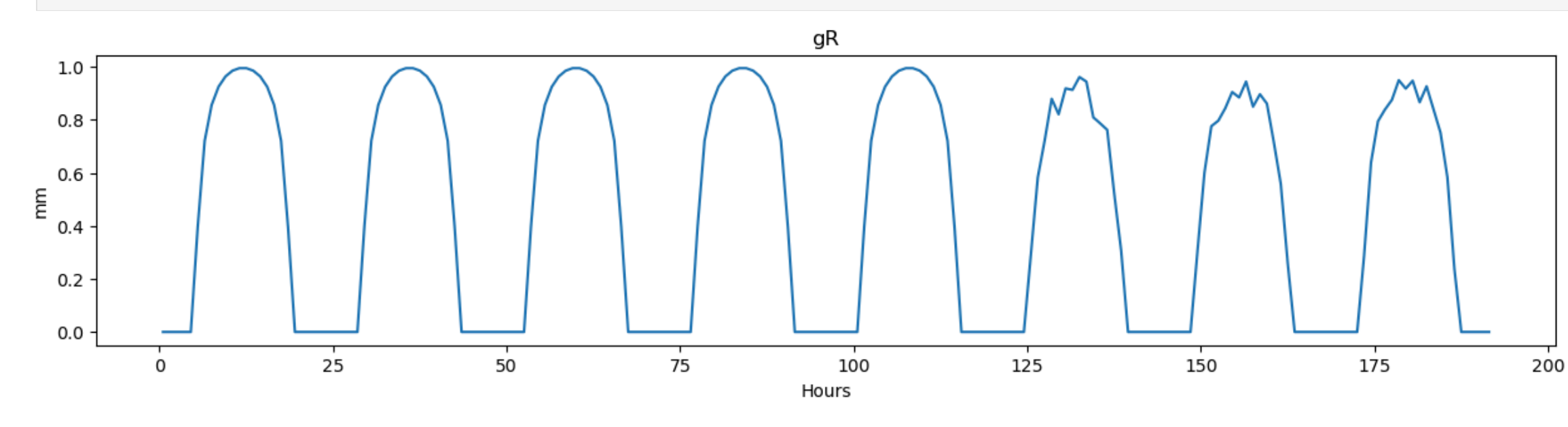
Out[16]:

	Total Hour	Hour	SR_down	LW_down	Ta	wind_speed	q	precip	ra	e	...	Cactual	Dcanopy	lambdaEi	Cfinal	lambdaEt	lambdaET	H	
0	0.5	0.5	0	269.131	12.697	2.429	2.444	0	14.968006	0.397641	...	0.0	0.0	0.0	0.0	0.018253	0.018253	-80.887253	284.89
1	1.5	1.5	0	271.000	13.160	2.390	2.030	0	15.212254	0.330283	...	0.0	0.0	0.0	0.0	0.020312	0.020312	-79.020312	285.36
2	2.5	2.5	0	265.400	11.770	2.330	2.360	0	15.603986	0.383974	...	0.0	0.0	0.0	0.0	0.016713	0.016713	-90.642753	283.80
3	3.5	3.5	0	265.100	11.700	2.310	2.190	0	15.739085	0.356315	...	0.0	0.0	0.0	0.0	0.017154	0.017154	-88.242302	283.75
4	4.5	4.5	0	265.200	11.720	2.210	2.140	0	16.451261	0.348180	...	0.0	0.0	0.0	0.0	0.017344	0.017344	-84.146152	283.77

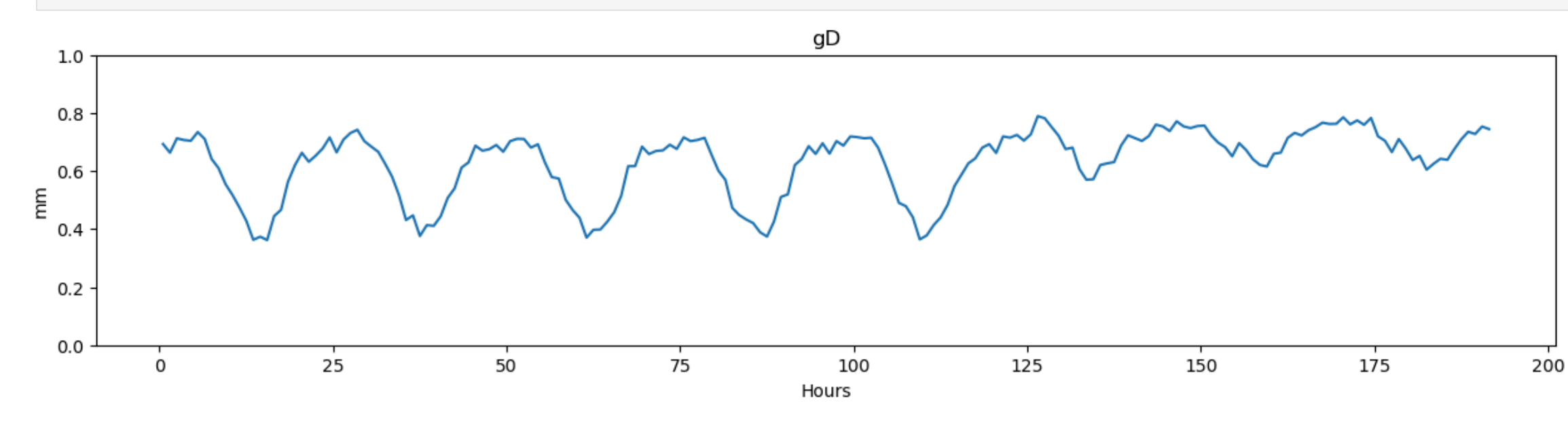
5 rows × 34 columns

gR, gD, gT

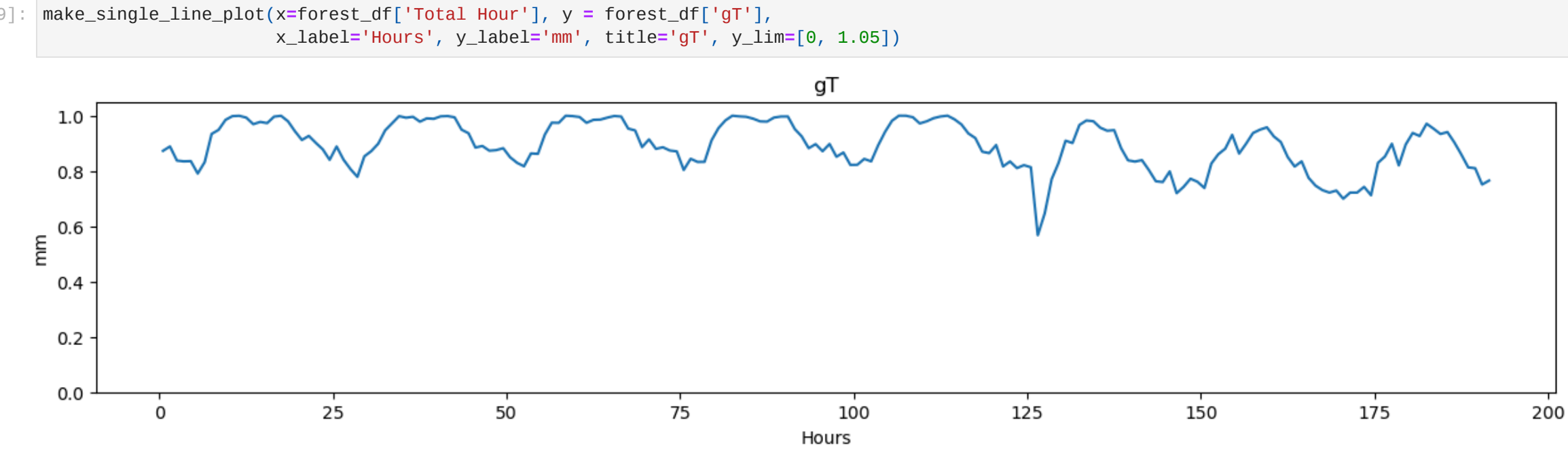
In [37]:
```python
make_single_line_plot(x=forest_df['Total Hour'], y = forest_df['gR'],
                      x_label='Hours', y_label='mm', title='gR')
```



In [38]:
```python
make_single_line_plot(x=forest_df['Total Hour'], y = forest_df['gD'],
                      x_label='Hours', y_label='mm', title='gD', y_lim=[0, 1])
```

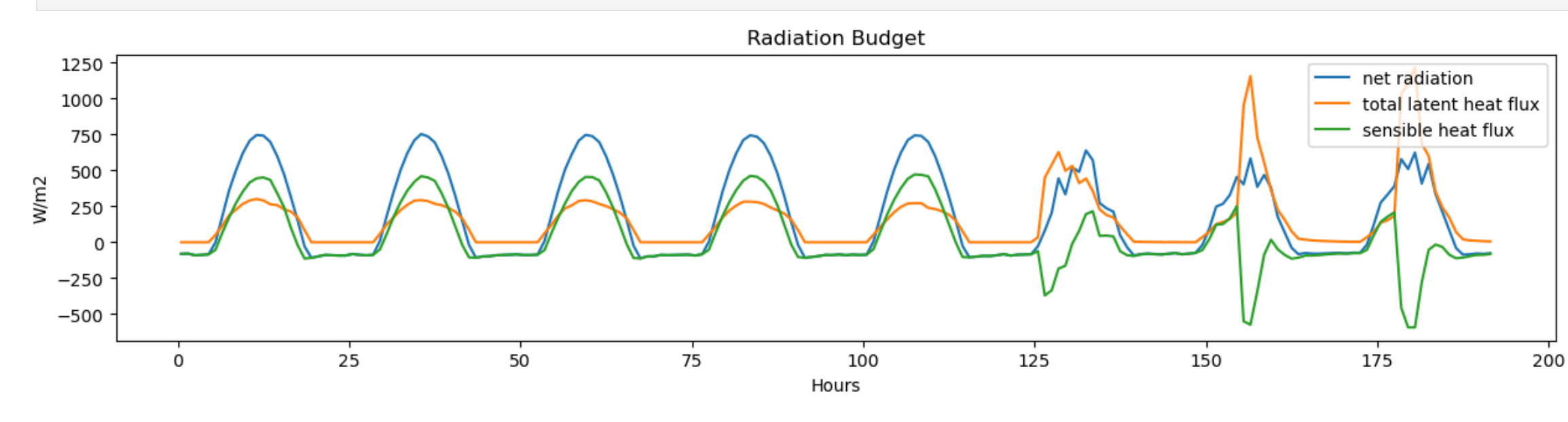


In [39]:
```python
make_single_line_plot(x=forest_df['Total Hour'], y = forest_df['gT'],
                      x_label='Hours', y_label='mm', title='gT', y_lim=[0, 1.05])
```



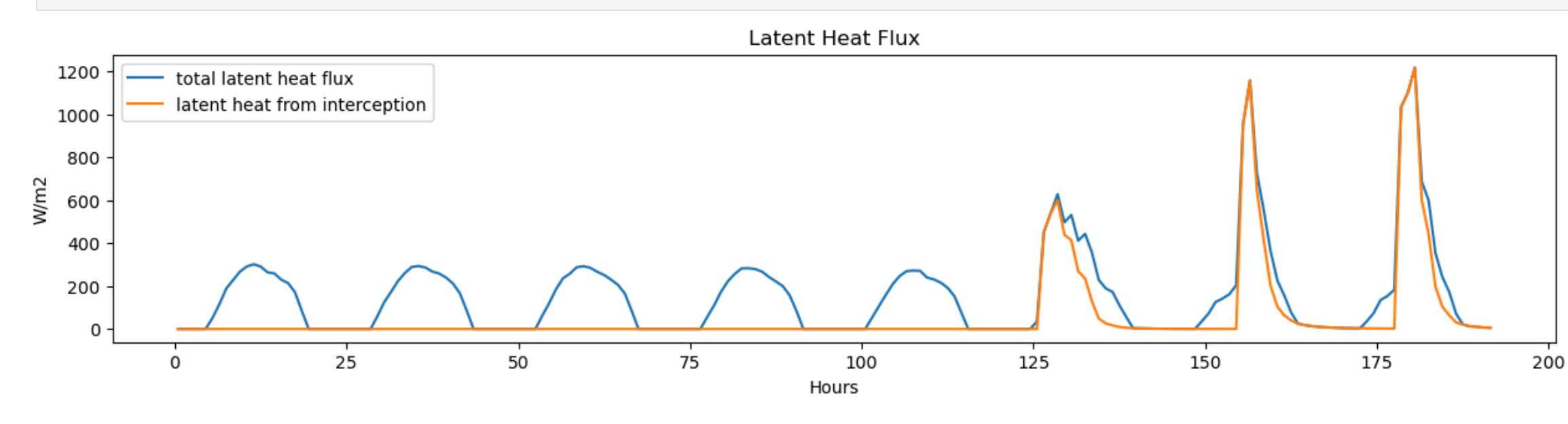
(I) Rn, labmdaET, and H

In [40]:
```python
make_multiline_plot(x1=forest_df['Total Hour'], y1=forest_df['Rn'], label1='net radiation',
                    x2=forest_df['Total Hour'], y2=forest_df['labmdaET'], label2='total latent heat flux',
                    x3=forest_df['Total Hour'], y3=forest_df['H'], label3='sensible heat flux',
                    x_label='Hours', y_label='W/m2',
                    title='Radiation Budget',
                    x_lim=None, y_lim=None)
```



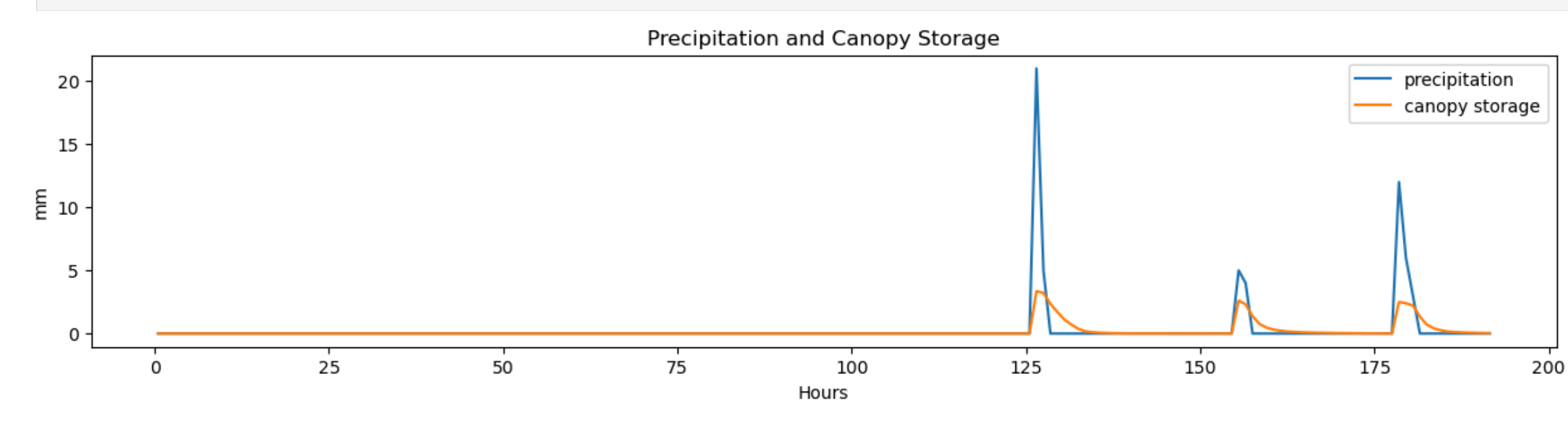
(II) labmdaET and labmdaEi

In [41]:
```python
make_multiline_plot(x1=forest_df['Total Hour'], y1=forest_df['labmdaET'], label1='total latent heat flux',
                    x2=forest_df['Total Hour'], y2=forest_df['labmdaEi'], label2='latent heat from interception',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='W/m2',
                    title='Latent Heat Flux',
                    x_lim=None, y_lim=None)
```



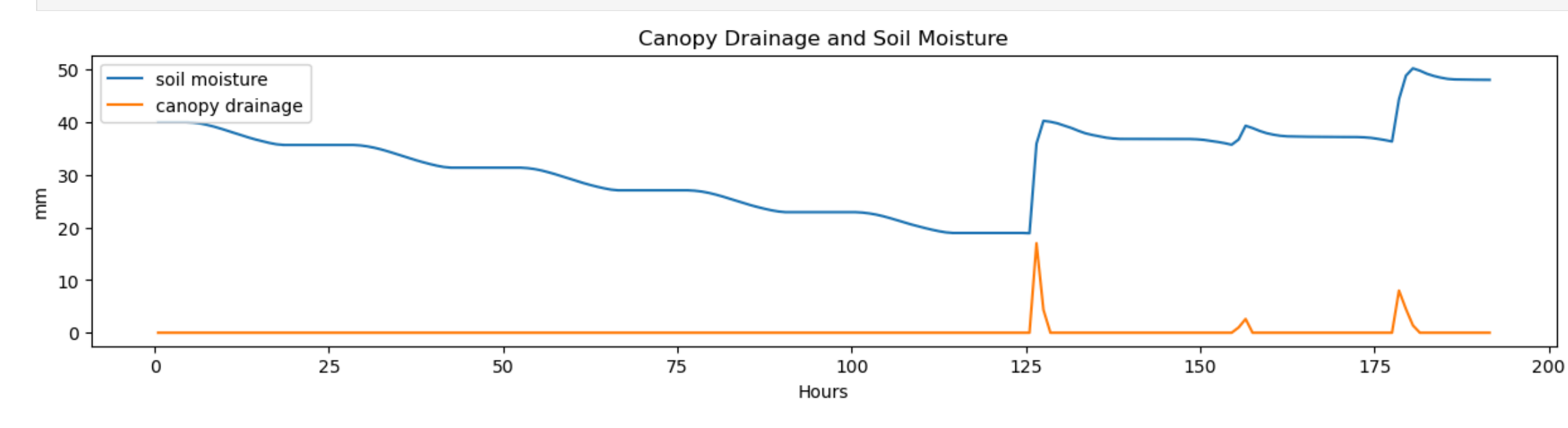
(III) Precip and Canopy Storage

In [42]:
```python
make_multiline_plot(x1=forest_df['Total Hour'], y1=forest_df['precip'], label1='precipitation',
                    x2=forest_df['Total Hour'], y2=forest_df['Cfinal'], label2='canopy storage',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='mm',
                    title='Precipitation and Canopy Storage',
                    x_lim=None, y_lim=None)
```



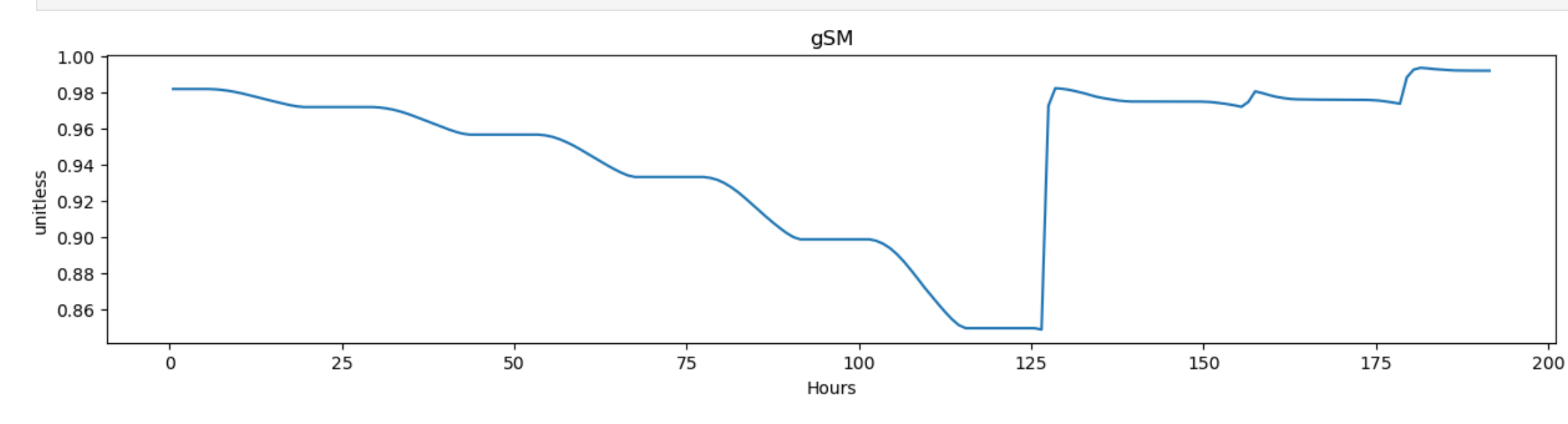
(IV) Canopy Drainage and Soil Moisture

In [43]:
```python
make_multiline_plot(x1=forest_df['Total Hour'], y1=forest_df['SMnew'], label1='soil moisture',
                    x2=forest_df['Total Hour'], y2=forest_df['Dcanopy'], label2='canopy drainage',
                    x3=None, y3=None, label3=None,
                    x_label='Hours', y_label='mm',
                    title='Canopy Drainage and Soil Moisture',
                    x_lim=None, y_lim=None)
```



(V) gSM

In [44]:
```python
make_single_line_plot(x=forest_df['Total Hour'], y = forest_df['gSM'],
                      x_label='Hours', y_label='unitless', title='gSM', y_lim=None)
```



(VI) Daily average fluxes

In [17]:
```python
# setting day number in the dataset
forest_df['day'] = (forest_df['Total Hour'] // 24)  + 1
```

In [19]:
```python
daily_df_forest = forest_df.groupby('day')[['precip', 'Rn', 'lambdaET', 'H', 'lambdaEi']].mean()
daily_df_forest = daily_df_forest.reset_index()
daily_df_forest['Bowen Ratio'] = daily_df_forest['H'] / daily_df_forest['lambdaET']
daily_df_forest['Fractional contribution of intercepted water'] = daily_df_forest['lambdaEi'] / daily_df_forest['lambdaET']
daily_df_forest
```

Out[19]:

	day	precip	Rn	lambdaET	H	lambdaEi	Bowen Ratio	Fractional contribution of intercepted water
0	1.0	0.000000	215.485220	123.277875	92.207346	0.000000	0.747963	0.000000
1	2.0	0.000000	215.201339	122.541387	92.659952	0.000000	0.756152	0.000000
2	3.0	0.000000	214.750542	122.174705	92.575837	0.000000	0.757733	0.000000
3	4.0	0.000000	214.481403	118.002869	96.478535	0.000000	0.817595	0.000000
4	5.0	0.000000	214.596319	112.229604	102.366715	0.000000	0.912119	0.000000
5	6.0	1.083333	130.971379	194.200587	-63.229207	133.080618	-0.325587	0.685274
6	7.0	0.375000	125.869781	209.770526	-83.900745	152.560135	-0.399964	0.727272
7	8.0	0.875000	149.624638	255.764494	-106.139857	203.505350	-0.414991	0.795675

At the beginning of simulation, soil water storage is maximum, and ET is maximum. The 1st 5 days of simulation has no rainfall, so all ET is sourced from available soil moisture. As soil moisture is the only source of water during the first 5 days, ET depletes with time during this period. Therefore, most of the net radiation becomes SH and SH increases in the first 5 days along with Bowen ratio. The 5th day of simulation has rainfall that replenishes soil moisture. This makes the soil wet and more of the net radiation goes toward latent heat, making SH negative. That's why during the last 3 days of the simulation, SH is negative and so is the bowen ratio. During the first 5 days of simulation, there was no rainfall. So, the contribution of intercepted water by canopy to ET is zero. As the last 3 days of simulation, rainfall occurs and canopy intercepts some of it. This intercepted water contributes toward ET and fraction contribution of intercepted water toward ET increases and comprisesmore thany half of ET. One notable thing is, in forest the absolute value of bowen ratio is comparatively higher than crops. This is because forests are more conservative in transpiring water because of their long life span. So, more net radiation goes towards SH. This helps perseverance of soil moisture in forests as ET is relatively low as the fraction of net radiation. This can be seen in the soil moisture plots. Soil moisture is quickly lost (to zero almost) as ET in absence of rainfall in grass, but in forests only some amount of soil moisture is lost as ET and there is still available soil moisture in soil.I.T.

In [ ]: