SuPy Documentation

Release 2020.5.25dev

Dr Ting Sun, Dr Hamidreza Omidvar and Prof Sue Grimmond

May 29, 2020

Contents

- **What is SuPy?**

  SuPy is a Python-enhanced urban climate model with SUEWS as its computation core.

  The scientific rigour in SuPy results is thus gurranteed by SUEWS (see SUEWS publications and Parameterisations and sub-models within SUEWS).

  Meanwhile, the data analysis ability of SuPy is greatly enhanced by the Python-based SciPy Stack, notably numpy and pandas. More details are described in our SuPy paper.

- **How to get SuPy?**

  SuPy is available on all major platforms (macOS, Windows, Linux) for Python 3.6+ (64-bit only) via PyPI:

```
python3 -m pip install supy --upgrade
```

- **How to use SuPy?**
  - Please follow *Quickstart of SuPy* and *other tutorials*.
  - Please see *API reference* for details.
  - Please see *FAQ* if any issue.
- **How to contribute to SuPy?**
  - Add your development via Pull Request
  - Report issues via the GitHub page.
  - Cite our SuPy paper.
  - Provide suggestions and feedback.

CHAPTER 1

Tutorials

To familiarise users with SuPy urban climate modelling and to demonstrate the functionality of SuPy, we provide the following tutorials in Jupyter notebooks:

The following section was generated from docs/source/tutorial/quick-start.ipynb

1.1 Quickstart of SuPy

This quickstart demonstrates the essential and simplest workflow of supy in SUEWS simulation:

1. *load input files*
2. *run simulation*
3. *examine results*

More advanced use of supy are available in the *tutorials*

Before start, we need to load the following necessary packages.

[1]:
```
import matplotlib.pyplot as plt
import supy as sp
import pandas as pd
import numpy as np
from pathlib import Path
get_ipython().run_line_magic('matplotlib', 'inline')

# produce high-quality figures, which can also be set as one of ['svg', 'pdf', 'retina
↪', 'png']
# 'svg' produces high quality vector figures
%config InlineBackend.figure_format = 'svg'
```

[2]:
```
sp.show_version()
```

```
supy: 2019.8.30dev
supy_driver: 2019a4
```

1.1.1 Load input files

For existing SUEWS users:

First, a path to SUEWS `RunControl.nml` should be specified, which will direct `supy` to locate input files.

```
[3]: path_runcontrol = Path('../sample_run') / 'RunControl.nml'
```

```
[4]: df_state_init = sp.init_supy(path_runcontrol)
```

```
INFO:root:All cache cleared.
```

A sample `df_state_init` looks below (note that `.T` is used here to a nicer tableform view):

```
[5]: df_state_init.filter(like='method').T
```

```
[5]: grid                                  98
     var                         ind_dim
     aerodynamicresistancemethod 0          2
     evapmethod                  0          2
     emissionsmethod             0          2
     netradiationmethod          0          3
     roughlenheatmethod          0          2
     roughlenmommethod           0          2
     smdmethod                   0          0
     stabilitymethod             0          3
     storageheatmethod           0          1
     waterusemethod              0          0
```

Following the convention of SUEWS, `supy` loads meteorological forcing (met-forcing) files at the grid level.

```
[6]: grid = df_state_init.index[0]
     df_forcing = sp.load_forcing_grid(path_runcontrol, grid)
```

```
INFO:root:All cache cleared.
```

For new users to SUEWS/SuPy:

To ease the input file preparation, a helper function `load_SampleData` is provided to get the sample input for SuPy simulations

```
[7]: df_state_init, df_forcing = sp.load_SampleData()
```

```
INFO:root:All cache cleared.
```

Overview of SuPy input

`df_state_init`

`df_state_init` includes model Initial state consisting of:

- surface characteristics (e.g., albedo, emissivity, land cover fractions, etc.; full details refer to SUEWS documentation)
- model configurations (e.g., stability; full details refer to SUEWS documentation)

Detailed description of variables in `df_state_init` refers to *SuPy input*

Surface land cover fraction information in the sample input dataset:

[8]:
```
df_state_init.loc[:,['bldgh','evetreeh','dectreeh']]
```

[8]:
```
var      bldgh  dectreeh  evetreeh
ind_dim      0         0         0
grid
98        22.0      13.1      13.1
```

[9]:
```
df_state_init.filter(like='sfr')
```

[9]:
```
var        sfr
ind_dim   (0,)  (1,)   (2,)   (3,)   (4,)   (5,)  (6,)
grid
98        0.43  0.38  0.001  0.019  0.029  0.001  0.14
```

`df_forcing`

`df_forcing` includes meteorological and other external forcing information.

Detailed description of variables in `df_forcing` refers to *SuPy input*.

Below is an overview of forcing variables of the sample data set used in the following simulations.

[10]:
```
list_var_forcing = [
    'kdown',
    'Tair',
    'RH',
    'pres',
    'U',
    'rain',
]
dict_var_label = {
    'kdown': 'Incoming Solar\n Radiation ($ \mathrm{W \ m^{-2}}$)',
    'Tair': 'Air Temperature ($^{\circ}$C)',
    'RH': r'Relative Humidity (%)',
    'pres': 'Air Pressure (hPa)',
    'rain': 'Rainfall (mm)',
    'U': 'Wind Speed (m $\mathrm{s^{-1}}$)'
}
df_plot_forcing_x = df_forcing.loc[:, list_var_forcing].copy().shift(
    -1).dropna(how='any')
df_plot_forcing = df_plot_forcing_x.resample('1h').mean()
df_plot_forcing['rain'] = df_plot_forcing_x['rain'].resample('1h').sum()

axes = df_plot_forcing.plot(
    subplots=True,
    figsize=(8, 12),
    legend=False,
)
fig = axes[0].figure
```

(continues on next page)

(continued from previous page)

```
fig.tight_layout()
fig.autofmt_xdate(bottom=0.2, rotation=0, ha='center')
for ax, var in zip(axes, list_var_forcing):
    ax.set_ylabel(dict_var_label[var])
```

Modification of SuPy input

Given `pandas.DataFrame` as the core data structure of SuPy, all operations, including modification, output, demonstration, etc., on SuPy inputs (`df_state_init` and `df_forcing`) can be done using `pandas`-based functions/methods.

Specifically, for modification, the following operations are essential:

locating data

Data can be located in two ways, namely: 1. by name via ` .loc <http://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#selection-by-label>‘__; 2. by position via ` .iloc <http://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#selection-by-position>‘__.

[11]:
```
# view the surface fraction variable: `sfr`
df_state_init.loc[:,'sfr']
```

[11]:
```
ind_dim  (0,)  (1,)   (2,)   (3,)   (4,)   (5,)  (6,)
grid
98       0.43  0.38  0.001  0.019  0.029  0.001  0.14
```

[12]:
```
# view the second row of `df_forcing`, which is a pandas Series
df_forcing.iloc[1]
```

[12]:
```
iy       2012.000000
id          1.000000
it          0.000000
imin       10.000000
qn       -999.000000
qh       -999.000000
qe       -999.000000
qs       -999.000000
qf       -999.000000
U           4.515000
RH         85.463333
Tair       11.773750
pres     1001.512500
rain        0.000000
kdown       0.153333
snow     -999.000000
ldown    -999.000000
fcld     -999.000000
Wuh      -999.000000
xsmd     -999.000000
lai      -999.000000
kdiff    -999.000000
kdir     -999.000000
wdir     -999.000000
```

(continues on next page)

(continued from previous page)

```
isec          0.000000
Name: 2012-01-01 00:10:00, dtype: float64
```

[13]:
```
# view a particular position of `df_forcing`, which is a value
df_forcing.iloc[8,9]
```

[13]:
```
4.455
```

setting new values

Setting new values is very straightforward: after locating the variables/data to modify, just set the new values accordingly:

[14]:
```
# modify surface fractions
df_state_init.loc[:,'sfr']=[.1,.1,.2,.3,.25,.05,0]
# check the updated values
df_state_init.loc[:,'sfr']
```

[14]:
```
ind_dim   (0,)   (1,)   (2,)   (3,)   (4,)   (5,)   (6,)
grid
98         0.1    0.1    0.2    0.3   0.25   0.05    0.0
```

1.1.2 Run simulations

Once met-forcing (via `df_forcing`) and initial conditions (via `df_state_init`) are loaded in, we call `sp.run_supy` to conduct a SUEWS simulation, which will return two `pandas DataFrames`: `df_output` and `df_state`.

[15]:
```
df_output, df_state_final = sp.run_supy(df_forcing, df_state_init)
```

```
INFO:root:====================
INFO:root:Simulation period:
INFO:root:  Start: 2012-01-01 00:05:00
INFO:root:  End: 2013-01-01 00:00:00
INFO:root:
INFO:root:No. of grids: 1
INFO:root:SuPy is running in serial mode
INFO:root:Execution time: 3.2 s
INFO:root:====================
```

`df_output`

`df_output` is an ensemble output collection of major SUEWS output groups, including:

- SUEWS: the essential SUEWS output variables
- DailyState: variables of daily state information
- snow: snow output variables (effective when `snowuse = 1` set in `df_state_init`)

Detailed description of variables in `df_output` refers to SuPy output

[16]:
```
df_output.columns.levels[0]
```

[16]:
```
Index(['SUEWS', 'snow', 'RSL', 'DailyState'], dtype='object', name='group')
```

df_state_final

df_state_final is a DataFrame for holding:

1. all model states if save_state is set to True when calling sp.run_supy and supy may run significantly slower for a large simulation;
2. or, only the final state if save_state is set to False (the default setting) in which mode supy has a similar performance as the standalone compiled SUEWS executable.

Entries in df_state_final have the same data structure as df_state_init and can thus be used for other SUEWS simulations staring at the timestamp as in df_state_final.

Detailed description of variables in df_state_final refers to SuPy output

[17]:
```
df_state_final.T.head()
```

[17]:
```
datetime                  2012-01-01 00:05:00 2013-01-01 00:05:00
grid                                       98                  98
var              ind_dim
ah_min           (0,)                    15.0                15.0
                 (1,)                    15.0                15.0
ah_slope_cooling (0,)                     2.7                 2.7
                 (1,)                     2.7                 2.7
ah_slope_heating (0,)                     2.7                 2.7
```

1.1.3 Examine results

Thanks to the functionality inherited from pandas and other packages under the PyData stack, compared with the standard SUEWS simulation workflow, supy enables more convenient examination of SUEWS results by statistics calculation, resampling, plotting (and many more).

Ouptut structure

df_output is organised with MultiIndex (grid,timestamp) and (group,varaible) as index and columns, respectively.

[18]:
```
df_output.head()
```

[18]:
```
group                       SUEWS                                        \
var                         Kdown       Kup       Ldown         Lup
grid datetime
98   2012-01-01 00:05:00  0.153333  0.021237  344.310184  372.417244
     2012-01-01 00:10:00  0.153333  0.021237  344.310184  372.417244
     2012-01-01 00:15:00  0.153333  0.021237  344.310184  372.417244
     2012-01-01 00:20:00  0.153333  0.021237  344.310184  372.417244
     2012-01-01 00:25:00  0.153333  0.021237  344.310184  372.417244

group                                                                    \
var                         Tsurf         QN          QF          QS
grid datetime
```

(continues on next page)

(continued from previous page)

```
98   2012-01-01 00:05:00  11.775859 -27.974963  40.569300 -45.253674
     2012-01-01 00:10:00  11.775859 -27.974963  39.719681 -45.070905
     2012-01-01 00:15:00  11.775859 -27.974963  38.870062 -44.895750
     2012-01-01 00:20:00  11.775859 -27.974963  38.020443 -44.727894
     2012-01-01 00:25:00  11.775859 -27.974963  37.170824 -44.567032

group                                         ...     DailyState  \
var                                QH         QE  ... DensSnow_Paved
grid datetime                                 ...
98   2012-01-01 00:05:00  57.807360  0.040651  ...            NaN
     2012-01-01 00:10:00  56.775225  0.040398  ...            NaN
     2012-01-01 00:15:00  55.750704  0.040145  ...            NaN
     2012-01-01 00:20:00  54.733480  0.039895  ...            NaN
     2012-01-01 00:25:00  53.723248  0.039645  ...            NaN

group                                                                \
var                      DensSnow_Bldgs DensSnow_EveTr DensSnow_DecTr
grid datetime
98   2012-01-01 00:05:00            NaN            NaN            NaN
     2012-01-01 00:10:00            NaN            NaN            NaN
     2012-01-01 00:15:00            NaN            NaN            NaN
     2012-01-01 00:20:00            NaN            NaN            NaN
     2012-01-01 00:25:00            NaN            NaN            NaN

group                                                                        \
var                      DensSnow_Grass DensSnow_BSoil DensSnow_Water  a1  a2
grid datetime
98   2012-01-01 00:05:00            NaN            NaN            NaN NaN NaN
     2012-01-01 00:10:00            NaN            NaN            NaN NaN NaN
     2012-01-01 00:15:00            NaN            NaN            NaN NaN NaN
     2012-01-01 00:20:00            NaN            NaN            NaN NaN NaN
     2012-01-01 00:25:00            NaN            NaN            NaN NaN NaN

group
var                       a3
grid datetime
98   2012-01-01 00:05:00 NaN
     2012-01-01 00:10:00 NaN
     2012-01-01 00:15:00 NaN
     2012-01-01 00:20:00 NaN
     2012-01-01 00:25:00 NaN

[5 rows x 340 columns]
```

Here we demonstrate several typical scenarios for SUEWS results examination.

The essential `SUEWS` output collection is extracted as a separate variable for easier processing in the following sections. More advanced slicing techniques are available in `pandas` documentation.

[19]:
```
df_output_suews = df_output['SUEWS']
```

Statistics Calculation

We can use `.describe()` method for a quick overview of the key surface energy balance budgets.

[20]:
```
df_output_suews.loc[:, ['QN', 'QS', 'QH', 'QE', 'QF']].describe()
```

[20]:
```
var                 QN             QS             QH             QE  \
count  105408.000000  105408.000000  105408.000000  105408.000000
mean       39.319914     -15.810252      88.755915      45.857651
std       130.797388      53.953592      69.057335      54.363737
min       -86.212629     -87.482114    -114.375930       0.000081
25%       -42.028676     -48.084784      41.334831       1.266435
50%       -25.694495     -40.948527      75.221473      22.980817
75%        73.254869      -2.433109     126.971057      75.607932
max       662.453669     239.033524     371.051513     378.152626

var                 QF
count  105408.000000
mean       79.068259
std        30.855099
min        26.506045
25%        50.520548
50%        82.815455
75%       104.577731
max       162.947824
```

Plotting

Basic example

Plotting is very straightforward via the `.plot` method bounded with `pandas.DataFrame`. Note the usage of `loc` for to slices of the output `DataFrame`.

[21]:
```
# a dict for better display variable names
dict_var_disp = {
    'QN': '$Q^*$',
    'QS': r'$\Delta Q_S$',
    'QE': '$Q_E$',
    'QH': '$Q_H$',
    'QF': '$Q_F$',
    'Kdown': r'$K_{\downarrow}$',
    'Kup': r'$K_{\uparrow}$',
    'Ldown': r'$L_{\downarrow}$',
    'Lup': r'$L_{\uparrow}$',
    'Rain': '$P$',
    'Irr': '$I$',
    'Evap': '$E$',
    'RO': '$R$',
    'TotCh': '$\Delta S$',
}
```

Quick look at the simulation results:

[22]:
```
ax_output = df_output_suews\
    .loc[grid]\
    .loc['2012 6 1':'2012 6 7',
         ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot()
ax_output.set_xlabel('Date')
```

(continues on next page)

(continued from previous page)

```
ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
ax_output.legend()
```

[22]: <matplotlib.legend.Legend at 0x7f8ec14566a0>

More examples

Below is a more complete example for examination of urban energy balance over the whole summer (June to August).

[23]:
```
# energy balance
ax_output = df_output_suews.loc[grid]\
    .loc['2012 6':'2012 8', ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot(
        figsize=(10, 3),
        title='Surface Energy Balance',
    )
ax_output.set_xlabel('Date')
ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
ax_output.legend()
```

[23]: <matplotlib.legend.Legend at 0x7f8ed08c3278>

Resampling

The suggested runtime/simulation frequency of SUEWS is `300 s`, which usually results a large output and may be over-weighted for storage and analysis. Also, you may feel apparent slowdown in producing the above figure as a large amount of data were used for the plotting. To slim down the result size for analysis and output, we can `resample` the default output very easily.

[24]:
```
rsmp_1d = df_output_suews.loc[grid].resample('1d')
# daily mean values
df_1d_mean = rsmp_1d.mean()
# daily sum values
df_1d_sum = rsmp_1d.sum()
```

We can then re-examine the above energy balance at hourly scale and plotting will be significantly faster.

[25]:
```
# energy balance
ax_output = df_1d_mean\
    .loc[:, ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot(
            figsize=(10, 3),
            title='Surface Energy Balance',
        )
ax_output.set_xlabel('Date')
ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
ax_output.legend()
```

[25]: <matplotlib.legend.Legend at 0x7f8ec1623908>

Then we use the hourly results for other analyses.

[26]:
```
# radiation balance
ax_output = df_1d_mean\
    .loc[:, ['QN', 'Kdown', 'Kup', 'Ldown', 'Lup']]\
    .rename(columns=dict_var_disp)\
    .plot(
        figsize=(10, 3),
        title='Radiation Balance',
    )
ax_output.set_xlabel('Date')
ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
ax_output.legend()
```

[26]:
```
<matplotlib.legend.Legend at 0x7f8eb149a0b8>
```

[27]:
```
# water balance
ax_output = df_1d_sum\
    .loc[:, ['Rain', 'Irr', 'Evap', 'RO', 'TotCh']]\
    .rename(columns=dict_var_disp)\
    .plot(
        figsize=(10, 3),
        title='Surface Water Balance',
    )
ax_output.set_xlabel('Date')
ax_output.set_ylabel('Water amount (mm)')
ax_output.legend()
```

[27]:
```
<matplotlib.legend.Legend at 0x7f8ef208bc18>
```

Get an overview of partitioning in energy and water balance at monthly scales:

[28]:
```
# get a monthly Resampler
df_plot=df_output_suews.loc[grid].copy()
df_plot.index=df_plot.index.set_names('Month')
rsmp_1M = df_plot\
    .shift(-1)\
    .dropna(how='all')\
    .resample('1M', kind='period')
# mean values
df_1M_mean = rsmp_1M.mean()
# sum values
df_1M_sum = rsmp_1M.sum()
```

[29]:
```
# month names
name_mon = [x.strftime('%b') for x in rsmp_1M.groups]
# create subplots showing two panels together
fig, axes = plt.subplots(2, 1, sharex=True)
# surface energy balance
df_1M_mean\
    .loc[:, ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot(
        ax=axes[0],  # specify the axis for plotting
        figsize=(10, 6),  # specify figure size
        title='Surface Energy Balance',
        kind='bar',
```

(continues on next page)

(continued from previous page)

```
    )
# surface water balance
df_1M_sum\
    .loc[:, ['Rain', 'Irr', 'Evap', 'RO', 'TotCh']]\
    .rename(columns=dict_var_disp)\
    .plot(
        ax=axes[1],  # specify the axis for plotting
        title='Surface Water Balance',
        kind='bar'
    )

# annotations
axes[0].set_ylabel('Mean Flux ($ \mathrm{W \ m^{-2}}$)')
axes[0].legend()
axes[1].set_xlabel('Month')
axes[1].set_ylabel('Total Water Amount (mm)')
axes[1].xaxis.set_ticklabels(name_mon, rotation=0)
axes[1].legend()
```

[29]:
```
<matplotlib.legend.Legend at 0x7f8ec195a9b0>
```

Output

The supy output can be saved as `txt` files for further analysis using supy function `save_supy`.

[30]:
```
list_path_save = sp.save_supy(df_output,df_state_final, path_runcontrol=path_
↪runcontrol)
```

[31]:
```
for file_out in list_path_save:
    print(file_out.name)
```

```
Kc98_2012_SUEWS_5.txt
Kc98_2012_snow_5.txt
Kc98_2012_RSL_5.txt
Kc98_2012_DailyState.txt
Kc98_2012_SUEWS_60.txt
Kc98_2012_snow_60.txt
Kc98_2012_RSL_60.txt
InitialConditionsKc98_2013_EndofRun.nml
```

End of `doc/tutorial/quick-start.ipynb`

The following section was generated from `docs/source/tutorial/impact-studies-parallel.ipynb`

1.2 Impact Studies Using SuPy

1.2.1 Aim

In this tutorial, we aim to perform sensitivity analysis using `supy` in a parallel mode to investigate the impacts on urban climate of

1. surface properties: the physical attributes of land covers (e.g., albedo, water holding capacity, etc.)

2. background climate: longterm meteorological conditions (e.g., air temperature, precipitation, etc.)

1.2.2 Prepare `supy` for the parallel mode

load `supy` and sample dataset

[1]:
```
from dask import delayed
from dask import dataframe as dd
import os
import supy as sp
import seaborn as sns
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
from time import time
import logging
logging.basicConfig()
logging.getLogger().setLevel(logging.WARNING)

get_ipython().run_line_magic('matplotlib', 'inline')
# produce high-quality figures, which can also be set as one of ['svg', 'pdf', 'retina
↪', 'png']
# 'svg' produces high quality vector figures
%config InlineBackend.figure_format = 'svg'
# show supy version info
sp.show_version()
```

```
supy: 2019.8.30dev
supy_driver: 2019a4
```

[2]:
```
# load sample datasets
df_state_init, df_forcing = sp.load_SampleData()
# perform an example run to get output samples for later use
df_output, df_state_final = sp.run_supy(df_forcing, df_state_init)
```

Paralell setup for `supy` using `dask`

Given the nature of impact studies that requires multiple independent models with selected parameters/variables varying across the setups, such simulations well fall into the scope of so-called *embarrassingly parallel computation* that is fully supported by `dask`. Also, as `supy` is readily built on the data structure `pandas.DataFrame`, we can fairly easily transfer it to the `dask` framework for parallel operations thanks to `` `dask.dataframe `` <http://docs.dask.org/en/latest/dataframe.html>`__, a specialized `dataframe` extending `pandas.DataFrame`'s ability in parallel operations.

Prior to version 2019.5, for a given forcing dataset `df_forcing`, `supy` would loop over the grids in a `df_state_init` to conduct simulations. Since version 2019.5, `supy` has been using the `dask.dataframe` to gain the parallel benefits through its parallelized `apply` method.

`dask.dataframe` essentially divides the work into pieces for parallel operations. As such, depending on the number of processors in your computer, it would be more efficient to set the partition number as the multipliers of CPU numbers.

[3]:
```
import platform
import psutil
list_info=['machine','system','mac_ver','processor']
for info in list_info:
    info_x=getattr(platform,info)()
    print(info,':',info_x)
cpu_count=psutil.cpu_count()
print('number of CPU processors:',cpu_count)
mem_size=psutil.virtual_memory().total/1024**3
print('memory size (GB):',mem_size)
```

```
machine : x86_64
system : Darwin
mac_ver : ('10.14.6', ('', '', ''), 'x86_64')
processor : i386
number of CPU processors: 12
memory size (GB): 32.0
```

To demonstrate the parallelization, we simply duplicate the contents in `df_state_init` to make it seemingly large. Note we intentionally choose `24` as the number for copies to accompany the power of CPU.

Before we move on to the parallel mode, we perform a simulation in the traditional serial way to see the baseline performance.

Baseline serial run

[4]:
```
# just run for 30 days
df_forcing_part = df_forcing.iloc[:288*30]
df_state_init_mgrids = df_state_init.copy()
# construct a multi-grid `df_state_init`
for i in range(24-1):
    df_state_init_mgrids = df_state_init_mgrids.append(
        df_state_init, ignore_index=True)
# perform a serial run
t0 = time()
for i in range(24-1):
    xx = sp.run_supy(df_forcing_part, df_state_init_mgrids.iloc[[i]])
t1 = time()
t_ser = t1-t0
logging.warning(f'Execution time: {t_ser:.2f} s')
```

```
WARNING:root:Execution time: 7.61 s
```

Parallel run

[5]:
```
# parallel run is enabled in supy by default
t0 = time()
xx = sp.run_supy(df_forcing_part, df_state_init_mgrids)
t1 = time()
t_par = t1-t0
logging.warning(f'Execution time: {t_par:.2f} s')
```

```
WARNING:root:Execution time: 4.13 s
```

Benchmark test

Note: this test may take a considerably long time depending on the machine performance

[6]:
```
# different running length
list_sim_len = [
    day * 288 for day in [30, 90, 120, 150, 180, 270, 365, 365 * 2, 365 * 3]
]

# number of test grids
n_grid = 12

# construct a multi-grid `df_state_init`
df_state_init_m = df_state_init.copy()
for i in range(n_grid - 1):
    df_state_init_m = df_state_init_m.append(df_state_init, ignore_index=True)

# construct a longer`df_forcing` for three years
df_forcing_m = pd.concat([df_forcing for i in range(3)])
df_forcing_m.index = pd.date_range(df_forcing.index[0],
                                   freq=df_forcing.index.freq,
                                   periods=df_forcing_m.index.size)

dict_time_ser = dict()
dict_time_par = dict()
for sim_len in list_sim_len:
    df_forcing_part = df_forcing_m.iloc[:sim_len]
    logging.warning(f'Sim days: {sim_len / 288}')
    logging.warning(f'No. of grids: {df_state_init_m.shape[0]}')
    # serial run
    logging.warning('serial:')
    t0 = time()
    for i in range(df_state_init_m.shape[0]):
        sp.run_supy(df_forcing_part, df_state_init_m.iloc[[i]])
    t1 = time()
    t_test = t1 - t0
    logging.warning(f'Execution time: {t_test:.2f} s')

    dict_time_ser.update({sim_len: t_test})

    # parallel run
    logging.warning('parallel:')
    t0 = time()
    sp.run_supy(df_forcing_part, df_state_init_m)
    t1 = time()
    t_test = t1 - t0
    logging.warning(f'Execution time: {t_test:.2f} s\n')

    dict_time_par.update({sim_len: t_test})
```

```
WARNING:root:Sim days: 30.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 4.07 s
WARNING:root:parallel:
WARNING:root:Execution time: 2.17 s

WARNING:root:Sim days: 90.0
```

(continues on next page)

(continued from previous page)

```
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 8.99 s
WARNING:root:parallel:
WARNING:root:Execution time: 4.07 s

WARNING:root:Sim days: 120.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 10.88 s
WARNING:root:parallel:
WARNING:root:Execution time: 5.08 s

WARNING:root:Sim days: 150.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 13.29 s
WARNING:root:parallel:
WARNING:root:Execution time: 5.80 s

WARNING:root:Sim days: 180.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 15.47 s
WARNING:root:parallel:
WARNING:root:Execution time: 6.70 s

WARNING:root:Sim days: 270.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 22.23 s
WARNING:root:parallel:
WARNING:root:Execution time: 9.84 s

WARNING:root:Sim days: 365.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 29.06 s
WARNING:root:parallel:
WARNING:root:Execution time: 13.65 s

WARNING:root:Sim days: 730.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 67.05 s
WARNING:root:parallel:
WARNING:root:Execution time: 28.66 s

WARNING:root:Sim days: 1095.0
WARNING:root:No. of grids: 12
WARNING:root:serial:
WARNING:root:Execution time: 98.66 s
WARNING:root:parallel:
WARNING:root:Execution time: 48.68 s
```

[7]:
```
df_benchmark = pd.DataFrame([
    dict_time_par,
    dict_time_ser])\
.transpose()\
.rename(columns={0: 'parallel', 1: 'serial'})
idx_bmk = (df_benchmark.index / 288).astype(int)
df_benchmark.index = idx_bmk.set_names('Length of Simulation Period (day)')

# calculate execution time ratio between parallel and serial runs
ser_ratio = df_benchmark['parallel'] / df_benchmark['serial']
df_benchmark = df_benchmark.assign(ratio=ser_ratio)\
    .rename(columns={'ratio': 'ratio (=p/s, right)'})

# show executation times and ratio on plot
ax = df_benchmark.plot(secondary_y='ratio (=p/s, right)',
                       marker='o',
                       fillstyle='none')
ax.set_ylabel('Execution Time (s)')

lines = ax.get_lines() + ax.right_ax.get_lines()
ax.legend(lines, [l.get_label() for l in lines], loc='best')

ax.right_ax.set_ylabel('Execution Ratio (=p/s)', color='C2')
ax.right_ax.spines['right'].set_color('C2')
ax.right_ax.tick_params(axis='y', colors='C2')
```

1.2.3 Surface properties: surface albedo

Examine the default albedo values loaded from the sample dataset

[8]:
```
df_state_init.alb
```

[8]:

ind_dim	(0,)	(1,)	(2,)	(3,)	(4,)	(5,)	(6,)
grid							
98	0.12	0.15	0.12	0.18	0.21	0.21	0.1

Copy the initial condition `DataFrame` to have a *clean slate* for our study

Note: `DataFrame.copy()` defaults to `deepcopy`

[9]:
```
df_state_init_test = df_state_init.copy()
```

Set the `Bldg` land cover to 100% for this study

[10]:
```
df_state_init_test.sfr = 0
df_state_init_test.loc[:, ('sfr', '(1,)')] = 1
df_state_init_test.sfr
```

[10]:
```
ind_dim  (0,)  (1,)  (2,)  (3,)  (4,)  (5,)  (6,)
grid
98          0     1     0     0     0     0     0
```

Construct a `df_state_init_x` dataframe to perform `supy` simulation with specified albedo

[11]:
```
# create a `df_state_init_x` with different surface properties
n_test = 48
list_alb_test = np.linspace(0.1, 0.8, n_test).round(2)
df_state_init_x = df_state_init_test.append(
    [df_state_init_test]*(n_test-1), ignore_index=True)

# here we modify surface albedo
df_state_init_x.loc[:, ('alb', '(1,)')] = list_alb_test
```

Conduct simulations with `supy`

[12]:
```
df_forcing_part = df_forcing.loc['2012 01':'2012 07']
df_res_alb_test,df_state_final_x = sp.run_supy(df_forcing_part, df_state_init_x)
```

Examine the simulation results

[13]:
```
# choose results of July 2012 for analysis
df_res_alb_test_july=df_res_alb_test.SUEWS.unstack(0).loc['2012 7']
df_res_alb_T2_stat = df_res_alb_test_july.T2.describe()
df_res_alb_T2_diff = df_res_alb_T2_stat.transform(
    lambda x: x - df_res_alb_T2_stat.iloc[:, 0])
df_res_alb_T2_diff.columns = list_alb_test-list_alb_test[0]
```

[14]:
```
ax_temp_diff = df_res_alb_T2_diff.loc[['max', 'mean', 'min']].T.plot()
ax_temp_diff.set_ylabel('$\Delta T_2$ ($^{\circ}}$C)')
ax_temp_diff.set_xlabel(r'$\Delta\alpha$')
ax_temp_diff.margins(x=0.2, y=0.2)
```

Why a bi-linear $\Delta\alpha - \Delta T_{2,max}$ relationship?

Although the relations for mean and minimum T_2 demonstrate single linear patterns, the one for maximum T_2, interestingly, consists of two linear sections.

[15]:
```
df_t2=df_res_alb_test_july.T2
df_t2.columns=list_alb_test

df_t2.idxmax().unique()
```

[15]:
```
array(['2012-07-25T13:35:00.000000000', '2012-07-25T15:30:00.000000000'],
      dtype='datetime64[ns]')
```

By looking into the peaking times of $T_{2,max}$, we see a shift in the peaking times from 13:35 to 15:30 on 2012-07-25 as albedo increases. Taking the two ending cases, $\alpha = 0.1$ and $\alpha = 0.8$, we see diurnal cycles of T_2 evolves according to the albedo: peak is delayed as albedo increases.

[16]:
```
df_t2.loc['2012-07-25'].iloc[:,[0,-1]].plot()
```

[16]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7f9630da73c8>
```

Furthermore, when the $\Delta\alpha - \Delta T_2$ relations at the two peaking times are shown below, we can see the bi-linear relation based on the $T_{2,max}$ values for the July 2012 is actually composed of two linear relations at different times under different peaking scenarios.

[17]:
```
ax_t2_max=df_t2.loc['2012-07-25 13:35':'2012-07-25 15:30'].iloc[[0,-1]].T.plot()
ax_t2_max.set_xlabel(r'$\alpha$')
ax_t2_max.set_ylabel('$T_{2,max}$ ($^{\circ}$C)')
```

[17]:
```
Text(0, 0.5, '$T_{2,max}$ ($^{\\circ}$C)')
```

1.2.4 Background climate: air temperature

Examine the monthly climatology of air temperature loaded from the sample dataset

[18]:
```
df_plot = df_forcing.Tair.iloc[:-1].resample('1m').mean()
ax_temp = df_plot.plot.bar(color='tab:blue')
ax_temp.set_xticklabels(df_plot.index.strftime('%b'))
ax_temp.set_ylabel('Mean Air Temperature ($^\degree$C)')
ax_temp.set_xlabel('Month')
ax_temp
```

[18]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7f9630d7f668>
```

Construct a function to perform parallel `supy` simulation with specified `diff_airtemp_test`: the difference in air temperature between the one used in simulation and loaded from sample dataset.

Note: forcing data ‘‘df_forcing‘‘ has different data structure from ‘‘df_state_init‘‘; so we need to modify ‘‘run_supy_mgrids‘‘ to implement a ‘‘run_supy_mclims‘‘ for different climate scenarios

Let’s start the implementation of `run_supy_mclims` with a small problem of four forcing groups (i.e., climate scenarios), where the air temperatures differ from the baseline scenario with a constant bias.

[19]:
```
# save loaded sample datasets
df_forcing_part_test = df_forcing.loc['2012 1':'2012 7'].copy()
df_state_init_test = df_state_init.copy()
```

[20]:
```
# create a dict with four forcing conditions as a test
n_test = 4
list_TairDiff_test = np.linspace(0., 2, n_test).round(2)
dict_df_forcing_x = {
    tairdiff: df_forcing_part_test.copy()
    for tairdiff in list_TairDiff_test}
for tairdiff in dict_df_forcing_x:
```

(continues on next page)

(continued from previous page)

```
    dict_df_forcing_x[tairdiff].loc[:, 'Tair'] += tairdiff

dd_forcing_x = {
    k: delayed(sp.run_supy)(df, df_state_init_test)[0]
    for k, df in dict_df_forcing_x.items()}


df_res_tairdiff_test0 = delayed(pd.concat)(
    dd_forcing_x,
    keys=list_TairDiff_test,
    names=['tairdiff'],
)
```

[21]:
```
# test the performance of a parallel run
t0 = time()
df_res_tairdiff_test = df_res_tairdiff_test0\
    .compute(scheduler='threads')\
    .reset_index('grid', drop=True)
t1 = time()
t_par = t1 - t0
print(f'Execution time: {t_par:.2f} s')
```

```
Execution time: 6.83 s
```

[22]:
```
# function for multi-climate `run_supy`
# wrapping the above code into one
def run_supy_mclims(df_state_init, dict_df_forcing_mclims):
    dd_forcing_x = {
        k: delayed(sp.run_supy)(df, df_state_init_test)[0]
        for k, df in dict_df_forcing_x.items()}
    df_output_mclims0 = delayed(pd.concat)(
        dd_forcing_x,
        keys=list(dict_df_forcing_x.keys()),
        names=['clm'],
    ).compute(scheduler='threads')
    df_output_mclims = df_output_mclims0.reset_index('grid', drop=True)

    return df_output_mclims
```

Construct `dict_df_forcing_x` with multiple forcing `DataFrames`

[23]:
```
# save loaded sample datasets
df_forcing_part_test = df_forcing.loc['2012 1':'2012 7'].copy()
df_state_init_test = df_state_init.copy()

# create a dict with a number of forcing conditions
n_test = 24 # can be set with a smaller value to save simulation time
list_TairDiff_test = np.linspace(0., 2, n_test).round(2)
dict_df_forcing_x = {
    tairdiff: df_forcing_part_test.copy()
    for tairdiff in list_TairDiff_test}
for tairdiff in dict_df_forcing_x:
    dict_df_forcing_x[tairdiff].loc[:, 'Tair'] += tairdiff
```

Perform simulations

[24]:
```
# run parallel simulations using `run_supy_mclims`
t0 = time()
df_airtemp_test_x = run_supy_mclims(df_state_init_test, dict_df_forcing_x)
t1 = time()
t_par = t1-t0
print(f'Execution time: {t_par:.2f} s')
```

```
Execution time: 38.52 s
```

Examine the results

[25]:
```
df_airtemp_test = df_airtemp_test_x.SUEWS.unstack(0)
df_temp_diff=df_airtemp_test.T2.transform(lambda x: x - df_airtemp_test.T2[0.0])
df_temp_diff_ana=df_temp_diff.loc['2012 7']
df_temp_diff_stat=df_temp_diff_ana.describe().loc[['max', 'mean', 'min']].T
```

[26]:
```
ax_temp_diff_stat=df_temp_diff_stat.plot()
ax_temp_diff_stat.set_ylabel('$\\Delta T_2$ ($^{\\circ}$C)')
ax_temp_diff_stat.set_xlabel('$\\Delta T_{a}$ ($^{\\circ}$C)')
ax_temp_diff_stat.set_aspect('equal')
```

The T_2 results indicate the increased T_a has different impacts on the T_2 metrics (minimum, mean and maximum) but all increase linearly with T_a. The maximum T_2 has the stronger response compared to the other metrics.

End of `doc/tutorial/impact-studies-parallel.ipynb`

The following section was generated from `docs/source/tutorial/external-interaction.ipynb`

1.3 Interaction between SuPy and external models

1.3.1 Introduction

SUEWS can be coupled to other models that provide or require forcing data using the SuPy single timestep running mode. We demonstrate this feature with a simple online anthropogenic heat flux model.

Anthropogenic heat flux (Q_F) is an additional term to the surface energy balance in urban areas associated with human activities (Gabey et al., 2018; Grimmond, 1992; Nie et al., 2014; 2016; Sailor, 2011). In most cities, the largest emission source is from buildings (Hamilton et al., 2009; Iamarino et al., 2011; Sailor, 2011) and is high dependent on outdoor ambient air temperature.

load necessary packages

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

(continues on next page)

(continued from previous page)

```
%matplotlib inline
# produce high-quality figures, which can also be set as one of ['svg', 'pdf', 'retina
↪', 'png']
# 'svg' produces high quality vector figures
from IPython.display import set_matplotlib_formats
set_matplotlib_formats('svg')
sp.show_version()
```

```
supy: 2019.8.30dev
supy_driver: 2019a4
```

run SUEWS with default settings

[2]:
```
# load sample run dataset
df_state_init, df_forcing = sp.load_SampleData()
df_state_init_def=df_state_init.copy()
# set QF as zero for later comparison
df_forcing_def=df_forcing.copy()
grid=df_state_init_def.index[0]
df_state_init_def.loc[:,'emissionsmethod']=0
df_forcing_def['qf']=0
# run supy
df_output, df_state = sp.run_supy(df_forcing_def, df_state_init_def)
df_output_def = df_output.loc[grid, 'SUEWS']
```

```
INFO:root:All cache cleared.
INFO:root:====================
INFO:root:Simulation period:
INFO:root:  Start: 2012-01-01 00:05:00
INFO:root:  End: 2013-01-01 00:00:00
INFO:root:
INFO:root:No. of grids: 1
INFO:root:SuPy is running in serial mode
INFO:root:Execution time: 3.0 s
INFO:root:====================
```

[3]:
```
df_output_def.columns
```

[3]:
```
Index(['Kdown', 'Kup', 'Ldown', 'Lup', 'Tsurf', 'QN', 'QF', 'QS', 'QH', 'QE',
       'QHlumps', 'QElumps', 'QHresis', 'Rain', 'Irr', 'Evap', 'RO', 'TotCh',
       'SurfCh', 'State', 'NWtrState', 'Drainage', 'SMD', 'FlowCh', 'AddWater',
       'ROSoil', 'ROPipe', 'ROImp', 'ROVeg', 'ROWater', 'WUInt', 'WUEveTr',
       'WUDecTr', 'WUGrass', 'SMDPaved', 'SMDBldgs', 'SMDEveTr', 'SMDDecTr',
       'SMDGrass', 'SMDBSoil', 'StPaved', 'StBldgs', 'StEveTr', 'StDecTr',
       'StGrass', 'StBSoil', 'StWater', 'Zenith', 'Azimuth', 'AlbBulk', 'Fcld',
       'LAI', 'z0m', 'zdm', 'UStar', 'Lob', 'RA', 'RS', 'Fc', 'FcPhoto',
       'FcRespi', 'FcMetab', 'FcTraff', 'FcBuild', 'FcPoint', 'QNSnowFr',
       'QNSnow', 'AlbSnow', 'QM', 'QMFreeze', 'QMRain', 'SWE', 'MeltWater',
       'MeltWStore', 'SnowCh', 'SnowRPaved', 'SnowRBldgs', 'Ts', 'T2', 'Q2',
       'U10', 'RH2'],
      dtype='object', name='var')
```

1.3.2 a simple QF model: `QF_simple`

model description

For demonstration purposes we have created a very simple model instead of using the SUEWS Q_F (Järvi et al. 2011) with feedback from outdoor air temperature. The simple Q_F model considers only building heating and cooling:

$$Q_F = \begin{cases} (T_2 - T_C) \times C_B, \; T_2 > T_C \\ (T_H - T_2) \times H_B, \; T_2 < T_H \\ Q_{F0} \end{cases}$$

where T_C (T_H) is the cooling (heating) threshold temperature of buildings, $_B$ ($_B$) is the building cooling (heating) rate, and $_{F0}$ is the baseline anthropogenic heat. The parameters used are: $_C$ ($_H$) set as 20 °C (10 °C), $_B$ ($_B$) set as 1.5 $\mathrm{W\ m^{-2}\ K^{-1}}$ (3 $\mathrm{W\ m^{-2}\ K^{-1}}$) and Q_{F0} is set as 0 $\mathrm{W\ m^{-2}}$, implying other building activities (e.g. lightning, water heating, computers) are zero and therefore do not change the temperature or change with temperature.

implementation

```
[4]: def QF_simple(T2):
         qf_cooling = (T2-20)*5 if T2 > 20 else 0
         qf_heating = (10-T2)*10 if T2 < 10 else 0
         qf_res = np.max([qf_heating, qf_cooling])*0.3
         return qf_res
```

Visualise the `QF_simple` model:

```
[6]: ser_temp = pd.Series(np.arange(-5, 45, 0.5),
                          index=np.arange(-5, 45, 0.5)).rename('temp_C')
     ser_qf_heating = ser_temp.loc[-5:10].map(QF_simple).rename(
         r'heating:$(T_H-T_a) \times H_B$')
     ser_qf_cooling = ser_temp.loc[20:45].map(QF_simple).rename(
         r'cooling: $(T_a-T_C) \times C_B$')
     ser_qf_zero = ser_temp.loc[10:20].map(QF_simple).rename('baseline: $Q_{F0}$')
     df_temp_qf = pd.concat([ser_temp, ser_qf_cooling, ser_qf_heating, ser_qf_zero],
                            axis=1).set_index('temp_C')
     ax_qf_func = df_temp_qf.plot()
     ax_qf_func.set_xlabel('$T_2$ ($^\circ$C)')
     ax_qf_func.set_ylabel('$Q_F$ ($ \mathrm{W \ m^{-2}}$)')
     ax_qf_func.legend(title='simple $Q_F$')
     ax_qf_func.annotate(
         "$T_C$",
         xy=(20, 0),
         xycoords='data',
         xytext=(25, 5),
         textcoords='data',
         arrowprops=dict(
             arrowstyle="->",
             color="0.5",
             shrinkA=5,
             shrinkB=5,
             patchA=None,
             patchB=None,
             connectionstyle='arc3',
         ),
     )

     ax_qf_func.annotate(
         "$T_H$",
```

(continues on next page)

(continued from previous page)

```
    xy=(10, 0),
    xycoords='data',
    xytext=(5, 5),
    textcoords='data',
    arrowprops=dict(
        arrowstyle="->",
        color="0.5",
        shrinkA=5,
        shrinkB=5,
        patchA=None,
        patchB=None,
        connectionstyle='arc3',
    ),
)
ax_qf_func.annotate(
    "slope: $C_B$",
    xy=(30, QF_simple(30)),
    xycoords='data',
    xytext=(20, 20),
    textcoords='data',
    arrowprops=dict(
        arrowstyle="->",
        color="0.5",
        shrinkA=5,
        shrinkB=5,
        patchA=None,
        patchB=None,
        connectionstyle='arc3, rad=0.3',
    ),
)
ax_qf_func.annotate(
    "slope: $H_B$",
    xy=(5, QF_simple(5)),
    xycoords='data',
    xytext=(10, 20),
    textcoords='data',
    arrowprops=dict(
        arrowstyle="->",
        color="0.5",
        shrinkA=5,
        shrinkB=5,
        patchA=None,
        patchB=None,
        connectionstyle='arc3, rad=-0.3',
    ),
)
ax_qf_func.plot(10, 0, 'o', color='C1', fillstyle='none')
_ = ax_qf_func.plot(20, 0, 'o', color='C0', fillstyle='none')
```

1.3.3 communication between `supy` and `QF_simple`

construct a new coupled function

The coupling between the simple Q_F model and SuPy is done via the low-level function `suews_cal_tstep`, which is an interface function in charge of communications between SuPy frontend and the calculation kernel. By setting

SuPy to receive external Q_F as forcing, at each timestep, the simple Q_F model is driven by the SuPy output T_2 and provides SuPy with Q_F, which thus forms a two-way coupled loop.

[7]:
```
# load extra low-level functions from supy to construct interactive functions
from supy._post import pack_df_output, pack_df_state
from supy._run import suews_cal_tstep, pack_grid_dict


def run_supy_qf(df_forcing_test, df_state_init_test):
    grid = df_state_init_test.index[0]
    df_state_init_test.loc[grid, 'emissionsmethod'] = 0

    df_forcing_test = df_forcing_test\
        .assign(
            metforcingdata_grid=0,
            ts5mindata_ir=0,
        )\
        .rename(
            # remanae is a workaround to resolve naming inconsistency between
            # suews fortran code interface and input forcing file hearders
            columns={
                '%' + 'iy': 'iy',
                'id': 'id',
                'it': 'it',
                'imin': 'imin',
                'qn': 'qn1_obs',
                'qh': 'qh_obs',
                'qe': 'qe',
                'qs': 'qs_obs',
                'qf': 'qf_obs',
                'U': 'avu1',
                'RH': 'avrh',
                'Tair': 'temp_c',
                'pres': 'press_hpa',
                'rain': 'precip',
                'kdown': 'avkdn',
                'snow': 'snowfrac_obs',
                'ldown': 'ldown_obs',
                'fcld': 'fcld_obs',
                'Wuh': 'wu_m3',
                'xsmd': 'xsmd',
                'lai': 'lai_obs',
                'kdiff': 'kdiff',
                'kdir': 'kdir',
                'wdir': 'wdir',
            }
        )

    t2_ext = df_forcing_test.iloc[0].temp_c
    qf_ext = QF_simple(t2_ext)

    # initialise dicts for holding results
    dict_state = {}
    dict_output = {}

    # starting tstep
    t_start = df_forcing_test.index[0]
    # convert df to dict with `itertuples` for better performance
```

(continues on next page)

(continued from previous page)

```
    dict_forcing = {
        row.Index: row._asdict()
        for row in df_forcing_test.itertuples()
    }
    # dict_state is used to save model states for later use
    dict_state = {(t_start, grid): pack_grid_dict(series_state_init)
                  for grid, series_state_init in df_state_init_test.iterrows()}

    # just use a single grid run for the test coupling
    for tstep in df_forcing_test.index:
        # load met forcing at `tstep`
        met_forcing_tstep = dict_forcing[tstep]
        # inject `qf_ext` to `met_forcing_tstep`
        met_forcing_tstep['qf_obs'] = qf_ext

        # update model state
        dict_state_start = dict_state[(tstep, grid)]

        dict_state_end, dict_output_tstep = suews_cal_tstep(
            dict_state_start, met_forcing_tstep)
        # the fourth to the last is `T2` stored in the result array
        t2_ext = dict_output_tstep['dataoutlinesuews'][-4]
        qf_ext = QF_simple(t2_ext)

        dict_output.update({(tstep, grid): dict_output_tstep})
        dict_state.update({(tstep + tstep.freq, grid): dict_state_end})

    # pack results as easier DataFrames
    df_output_test = pack_df_output(dict_output).swaplevel(0, 1)
    df_state_test = pack_df_state(dict_state).swaplevel(0, 1)
    return df_output_test.loc[grid, 'SUEWS'], df_state_test
```

simulations for summer and winter months

The simulation using SuPy coupled is performed for London 2012. The data analysed are a summer (July) and a winter (December) month. Initially Q_F is 0 $\mathrm{W\ m^{-2}}$ the T_2 is determined and used to determine $Q_{F[1]}$ which in turn modifies $T_{2[1]}$ and therefore modifies $Q_{F[2]}$ and the diagnosed $T_{2[2]}$.

spin-up run (January to June) for summer simulation

[8]:
```
df_output_june, df_state_jul = sp.run_supy(
    df_forcing.loc[:'2012 6'], df_state_init)
df_state_jul_init = df_state_jul.reset_index('datetime', drop=True).iloc[[-1]]
```

```
INFO:root:====================
INFO:root:Simulation period:
INFO:root:  Start: 2012-01-01 00:05:00
INFO:root:  End: 2012-06-30 23:55:00
INFO:root:
INFO:root:No. of grids: 1
INFO:root:SuPy is running in serial mode
INFO:root:Execution time: 1.6 s
INFO:root:====================
```

spin-up run (July to October) for winter simulation

[9]:
```
df_output_oct, df_state_dec = sp.run_supy(
    df_forcing.loc['2012 7':'2012 11'], df_state_jul_init)
df_state_dec_init = df_state_dec.reset_index('datetime', drop=True).iloc[[-1]]
```

```
INFO:root:====================
INFO:root:Simulation period:
INFO:root:  Start: 2012-07-01 00:00:00
INFO:root:  End: 2012-11-30 23:55:00
INFO:root:
INFO:root:No. of grids: 1
INFO:root:SuPy is running in serial mode
INFO:root:Execution time: 1.3 s
INFO:root:====================
```

coupled simulation

[10]:
```
df_output_test_summer, df_state_summer_test = run_supy_qf(
    df_forcing.loc['2012 7'], df_state_jul_init.copy())
df_output_test_winter, df_state_winter_test = run_supy_qf(
    df_forcing.loc['2012 12'], df_state_dec_init.copy())
```

examine the results

sumer

[11]:
```
var = 'QF'
var_label = '$Q_F$ ($ \mathrm{W \ m^{-2}}$)'
var_label_right = '$\Delta Q_F$ ($ \mathrm{W \ m^{-2}}$)'
period = '2012 7'
df_test = df_output_test_summer
y1 = df_test.loc[period, var].rename('qf_simple')
y2 = df_output_def.loc[period, var].rename('suews')
y3 = (y1-y2).rename('diff')
df_plot = pd.concat([y1, y2, y3], axis=1)
ax = df_plot.plot(secondary_y='diff')
ax.set_ylabel(var_label)
# sns.lmplot(data=df_plot,x='qf_simple',y='diff')
ax.right_ax.set_ylabel(var_label_right)
lines = ax.get_lines() + ax.right_ax.get_lines()
ax.legend(lines, [l.get_label() for l in lines], loc='best')
```

[11]:
```
<matplotlib.legend.Legend at 0x7fa3853c1b00>
```

[12]:
```
var = 'T2'
var_label = '$T_2$ ($^{\circ}$C)'
var_label_right = '$\Delta T_2$ ($^{\circ}$C)'
period = '2012 7'
df_test = df_output_test_summer
```

(continues on next page)

(continued from previous page)

```
y1 = df_test.loc[period, var].rename('qf_simple')
y2 = df_output_def.loc[period, var].rename('suews')
y3 = (y1-y2).rename('diff')
df_plot = pd.concat([y1, y2, y3], axis=1)
ax = df_plot.plot(secondary_y='diff')
ax.set_ylabel(var_label)
ax.right_ax.set_ylabel(var_label_right)
lines = ax.get_lines() + ax.right_ax.get_lines()
ax.legend(lines, [l.get_label() for l in lines], loc='best')
```

[12]: <matplotlib.legend.Legend at 0x7fa3852ccb70>

winter

[13]:
```
var = 'QF'
var_label = '$Q_F$ ($ \mathrm{W \ m^{-2}}$)'
var_label_right = '$\Delta Q_F$ ($ \mathrm{W \ m^{-2}}$)'
period = '2012 12'
df_test = df_output_test_winter
y1 = df_test.loc[period, var].rename('qf_simple')
y2 = df_output_def.loc[period, var].rename('suews')
y3 = (y1-y2).rename('diff')
df_plot = pd.concat([y1, y2, y3], axis=1)
ax = df_plot.plot(secondary_y='diff')
ax.set_ylabel(var_label)
# sns.lmplot(data=df_plot,x='qf_simple',y='diff')
ax.right_ax.set_ylabel(var_label_right)
lines = ax.get_lines() + ax.right_ax.get_lines()
ax.legend(lines, [l.get_label() for l in lines], loc='best')
```

[13]: <matplotlib.legend.Legend at 0x7fa3852cc0b8>

[14]:
```
var = 'T2'
var_label = '$T_2$ ($^{\circ}$C)'
var_label_right = '$\Delta T_2$ ($^{\circ}$C)'
period = '2012 12'
df_test = df_output_test_winter
y1 = df_test.loc[period, var].rename('qf_simple')
y2 = df_output_def.loc[period, var].rename('suews')
y3 = (y1-y2).rename('diff')
df_plot = pd.concat([y1, y2, y3], axis=1)
ax = df_plot.plot(secondary_y='diff')
ax.set_ylabel(var_label)
ax.right_ax.set_ylabel(var_label_right)
lines = ax.get_lines() + ax.right_ax.get_lines()
ax.legend(lines, [l.get_label() for l in lines], loc='center right')
```

[14]: <matplotlib.legend.Legend at 0x7fa2d0e6f940>

comparison in ΔQ_F-$\Delta T2$ feedback between summer and winter

[15]:
```
# filter results using `where` to choose periods when `QF_simple` is effective
# (i.e. activated by outdoor air temperatures)
df_diff_summer = (df_output_test_summer - df_output_def)\
    .where(df_output_def.T2 > 20, np.nan)\
    .dropna(how='all', axis=0)
df_diff_winter = (df_output_test_winter - df_output_def)\
    .where(df_output_test_winter.T2 < 10, np.nan)\
    .dropna(how='all', axis=0)

set_matplotlib_formats('svg')
# set_matplotlib_formats('retina')
df_diff_season = pd.concat([
    df_diff_winter.assign(season='winter'),
    df_diff_summer.assign(season='summer'),
]).loc[:, ['season', 'QF', 'T2']]
g = sns.lmplot(
    data=df_diff_season,
    x='QF',
    y='T2',
    hue='season',
    height=4,
    truncate=False,
    markers='o',
    legend_out=False,
    scatter_kws={
        's': 1,
        'zorder': 0,
        'alpha': 0.8,
    },
    line_kws={
        'zorder': 6,
        'linestyle': '--'
    },
)
g.set_axis_labels(
    '$\Delta Q_F$ ($ \mathrm{W \ m^{-2}}$)',
    '$\Delta T_2$ ($^{\circ}$C)',
)
g.ax.legend(markerscale=4)
g.despine(top=False, right=False)
```

[15]:
```
<seaborn.axisgrid.FacetGrid at 0x7fa35b350748>
```

The above figure indicate a positive feedback, as Q_F is increased there is an elevated T_2 but with different magnitudes given the non-linearlity in the SUEWS modelling system. Of particular note is the positive feedback loop under warm air temperatures: the anthropogenic heat emissions increase which in turn elevates the outdoor air temperature causing yet more anthropogenic heat release. Note that London is relatively cool so the enhancement is much less than it would be in warmer cities.

End of doc/tutorial/external-interaction.ipynb

The following section was generated from docs/source/tutorial/AMF-sim.ipynb

1.4 Modelling Surface Energy Balance at an AmeriFlux Site Using SuPy

This tutorial aims to demonstrate how to use an advanced land surface model (SuPy, SUEWS in Python) to better understand the surface energy balance (SEB) features by conducting simulation at an AmeriFlux site. This would be particularly useful after building your own model: as you will learn how sophisticated models could be developed from those simpler ones.

SuPy is a Python-enhanced urban climate model with SUEWS, *Surface Urban Energy and Water Balance Scheme*, as its computation core. More SuPy tutorials are available here.

In this tutorial the workflow to model the surface energy balance (SEB) at a chosen AmeriFlux (AMF) site using SuPy/SUEWS is undertaken. The steps, consist of

1. *Preparing the input data*;
2. *Running a simulation*;
3. *Examination of results*; and
4. *Further exploration*

Before starting, you need to install SuPy and load the following necessary packages.

```
pip install supy==2019.11.18.dev0
```

[1]:
```
# !pip install supy==2019.11.18.dev0 &> install.log
```

[2]:
```
import matplotlib.pyplot as plt
import supy as sp
import pandas as pd
import numpy as np
from pathlib import Path
%matplotlib inline
```

[3]:
```
%load_ext autoreload
%autoreload 2
```

[4]:
```
sp.show_version()
```

```
supy: 2019.11.18dev
supy_driver: 2019a18
```

1.4.1 Prepare input data

Overview of SuPy input

Load sample data:

To ease the preparation of model input, a helper function `load_SampleData` is provided to get the sample input for SuPy simulations, which will later be used as template to populate your specific model configurations and forcing input.

[5]:
```
df_state_init, df_forcing = sp.load_SampleData()
```

```
2019-11-22 09:16:28,573 -- SuPy -- INFO -- All cache cleared.
```

df_state_init

df_state_init includes model Initial state consisting of:

- surface characteristics (e.g., albedo, emissivity, land cover fractions, etc.; full details refer to SUEWS documentation).
- model configurations (e.g., stability; full details refer to SUEWS documentation).

Detailed description of variables in df_state_init refers to *SuPy input*.

- Surface land cover fraction information in the sample input dataset:

[6]:
```
df_state_init.filter(like='sfr')
```

[6]:
```
var        sfr
ind_dim   (0,)  (1,)   (2,)   (3,)   (4,)   (5,)  (6,)
grid
98        0.43  0.38  0.001  0.019  0.029  0.001  0.14
```

- Heights of bluff-bodies (m):

[7]:
```
df_state_init.loc[:, ['bldgh', 'evetreeh', 'dectreeh']]
```

[7]:
```
var      bldgh dectreeh evetreeh
ind_dim      0        0        0
grid
98        22.0     13.1     13.1
```

df_forcing

df_forcing includes meteorological and other external forcing information.

Detailed description of variables in df_forcing refers to *SuPy input*.

Below is a view of heading lines of the forcing variables.

[8]:
```
df_forcing.head()
```

[8]:
```
                       iy  id  it  imin     qn     qh     qe     qs     qf  \
2012-01-01 00:05:00  2012   1   0     5 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:10:00  2012   1   0    10 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:15:00  2012   1   0    15 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:20:00  2012   1   0    20 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:25:00  2012   1   0    25 -999.0 -999.0 -999.0 -999.0 -999.0

                          U  ...   snow  ldown   fcld    Wuh   xsmd    lai  \
2012-01-01 00:05:00  4.5225  ... -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:10:00  4.5225  ... -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:15:00  4.5225  ... -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:20:00  4.5225  ... -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:25:00  4.5225  ... -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
```

(continues on next page)

(continued from previous page)

```
                         kdiff   kdir   wdir  isec
2012-01-01 00:05:00 -999.0 -999.0 -999.0   0.0
2012-01-01 00:10:00 -999.0 -999.0 -999.0   0.0
2012-01-01 00:15:00 -999.0 -999.0 -999.0   0.0
2012-01-01 00:20:00 -999.0 -999.0 -999.0   0.0
2012-01-01 00:25:00 -999.0 -999.0 -999.0   0.0

[5 rows x 25 columns]
```

Site-specific configuration of surface parameters

Given `pandas.DataFrame` as the core data structure of SuPy, all operations, including modification, output, demonstration, etc., on SuPy inputs (`df_state_init` and `df_forcing`) can be done using `pandas`-based functions/methods. Please see SuPy quickstart for methods to do so.

Below we will modify several key properties of the chosen site with appropriate values to run SuPy. First, we copy the `df_state_init` to have a new DataFrame for manipulation.

[9]:
```
df_state_amf = df_state_init.copy()
```

[10]:
```
# site identifier
name_site = 'US-AR1'
```

location

[11]:
```
# latitude
df_state_amf.loc[:, 'lat'] = 41.37
# longitude
df_state_amf.loc[:, 'lng'] = -106.24
# altitude
df_state_amf.loc[:, 'alt'] = 611.
```

land cover fraction

Land covers in SUEWS

[12]:
```
# view the surface fraction variable: `sfr`
df_state_amf.loc[:, 'sfr'] = 0
df_state_amf.loc[:, ('sfr', '(4,)')] = 1
df_state_amf.loc[:, 'sfr']
```

[12]:
```
ind_dim   (0,)   (1,)   (2,)   (3,)   (4,)   (5,)   (6,)
grid
98         0.0    0.0    0.0    0.0    1.0    0.0    0.0
```

albedo

[13]:
```
# we only set values for grass as the modelled site has a single land cover type:␣
↪grass.
df_state_amf.albmax_grass = 0.19
df_state_amf.albmin_grass = 0.14
```

[14]:
```
# initial albedo value
df_state_amf.loc[:, 'albgrass_id'] = 0.14
```

LAI/phenology

[15]:
```
df_state_amf.filter(like='lai')
```

[15]:
```
var      laimax             laimin             laipower                          ...  \
ind_dim    (0,)  (1,)  (2,)   (0,)  (1,)  (2,)    (0, 0)  (0, 1)  (0, 2)  (1, 0)  ...
grid                                                                             ...
98          5.1   5.5   5.9    4.0   1.0   1.6      0.03    0.03    0.03  0.0005  ...

var                                  laitype            laicalcyes lai_id
ind_dim   (3, 0)   (3, 1)   (3, 2)     (0,)  (1,)  (2,)          0   (0,)  (1,)  (2,)
grid
98        0.0005   0.0005   0.0005      0.0   0.0   0.0          1    4.0   1.0   1.6

[1 rows x 25 columns]
```

[16]:
```
# properties to control vegetation phenology
# you can skip the details for and just set them as provided below

# LAI paramters
df_state_amf.loc[:, ('laimax', '(2,)')] = 1
df_state_amf.loc[:, ('laimin', '(2,)')] = 0.2
# initial LAI
df_state_amf.loc[:, ('lai_id', '(2,)')] = 0.2

# BaseT
df_state_amf.loc[:, ('baset', '(2,)')] = 5
# BaseTe
df_state_amf.loc[:, ('basete', '(2,)')] = 20

# SDDFull
df_state_amf.loc[:, ('sddfull', '(2,)')] = -1000
# GDDFull
df_state_amf.loc[:, ('gddfull', '(2,)')] = 1000
```

surface resistance

[17]:
```
# parameters to model surface resistance
df_state_amf.maxconductance = 18.7
df_state_amf.g1 = 1
df_state_amf.g2 = 104.215
df_state_amf.g3 = 0.424
df_state_amf.g4 = 0.814
df_state_amf.g5 = 36.945
df_state_amf.g6 = 0.025
```

measurement height

[18]:
```
# height where forcing variables are measured/collected
df_state_amf.z = 2.84
```

urban feature

[19]:
```
# disable anthropogenic heat by setting zero population
df_state_amf.popdensdaytime = 0
df_state_amf.popdensnighttime = 0
```

check `df_state`

[20]:
```
# this procedure is to double-check proper values are set in `df_state_amf`
sp.check_state(df_state_amf)
```

```
2019-11-22 09:16:30,954 -- SuPy -- INFO -- SuPy is validating `df_state`...
2019-11-22 09:16:31,120 -- SuPy -- INFO -- All checks for `df_state` passed!
```

prepare forcing conditions

Here we use the a SuPy utility function `read_forcing` to read in forcing data from an external file in the format of SUEWS input. Also note, this `read_forcing` utility will also resample the forcing data to a proper temporal resolution to run SuPy/SUEWS, which is usually 5 min (300 s).

load and resample forcing data

[21]:
```
# load forcing data from an external file and resample to a resolution of 300 s.
# Note this dataset has been gap-filled.
df_forcing_amf = sp.util.read_forcing('./data/US-AR1_2010_data_60.txt',
                                      tstep_mod=300)

# this procedure is to double-check proper forcing values are set in `df_forcing_amf`
_ = sp.check_forcing(df_forcing_amf)
```

```
2019-11-22 09:16:32,059 -- SuPy -- INFO -- SuPy is validating `df_forcing`...
2019-11-22 09:16:34,374 -- SuPy -- ERROR -- Issues found in `df_forcing`:
`kdown` should be between [0, 1400] but `-1.3057500000000002` is found at 2010-01-01␣
↪00:05:00
```

The checker detected invalid values in variable `kdown`: negative incoming solar radiation is found. We then need to fix this as follows:

[22]:
```
# modify invalid values
df_forcing_amf.kdown = df_forcing_amf.kdown.where(df_forcing_amf.kdown > 0, 0)
```

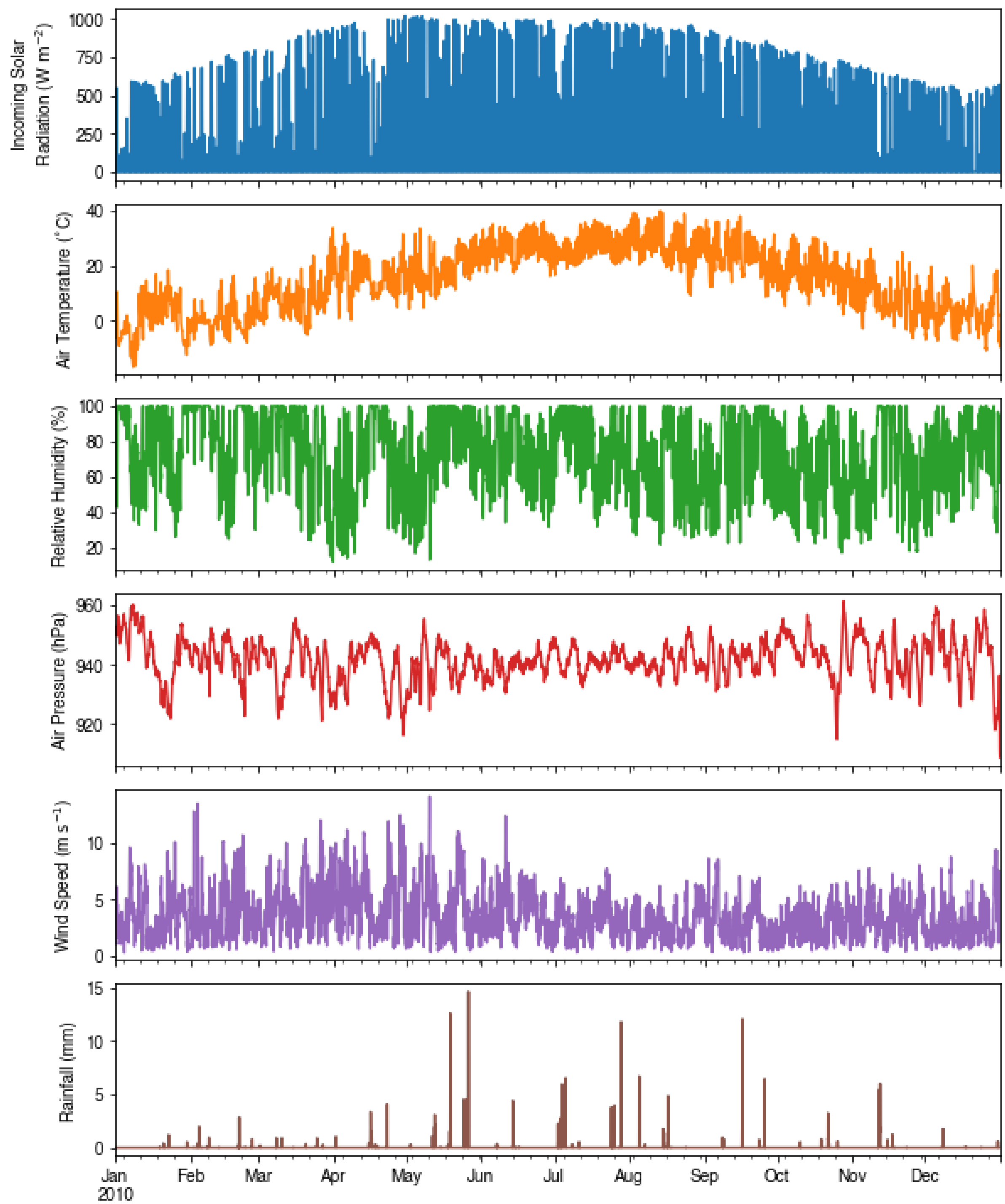
[23]:
```
# check `df_forcing` again
_ = sp.check_forcing(df_forcing_amf)
```

```
2019-11-22 09:16:34,466 -- SuPy -- INFO -- SuPy is validating `df_forcing`...
2019-11-22 09:16:36,946 -- SuPy -- INFO -- All checks for `df_forcing` passed!
```

examine forcing data

We can examine the forcing data:

[24]:
```
list_var_forcing = [
    'kdown',
    'Tair',
    'RH',
    'pres',
    'U',
    'rain',
]
dict_var_label = {
    'kdown': 'Incoming Solar\n Radiation ($ \mathrm{W \ m^{-2}}$)',
    'Tair': 'Air Temperature ($^{\circ}$C)',
    'RH': r'Relative Humidity (%)',
    'pres': 'Air Pressure (hPa)',
    'rain': 'Rainfall (mm)',
    'U': 'Wind Speed (m $\mathrm{s^{-1}}$)'
}
df_plot_forcing_x = df_forcing_amf.loc[:, list_var_forcing].copy().shift(
    -1).dropna(how='any')
df_plot_forcing = df_plot_forcing_x.resample('1h').mean()
df_plot_forcing['rain'] = df_plot_forcing_x['rain'].resample('1h').sum()

axes = df_plot_forcing.plot(
    subplots=True,
    figsize=(8, 12),
    legend=False,
)
fig = axes[0].figure
fig.tight_layout()
fig.autofmt_xdate(bottom=0.2, rotation=0, ha='center')
for ax, var in zip(axes, list_var_forcing):
    _ = ax.set_ylabel(dict_var_label[var])
```



1.4.2 Run simulations

Once met-forcing (via `df_forcing_amf`) and initial conditions (via `df_state_amf`) are loaded in, we call `sp.run_supy` to conduct a SUEWS simulation, which will return two `pandas DataFrames`: `df_output` and `df_state_final`.

[25]:
```
df_output, df_state_final = sp.run_supy(df_forcing_amf, df_state_amf)
```

```
2019-11-22 09:16:40,809 -- SuPy -- INFO -- ====================
2019-11-22 09:16:40,810 -- SuPy -- INFO -- Simulation period:
2019-11-22 09:16:40,811 -- SuPy -- INFO --   Start: 2010-01-01 00:05:00
2019-11-22 09:16:40,811 -- SuPy -- INFO --   End: 2011-01-01 00:00:00
2019-11-22 09:16:40,812 -- SuPy -- INFO --
2019-11-22 09:16:40,813 -- SuPy -- INFO -- No. of grids: 1
2019-11-22 09:16:40,813 -- SuPy -- INFO -- SuPy is running in serial mode
2019-11-22 09:16:54,304 -- SuPy -- INFO -- Execution time: 13.5 s
2019-11-22 09:16:54,305 -- SuPy -- INFO -- ====================
```

df_output

df_output is an ensemble output collection of major SUEWS output groups, including:

- SUEWS: the essential SUEWS output variables
- DailyState: variables of daily state information
- snow: snow output variables (effective when snowuse = 1 set in df_state_init)
- RSL: profile of air temperature, humidity and wind speed within roughness sub-layer.

Detailed description of variables in df_output refers to SuPy output

[26]:
```
df_output.columns.levels[0]
```

[26]:
```
Index(['SUEWS', 'snow', 'RSL', 'DailyState'], dtype='object', name='group')
```

df_state_final

df_state_final is a DataFrame for holding:

1. all model states if save_state is set to True when calling sp.run_supy and supy may run significantly slower for a large simulation;
2. or, only the final state if save_state is set to False (the default setting) in which mode supy has a similar performance as the standalone compiled SUEWS executable.

Entries in df_state_final have the same data structure as df_state_init and can thus be used for other SUEWS simulations staring at the timestamp as in df_state_final.

Detailed description of variables in df_state_final refers to SuPy output

[27]:
```
df_state_final.T.head()
```

[27]:
```
datetime                     2010-01-01 00:05:00 2011-01-01 00:05:00
grid                                          98                  98
var               ind_dim
ah_min            (0,)                      15.0                15.0
                  (1,)                      15.0                15.0
ah_slope_cooling  (0,)                       2.7                 2.7
                  (1,)                       2.7                 2.7
ah_slope_heating  (0,)                       2.7                 2.7
```

1.4.3 Examine results

Thanks to the functionality inherited from `pandas` and other packages under the PyData stack, compared with the standard SUEWS simulation workflow, `supy` enables more convenient examination of SUEWS results by statistics calculation, resampling, plotting (and many more).

Ouptut structure

`df_output` is organised with `MultiIndex` `(grid,timestamp)` and `(group,varaible)` as `index` and `columns`, respectively.

[28]:
```
df_output.head()
```

[28]:
```
group                       SUEWS                                             \
var                         Kdown  Kup       Ldown         Lup      Tsurf
grid datetime
98   2010-01-01 00:05:00      0.0  0.0  265.638676  305.413842 -1.587667
     2010-01-01 00:10:00      0.0  0.0  265.638676  305.413842 -1.587667
     2010-01-01 00:15:00      0.0  0.0  265.638676  305.413842 -1.587667
     2010-01-01 00:20:00      0.0  0.0  265.638676  305.413842 -1.587667
     2010-01-01 00:25:00      0.0  0.0  265.638676  305.413842 -1.587667

group                                                                          ...   \
var                                QN   QF         QS         QH         QE  ...
grid datetime                                                                 ...
98   2010-01-01 00:05:00 -39.775166  0.0 -50.989269  11.054221  0.159883  ...
     2010-01-01 00:10:00 -39.775166  0.0 -50.729902  10.795477  0.159259  ...
     2010-01-01 00:15:00 -39.775166  0.0 -50.481342  10.547515  0.158661  ...
     2010-01-01 00:20:00 -39.775166  0.0 -50.243138  10.309886  0.158086  ...
     2010-01-01 00:25:00 -39.775166  0.0 -50.014860  10.082159  0.157534  ...

group                        DailyState                                       \
var                         DensSnow_Paved DensSnow_Bldgs DensSnow_EveTr
grid datetime
98   2010-01-01 00:05:00               NaN            NaN            NaN
     2010-01-01 00:10:00               NaN            NaN            NaN
     2010-01-01 00:15:00               NaN            NaN            NaN
     2010-01-01 00:20:00               NaN            NaN            NaN
     2010-01-01 00:25:00               NaN            NaN            NaN

group                                                                          \
var                         DensSnow_DecTr DensSnow_Grass DensSnow_BSoil
grid datetime
98   2010-01-01 00:05:00               NaN            NaN            NaN
     2010-01-01 00:10:00               NaN            NaN            NaN
     2010-01-01 00:15:00               NaN            NaN            NaN
     2010-01-01 00:20:00               NaN            NaN            NaN
     2010-01-01 00:25:00               NaN            NaN            NaN

group
var                         DensSnow_Water   a1   a2   a3
grid datetime
98   2010-01-01 00:05:00               NaN  NaN  NaN  NaN
     2010-01-01 00:10:00               NaN  NaN  NaN  NaN
     2010-01-01 00:15:00               NaN  NaN  NaN  NaN
     2010-01-01 00:20:00               NaN  NaN  NaN  NaN
     2010-01-01 00:25:00               NaN  NaN  NaN  NaN
```

(continues on next page)

(continued from previous page)

```
[5 rows x 345 columns]
```

Here we demonstrate several typical scenarios for SUEWS results examination.

The essential SUEWS output collection is extracted as a separate variable for easier processing in the following sections. More advanced slicing techniques are available in pandas documentation.

[29]:
```
grid = df_state_amf.index[0]
df_output_suews = df_output.loc[grid, 'SUEWS']
```

Statistics Calculation

We can use .describe() method for a quick overview of the key surface energy balance budgets.

[30]:
```
df_output_suews.loc[:, ['QN', 'QS', 'QH', 'QE', 'QF']].describe()
```

[30]:
```
var                QN             QS             QH             QE        QF
count  105120.000000  105120.000000  105120.000000  105120.000000  105120.0
mean      118.291222       9.117453      53.611159      56.302547       0.0
std       213.150698      82.433076      72.044586      93.959856       0.0
min       -98.895138    -103.332153    -136.770097     -10.592811       0.0
25%       -32.252113     -46.922708       9.790903       0.633106       0.0
50%        -1.216564     -33.883630      25.756834       4.240341       0.0
75%       247.458581      55.231281      75.382465      67.207728       0.0
max       746.187700     262.700179     403.492712     445.496829       0.0
```

Plotting

Basic example

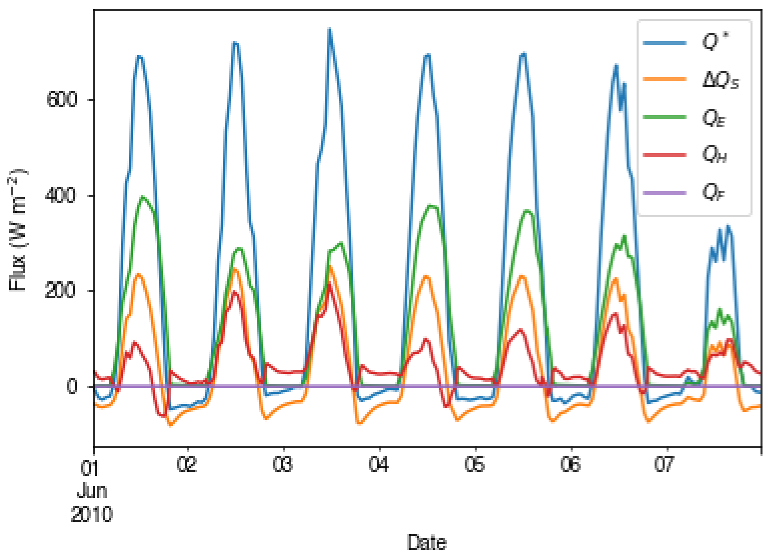
Plotting is very straightforward via the .plot method bounded with pandas.DataFrame. Note the usage of loc for to slices of the output DataFrame.

[31]:
```
# a dict for better display variable names
dict_var_disp = {
    'QN': '$Q^*$',
    'QS': r'$\Delta Q_S$',
    'QE': '$Q_E$',
    'QH': '$Q_H$',
    'QF': '$Q_F$',
    'Kdown': r'$K_{\downarrow}$',
    'Kup': r'$K_{\uparrow}$',
    'Ldown': r'$L_{\downarrow}$',
    'Lup': r'$L_{\uparrow}$',
    'Rain': '$P$',
    'Irr': '$I$',
    'Evap': '$E$',
    'RO': '$R$',
    'TotCh': '$\Delta S$',
}
```

Peek at the simulation results:

[32]:
```
grid = df_state_init.index[0]
```

[33]:
```
ax_output = df_output_suews\
    .loc['2010-06-01':'2010-06-07',
         ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot()
_ = ax_output.set_xlabel('Date')
_ = ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
_ = ax_output.legend()
```



Plotting after resampling

The suggested runtime/simulation frequency of SUEWS is `300 s`, which usually results a large output and may be over-weighted for storage and analysis. Also, you may feel apparent slowdown in producing the above figure as a large amount of data were used for the plotting. To slim down the result size for analysis and output, we can `resample` the default output very easily.

[34]:
```
rsmp_1d = df_output_suews.resample('1d')
# daily mean values
df_1d_mean = rsmp_1d.mean()
# daily sum values
df_1d_sum = rsmp_1d.sum()
```

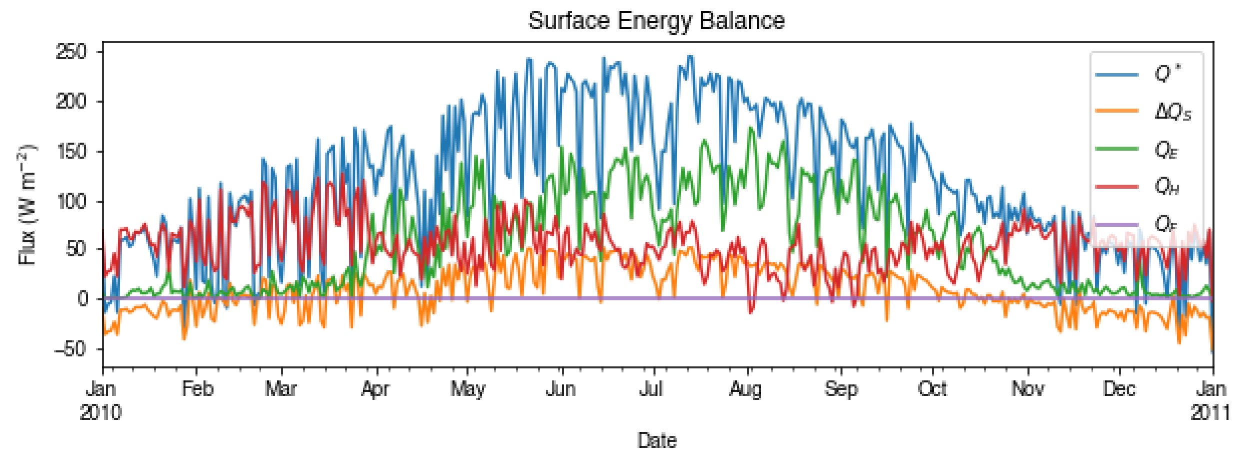
We can then re-examine the above energy balance at hourly scale and plotting will be significantly faster.

[35]:
```
# energy balance
ax_output = df_1d_mean\
    .loc[:, ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot(
            figsize=(10, 3),
            title='Surface Energy Balance',
        )
_ = ax_output.set_xlabel('Date')
```

(continues on next page)

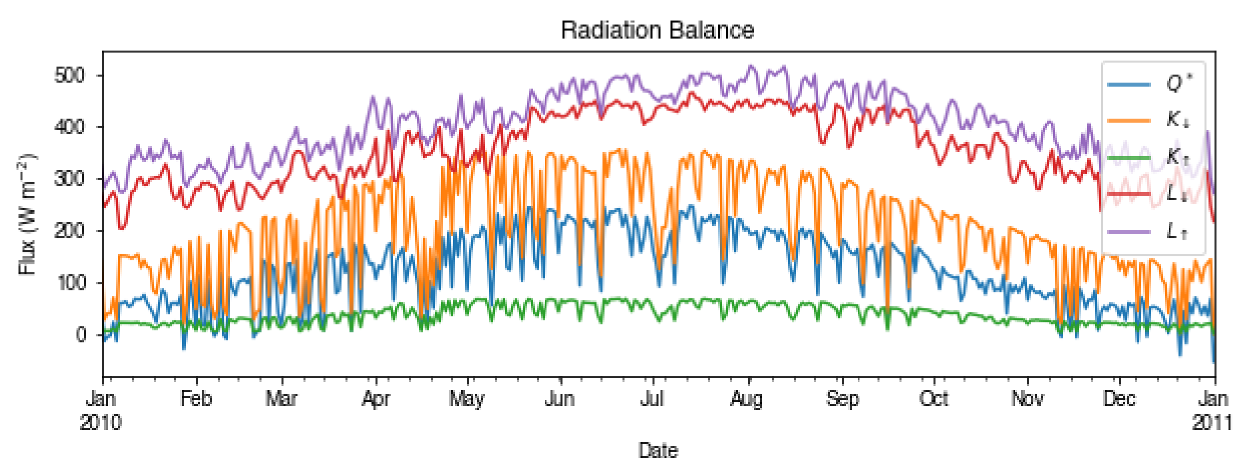
(continued from previous page)

```
_ = ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
_ = ax_output.legend()
```



Then we use the hourly results for other analyses.

[36]:
```
# radiation balance
ax_output = df_1d_mean\
    .loc[:, ['QN', 'Kdown', 'Kup', 'Ldown', 'Lup']]\
    .rename(columns=dict_var_disp)\
    .plot(
        figsize=(10, 3),
        title='Radiation Balance',
    )
_ = ax_output.set_xlabel('Date')
_ = ax_output.set_ylabel('Flux ($ \mathrm{W \ m^{-2}}$)')
_ = ax_output.legend()
```

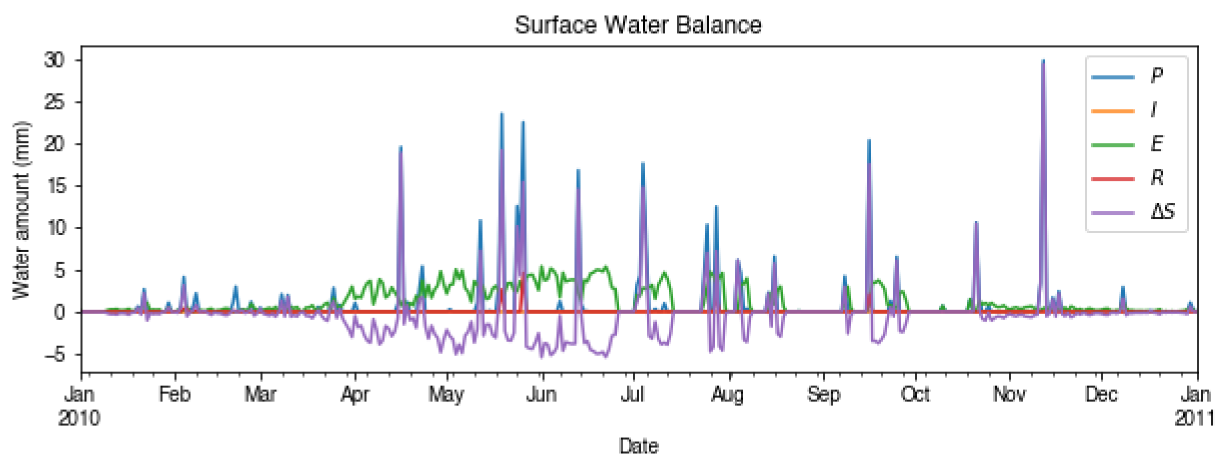


[37]:
```
# water balance
ax_output = df_1d_sum\
    .loc[:, ['Rain', 'Irr', 'Evap', 'RO', 'TotCh']]\
    .rename(columns=dict_var_disp)\
    .plot(
        figsize=(10, 3),
```

(continues on next page)

(continued from previous page)

```
        title='Surface Water Balance',
    )
_ = ax_output.set_xlabel('Date')
_ = ax_output.set_ylabel('Water amount (mm)')
_ = ax_output.legend()
```



Get an overview of partitioning in energy and water balance at monthly scales:

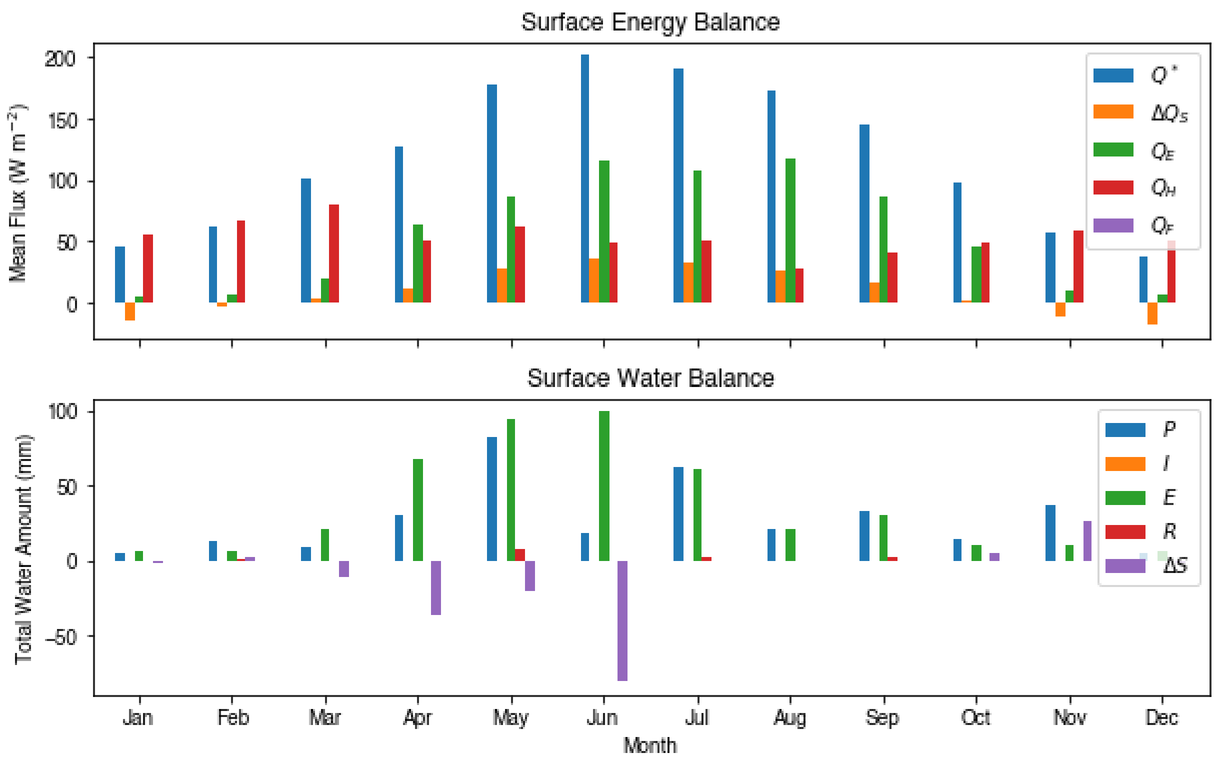
[38]:
```
# get a monthly Resampler
df_plot = df_output_suews.copy()
df_plot.index = df_plot.index.set_names('Month')
rsmp_1M = df_plot\
    .shift(-1)\
    .dropna(how='all')\
    .resample('1M', kind='period')
# mean values
df_1M_mean = rsmp_1M.mean()
# sum values
df_1M_sum = rsmp_1M.sum()
```

[39]:
```
# month names
name_mon = [x.strftime('%b') for x in rsmp_1M.groups]
# create subplots showing two panels together
fig, axes = plt.subplots(2, 1, sharex=True)
# surface energy balance
_=df_1M_mean\
    .loc[:, ['QN', 'QS', 'QE', 'QH', 'QF']]\
    .rename(columns=dict_var_disp)\
    .plot(
        ax=axes[0],  # specify the axis for plotting
        figsize=(10, 6),  # specify figure size
        title='Surface Energy Balance',
        kind='bar',
    )
# surface water balance
_=df_1M_sum\
    .loc[:, ['Rain', 'Irr', 'Evap', 'RO', 'TotCh']]\
    .rename(columns=dict_var_disp)\
    .plot(
        ax=axes[1],  # specify the axis for plotting
```

(continues on next page)

(continued from previous page)

```
        title='Surface Water Balance',
        kind='bar'
    )

# annotations
_ = axes[0].set_ylabel('Mean Flux ($ \mathrm{W \ m^{-2}}$)')
_ = axes[0].legend()
_ = axes[1].set_xlabel('Month')
_ = axes[1].set_ylabel('Total Water Amount (mm)')
_ = axes[1].xaxis.set_ticklabels(name_mon, rotation=0)
_ = axes[1].legend()
```



Save results to external files

The supy output can be saved as `txt` files for further analysis using supy function `save_supy`.

[40]:
```
list_path_save = sp.save_supy(df_output, df_state_final)
```

[41]:
```
for file_out in list_path_save:
    print(file_out.name)
```

```
98_2010_SUEWS_5.txt
98_2010_snow_5.txt
98_2010_RSL_5.txt
98_2010_DailyState.txt
98_2010_SUEWS_60.txt
98_2010_snow_60.txt
98_2010_RSL_60.txt
df_state.csv
```

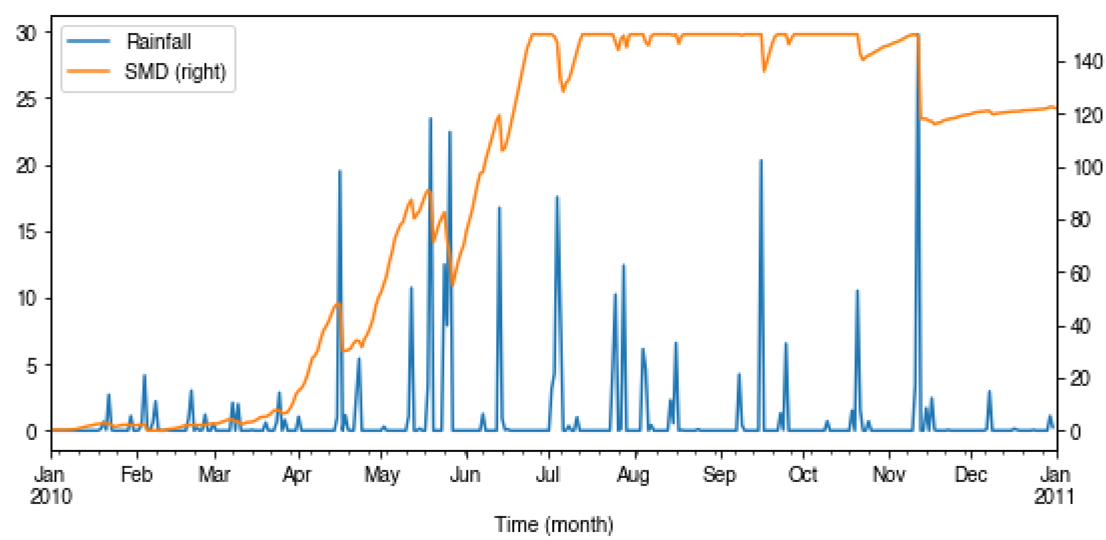
1.4.4 More explorations into simulation results

In this section, we will use the simulation results to explore more features revealed by SuPy/SUEWS simulations but *unavailable in your simple model*.

Dynamics in rainfall and soil moisture deficit (SMD)

[42]:
```
df_dailystate = df_output.loc[grid, 'DailyState'].dropna(
    how='all').resample('1d').mean()
```

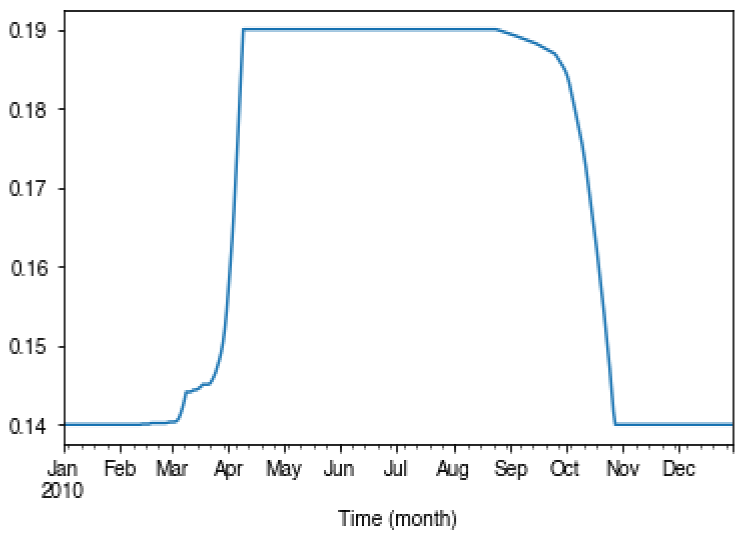
[43]:
```
# daily rainfall
ser_p = df_dailystate.P_day.rename('Rainfall')
ser_smd = df_output_suews.SMD
ser_smd_dmax = ser_smd.resample('1d').max().rename('SMD')

ax = pd.concat([ser_p, ser_smd_dmax], axis=1).plot(secondary_y='SMD',
                                                   figsize=(9, 4))
_ = ax.set_xlabel('Time (month)')
```



Variability in albedo

How does albedo change over time?

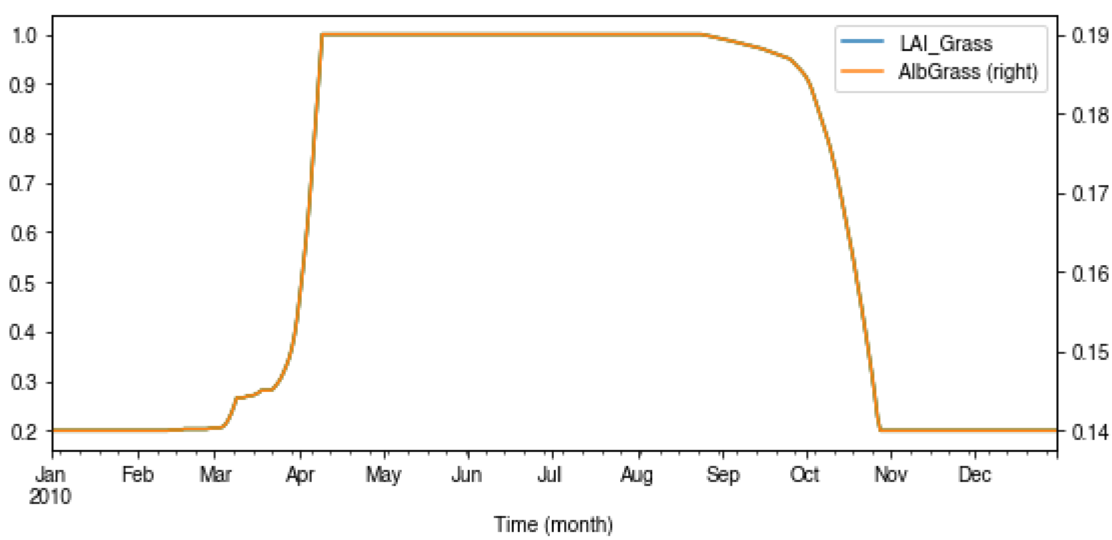
[44]:
```
ser_alb = df_dailystate.AlbGrass
ax = ser_alb.plot()
_ = ax.set_xlabel('Time (month)')
```



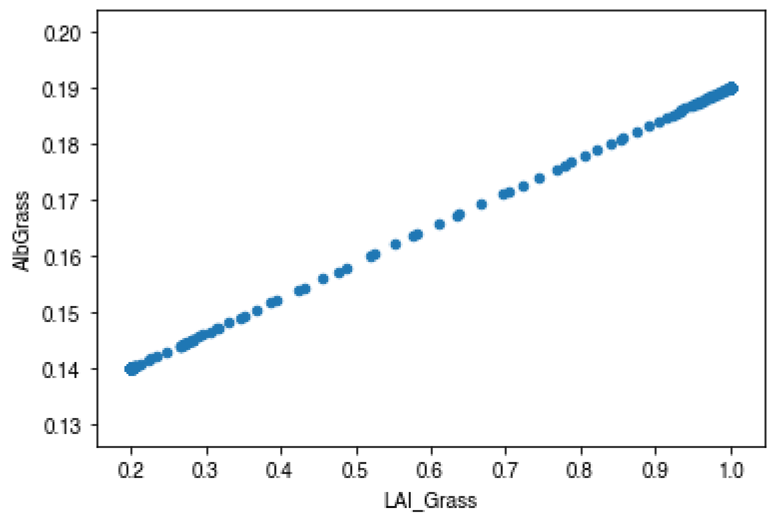
How is albedo associated with vegetation phenology?

[45]:
```
ser_lai = df_dailystate.LAI_Grass
pd.concat([ser_lai, ser_alb], axis=1).plot(secondary_y='AlbGrass',
                                          figsize=(9, 4))
ax = ser_lai.plot()
_ = ax.set_xlabel('Time (month)')
```

[45]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7fc9989c9ac8>
```



[46]:
```
ax_alb_lai = df_dailystate[['LAI_Grass', 'AlbGrass']].plot.scatter(
    x='LAI_Grass',
    y='AlbGrass',
)
ax_alb_lai.set_aspect('auto')
```



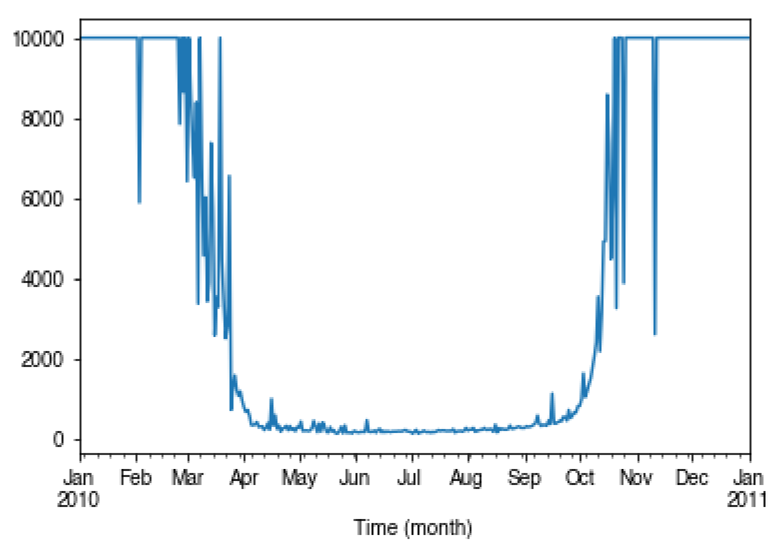
Variability in surface resistance

How does surface resistance vary over time?

[47]:
```
ser_rs = df_output_suews.RS
```

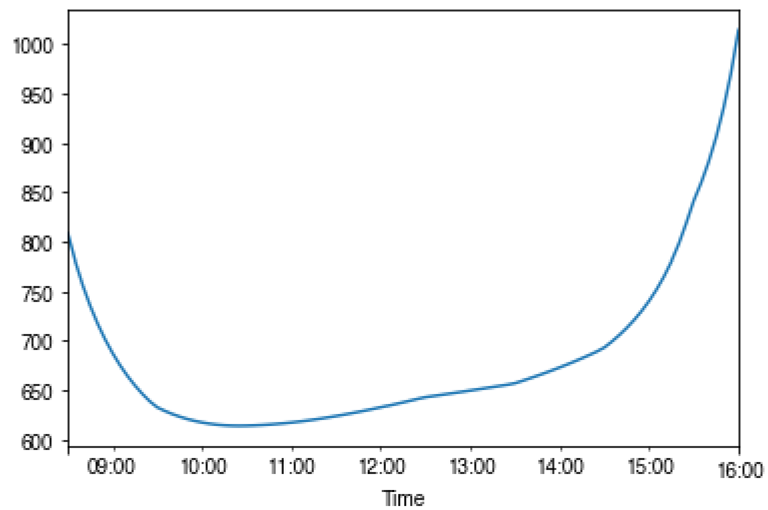
- intra-annual

[48]:
```
ax = ser_rs.resample('1d').median().plot()
_ = ax.set_xlabel('Time (month)')
```

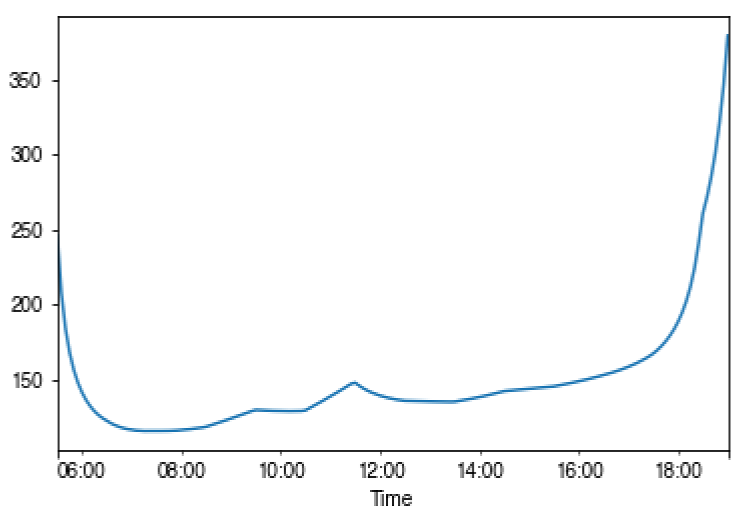


- intra-daily

[49]:
```
# a winter day
ax = ser_rs.loc['2010-01-22'].between_time('0830', '1600').plot()
_ = ax.set_xlabel('Time')
```

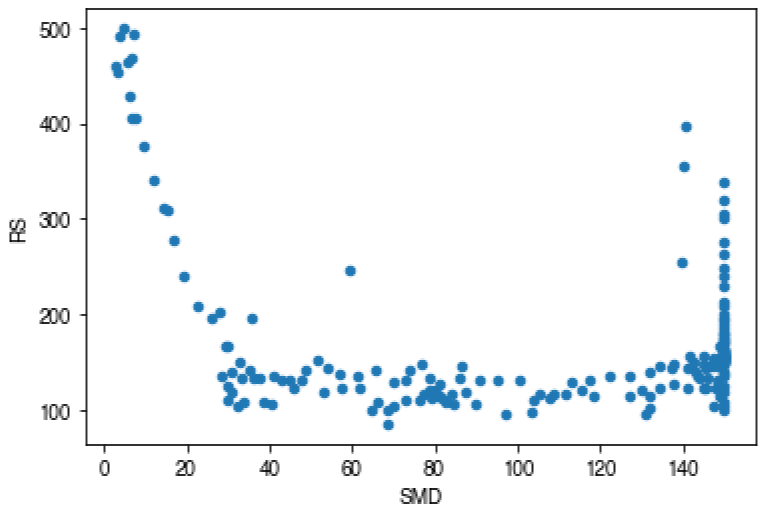



```
[50]: # a summer day
ax = ser_rs.loc['2010-07-01'].between_time('0530', '1900').plot()
_ = ax.set_xlabel('Time')
```

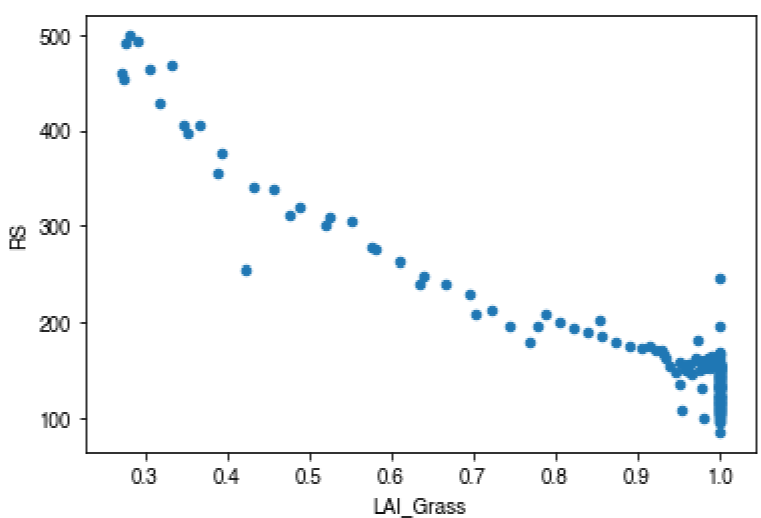


How is surface resistance associated with other surface properties?

```
[51]: # SMD
ser_smd = df_output_suews.SMD
df_x = pd.concat([ser_smd, ser_rs],
                 axis=1).between_time('1000', '1600').resample('1d').mean()
df_x = df_x.loc[df_x.RS < 500]
_ = df_x.plot.scatter(
    x='SMD',
    y='RS',
)
```



[52]:
```
# LAI
df_x = pd.concat(
    [ser_lai,
     ser_rs.between_time('1000', '1600').resample('1d').mean()],
    axis=1)
df_x = df_x.loc[df_x.RS < 500]
_ = df_x.plot.scatter(
    x='LAI_Grass',
    y='RS',
)
```



How is surface resistance dependent on meteorological conditions?

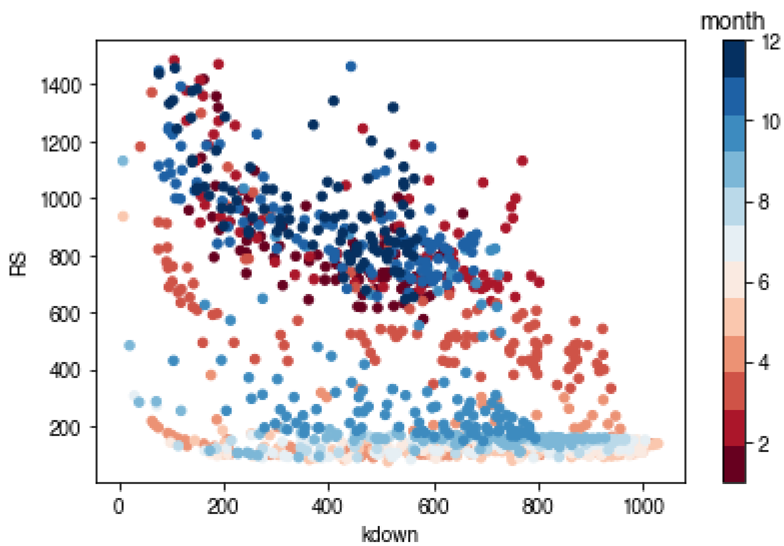
[53]:
```
cmap_sel = plt.cm.get_cmap('RdBu', 12)
```

[54]:
```
# solar radiation
# colour by season
```

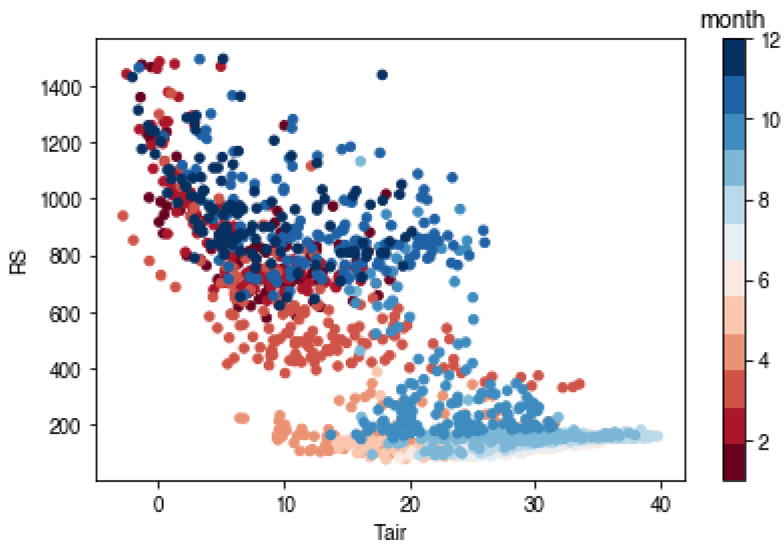
(continues on next page)

(continued from previous page)

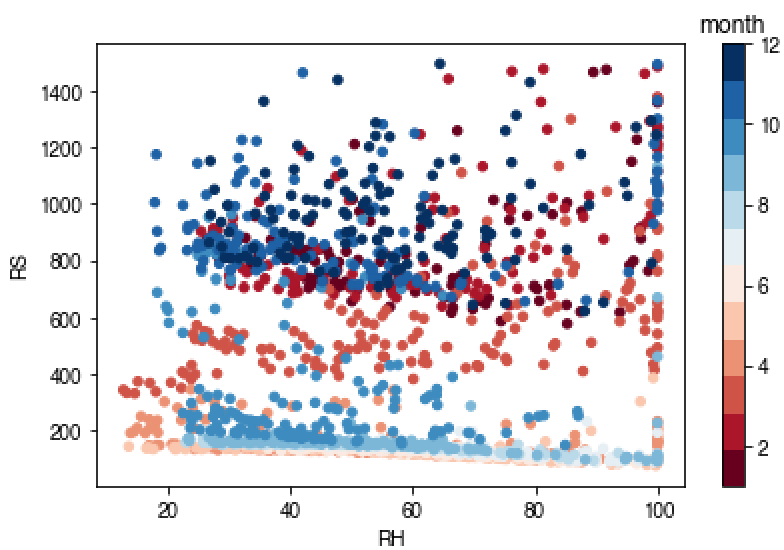
```
ser_kdown = df_forcing_amf.kdown
df_x = pd.concat([ser_kdown, ser_rs], axis=1).between_time('1000', '1600')
df_x = df_x.loc[df_x.RS < 1500]
df_plot = df_x.iloc[::20]
ax = df_plot.plot.scatter(x='kdown',
                          y='RS',
                          c=df_plot.index.month,
                          cmap=cmap_sel,
                          sharex=False)
fig = ax.figure
_ = fig.axes[1].set_title('month')
fig.tight_layout()
```



[55]:
```
# air temperature
ser_ta = df_forcing_amf.Tair
df_x = pd.concat([ser_ta, ser_rs], axis=1).between_time('1000', '1600')
df_x = df_x.loc[df_x.RS < 1500]
df_plot = df_x.iloc[::15]
ax = df_plot.plot.scatter(x='Tair',
                          y='RS',
                          c=df_plot.index.month,
                          cmap=cmap_sel,
                          sharex=False)
fig = ax.figure
_ = fig.axes[1].set_title('month')
fig.tight_layout()
```



[56]:
```
# air humidity
ser_rh = df_forcing_amf.RH
df_x = pd.concat([ser_rh, ser_rs], axis=1).between_time('1000', '1600')
df_x = df_x.loc[df_x.RS < 1500]
df_plot = df_x.iloc[::15]
ax = df_plot.plot.scatter(x='RH',
                          y='RS',
                          c=df_plot.index.month,
                          cmap=cmap_sel,
                          sharex=False)
fig = ax.figure
_ = fig.axes[1].set_title('month')
fig.tight_layout()
```



- **Task:**

Based on the above plots showing `RS` vs. met. conditions, explore these relationships again at the intra-daily scales.

End of `doc/tutorial/AMF-sim.ipynb`

Note:

1. The Anaconda distribution is suggested as the scientific Python 3 environment for its completeness in necessary packages. Please follow the official guide for its installation.
2. Users with less experience in Python are suggested to go through the following section first before using SuPy.

1.5 Python 101 before SuPy

Admittedly, this header is somewhat misleading: given the enormity of Python, it's more challenging to get this section *correct* than coding SuPy per se. As such, here a collection of data analysis oriented links to useful Python resources is provided to help novices start using Python and **then** SuPy.

- The gist of Python: a quick introductory blog that covers Python basics for data analysis.
- Jupyter Notebook: Jupyter Notebook provides a powerful notebook-based data analysis environment that SuPy users are strongly encouraged to use. Jupyter notebooks can run in browsers (desktop, mobile) either by easy local configuration or on remote servers with pre-set environments (e.g., Google Colaboratory, Microsoft Azure Notebooks). In addition, Jupyter notebooks allow great shareability by incorporating source code and detailed notes in one place, which helps users to organise their computation work.
  - Installation

    Jupyter notebooks can be installed with pip on any desktop/server system and open .ipynb notebook files locally:

    ```
    python3 -m pip install jupyter -U
    ```
  - Extensions: To empower your Jupyter Notebook environment with better productivity, please check out the Unofficial Jupyter Notebook Extensions. Quick introductory blogs can be found here and here.
- pandas: `pandas` is heavily used in SuPy and thus better understanding of pandas is essential in SuPy workflows.
  - Introductory blogs:
    - Quick dive into Pandas for Data Science: introduction to pandas.
    - Basic Time Series Manipulation with Pandas: pandas-based time series manipulation.
    - Introduction to Data Visualization in Python: plotting using pandas and related libraries.
  - A detailed tutorial in Jupyter Notebooks:
    - Introduction to pandas
    - pandas fundamentals
    - Data Wrangling with pandas

The following section was generated from `docs/source/data-structure/supy-io.ipynb`

CHAPTER 2

Key IO Data Structures in SuPy

2.1 Introduction

The cell below demonstrates a minimal case of SuPy simulation with all key IO data structures included:

[1]:
```
import supy as sp
df_state_init, df_forcing = sp.load_SampleData()
df_output, df_state_final = sp.run_supy(df_forcing, df_state_init)
```

- Input: SuPy requires two `DataFrames` to perform a simulation, which are:
  - `df_state_init`: model initial states;
  - `df_forcing`: forcing data.

  These input data can be loaded either through calling load_SampleData() as shown above or using init_supy. Or, based on the loaded sample `DataFrames`, you can modify the content to create new `DataFrames` for your specific needs.
- Output: The output data by SuPy consists of two `DataFrames`:
  - `df_output`: model output results; this is usually the basis for scientific analysis.
  - `df_state_final`: model final states; any of its entries can be used as a `df_state_init` to start another SuPy simulation.

2.2 Input

2.2.1 `df_state_init`: model initial states

[2]:
```
df_state_init.head()
```

[2]:
```
var      ah_min        ah_slope_cooling      ah_slope_heating      ahprof_24hr  \
ind_dim   (0,)  (1,)              (0,)  (1,)              (0,)  (1,)       (0, 0)
grid
98        15.0  15.0               2.7   2.7               2.7   2.7         0.57

var                                                                  ... tair24hr  \
ind_dim (0, 1) (1, 0) (1, 1) (2, 0) (2, 1) (3, 0) (3, 1) (4, 0)  ...    (275,)
grid                                                              ...
98        0.65   0.45   0.49   0.43   0.46    0.4   0.47    0.4  ...   273.15

var                                                                    \
ind_dim  (276,)  (277,)  (278,)  (279,)  (280,)  (281,)  (282,)  (283,)
grid
98       273.15  273.15  273.15  273.15  273.15  273.15  273.15  273.15

var                                     numcapita gridiv
ind_dim  (284,)  (285,)  (286,)  (287,)          0      0
grid
98       273.15  273.15  273.15  273.15    204.58     98

[1 rows x 1200 columns]
```

`df_state_init` is organised with ***grids*** in **rows** and ***their states*** in **columns**. The details of all state variables can be found in *the description page*.

Please note the properties are stored as *flattened values* to fit into the tabular format due to the nature of `DataFrame` though they may actually be of higher dimension (e.g. *ahprof_24hr* with the dimension {24, 2}). To indicate the variable dimensionality of these properties, SuPy use the `ind_dim` level in columns for indices of values:

- `0` for scalars;
- `(ind_dim1, ind_dim2, ...)` for arrays (for a generic sense, vectors are 1D arrays).

Take `ohm_coef` below for example, it has a dimension of {8, 4, 3} according to *the description*, which implies the actual values used by SuPy in simulations are passed in a layout as an array of the dimension {8, 4, 3}. As such, to get proper values passed in, users should follow the dimensionality requirement to prepare/modify `df_state_init`.

[3]:
```
df_state_init.loc[:,'ohm_coef']
```

[3]:
```
ind_dim  (0, 0, 0)  (0, 0, 1)  (0, 0, 2)  (0, 1, 0)  (0, 1, 1)  (0, 1, 2)  \
grid
98           0.719      0.194      -36.6      0.719      0.194      -36.6

ind_dim  (0, 2, 0)  (0, 2, 1)  (0, 2, 2)  (0, 3, 0)  (0, 3, 1)  (0, 3, 2)  \
grid
98           0.719      0.194      -36.6      0.719      0.194      -36.6

ind_dim  (1, 0, 0)  (1, 0, 1)  (1, 0, 2)  ...  (6, 3, 0)  (6, 3, 1)  \
grid                                      ...
98           0.238      0.427      -16.7  ...        0.5       0.21

ind_dim  (6, 3, 2)  (7, 0, 0)  (7, 0, 1)  (7, 0, 2)  (7, 1, 0)  (7, 1, 1)  \
grid
98           -39.1       0.25        0.6      -30.0       0.25        0.6

ind_dim  (7, 1, 2)  (7, 2, 0)  (7, 2, 1)  (7, 2, 2)  (7, 3, 0)  (7, 3, 1)  \
grid
98           -30.0       0.25        0.6      -30.0       0.25        0.6
```

(continues on next page)

(continued from previous page)

```
ind_dim  (7, 3, 2)
grid
98             -30.0

[1 rows x 96 columns]
```

2.2.2 `df_forcing`: forcing data

`df_forcing` is organised with ***temporal records*** in **rows** and ***forcing variables*** in **columns**. The details of all forcing variables can be found in *the description page*.

The missing values can be specified with `-999`s, which are the default NANs accepted by SuPy and its backend SUEWS.

[4]:
```
df_forcing.head()
```

[4]:
```
                       iy  id  it  imin     qn     qh     qe     qs     qf  \
2012-01-01 00:05:00  2012   1   0     5 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:10:00  2012   1   0    10 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:15:00  2012   1   0    15 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:20:00  2012   1   0    20 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:25:00  2012   1   0    25 -999.0 -999.0 -999.0 -999.0 -999.0

                         U         RH      Tair       pres  rain     kdown  \
2012-01-01 00:05:00  4.515  85.463333  11.77375  1001.5125   0.0  0.153333
2012-01-01 00:10:00  4.515  85.463333  11.77375  1001.5125   0.0  0.153333
2012-01-01 00:15:00  4.515  85.463333  11.77375  1001.5125   0.0  0.153333
2012-01-01 00:20:00  4.515  85.463333  11.77375  1001.5125   0.0  0.153333
2012-01-01 00:25:00  4.515  85.463333  11.77375  1001.5125   0.0  0.153333

                      snow  ldown   fcld    Wuh   xsmd    lai  kdiff   kdir  \
2012-01-01 00:05:00 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:10:00 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:15:00 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:20:00 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
2012-01-01 00:25:00 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0

                      wdir  isec
2012-01-01 00:05:00 -999.0   0.0
2012-01-01 00:10:00 -999.0   0.0
2012-01-01 00:15:00 -999.0   0.0
2012-01-01 00:20:00 -999.0   0.0
2012-01-01 00:25:00 -999.0   0.0
```

Note:

The index of `df_forcing` **SHOULD BE** strictly of `DatetimeIndex` type if you want create a `df_forcing` for SuPy simulation. The SuPy runtime time-step size is instructed by the `df_forcing` with its index information.

The infomation below indicates SuPy will run at a 5 min (i.e. 300 s) time-step if driven by this specific `df_forcing`:

[5]:
```
freq_forcing=df_forcing.index.freq
freq_forcing
```

```
[5]: <300 * Seconds>
```

2.3 Output

2.3.1 df_output: model output results

`df_output` is organised with ***temporal records of grids*** in **rows** and ***output variables of different groups*** in **columns**. The details of all forcing variables can be found in *the description page*.

```
[6]: df_output.head()
```

```
[6]: group                        SUEWS                                     \
var                          Kdown       Kup      Ldown        Lup
grid datetime
98   2012-01-01 00:05:00  0.153333  0.018279  344.310184  371.986259
     2012-01-01 00:10:00  0.153333  0.018279  344.310184  371.986259
     2012-01-01 00:15:00  0.153333  0.018279  344.310184  371.986259
     2012-01-01 00:20:00  0.153333  0.018279  344.310184  371.986259
     2012-01-01 00:25:00  0.153333  0.018279  344.310184  371.986259

group                                                                   \
var                          Tsurf         QN          QF         QS
grid datetime
98   2012-01-01 00:05:00  11.775615 -27.541021  40.574001 -46.53243
     2012-01-01 00:10:00  11.775615 -27.541021  39.724283 -46.53243
     2012-01-01 00:15:00  11.775615 -27.541021  38.874566 -46.53243
     2012-01-01 00:20:00  11.775615 -27.541021  38.024849 -46.53243
     2012-01-01 00:25:00  11.775615 -27.541021  37.175131 -46.53243

group                                                                        \
var                             QH         QE    QHlumps   QElumps   QHresis
grid datetime
98   2012-01-01 00:05:00  62.420064  3.576493  49.732605  9.832804  0.042327
     2012-01-01 00:10:00  61.654096  3.492744  48.980360  9.735333  0.042294
     2012-01-01 00:15:00  60.885968  3.411154  48.228114  9.637861  0.042260
     2012-01-01 00:20:00  60.115745  3.331660  47.475869  9.540389  0.042226
     2012-01-01 00:25:00  59.343488  3.254200  46.723623  9.442917  0.042192

group                                   ... DailyState                     \
var                        Rain  Irr  ...  WU_Grass2 WU_Grass3 deltaLAI
grid datetime                          ...
98   2012-01-01 00:05:00  0.0  0.0  ...        NaN       NaN      NaN
     2012-01-01 00:10:00  0.0  0.0  ...        NaN       NaN      NaN
     2012-01-01 00:15:00  0.0  0.0  ...        NaN       NaN      NaN
     2012-01-01 00:20:00  0.0  0.0  ...        NaN       NaN      NaN
     2012-01-01 00:25:00  0.0  0.0  ...        NaN       NaN      NaN

group                                                                      \
var                        LAIlumps AlbSnow DensSnow_Paved DensSnow_Bldgs
grid datetime
98   2012-01-01 00:05:00       NaN     NaN            NaN            NaN
     2012-01-01 00:10:00       NaN     NaN            NaN            NaN
     2012-01-01 00:15:00       NaN     NaN            NaN            NaN
     2012-01-01 00:20:00       NaN     NaN            NaN            NaN
     2012-01-01 00:25:00       NaN     NaN            NaN            NaN
```

(continues on next page)

(continued from previous page)

```
group                                                                    \
var                        DensSnow_EveTr DensSnow_DecTr DensSnow_Grass
grid datetime
98   2012-01-01 00:05:00            NaN            NaN            NaN
     2012-01-01 00:10:00            NaN            NaN            NaN
     2012-01-01 00:15:00            NaN            NaN            NaN
     2012-01-01 00:20:00            NaN            NaN            NaN
     2012-01-01 00:25:00            NaN            NaN            NaN

group
var                        DensSnow_BSoil DensSnow_Water  a1  a2  a3
grid datetime
98   2012-01-01 00:05:00            NaN            NaN NaN NaN NaN
     2012-01-01 00:10:00            NaN            NaN NaN NaN NaN
     2012-01-01 00:15:00            NaN            NaN NaN NaN NaN
     2012-01-01 00:20:00            NaN            NaN NaN NaN NaN
     2012-01-01 00:25:00            NaN            NaN NaN NaN NaN

[5 rows x 218 columns]
```

`df_output` are recorded at the same temporal resolution as `df_forcing`:

[7]:
```
freq_out = df_output.index.levels[1].freq
(freq_out, freq_out == freq_forcing)
```

[7]:
```
(<300 * Seconds>, True)
```

2.3.2 `df_state_final`: model final states

`df_state_final` has the identical data structure as `df_state_init` except for the extra level `datetime` in index, which stores the temporal information associated with model states. Such structure can facilitate the reuse of it as initial model states for other simulations (e.g., diagnostics of runtime model states with `save_state=True` set in `run_supy`; or simply using it as the initial conditions for future simulations starting at the ending times of previous runs).

The meanings of state variables in `df_state_final` can be found in *the description page*.

[8]:
```
df_state_final.head()
```

[8]:
```
var                        aerodynamicresistancemethod ah_min        \
ind_dim                                              0   (0,)   (1,)
datetime            grid
2012-01-01 00:05:00 98                               2   15.0   15.0
2013-01-01 00:05:00 98                               2   15.0   15.0

var                        ah_slope_cooling      ah_slope_heating       \
ind_dim                                (0,)  (1,)             (0,)  (1,)
datetime            grid
2012-01-01 00:05:00 98                  2.7   2.7              2.7   2.7
2013-01-01 00:05:00 98                  2.7   2.7              2.7   2.7

var                        ahprof_24hr                                      \
ind_dim                         (0, 0) (0, 1) (1, 0) (1, 1) (2, 0) (2, 1)
datetime            grid
2012-01-01 00:05:00 98            0.57   0.65   0.45   0.49   0.43   0.46
```

(continues on next page)

(continued from previous page)

```
2013-01-01 00:05:00 98          0.57   0.65   0.45   0.49   0.43   0.46

var                                    ... wuprofm_24hr                  \
ind_dim                   (3, 0) (3, 1)  ...      (18, 0) (18, 1) (19, 0)
datetime            grid                 ...
2012-01-01 00:05:00 98      0.4   0.47  ...       -999.0  -999.0  -999.0
2013-01-01 00:05:00 98      0.4   0.47  ...       -999.0  -999.0  -999.0

var                                                                      \
ind_dim                   (19, 1) (20, 0) (20, 1) (21, 0) (21, 1) (22, 0)
datetime            grid
2012-01-01 00:05:00 98    -999.0  -999.0  -999.0  -999.0  -999.0  -999.0
2013-01-01 00:05:00 98    -999.0  -999.0  -999.0  -999.0  -999.0  -999.0

var                                                  z z0m_in zdm_in
ind_dim                   (22, 1) (23, 0) (23, 1)    0      0      0
datetime            grid
2012-01-01 00:05:00 98    -999.0  -999.0  -999.0  49.6    1.9   14.2
2013-01-01 00:05:00 98    -999.0  -999.0  -999.0  49.6    1.9   14.2

[2 rows x 1200 columns]
```

End of doc/data-structure/supy-io.ipynb

CHAPTER 3

API reference

3.1 Top-level Functions

init_supy(path_init[, force_reload, check_input])	Initialise supy by loading initial model states.
load_forcing_grid(path_runcontrol, grid[, . . .])	Load forcing data for a specific grid included in the index of *df_state_init*.
run_supy(df_forcing, df_state_init[, . . .])	Perform supy simulation.
save_supy(df_output, df_state_final, freq_s, . . .)	Save SuPy run results to files
load_SampleData()	Load sample data for quickly starting a demo run.
show_version()	print `SuPy` and `supy_driver` version information.

3.1.1 supy.init_supy

`supy.`**`init_supy`**(*path_init: str*, *force_reload=True*, *check_input=False*) → pandas.core.frame.DataFrame

Initialise supy by loading initial model states.

Parameters

- **`path_init`** (*`str`*) –

  Path to a file that can initialise SuPy, which can be either of the follows:

  – SUEWS RunControl.nml: a namelist file for SUEWS configurations

  – SuPy `df_state.csv`: a CSV file including model states produced by a SuPy run via *`supy.save_supy()`*

- **`force_reload`** (*`boolean, optional`*) – Flag to force reload all initialisation files by clearing all cached states, with default value `True` (i.e., force reload all files). Note: If the number of simulation grids is large (e.g., > 100), `force_reload=False` is strongly recommended for better performance.

- **`check_input`** (*`boolean, optional`*) – flag for checking validity of input: `df_forcing` and `df_state_init`. If set to `True`, any detected invalid input will stop SuPy simulation; a `False` flag will bypass such validation and may incur kernel error if any invalid input. *Note: such checking procedure may take some time if the input is large.* (the default is `False`, which bypasses the validation).

Returns **df_state_init** – Initial model states. See *df_state variables* for details.

Return type pandas.DataFrame

Examples

1. Use RunControl.nml to initialise SuPy

```
>>> path_init = "~/SUEWS_sims/RunControl.nml"
>>> df_state_init = supy.init_supy(path_init)
```

2. Use `df_state.csv` to initialise SuPy

```
>>> path_init = "~/SuPy_res/df_state_test.csv"
>>> df_state_init = supy.init_supy(path_init)
```

3.1.2 supy.load_forcing_grid

`supy.load_forcing_grid`(*path_runcontrol: str*, *grid: int*, *check_input=False*) → pandas.core.frame.DataFrame

Load forcing data for a specific grid included in the index of *df_state_init*.

Parameters

- **path_runcontrol** (*str*) – Path to SUEWS RunControl.nml
- **grid** (*int*) – Grid number
- **check_input** (*bool, optional*) – flag for checking validity of input: `df_forcing` and `df_state_init`. If set to `True`, any detected invalid input will stop SuPy simulation; a `False` flag will bypass such validation and may incur kernel error if any invalid input. *Note: such checking procedure may take some time if the input is large.* (the default is `False`, which bypasses the validation).

Returns **df_forcing** – Forcing data. See *df_forcing variables* for details.

Return type pandas.DataFrame

Examples

```
>>> path_runcontrol = "~/SUEWS_sims/RunControl.nml"  # a valid path to␣
↪`RunControl.nml`
>>> df_state_init = supy.init_supy(path_runcontrol) # get `df_state_init`
>>> grid = df_state_init.index[0] # first grid number included in `df_state_init`
>>> df_forcing = supy.load_forcing_grid(path_runcontrol, grid) # get df_forcing
```

3.1.3 supy.run_supy

supy.**run_supy**(*df_forcing: pandas.core.frame.DataFrame*, *df_state_init: pandas.core.frame.DataFrame*, *save_state=False*, *chunk_day=3660*, *logging_level=20*, *check_input=False*, *serial_mode=False*) → Tuple[pandas.core.frame.DataFrame, pandas.core.frame.DataFrame]

Perform supy simulation.

Parameters

- **df_forcing** (*pandas.DataFrame*) – forcing data for all grids in df_state_init.
- **df_state_init** (*pandas.DataFrame*) – initial model states; or a collection of model states with multiple timestamps, whose last temporal record will be used as the initial model states.
- **save_state** (*bool, optional*) – flag for saving model states at each time step, which can be useful in diagnosing model runtime performance or performing a restart run. (the default is False, which instructs supy not to save runtime model states).
- **chunk_day** (*int, optional*) – chunk size (chunk_day days) to split simulation periods so memory usage can be reduced. (the default is 3660, which implies ~10-year forcing chunks used in simulations).
- **logging_level** (*logging level*) – one of these values [50 (CRITICAL), 40 (ERROR), 30 (WARNING), 20 (INFO), 10 (DEBUG)]. A lower value informs SuPy for more verbose logging info.
- **check_input** (*bool, optional*) – flag for checking validity of input: df_forcing and df_state_init. If set to True, any detected invalid input will stop SuPy simulation; a False flag will bypass such validation and may incur kernel error if any invalid input. *Note: such checking procedure may take some time if the input is large.* (the default is False, which bypasses the validation).
- **serial_mode** (*bool, optional*) – If set to True, SuPy simulation will be conducted in serial mode; a False flag will try parallel simulation if possible (Windows not supported, i.e., always serial). (the default is False).

Returns

df_output, df_state_final –

- df_output: *output results*
- df_state_final: *final model states*

Return type Tuple[pandas.DataFrame, pandas.DataFrame]

Examples

```
>>> df_output, df_state_final = supy.run_supy(df_forcing, df_state_init)
```

3.1.4 supy.save_supy

supy.**save_supy**(*df_output: pandas.core.frame.DataFrame*, *df_state_final: pandas.core.frame.DataFrame*, *freq_s: int = 3600*, *site: str = ''*, *path_dir_save: str = PosixPath('.')*, *path_runcontrol: str = None*, *save_tstep=False*, *logging_level=50*, *output_level=1*, *debug=False*) → list

Save SuPy run results to files

Parameters

- **df_output** (*pandas.DataFrame*) – DataFrame of output
- **df_state_final** (*pandas.DataFrame*) – DataFrame of final model states
- **freq_s** (*int, optional*) – Output frequency in seconds (the default is 3600, which indicates hourly output)
- **site** (*str, optional*) – Site identifier (the default is '', which indicates site identifier will be left empty)
- **path_dir_save** (*str, optional*) – Path to directory to saving the files (the default is Path('.'), which indicates the current working directory)
- **path_runcontrol** (*str, optional*) – Path to SUEWS RunControl.nml, which, if set, will be preferably used to derive `freq_s`, `site` and `path_dir_save`. (the default is None, which is unset)
- **save_tstep** (*bool, optional*) – whether to save results in temporal resolution as in simulation (which may result very large files and slow progress), by default False.
- **logging_level** (*logging level*) – one of these values [50 (CRITICAL), 40 (ERROR), 30 (WARNING), 20 (INFO), 10 (DEBUG)]. A lower value informs SuPy for more verbose logging info.
- **output_level** (*integer, optional*) – option to determine selection of output variables, by default 1. Notes: 0 for all but snow-related; 1 for all; 2 for a minimal set without land cover specific information.
- **debug** (*bool, optional*) – whether to enable debug mode (e.g., writing out in serial mode, and other debug uses), by default False.

Returns a list of paths of saved files

Return type list

Examples

1. save results of a supy run to the current working directory with default settings

```
>>> list_path_save = supy.save_supy(df_output, df_state_final)
```

2. save results according to settings in RunControl.nml

```
>>> list_path_save = supy.save_supy(df_output, df_state_final, path_runcontrol=
↪'path/to/RunControl.nml')
```

3. save results of a supy run at resampling frequency of 1800 s (i.e., half-hourly results) under the site code `Test` to a customised location 'path/to/some/dir'

```
>>> list_path_save = supy.save_supy(df_output, df_state_final, freq_s=1800, site=
↪'Test', path_dir_save='path/to/some/dir')
```

3.1.5 supy.load_SampleData

`supy.load_SampleData()` → Tuple[pandas.core.frame.DataFrame, pandas.core.frame.DataFrame]

Load sample data for quickly starting a demo run.

Returns

df_state_init, df_forcing –

- df_state_init: *initial model states*
- df_forcing: *forcing data*

Return type Tuple[pandas.DataFrame, pandas.DataFrame]

Examples

```
>>> df_state_init, df_forcing = supy.load_SampleData()
```

3.1.6 supy.show_version

`supy.show_version()`

print `SuPy` and `supy_driver` version information.

3.2 Utility Functions

3.2.1 ERA-5 Data Downloader

download_era5(lat_x, lon_x, start, end[, ...])	Generate ERA-5 cdsapi-based requests and download data for area of interests.
gen_forcing_era5(lat_x, lon_x, start, end[, ...])	Generate SUEWS forcing files using ERA-5 data.

supy.util.download_era5

`supy.util.download_era5`(*lat_x: float*, *lon_x: float*, *start: str*, *end: str*, *dir_save=PosixPath('.')*, *grid=None*, *scale=0*, *logging_level=20*) → dict

Generate ERA-5 cdsapi-based requests and download data for area of interests.

Parameters

- **lat_x** (*float*) – Latitude of centre at the area of interest.
- **lon_x** (*float*) – Longitude of centre at the area of interest.
- **start** (*str*) – Any datetime-like string that can be parsed by `pandas.daterange()`.
- **end** (*str*) – Any datetime-like string that can be parsed by `pandas.daterange()`.
- **grid** (*list, optional*) – grid size used in CDS request API, by default [0.125, 0.125].
- **scale** (*int, optional*) – scaling factor that determines the area of interest (i.e., `area=grid[0]*scale`), by default 0.
- **dir_save** (*Path or path-like string*) – path to directory for saving downloaded ERA5 netCDF files.

- **logging_level** (*logging level*) – one of these values [50 (CRITICAL), 40 (ERROR), 30 (WARNING), 20 (INFO), 10 (DEBUG)]. A lower value informs SuPy for more verbose logging info.

Returns key: name of downloaded file. value: CDS API request used for downloading the file named by the corresponding key.

Return type dict

Note: This function uses CDS API to download ERA5 data; follow this for configuration first: https://cds.climate.copernicus.eu/api-how-to

---

supy.util.gen_forcing_era5

`supy.util.`**`gen_forcing_era5`**(*lat_x: float, lon_x: float, start: str, end: str, dir_save=PosixPath('.'), grid=None, hgt_agl_diag=100.0, scale=0, simple_mode=True, logging_level=20*) → list

Generate SUEWS forcing files using ERA-5 data.

Parameters

- **lat_x** (*float*) – Latitude of centre at the area of interest.
- **lon_x** (*float*) – Longitude of centre at the area of interest.
- **start** (*str*) – Any datetime-like string that can be parsed by `pandas.daterange()`.
- **end** (*str*) – Any datetime-like string that can be parsed by `pandas.daterange()`.
- **dir_save** (*Path or path-like string*) – path to directory for saving downloaded ERA5 netCDF files.
- **grid** (*list, optional*) – grid size used in CDS request API, by default [0.125, 0.125].
- **hgt_agl_diag** (*float*) – height above ground level to diagnose forcing variables, by default 0; the ground level is taken from ERA5 grid altitude.
- **scale** (*int, optional*) – scaling factor that determines the area of interest (i.e., `area=grid[0]*scale`), by default 0
- **simple_mode** (*boolean*) – if use the *simple* mode for diagnosing the forcing variables, by default `True`. In the simple mode, temperature is diagnosed using environmental lapse rate 6.5 K/km and wind speed using MOST under neutral condition. If `False`, MOST with consideration of stability conditions will be used to diagnose forcing variables.
- **logging_level** (*logging level*) – one of these values [50 (CRITICAL), 40 (ERROR), 30 (WARNING), 20 (INFO), 10 (DEBUG)]. A lower value informs SuPy for more verbose logging info.

Returns A list of files in SUEWS forcing input format.

Return type List

Note:

1. This function uses CDS API to download ERA5 data; follow this for configuration first: https://cds.climate.copernicus.eu/api-how-to
2. The generated forcing files can be imported using `supy.util.read_forcing` to get simulation-ready 'pandas.DataFrame's.

---

3. See Section 3.10.2 and 3.10.3 in the reference for details of diagnostics calculation.

   ECMWF, S. P. (2016). In IFS documentation CY41R2 Part IV: Physical Processes. ECMWF: Reading, UK, 111-113. https://www.ecmwf.int/en/elibrary/16648-part-iv-physical-processes

---

3.2.2 Typical Meteorological Year

gen_epw(df_output, lat, lon[, tz, path_epw])	Generate an `epw` file of uTMY (urbanised Typical Meteorological Year) using SUEWS simulation results
read_epw(path_epw)	Read in `epw` file as a DataFrame

supy.util.gen_epw

`supy.util.`**`gen_epw`**(*df_output: pandas.core.frame.DataFrame*, *lat*, *lon*, *tz=0*, *path_epw=PosixPath('uTMY.epw')*) → Tuple[pandas.core.frame.DataFrame, str, pathlib.Path]

Generate an `epw` file of uTMY (urbanised Typical Meteorological Year) using SUEWS simulation results

Parameters

- **df_output** (*pd.DataFrame*) – SUEWS simulation results.
- **path_epw** (*Path, optional*) – Path to store generated epw file, by default Path('./uTMY.epw').
- **lat** (*float*) – Latitude of the site, used for calculating solar angle.
- **lon** (*float*) – Longitude of the site, used for calculating solar angle.
- **tz** (*float*) – time zone represented by time difference from UTC+0 (e.g., 8 for UTC+8), by default 0 (i.e., UTC+0)

Returns

df_epw, text_meta, path_epw –

- df_epw: uTMY result
- text_meta: meta-info text
- path_epw: path to generated `epw` file

Return type Tuple[pd.DataFrame, str, Path]

supy.util.read_epw

`supy.util.`**`read_epw`**(*path_epw: pathlib.Path*) → pandas.core.frame.DataFrame

Read in `epw` file as a DataFrame

Parameters **path_epw** (*Path*) – path to `epw` file

Returns **df_tmy** – TMY results of `epw` file

Return type pd.DataFrame

3.2.3 Gap Filling

fill_gap_all(ser_to_fill[, freq])	Fill all gaps in a time series using data from neighbouring divisions of 'freq'

supy.util.fill_gap_all

`supy.util.fill_gap_all`(*ser_to_fill: pandas.core.series.Series*, *freq='1D'*) → pandas.core.series.Series

Fill all gaps in a time series using data from neighbouring divisions of 'freq'

Parameters

- **ser_to_fill** (*pd.Series*) – Time series to gap-fill
- **freq** (*str, optional*) – Frequency to identify gapped divisions, by default '1D'

Returns

- **ser_test_filled** (*pd.Series*) – Gap-filled time series.
- *Patterns*
- ———
- **010** (*missing data in division between others with no missing data*)
- **01** (*missing data in division after one with no missing data*)
- **10** (*division with missing data before one with no missing data*)

3.2.4 OHM

derive_ohm_coef(ser_QS, ser_QN)	A function to linearly fit two independant variables to a dependent one.
sim_ohm(ser_qn, a1, a2, a3)	Calculate QS using OHM (Objective Hysteresis Model).

supy.util.derive_ohm_coef

`supy.util.derive_ohm_coef`(*ser_QS*, *ser_QN*)

A function to linearly fit two independant variables to a dependent one. Input params: QS_Ser: The dependent variable QS (Surface heat storage). Pandas Series.

QN_Ser: The first independent variable (Net all wave radiation). Pandas Series. dt: The time interval with which the rate of change of QN is calculated. Float (hours).

Returns: a1, a2 coefficients and a3 (intercept)

supy.util.sim_ohm

`supy.util.sim_ohm`(*ser_qn: pandas.core.series.Series*, *a1: float*, *a2: float*, *a3: float*) → pandas.core.series.Series

Calculate QS using OHM (Objective Hysteresis Model).

Parameters

- **ser_qn** (*pd.Series*) – net all-wave radiation.

- **a1** (*float*) – a1 of OHM coefficients.
- **a2** (*float*) – a2 of OHM coefficients.
- **a3** (*float*) – a3 of OHM coefficients.

Returns heat storage flux calculated by OHM.

Return type pd.Series

3.2.5 Surface Conductance

cal_gs_mod(kd, ta_k, rh, pa, smd, lai, g_cst)	Model surface conductance/resistance using phenology and atmospheric forcing conditions.
cal_gs_obs(qh, qe, ta, rh, pa)	Calculate surface conductance based on observations, notably turbulent fluxes.
calib_g(df_fc_suews[, g_max, lai_max, s1, . . .])	Calibrate parameters for modelling surface conductance over vegetated surfaces using LMFIT.

supy.util.cal_gs_mod

supy.util.**cal_gs_mod**(*kd, ta_k, rh, pa, smd, lai, g_cst, g_max=30.0, lai_max=6.0, s1=5.56*)

Model surface conductance/resistance using phenology and atmospheric forcing conditions.

Parameters

- **kd** (*numeric*) – Incoming solar radiation [W m-2]
- **ta_k** (*numeric*) – Air temperature [K]
- **rh** (*numeric*) – Relative humidity [%]
- **pa** (*numeric*) – Air pressure
- **smd** (*numeric*) – Soil moisture deficit [mm]
- **lai** (*numeric*) – Leaf area index [m2 m-2]
- **g_cst** (*size-6 array*) – Parameters to determine surface conductance/resistance: g1 (LAI related), g2 (solar radiation related), g3 (humidity related), g4 (humidity related), g5 (air temperature related), g6 (soil moisture related)
- **g_max** (*numeric, optional*) – Maximum surface conductance [mm s-1], by default 30
- **lai_max** (*numeric, optional*) – Maximum LAI [m2 m-2], by default 6
- **s1** (*numeric, optional*) – Wilting point (WP=s1/g6, indicated as deficit [mm]) related parameter, by default 5.56

Returns Modelled surface conductance [mm s-1]

Return type numeric

supy.util.cal_gs_obs

supy.util.**cal_gs_obs**(*qh, qe, ta, rh, pa*)

Calculate surface conductance based on observations, notably turbulent fluxes.

Parameters

- **qh** (*numeric*) – Sensible heat flux [W m-2]
- **qe** (*numeric*) – Latent heat flux [W m-2]
- **ta** (*numeric*) – Air temperature [K]
- **rh** (*numeric*) – Relative humidity [%]
- **pa** (*numeric*) – Air pressure [Pa]

Returns Surface conductance based on observations [mm s-1]

Return type numeric

supy.util.calib_g

`supy.util.calib_g`(*df_fc_suews*, *g_max=33.1*, *lai_max=5.9*, *s1=5.56*, *method='cobyla'*, *prms_init=None*, *debug=False*)

Calibrate parameters for modelling surface conductance over vegetated surfaces using `LMFIT`.

Parameters

- **df_fc_suews** (*pandas.DataFrame*) – DataFrame in SuPy forcing format
- **g_max** (*numeric, optional*) – Maximum surface conductance [mm s-1], by default 30
- **lai_max** (*numeric, optional*) – Maximum LAI [m2 m-2], by default 6
- **s1** (*numeric, optional*) – Wilting point (WP=s1/g6, indicated as deficit [mm]) related parameter, by default 5.56
- **method** (*str, optional*) – Method used in minimisation by `lmfit.minimize`: details refer to its `method`.
- **prms_init** (*lmfit.Parameters*) – Initial parameters for calibration
- **debug** (*bool, optional*) – Option to output final calibrated `ModelResult`, by default False

Returns

dict, or ‘ModelResult <lmfit –

1. dict: {parameter_name -> best_fit_value}
2. `ModelResult`

Note: Parameters for surface conductance: g1 (LAI related), g2 (solar radiation related), g3 (humidity related), g4 (humidity related), g5 (air temperature related), g6 (soil moisture related)

Return type ModelResult>‘ if `debug==True`

Note: For calibration validity, turbulent fluxes, QH and QE, in `df_fc_suews` should ONLY be observations, i.e., interpolated values should be avoided. To do so, please place `np.nan` as missing values for QH and QE.

3.2.6 WRF-SUEWS

extract_reclassification(path_nml)	Extract reclassification info from path_nml as a DataFrame.
plot_reclassification(path_nml[, path_save, . . .])	Produce Sankey Diagram to visualise the reclassification specified in path_nml

supy.util.extract_reclassification

supy.util.**extract_reclassification**(*path_nml: str*) → pandas.core.frame.DataFrame

Extract reclassification info from path_nml as a DataFrame.

Parameters **path_nml** (*str*) – Path to namelist.suews

Returns Reclassification DataFrame with rows for WRF land covers while columns for SUEWS.

Return type pd.DataFrame

supy.util.plot_reclassification

supy.util.**plot_reclassification**(*path_nml: str*, *path_save='LC-WRF-SUEWS.png'*, *width=800*, *height=360*, *top=10*, *bottom=10*, *left=260*, *right=60*)

Produce Sankey Diagram to visualise the reclassification specified in path_nml

Parameters

- **path_nml** (*str*) – Path to namelist.suews
- **path_save** (*str, optional*) – Path to save Sankey diagram, by default 'LC-WRF-SUEWS.png'
- **width** (*int, optional*) – Width of diagram, by default 800
- **height** (*int, optional*) – Height of diagram, by default 360
- **top** (*int, optional*) – Top margin of diagram, by default 10
- **bottom** (*int, optional*) – Bottom margin of diagram, by default 10
- **left** (*int, optional*) – Left margin of diagram, by default 260
- **right** (*int, optional*) – Right margin of diagram, by default 60

Returns Sankey Diagram showing the reclassification.

Return type Sankey Diagram

3.2.7 Plotting

plot_comp(df_var[, scatter_kws, kde_kws, . . .])	Produce a scatter plot with linear regression line to compare simulation results and observations.
plot_day_clm(df_var[, fig, ax, show_dif, . . .])	Produce a ensemble diurnal climatologies with uncertainties shown in inter-quartile ranges.
plot_rsl(df_output[, var, fig, ax])	Produce a quick plot of RSL results

supy.util.plot_comp

`supy.util.plot_comp`(*df_var*, *scatter_kws={'alpha': 0.1, 'color': 'k', 's': 0.3}*, *kde_kws={'levels': 4, 'shade': True, 'shade_lowest': False}*, *show_pdf=False*, *fig=None*, *ax=None*)

Produce a scatter plot with linear regression line to compare simulation results and observations.

Parameters

- **df_var** (*pd.DataFrame*) – DataFrame containing variables to plot with datetime as index. Two columns, 'Obs' and 'Sim' for observations and simulation results, respectively, must exist.
- **scatter_kws** (*dict*) – keyword arguments passed to `sns.regplot`. By default, `{"alpha": 0.1, "s": 0.3, "color": "k"}`.
- **show_pdf** (*boolean*) – if a PDF overlay should be added. By default, `False`.
- **kde_kws** (*dict*) – `kde_kws` passed to `sns.kdeplot` when `show_pdf=True`

Returns figure showing 1:1 line plot

Return type MPL.figure

supy.util.plot_day_clm

`supy.util.plot_day_clm`(*df_var*, *fig=None*, *ax=None*, *show_dif=False*, *col_ref='Obs'*)

Produce a ensemble diurnal climatologies with uncertainties shown in inter-quartile ranges.

Parameters

- **df_var** (*pd.DataFrame*) – DataFrame containing variables to plot with datetime as index.
- **show_dif** (*boolean*) – flag to determine if differences against `col_ref` should be plotted.
- **col_ref** (*str*) – name of column that is used as reference to show differences instead of original values.

Returns figure showing median lines and IQR in shadings

Return type MPL.figure

supy.util.plot_rsl

`supy.util.plot_rsl`(*df_output*, *var=None*, *fig=None*, *ax=None*)

Produce a quick plot of RSL results

Parameters

- **df_output** (*pandas.DataFrame*) – SuPy output dataframe with RSL results.
- **var** (*str, optional*) – Varible to plot; must be one of 'U', 'T', or 'q'; or use `None` to plot all; by default None

Returns `(fig,ax)` of plot.

Return type tuple

Raises `issue` – If an invalid variable is specified, an issue will be raised.

3.2.8 Roughness Calculation

optimize_MO(df_val, z_meas, h_sfc)	Calculates surface roughness and zero plane displacement height.
cal_neutral(df_val, z_meas, h_sfc)	Calculates the rows associated with neutral condition (threshold=0.01)

supy.util.optimize_MO

supy.util.**optimize_MO**(*df_val*, *z_meas*, *h_sfc*)

Calculates surface roughness and zero plane displacement height. Refer to https://suews-parameters-docs.readthedocs.io/en/latest/steps/roughness-SuPy.html for example

Parameters

- **df_val** (*pd.DataFrame*) – Index should be time with columns: 'H', 'USTAR', 'TA', 'RH', 'PA', 'WS'
- **z_meas** – measurement height in m
- **h_sfc** – vegetation height in m

Returns

- *z0* – surface roughness
- *d* – zero displacement height
- **ser_ws** (*pd.series*) – observation time series of WS (Neutral conditions)
- **ser_ustar** (*pd.series*) – observation time series of u* (Neutral conditions)

supy.util.cal_neutral

supy.util.**cal_neutral**(*df_val*, *z_meas*, *h_sfc*)

Calculates the rows associated with neutral condition (threshold=0.01)

Parameters

- **df_val** (*pd.DataFrame*) – Index should be time with columns: 'H', 'USTAR', 'TA', 'RH', 'PA', 'WS'
- **z_meas** – measurement height in m
- **h_sfc** – vegetation height in m

Returns

- **ser_ws** (*pd.series*) – observation time series of WS (Neutral conditions)
- **ser_ustar** (*pd.series*) – observation time series of u* (Neutral conditions)

3.3 Command-Line Tools

3.3.1 suews-run

Run SUEWS simulation using settings in PATH_RUNCONTROL (default: "./RunControl.nml", i.e., the RunControl namelist file in the current directory).

```
suews-run [OPTIONS] [PATH_RUNCONTROL]
```

Arguments

PATH_RUNCONTROL
Optional argument

3.3.2 suews-convert

Convert SUEWS input tables from older versions to newer ones (one-way only).

```
suews-convert [OPTIONS]
```

Options

-f, --from <fromVer>
Version to convert from [required]

Options 2019b|2019a|2018c|2018b|2018a|2017a|2016a

-t, --to <toVer>
Version to convert to [required]

Options 2020a|2019b|2019a|2018c|2018b|2018a|2017a

-i, --input <fromDir>
Original directory to convert, which must have the `RunControl.nml` file [required]

-o, --output <toDir>
New directory to create for converted tables. Note: the created directory will have the same structure as the origianl one; however, forcing files and output folder won't be includede. [required]

3.4 Key Data Structures

3.4.1 `df_state` variables

Note: Data structure of `df_state` is explained *here*.

aerodynamicresistancemethod

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

ah_min

Description Minimum QF values.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables AHMin_WD, AHMin_WE

ah_slope_cooling

Description Cooling slope of QF calculation.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables AHSlope_Cooling_WD, AHSlope_Cooling_WE

ah_slope_heating

Description Heating slope of QF calculation.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables AHSlope_Heating_WD, AHSlope_Heating_WE

ahprof_24hr

Description Hourly profile values used in energy use calculation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables EnergyUseProfWD, EnergyUseProfWE

alb

Description Effective surface albedo (middle of the day value) for summertime.

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables AlbedoMax

albdectr_id

Description Albedo of deciduous surface DecTr on day 0 of run

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables albDecTr0

albevetr_id

Description Albedo of evergreen surface EveTr on day 0 of run

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables albEveTr0

albgrass_id

Description Albedo of grass surface Grass on day 0 of run

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables albGrass0

albmax_dectr

Description Effective surface albedo (middle of the day value) for summertime.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMax

albmax_evetr

Description Effective surface albedo (middle of the day value) for summertime.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMax

albmax_grass

Description Effective surface albedo (middle of the day value) for summertime.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMax

albmin_dectr

Description Effective surface albedo (middle of the day value) for wintertime (not including snow).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMin

albmin_evetr

Description Effective surface albedo (middle of the day value) for wintertime (not including snow).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMin

albmin_grass

Description Effective surface albedo (middle of the day value) for wintertime (not including snow).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables AlbedoMin

alpha_bioco2

Description The mean apparent ecosystem quantum. Represents the initial slope of the light-response curve.

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables `alpha`

`alpha_enh_bioco2`

Description Part of the `alpha` coefficient related to the fraction of vegetation.

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables `alpha_enh`

`alt`

Description Altitude of grids [m].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `Alt`

`baset`

Description Base Temperature for initiating growing degree days (GDD) for leaf growth. [°C]

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables `BaseT`

`baset_cooling`

Description Critical cooling temperature.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables `TCritic_Cooling_WD`, `TCritic_Cooling_WE`

`baset_hc`

Description Base temperature for heating degree days [°C]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `BaseT_HC`

`baset_heating`

Description Critical heating temperature.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables `TCritic_Heating_WD`, `TCritic_Heating_WE`

`basete`

Description Base temperature for initiating sensesance degree days (SDD) for leaf off. [°C]

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables BaseTe

basetmethod

Description Determines method for base temperature used in HDD/CDD calculations.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables BaseTMethod

beta_bioco2

Description The light-saturated gross photosynthesis of the canopy. [umol m^{-2} s^{-1}]

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables beta

beta_enh_bioco2

Description Part of the beta coefficient related to the fraction of vegetation.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables beta_enh

bldgh

Description Mean building height [m]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables H_Bldgs

capmax_dec

Description Maximum water storage capacity for upper surfaces (i.e. canopy)

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables StorageMax

capmin_dec

Description Minimum water storage capacity for upper surfaces (i.e. canopy).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables StorageMin

chanohm

Description Bulk transfer coefficient for this surface to use in AnOHM [-]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables AnOHM_Ch

co2pointsource

Description CO2 emission factor [kg km^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `CO2PointSource`

cpanohm

Description Volumetric heat capacity for this surface to use in AnOHM [J m^{-3}]

Dimensionality (7,)

Dimensionality Remarks 7: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`}

SUEWS-related variables `AnOHM_Cp`

crwmax

Description Maximum water holding capacity of snow [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `CRWMax`

crwmin

Description Minimum water holding capacity of snow [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `CRWMin`

daywat

Description Irrigation flag: 1 for on and 0 for off.

Dimensionality (7,)

Dimensionality Remarks 7: {Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday}

SUEWS-related variables `DayWat(1)`, `DayWat(2)`, `DayWat(3)`, `DayWat(4)`, `DayWat(5)`, `DayWat(6)`, `DayWat(7)`

daywatper

Description Fraction of properties using irrigation for each day of a week.

Dimensionality (7,)

Dimensionality Remarks 7: {Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday}

SUEWS-related variables `DayWatPer(1)`, `DayWatPer(2)`, `DayWatPer(3)`, `DayWatPer(4)`, `DayWatPer(5)`, `DayWatPer(6)`, `DayWatPer(7)`

decidcap_id

Description Storage capacity of deciduous surface `DecTr` on day 0 of run.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `decidCap0`

dectreeh

Description Mean height of deciduous trees [m]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables H_DecTr

diagnose

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

diagqn

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

diagqs

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

drainrt

Description Drainage rate of bucket for LUMPS [mm h^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables LUMPS_DrRate

ef_umolco2perj

Description Emission factor for fuels used for building heating.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables EF_umolCO2perJ

emis

Description Effective surface emissivity.

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables Emissivity

emissionsmethod

Description Determines method for QF calculation.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `EmissionsMethod`

enddls

Description End of the day light savings [DOY]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `EndDLS`

enef_v_jkm

Description Emission factor for heat [J k|m^-1|].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `EnEF_v_Jkm`

evapmethod

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

evetreeh

Description Mean height of evergreen trees [m]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `H_EveTr`

faibldg

Description Frontal area index for buildings [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `FAI_Bldgs`

faidectree

Description Frontal area index for deciduous trees [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `FAI_DecTr`

faievetree

Description Frontal area index for evergreen trees [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables FAI_EveTr

faut

Description Fraction of irrigated area that is irrigated using automated systems

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables Faut

fcef_v_kgkm

Description CO2 emission factor for weekdays [kg km^{-1}];;CO2 emission factor for weekends [kg km^{-1}]

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables FcEF_v_kgkmWD, FcEF_v_kgkmWE

flowchange

Description Difference in input and output flows for water surface [mm h^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables FlowChange

frfossilfuel_heat

Description Fraction of fossil fuels used for building heating [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables FrFossilFuel_Heat

frfossilfuel_nonheat

Description Fraction of fossil fuels used for building energy use [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables FrFossilFuel_NonHeat

g1

Description Related to maximum surface conductance [mm s^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G1

g2

Description Related to Kdown dependence [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G2

g3

Description Related to VPD dependence [units depend on gsModel]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G3

g4

Description Related to VPD dependence [units depend on gsModel]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G4

g5

Description Related to temperature dependence [°C]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G5

g6

Description Related to soil moisture dependence [mm^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables G6

gddfull

Description The growing degree days (GDD) needed for full capacity of the leaf area index (LAI) [°C].

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables GDDFull

gsmodel

Description Formulation choice for conductance calculation.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables gsModel

h_maintain

Description water depth to maintain used in automatic irrigation (e.g., ponding water due to flooding irrigation in rice crop-field) [mm].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables H_maintain

humactivity_24hr

Description Hourly profile values used in human activity calculation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables ActivityProfWD, ActivityProfWE

ie_a

Description Coefficient for automatic irrigation model.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables Ie_a1, Ie_a2, Ie_a3

ie_end

Description Day when irrigation ends [DOY]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables Ie_end

ie_m

Description Coefficient for manual irrigation model.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables Ie_m1, Ie_m2, Ie_m3

ie_start

Description Day when irrigation starts [DOY]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables Ie_start

internalwateruse_h

Description Internal water use [mm h^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables InternalWaterUse

irrfracbldgs

Description Fraction of Bldgs that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_Bldgs

irrfracbsoil

Description Fraction of BSoil that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_BSoil

irrfracdectr

Description Fraction of DecTr that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_DecTr

irrfracevetr

Description Fraction of EveTr that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_EveTr

irrfracgrass

Description Fraction of Grass that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_Grass

irrfracpaved

Description Fraction of Paved that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_Paved

irrfracwater

Description Fraction of Water that is irrigated [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables IrrFr_Water

kkanohm

Description Thermal conductivity for this surface to use in AnOHM [W m K^{-1}]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables AnOHM_Kk

kmax

Description Maximum incoming shortwave radiation [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables Kmax

lai_id

Description Initial LAI values.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables LAIinitialDecTr, LAIinitialEveTr, LAIinitialGrass

laicalcyes

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

laimax

Description full leaf-on summertime value

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables LAIMax

laimin

Description leaf-off wintertime value

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables LAIMin

laipower

Description parameters required by LAI calculation.

Dimensionality (4, 3)

Dimensionality Remarks 4: {LeafGrowthPower1, LeafGrowthPower2, LeafOffPower1, LeafOffPower2}

3: { EveTr, DecTr, Grass}

SUEWS-related variables LeafGrowthPower1, LeafGrowthPower2, LeafOffPower1, LeafOffPower2

laitype

Description LAI calculation choice.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables LAIEq

lat

Description Latitude [deg].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables lat

lng

Description longitude [deg]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables lng

maxconductance

Description The maximum conductance of each vegetation or surface type. [mm s^{-1}]

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables MaxConductance

maxfcmetab

Description Maximum (day) CO2 from human metabolism. [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables MaxFCMetab

maxqfmetab

Description Maximum value for human heat emission. [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables MaxQFMetab

min_res_bioco2

Description Minimum soil respiration rate (for cold-temperature limit) [umol m^{-2} s^{-1}].

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables min_respi

minfcmetab

Description Minimum (night) CO2 from human metabolism. [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `MinFCMetab`

minqfmetab

Description Minimum value for human heat emission. [W m^{-2}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `MinQFMetab`

narp_emis_snow

Description Effective surface emissivity.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `Emissivity`

narp_trans_site

Description Atmospheric transmissivity for NARP [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `NARP_Trans`

netradiationmethod

Description Determines method for calculation of radiation fluxes.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `NetRadiationMethod`

ohm_coef

Description Coefficients for OHM calculation.

Dimensionality (8, 4, 3)

Dimensionality Remarks 8: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`, one extra land cover type (currently NOT used)}

4: {SummerWet, SummerDry, WinterWet, WinterDry}

3: {a1, a2, a3}

SUEWS-related variables `a1`, `a2`, `a3`

ohm_threshsw

Description Temperature threshold determining whether summer/winter OHM coefficients are applied [°C]

Dimensionality (8,)

Dimensionality Remarks 8: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`, one extra land cover type (currently NOT used)}

SUEWS-related variables `OHMThresh_SW`

ohm_threshwd

Description Soil moisture threshold determining whether wet/dry OHM coefficients are applied [-]

Dimensionality (8,)

Dimensionality Remarks 8: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`, one extra land cover type (currently NOT used)}

SUEWS-related variables `OHMThresh_WD`

ohmincqf

Description Determines whether the storage heat flux calculation uses Q^* or (Q^* +QF).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `OHMIncQF`

pipecapacity

Description Storage capacity of pipes [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `PipeCapacity`

popdensdaytime

Description Daytime population density (i.e. workers, tourists) [people ha^{-1}]

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables `PopDensDay`

popdensnighttime

Description Night-time population density (i.e. residents) [people ha^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `PopDensNight`

popprof_24hr

Description Hourly profile values used in dynamic population estimation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables `PopProfWD`, `PopProfWE`

pormax_dec

Description full leaf-on summertime value Used only for `DecTr` (can affect roughness calculation)

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables PorosityMax

pormin_dec

Description leaf-off wintertime value Used only for DecTr (can affect roughness calculation)

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables PorosityMin

porosity_id

Description Porosity of deciduous vegetation on day 0 of run.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables porosity0

preciplimit

Description Temperature limit when precipitation falls as snow [°C]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables PrecipLimSnow

preciplimitalb

Description Limit for hourly precipitation when the ground is fully covered with snow [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables PrecipLimAlb

qf0_beu

Description Building energy use [W m^{-2}]

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables QF0_BEU_WD, QF0_BEU_WE

qf_a

Description Base value for QF calculation.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables QF_A_WD, QF_A_WE

qf_b

Description Parameter related to heating degree days.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables QF_B_WD, QF_B_WE

qf_c

Description Parameter related to heating degree days.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables QF_C_WD, QF_C_WE

radmeltfact

Description Hourly radiation melt factor of snow [mm W^{-1} h^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables RadMeltFactor

raincover

Description Limit when surface totally covered with water for LUMPS [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables LUMPS_Cover

rainmaxres

Description Maximum water bucket reservoir [mm] Used for LUMPS surface wetness control.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables LUMPS_MaxRes

resp_a

Description Respiration coefficient a.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables resp_a

resp_b

Description Respiration coefficient b - related to air temperature dependency.

Dimensionality (3,)

Dimensionality Remarks 3: { EveTr, DecTr, Grass}

SUEWS-related variables resp_b

roughlenheatmethod

Description Determines method for calculating roughness length for heat.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables RoughLenHeatMethod

roughlenmommethod

Description Determines how aerodynamic roughness length (z0m) and zero displacement height (zdm) are calculated.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `RoughLenMomMethod`

runofftowater

Description Fraction of above-ground runoff flowing to water surface during flooding [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `RunoffToWater`

s1

Description A parameter related to soil moisture dependence [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `S1`

s2

Description A parameter related to soil moisture dependence [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `S2`

sathydraulicconduct

Description Hydraulic conductivity for saturated soil [mm s^{-1}]

Dimensionality (7,)

Dimensionality Remarks 7: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`}

SUEWS-related variables `SatHydraulicCond`

sddfull

Description The sensesence degree days (SDD) needed to initiate leaf off. [°C]

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables `SDDFull`

sfr

Description Surface cover fractions.

Dimensionality (7,)

Dimensionality Remarks 7: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`}

SUEWS-related variables `Fr_Bldgs`, `Fr_Bsoil`, `Fr_DecTr`, `Fr_EveTr`, `Fr_Grass`, `Fr_Paved`, `Fr_Water`

smdmethod

Description Determines method for calculating soil moisture deficit (SMD).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `SMDMethod`

`snowalb`

Description Initial snow albedo

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `SnowAlb0`

`snowalbmax`

Description Effective surface albedo (middle of the day value) for summertime.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `AlbedoMax`

`snowalbmin`

Description Effective surface albedo (middle of the day value) for wintertime (not including snow).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `AlbedoMin`

`snowdens`

Description Initial snow density of each land cover.

Dimensionality (7,)

Dimensionality Remarks 7: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`}

SUEWS-related variables `SnowDensBldgs`, `SnowDensPaved`, `SnowDensDecTr`, `SnowDensEveTr`, `SnowDensGrass`, `SnowDensBSoil`, `SnowDensWater`

`snowdensmax`

Description Maximum snow density [kg m^{-3}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `SnowDensMax`

`snowdensmin`

Description Fresh snow density [kg m^{-3}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `SnowDensMin`

`snowfrac`

Description Initial plan area fraction of snow on each land cover‘

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SnowFracBldgs, SnowFracPaved, SnowFracDecTr, SnowFracEveTr, SnowFracGrass, SnowFracBSoil, SnowFracWater

snowlimbldg

Description Limit of the snow water equivalent for snow removal from roads and roofs [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables SnowLimRemove

snowlimpaved

Description Limit of the snow water equivalent for snow removal from roads and roofs [mm]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables SnowLimRemove

snowpack

Description Initial snow water equivalent on each land cover

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SnowPackBldgs, SnowPackPaved, SnowPackDecTr, SnowPackEveTr, SnowPackGrass, SnowPackBSoil, SnowPackWater

snowpacklimit

Description Limit for the snow water equivalent when snow cover starts to be patchy [mm]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SnowLimPatch

snowprof_24hr

Description Hourly profile values used in snow clearing.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables SnowClearingProfWD, SnowClearingProfWE

snowuse

Description Determines whether the snow part of the model runs.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables SnowUse

snowwater

Description Initial amount of liquid water in the snow on each land cover

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SnowWaterBldgsState, SnowWaterPavedState, SnowWaterDecTrState, SnowWaterEveTrState, SnowWaterGrassState, SnowWaterBSoilState, SnowWaterWaterState

soildepth

Description Depth of soil beneath the surface [mm]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SoilDepth

soilstore_id

Description Initial water stored in soil beneath each land cover

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SoilstoreBldgsState, SoilstorePavedState, SoilstoreDecTrState, SoilstoreEveTrState, SoilstoreGrassState, SoilstoreBSoilState

soilstorecap

Description Limit value for SoilDepth [mm]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables SoilStoreCap

stabilitymethod

Description Defines which atmospheric stability functions are used.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables StabilityMethod

startdls

Description Start of the day light savings [DOY]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables StartDLS

state_id

Description Initial wetness condition on each land cover

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables BldgsState, PavedState, DecTrState, EveTrState, GrassState, BSoilState, WaterState

statelimit

Description Upper limit to the surface state. [mm]

Dimensionality (7,)

Dimensionality Remarks 7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables StateLimit

storageheatmethod

Description Determines method for calculating storage heat flux ΔQS.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables StorageHeatMethod

storedrainprm

Description Coefficients used in drainage calculation.

Dimensionality (6, 7)

Dimensionality Remarks 6: { StorageMin, DrainageEq, DrainageCoef1, DrainageCoef2, StorageMax, current storage}

7: { Paved, Bldgs, EveTr, DecTr, Grass, BSoil, Water}

SUEWS-related variables DrainageCoef1, DrainageCoef2, DrainageEq, StorageMax, StorageMin

surfacearea

Description Area of the grid [ha].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables SurfaceArea

tau_a

Description Time constant for snow albedo aging in cold snow [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables tau_a

tau_f

Description Time constant for snow albedo aging in melting snow [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables tau_f

tau_r

Description Time constant for snow density ageing [-]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `tau_r`

`tempmeltfact`

Description Hourly temperature melt factor of snow [mm K^{-1} h^{-1}]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `TempMeltFactor`

`th`

Description Upper air temperature limit [°C]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `TH`

`theta_bioco2`

Description The convexity of the curve at light saturation.

Dimensionality (3,)

Dimensionality Remarks 3: { `EveTr`, `DecTr`, `Grass`}

SUEWS-related variables `theta`

`timezone`

Description Time zone [h] for site relative to UTC (east is positive). This should be set according to the times given in the meteorological forcing file(s).

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `Timezone`

`tl`

Description Lower air temperature limit [°C]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `TL`

`trafficrate`

Description Traffic rate used for CO2 flux calculation.

Dimensionality (2,)

Dimensionality Remarks 2: {Weekday, Weekend}

SUEWS-related variables `TrafficRate_WD`, `TrafficRate_WE`

`trafficunits`

Description Units for the traffic rate for the study area. Not used in v2018a.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `TrafficUnits`

traffprof_24hr

Description Hourly profile values used in traffic activity calculation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables `TraffProfWD`, `TraffProfWE`

tstep

Description Specifies the model time step [s].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `Tstep`

veg_type

Description Internal use. Please DO NOT modify

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables None

waterdist

Description Fraction of water redistribution

Dimensionality (8, 6)

Dimensionality Remarks 8: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`, one extra land cover type (currently NOT used)}

6: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`}

SUEWS-related variables `ToBSoil`, `ToBldgs`, `ToDecTr`, `ToEveTr`, `ToGrass`, `ToPaved`, `ToRunoff`, `ToSoilStore`, `ToWater`

waterusemethod

Description Defines how external water use is calculated.

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `WaterUseMethod`

wetthresh

Description Depth of water which determines whether evaporation occurs from a partially wet or completely wet surface [mm].

Dimensionality (7,)

Dimensionality Remarks 7: { `Paved`, `Bldgs`, `EveTr`, `DecTr`, `Grass`, `BSoil`, `Water`}

SUEWS-related variables `WetThreshold`

`wuprofa_24hr`

Description Hourly profile values used in automatic irrigation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables `WaterUseProfAutoWD`, `WaterUseProfAutoWE`

`wuprofm_24hr`

Description Hourly profile values used in manual irrigation.

Dimensionality (24, 2)

Dimensionality Remarks 24: hours of a day

2: {Weekday, Weekend}

SUEWS-related variables `WaterUseProfManuWD`, `WaterUseProfManuWE`

`z`

Description Measurement height [m].

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `z`

`z0m_in`

Description Roughness length for momentum [m]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `z0`

`zdm_in`

Description Zero-plane displacement [m]

Dimensionality 0

Dimensionality Remarks Scalar

SUEWS-related variables `zd`

3.4.2 `df_forcing` variables

Note: Data structure of `df_forcing` is explained *here*.

`RH`

Description Relative Humidity [%]

`Tair`

Description Air temperature [°C]

U

Description Wind speed [m s-1] Height of the wind speed measurement (z) is needed in `SUEWS_SiteSelect.txt`.

Wuh

Description External water use [m^3]

fcld

Description Cloud fraction [tenths]

id

Description Day of year [DOY]

imin

Description Minute [M]

isec

Description Second [S]

it

Description Hour [H]

iy

Description Year [YYYY]

kdiff

Description Diffuse radiation [W m^{-2}] **Recommended in this version.** if `SOLWEIGUse` = 1

kdir

Description Direct radiation [W m^{-2}] **Recommended in this version.** if `SOLWEIGUse` = 1

kdown

Description Incoming shortwave radiation [W m^{-2}] Must be > 0 W m^{-2}.

lai

Description Observed leaf area index [m^{-2} m^{-2}]

ldown

Description Incoming longwave radiation [W m^{-2}]

pres

Description Barometric pressure [kPa]

qe

Description Latent heat flux [W m^{-2}]

qf

Description Anthropogenic heat flux [W m^{-2}]

qh

Description Sensible heat flux [W m^{-2}]

qn

Description Net all-wave radiation [W m^{-2}] Required if `NetRadiationMethod` = 0.

qs

Description Storage heat flux [W m^{-2}]

rain

Description Rainfall [mm]

snow

Description Snow cover fraction (0 – 1) [-] Required if `SnowUse` = 1

wdir

Description Wind direction [°] **Not available in this version.**

xsmd

Description Observed soil moisture [m^{3} m^{-3}] or [kg kg^{-1}]

3.4.3 `df_output` variables

Note: Data structure of `df_output` is explained *here*.

AddWater

Description Additional water flow received from other grids [mm]

Group SUEWS

AlbBulk

Description Bulk albedo [-]

Group SUEWS

AlbDecTr

Description Albedo of deciduous trees [-]

Group DailyState

AlbEveTr

Description Albedo of evergreen trees [-]

Group DailyState

AlbGrass

Description Albedo of grass [-]

Group DailyState

AlbSnow

Description Snow albedo [-]

Group SUEWS

AlbSnow

Description Snow albedo [-]

Group DailyState

Azimuth

Description Solar azimuth angle [°]

Group SUEWS

CI

Description clearness index for Ldown (Lindberg et al. 2008)

Group SOLWEIG

DLHrs

Description Day length [h]

Group DailyState

DaysSR

Description Days since rain [days]

Group DailyState

DecidCap

Description Moisture storage capacity of deciduous trees [mm]

Group DailyState

DensSnow_BSoil

Description Snow density – bare soil surface [kg m^{-3}]

Group DailyState

DensSnow_BSoil

Description Snow density - bare soil surface [kg m^{-3}]

Group snow

DensSnow_BSoil

Description Snow density - bare soil surface [kg m^{-3}]

Group DailyState

DensSnow_BSoil

Description Snow density – bare soil surface [kg m^{-3}]

Group snow

DensSnow_Bldgs

Description Snow density - building surface [kg m^{-3}]

Group DailyState

DensSnow_Bldgs

Description Snow density - building surface [kg m^{-3}]

Group snow

DensSnow_Bldgs

Description Snow density – building surface [kg m^{-3}]

Group snow

DensSnow_Bldgs

Description Snow density – building surface [kg m^{-3}]

Group DailyState

DensSnow_DecTr

Description Snow density – deciduous surface [kg m^{-3}]

Group DailyState

DensSnow_DecTr

Description Snow density - deciduous surface [kg m^{-3}]

Group DailyState

DensSnow_DecTr

Description Snow density – deciduous surface [kg m^{-3}]

Group snow

DensSnow_DecTr

Description Snow density - deciduous surface [kg m^{-3}]

Group snow

DensSnow_EveTr

Description Snow density - evergreen surface [kg m^{-3}]

Group snow

DensSnow_EveTr

Description Snow density – evergreen surface [kg m^{-3}]

Group snow

DensSnow_EveTr

Description Snow density - evergreen surface [kg m^{-3}]

Group DailyState

DensSnow_EveTr

Description Snow density – evergreen surface [kg m^{-3}]

Group DailyState

DensSnow_Grass

Description Snow density - grass surface [kg m^{-3}]

Group snow

DensSnow_Grass

Description Snow density – grass surface [kg m^{-3}]

Group DailyState

DensSnow_Grass

Description Snow density – grass surface [kg m^{-3}]

Group snow

DensSnow_Grass

Description Snow density - grass surface [kg m^{-3}]

Group DailyState

DensSnow_Paved

Description Snow density - paved surface [kg m^{-3}]

Group snow

DensSnow_Paved

Description Snow density – paved surface [kg m^{-3}]

Group snow

DensSnow_Paved

Description Snow density - paved surface [kg m^{-3}]

Group DailyState

DensSnow_Paved

Description Snow density – paved surface [kg m^{-3}]

Group DailyState

DensSnow_Water

Description Snow density – water surface [kg m^{-3}]

Group DailyState

DensSnow_Water

Description Snow density - water surface [kg m^{-3}]

Group DailyState

DensSnow_Water

Description Snow density – water surface [kg m^{-3}]

Group snow

DensSnow_Water

Description Snow density - water surface [kg m^{-3}]

Group snow

DiffuseRad

Description Diffuse shortwave radiation

Group SOLWEIG

DirectRad

Description Direct shortwave radiation

Group SOLWEIG

Drainage

Description Drainage [mm]

Group SUEWS

Evap

Description Evaporation [mm]

Group SUEWS

Fc

Description CO2 flux [umol m^{-2} s^{-1}]

Group SUEWS

FcBuild

Description CO2 flux from buildings [umol m^{-2} s^{-1}]

Group SUEWS

FcMetab

Description CO2 flux from metabolism [umol m^{-2} s^{-1}]

Group SUEWS

FcPhoto

Description CO2 flux from photosynthesis [umol m^{-2} s^{-1}]

Group SUEWS

FcPoint

Description CO2 flux from point source [umol m^{-2} s^{-1}]

Group SUEWS

FcRespi

Description CO2 flux from respiration [umol m^{-2} s^{-1}]

Group SUEWS

FcTraff

Description CO2 flux from traffic [umol m^{-2} s^{-1}]

Group SUEWS

Fcld

Description Cloud fraction [-]

Group SUEWS

FlowCh

Description Additional flow into water body [mm]

Group SUEWS

GDD_DecTr

Description Growing degree days for deciduous tree [°C d]

Group DailyState

GDD_EveTr

Description Growing degree days for evergreen eree [°C d]

Group DailyState

GDD_Grass

Description Growing degree days for grass [°C d]

Group DailyState

GlobalRad

Description Input Kdn

Group SOLWEIG

HDD1_h

Description Heating degree days [°C d]

Group DailyState

HDD2_c

Description Cooling degree days [°C d]

Group DailyState

HDD3_Tmean

Description Average daily air temperature [°C]

Group DailyState

HDD4_T5d

Description 5-day running-mean air temperature [°C]

Group DailyState

I0

Description theoretical value of maximum incoming solar radiation

Group SOLWEIG

Irr

Description Irrigation [mm]

Group SUEWS

Kdown

Description Incoming shortwave radiation [W m^{-2}]

Group SUEWS

Kdown2d

Description Incoming shortwave radiation at POI

Group SOLWEIG

Keast

Description Shortwave radiation from east at POI

Group SOLWEIG

Knorth

Description Shortwave radiation from north at POI

Group SOLWEIG

Ksouth

Description Shortwave radiation from south at POI

Group SOLWEIG

Kup

Description Outgoing shortwave radiation [W m^{-2}]

Group SUEWS

Kup2d

Description Outgoing shortwave radiation at POI

Group SOLWEIG

Kwest

Description Shortwave radiation from west at POI

Group SOLWEIG

LAI

Description Leaf area index [m 2 m^{-2}]

Group SUEWS

LAI_DecTr

Description Leaf area index of deciduous trees [m^{-2} m^{-2}]

Group DailyState

LAI_EveTr

Description Leaf area index of evergreen trees [m^{-2} m^{-2}]

Group DailyState

LAI_Grass

Description Leaf area index of grass [m^{-2} m^{-2}]

Group DailyState

LAIlumps

Description Leaf area index used in LUMPS (normalised 0-1) [-]

Group DailyState

Ldown

Description Incoming longwave radiation [W m^{-2}]

Group SUEWS

Ldown2d

Description Incoming longwave radiation at POI

Group SOLWEIG

Least

Description Longwave radiation from east at POI

Group SOLWEIG

Lnorth

Description Longwave radiation from north at POI

Group SOLWEIG

Lob

Description Obukhov length [m]

Group SUEWS

Lsouth

Description Longwave radiation from south at POI

Group SOLWEIG

Lup

Description Outgoing longwave radiation [W m^{-2}]

Group SUEWS

Lup2d

Description Outgoing longwave radiation at POI

Group SOLWEIG

Lwest

Description Longwave radiation from west at POI

Group SOLWEIG

MeltWStore

Description Meltwater store [mm]

Group SUEWS

MeltWater

Description Meltwater [mm]

Group SUEWS

MwStore_BSoil

Description Melt water store – bare soil surface [mm]

Group snow

MwStore_Bldgs

Description Melt water store – building surface [mm]

Group snow

MwStore_DecTr

Description Melt water store – deciduous surface [mm]

Group snow

MwStore_EveTr

Description Melt water store – evergreen surface [mm]

Group snow

MwStore_Grass

Description Melt water store – grass surface [mm]

Group snow

MwStore_Paved

Description Melt water store – paved surface [mm]

Group snow

MwStore_Water

Description Melt water store – water surface [mm]

Group snow

Mw_BSoil

Description Meltwater – bare soil surface [mm h^{-1}]

Group snow

Mw_Bldgs

Description Meltwater – building surface [mm h^{-1}]

Group snow

Mw_DecTr

Description Meltwater – deciduous surface [mm h^{-1}]

Group snow

Mw_EveTr

Description Meltwater – evergreen surface [mm h^{-1}]

Group snow

Mw_Grass

Description Meltwater – grass surface [mm h^{-1} 1]

Group snow

Mw_Paved

Description Meltwater – paved surface [mm h^{-1}]

Group snow

Mw_Water

Description Meltwater – water surface [mm h^{-1}]

Group snow

NWtrState

Description Surface wetness state (for non-water surfaces) [mm]

Group SUEWS

P_day

Description Daily total precipitation [mm]

Group DailyState

Porosity

Description Porosity of deciduous trees [-]

Group DailyState

Q2

Description Air specific humidity at 2 m agl [g kg^{-1}]

Group SUEWS

QE

Description Latent heat flux (calculated using SUEWS) [W m^{-2}]

Group SUEWS

QElumps

Description Latent heat flux (calculated using LUMPS) [W m^{-2}]

Group SUEWS

QF

Description Anthropogenic heat flux [W m^{-2}]

Group SUEWS

QH

Description Sensible heat flux (calculated using SUEWS) [W m^{-2}]

Group SUEWS

QHlumps

Description Sensible heat flux (calculated using LUMPS) [W m^{-2}]

Group SUEWS

QHresis

Description Sensible heat flux (calculated using resistance method) [W m^{-2}]

Group SUEWS

QM

Description Snow-related heat exchange [W m^{-2}]

Group SUEWS

QMFreeze

Description Internal energy change [W m^{-2}]

Group SUEWS

QMRain

Description Heat released by rain on snow [W m^{-2}]

Group SUEWS

QN

Description Net all-wave radiation [W m^{-2}]

Group SUEWS

QNSnow

Description Net all-wave radiation for snow area [W m^{-2}]

Group SUEWS

QNSnowFr

Description Net all-wave radiation for snow-free area [W m^{-2}]

Group SUEWS

QS

Description Storage heat flux [W m^{-2}]

Group SUEWS

Qa_BSoil

Description Advective heat – bare soil surface [W m^{-2}]

Group snow

Qa_Bldgs

Description Advective heat – building surface [W m^{-2}]

Group snow

Qa_DecTr

Description Advective heat – deciduous surface [W m^{-2}]

Group snow

Qa_EveTr

Description Advective heat – evergreen surface [W m^{-2}]

Group snow

Qa_Grass

Description Advective heat – grass surface [W m^{-2}]

Group snow

Qa_Paved

Description Advective heat – paved surface [W m^{-2}]

Group snow

Qa_Water

Description Advective heat – water surface [W m^{-2}]

Group snow

QmFr_BSoil

Description Heat related to freezing of surface store – bare soil surface [W m^{-2}]

Group snow

QmFr_Bldgs

Description Heat related to freezing of surface store – building surface [W m^{-2}]

Group snow

QmFr_DecTr

Description Heat related to freezing of surface store – deciduous surface [W m^{-2}]

Group snow

QmFr_EveTr

Description Heat related to freezing of surface store – evergreen surface [W m^{-2}]

Group snow

QmFr_Grass

Description Heat related to freezing of surface store – grass surface [W m^{-2}]

Group snow

QmFr_Paved

Description Heat related to freezing of surface store – paved surface [W m^{-2}]

Group snow

QmFr_Water

Description Heat related to freezing of surface store – water [W m^{-2}]

Group snow

Qm_BSoil

Description Snowmelt-related heat – bare soil surface [W m^{-2}]

Group snow

Qm_Bldgs

Description Snowmelt-related heat – building surface [W m^{-2}]

Group snow

Qm_DecTr

Description Snowmelt-related heat – deciduous surface [W m^{-2}]

Group snow

Qm_EveTr

Description Snowmelt-related heat – evergreen surface [W m^{-2}]

Group snow

Qm_Grass

Description Snowmelt-related heat – grass surface [W m^{-2}]

Group snow

Qm_Paved

Description Snowmelt-related heat – paved surface [W m^{-2}]

Group snow

Qm_Water

Description Snowmelt-related heat – water surface [W m^{-2}]

Group snow

RA

Description Aerodynamic resistance [s m^{-1}]

Group SUEWS

RH2

Description Relative humidity at 2 m agl [%]

Group SUEWS

RO

Description Runoff [mm]

Group SUEWS

ROImp

Description Above ground runoff over impervious surfaces [mm]

Group SUEWS

ROPipe

Description Runoff to pipes [mm]

Group SUEWS

ROSoil

Description Runoff to soil (sub-surface) [mm]

Group SUEWS

ROVeg

Description Above ground runoff over vegetated surfaces [mm]

Group SUEWS

ROWater

Description Runoff for water body [mm]

Group SUEWS

RS

Description Surface resistance [s m^{-1}]

Group SUEWS

Rain

Description Rain [mm]

Group SUEWS

RainSn_BSoil

Description Rain on snow – bare soil surface [mm]

Group snow

RainSn_Bldgs

Description Rain on snow – building surface [mm]

Group snow

RainSn_DecTr

Description Rain on snow – deciduous surface [mm]

Group snow

RainSn_EveTr

Description Rain on snow – evergreen surface [mm]

Group snow

RainSn_Grass

Description Rain on snow – grass surface [mm]

Group snow

RainSn_Paved

Description Rain on snow – paved surface [mm]

Group snow

RainSn_Water

Description Rain on snow – water surface [mm]

Group snow

SDD_DecTr

Description Senescence degree days for deciduous tree [°C d]

Group DailyState

SDD_EveTr

Description Senescence degree days for evergreen eree [°C d]

Group DailyState

SDD_Grass

Description Senescence degree days for grass [°C d]

Group DailyState

SMD

Description Soil moisture deficit [mm]

Group SUEWS

SMDBSoil

Description Soil moisture deficit for bare soil surface [mm]

Group SUEWS

SMDBldgs

Description Soil moisture deficit for building surface [mm]

Group SUEWS

SMDDecTr

Description Soil moisture deficit for deciduous surface [mm]

Group SUEWS

SMDEveTr

Description Soil moisture deficit for evergreen surface [mm]

Group SUEWS

SMDGrass

Description Soil moisture deficit for grass surface [mm]

Group SUEWS

SMDPaved

Description Soil moisture deficit for paved surface [mm]

Group SUEWS

SWE

Description Snow water equivalent [mm]

Group SUEWS

SWE_BSoil

Description Snow water equivalent – bare soil surface [mm]

Group snow

SWE_Bldgs

Description Snow water equivalent – building surface [mm]

Group snow

SWE_DecTr

Description Snow water equivalent – deciduous surface [mm]

Group snow

SWE_EveTr

Description Snow water equivalent – evergreen surface [mm]

Group snow

SWE_Grass

Description Snow water equivalent – grass surface [mm]

Group snow

SWE_Paved

Description Snow water equivalent – paved surface [mm]

Group snow

SWE_Water

Description Snow water equivalent – water surface [mm]

Group snow

Sd_BSoil

Description Snow depth – bare soil surface [mm]

Group snow

Sd_Bldgs

Description Snow depth – building surface [mm]

Group snow

Sd_DecTr

Description Snow depth – deciduous surface [mm]

Group snow

Sd_EveTr

Description Snow depth – evergreen surface [mm]

Group snow

Sd_Grass

Description Snow depth – grass surface [mm]

Group snow

Sd_Paved

Description Snow depth – paved surface [mm]

Group snow

Sd_Water

Description Snow depth – water surface [mm]

Group snow

SnowCh

Description Change in snow pack [mm]

Group SUEWS

SnowRBldgs

Description Snow removed from building surface [mm]

Group SUEWS

SnowRPaved

Description Snow removed from paved surface [mm]

Group SUEWS

StBSoil

Description Surface wetness state for bare soil surface [mm]

Group SUEWS

StBldgs

Description Surface wetness state for building surface [mm]

Group SUEWS

StDecTr

Description Surface wetness state for deciduous tree surface [mm]

Group SUEWS

StEveTr

Description Surface wetness state for evergreen tree surface [mm]

Group SUEWS

StGrass

Description Surface wetness state for grass surface [mm]

Group SUEWS

StPaved

Description Surface wetness state for paved surface [mm]

Group SUEWS

StWater

Description Surface wetness state for water surface [mm]

Group SUEWS

State

Description Surface wetness state [mm]

Group SUEWS

SurfCh

Description Change in surface moisture store [mm]

Group SUEWS

T2

Description Air temperature at 2 m agl [°C]

Group SUEWS

T_1

Description Air temperature at level 1 [°C]

Group RSL

T_10

Description Air temperature at level 10 [°C]

Group RSL

T_11

Description Air temperature at level 11 [°C]

Group RSL

T_12

Description Air temperature at level 12 [°C]

Group RSL

T_13

Description Air temperature at level 13 [°C]

Group RSL

T_14

Description Air temperature at level 14 [°C]

Group RSL

T_15

Description Air temperature at level 15 [°C]

Group RSL

T_16

Description Air temperature at level 16 [°C]

Group RSL

T_17

Description Air temperature at level 17 [°C]

Group RSL

T_18

Description Air temperature at level 18 [°C]

Group RSL

T_19

Description Air temperature at level 19 [°C]

Group RSL

T_2

Description Air temperature at level 2 [°C]

Group RSL

T_20

Description Air temperature at level 20 [°C]

Group RSL

T_21

Description Air temperature at level 21 [°C]

Group RSL

T_22

Description Air temperature at level 22 [°C]

Group RSL

T_23

Description Air temperature at level 23 [°C]

Group RSL

T_24

Description Air temperature at level 24 [°C]

Group RSL

T_25

Description Air temperature at level 25 [°C]

Group RSL

T_26

Description Air temperature at level 26 [°C]

Group RSL

T_27

Description Air temperature at level 27 [°C]

Group RSL

T_28

Description Air temperature at level 28 [°C]

Group RSL

T_29

Description Air temperature at level 29 [°C]

Group RSL

T_3

Description Air temperature at level 3 [°C]

Group RSL

T_30

Description Air temperature at level 30 [°C]

Group RSL

T_4

Description Air temperature at level 4 [°C]

Group RSL

T_5

Description Air temperature at level 5 [°C]

Group RSL

T_6

Description Air temperature at level 6 [°C]

Group RSL

T_7

Description Air temperature at level 7 [°C]

Group RSL

T_8

Description Air temperature at level 8 [°C]

Group RSL

T_9

Description Air temperature at level 9 [°C]

Group RSL

Ta

Description Air temperature

Group SOLWEIG

Tg

Description Surface temperature

Group SOLWEIG

Tmax

Description Daily maximum temperature [°C]

Group DailyState

Tmin

Description Daily minimum temperature [°C]

Group DailyState

Tmrt

Description Mean Radiant Temperature

Group SOLWEIG

TotCh

Description Change in surface and soil moisture stores [mm]

Group SUEWS

Ts

Description Skin temperature [°C]

Group SUEWS

Tsnow_BSoil

Description Snow surface temperature – bare soil surface [°C]

Group snow

Tsnow_Bldgs

Description Snow surface temperature – building surface [°C]

Group snow

Tsnow_DecTr

Description Snow surface temperature – deciduous surface [°C]

Group snow

Tsnow_EveTr

Description Snow surface temperature – evergreen surface [°C]

Group snow

`Tsnow_Grass`

Description Snow surface temperature – grass surface [°C]

Group snow

`Tsnow_Paved`

Description Snow surface temperature – paved surface [°C]

Group snow

`Tsnow_Water`

Description Snow surface temperature – water surface [°C]

Group snow

`Tsurf`

Description Bulk surface temperature [°C]

Group SUEWS

`U10`

Description Wind speed at 10 m agl [m s^{-1}]

Group SUEWS

`U_1`

Description Wind speed at level 1 [m s^{-1}]

Group RSL

`U_10`

Description Wind speed at level 10 [m s^{-1}]

Group RSL

`U_11`

Description Wind speed at level 11 [m s^{-1}]

Group RSL

`U_12`

Description Wind speed at level 12 [m s^{-1}]

Group RSL

`U_13`

Description Wind speed at level 13 [m s^{-1}]

Group RSL

`U_14`

Description Wind speed at level 14 [m s^{-1}]

Group RSL

`U_15`

Description Wind speed at level 15 [m s^{-1}]

Group RSL

`U_16`

Description Wind speed at level 16 [m s^{-1}]

Group RSL

`U_17`

Description Wind speed at level 17 [m s^{-1}]

Group RSL

`U_18`

Description Wind speed at level 18 [m s^{-1}]

Group RSL

`U_19`

Description Wind speed at level 19 [m s^{-1}]

Group RSL

`U_2`

Description Wind speed at level 2 [m s^{-1}]

Group RSL

`U_20`

Description Wind speed at level 20 [m s^{-1}]

Group RSL

`U_21`

Description Wind speed at level 21 [m s^{-1}]

Group RSL

`U_22`

Description Wind speed at level 22 [m s^{-1}]

Group RSL

`U_23`

Description Wind speed at level 23 [m s^{-1}]

Group RSL

`U_24`

Description Wind speed at level 24 [m s^{-1}]

Group RSL

`U_25`

Description Wind speed at level 25 [m s^{-1}]

Group RSL

`U_26`

Description Wind speed at level 26 [m s^{-1}]

Group RSL

U_27

Description Wind speed at level 27 [m s^{-1}]

Group RSL

U_28

Description Wind speed at level 28 [m s^{-1}]

Group RSL

U_29

Description Wind speed at level 29 [m s^{-1}]

Group RSL

U_3

Description Wind speed at level 3 [m s^{-1}]

Group RSL

U_30

Description Wind speed at level 30 [m s^{-1}]

Group RSL

U_4

Description Wind speed at level 4 [m s^{-1}]

Group RSL

U_5

Description Wind speed at level 5 [m s^{-1}]

Group RSL

U_6

Description Wind speed at level 6 [m s^{-1}]

Group RSL

U_7

Description Wind speed at level 7 [m s^{-1}]

Group RSL

U_8

Description Wind speed at level 8 [m s^{-1}]

Group RSL

U_9

Description Wind speed at level 9 [m s^{-1}]

Group RSL

WUDecTr

Description Water use for irrigation of deciduous trees [mm]

Group SUEWS

WUEveTr

Description Water use for irrigation of evergreen trees [mm]

Group SUEWS

WUGrass

Description Water use for irrigation of grass [mm]

Group SUEWS

WUInt

Description Internal water use [mm]

Group SUEWS

WU_DecTr1

Description Total water use for deciduous trees [mm]

Group DailyState

WU_DecTr2

Description Automatic water use for deciduous trees [mm]

Group DailyState

WU_DecTr3

Description Manual water use for deciduous trees [mm]

Group DailyState

WU_EveTr1

Description Total water use for evergreen trees [mm]

Group DailyState

WU_EveTr2

Description Automatic water use for evergreen trees [mm]

Group DailyState

WU_EveTr3

Description Manual water use for evergreen trees [mm]

Group DailyState

WU_Grass1

Description Total water use for grass [mm]

Group DailyState

WU_Grass2

Description Automatic water use for grass [mm]

Group DailyState

WU_Grass3

Description Manual water use for grass [mm]

Group DailyState

Zenith

Description Solar zenith angle [°]

Group SUEWS

a1

Description OHM cofficient a1 - [-]

Group DailyState

a2

Description OHM cofficient a2 [W m^{-2} h^{-1}]

Group DailyState

a3

Description OHM cofficient a3 - [W m^{-2}]

Group DailyState

altitude

Description Altitude angle of the Sun

Group SOLWEIG

azimuth

Description Azimuth angle of the Sun

Group SOLWEIG

deltaLAI

Description Change in leaf area index (normalised 0-1) [-]

Group DailyState

frMelt_BSoil

Description Amount of freezing melt water – bare soil surface [mm]

Group snow

frMelt_Bldgs

Description Amount of freezing melt water – building surface [mm]

Group snow

frMelt_DecTr

Description Amount of freezing melt water – deciduous surface [mm]

Group snow

frMelt_EveTr

Description Amount of freezing melt water – evergreen surface [mm]

Group snow

frMelt_Grass

Description Amount of freezing melt water – grass surface [mm]

Group snow

frMelt_Paved

Description Amount of freezing melt water – paved surface [mm]

Group snow

frMelt_Water

Description Amount of freezing melt water – water surface [mm]

Group snow

fr_Bldgs

Description Fraction of snow – building surface [-]

Group snow

fr_DecTr

Description Fraction of snow – deciduous surface [-]

Group snow

fr_EveTr

Description Fraction of snow – evergreen surface [-]

Group snow

fr_Grass

Description Fraction of snow – grass surface [-]

Group snow

fr_Paved

Description Fraction of snow – paved surface [-]

Group snow

gvf

Description Ground view factor (Lindberg and Grimmond 2011)

Group SOLWEIG

kup_BSoilSnow

Description Reflected shortwave radiation – bare soil surface [W m^{-2}]

Group snow

kup_BldgsSnow

Description Reflected shortwave radiation – building surface [W m^{-2}]

Group snow

kup_DecTrSnow

Description Reflected shortwave radiation – deciduous surface [W m^{-2}]

Group snow

kup_EveTrSnow

Description Reflected shortwave radiation – evergreen surface [W m^{-2}]

Group snow

kup_GrassSnow

Description Reflected shortwave radiation – grass surface [W m^{-2}]

Group snow

kup_PavedSnow

Description Reflected shortwave radiation – paved surface [W m^{-2}]

Group snow

kup_WaterSnow

Description Reflected shortwave radiation – water surface [W m^{-2}]

Group snow

q_1

Description Specific humidity at level 1 [g kg^{-1}]

Group RSL

q_10

Description Specific humidity at level 10 [g kg^{-1}]

Group RSL

q_11

Description Specific humidity at level 11 [g kg^{-1}]

Group RSL

q_12

Description Specific humidity at level 12 [g kg^{-1}]

Group RSL

q_13

Description Specific humidity at level 13 [g kg^{-1}]

Group RSL

q_14

Description Specific humidity at level 14 [g kg^{-1}]

Group RSL

q_15

Description Specific humidity at level 15 [g kg^{-1}]

Group RSL

q_16

Description Specific humidity at level 16 [g kg^{-1}]

Group RSL

q_17

Description Specific humidity at level 17 [g kg^{-1}]

Group RSL

q_18

Description Specific humidity at level 18 [g kg^{-1}]

Group RSL

q_19

Description Specific humidity at level 19 [g kg^{-1}]

Group RSL

q_2

Description Specific humidity at level 2 [g kg^{-1}]

Group RSL

q_20

Description Specific humidity at level 20 [g kg^{-1}]

Group RSL

q_21

Description Specific humidity at level 21 [g kg^{-1}]

Group RSL

q_22

Description Specific humidity at level 22 [g kg^{-1}]

Group RSL

q_23

Description Specific humidity at level 23 [g kg^{-1}]

Group RSL

q_24

Description Specific humidity at level 24 [g kg^{-1}]

Group RSL

q_25

Description Specific humidity at level 25 [g kg^{-1}]

Group RSL

q_26

Description Specific humidity at level 26 [g kg^{-1}]

Group RSL

q_27

Description Specific humidity at level 27 [g kg^{-1}]

Group RSL

q_28

Description Specific humidity at level 28 [g kg^{-1}]

Group RSL

q_29

Description Specific humidity at level 29 [g kg^{-1}]

Group RSL

q_3

Description Specific humidity at level 3 [g kg^{-1}]

Group RSL

q_30

Description Specific humidity at level 30 [g kg^{-1}]

Group RSL

q_4

Description Specific humidity at level 4 [g kg^{-1}]

Group RSL

q_5

Description Specific humidity at level 5 [g kg^{-1}]

Group RSL

q_6

Description Specific humidity at level 6 [g kg^{-1}]

Group RSL

q_7

Description Specific humidity at level 7 [g kg^{-1}]

Group RSL

q_8

Description Specific humidity at level 8 [g kg^{-1}]

Group RSL

q_9

Description Specific humidity at level 9 [g kg^{-1}]

Group RSL

shadow

Description Shadow value (0= shadow, 1 = sun)

Group SOLWEIG

svf

Description Sky View Factor from ground and buildings

Group SOLWEIG

svfbuveg

Description Sky View Factor from ground, buildings and vegetation

Group SOLWEIG

z0m

Description Roughness length for momentum [m]

Group SUEWS

z_1

Description Height at level 1 [m]

Group RSL

z_10

Description Height at level 10 [m]

Group RSL

z_11

Description Height at level 11 [m]

Group RSL

z_12

Description Height at level 12 [m]

Group RSL

z_13

Description Height at level 13 [m]

Group RSL

z_14

Description Height at level 14 [m]

Group RSL

z_15

Description Height at level 15 [m]

Group RSL

z_16

Description Height at level 16 [m]

Group RSL

z_17

Description Height at level 17 [m]

Group RSL

z_18

Description Height at level 18 [m]

Group RSL

z_19

Description Height at level 19 [m]

Group RSL

z_2

Description Height at level 2 [m]

Group RSL

z_20

Description Height at level 20 [m]

Group RSL

z_21

Description Height at level 21 [m]

Group RSL

z_22

Description Height at level 22 [m]

Group RSL

z_23

Description Height at level 23 [m]

Group RSL

z_24

Description Height at level 24 [m]

Group RSL

z_25

Description Height at level 25 [m]

Group RSL

z_26

Description Height at level 26 [m]

Group RSL

z_27

Description Height at level 27 [m]

Group RSL

z_28

Description Height at level 28 [m]

Group RSL

z_29

Description Height at level 29 [m]

Group RSL

z_3

Description Height at level 3 [m]

Group RSL

`z_30`

Description Height at level 30 [m]

Group RSL

`z_4`

Description Height at level 4 [m]

Group RSL

`z_5`

Description Height at level 5 [m]

Group RSL

`z_6`

Description Height at level 6 [m]

Group RSL

`z_7`

Description Height at level 7 [m]

Group RSL

`z_8`

Description Height at level 8 [m]

Group RSL

`z_9`

Description Height at level 9 [m]

Group RSL

`zdm`

Description Zero-plane displacement height [m]

Group SUEWS

CHAPTER 4

FAQ

Contents

4.1 I cannot install SuPy following the docs, what is wrong there?

please check if your environment meets the following requirements:

1. Operating system (OS):

   a. is it 64 bit? only 64 bit systems are supported.

   b. is your OS up to date? only recent desktop systems are supported:

      - Windows 10 and above
      - macOS 10.13 and above
      - Linux: no restriction; If SuPy cannot run on your specific Linux distribution, please report it to us.

   You can get the OS information with the following code:

   ```
   import platform
   platform.platform()
   ```

2. Python interpreter:

a. is your Python interpreter 64 bit?

   Check running mode with the following code:

```
import struct
struct.calcsize('P')*8
```

b. is your Python version above 3.5?

   Check version info with the following code:

```
import sys
sys.version
```

If your environment doesn't meet the requirement by SuPy, please use a proper environment; otherwise, please report your issue.

4.2 How do I know which version of SuPy I am using?

Use the following code:

```
import supy
supy.show_version()
```

Note: *show_version* is only available after v2019.5.28.

4.3 A `kernel may have died` exception happened, where did I go wrong?

The issue is highly likely due to invalid input to SuPy and SUEWS kernel. We are trying to avoid such exceptions, but unfortunately they might happen in some edge cases.

Please report such issues to us with your input files for debugging. Thanks!

4.4 How can I upgrade SuPy to an up-to-date version?

Run the following code in your terminal:

```
python3 -m pip install supy --upgrade
```

CHAPTER 5

Version History

5.1 Version 2020.5.29

- **New**
  1. Update supy-driver to `2020a` iteration.
  2. Add function for plotting RSL variables *supy.util.plot_rsl*.
- **Improvement**

  None.
- **Changes**

  None.
- **Fix**
  1. Fix the humidity variable in ERA5-based forcing generation.
  2. Fix the impact study tutorial.
- **Known issue**
  1. ESTM is not supported yet.
  2. BLUEWS, a CBL modules in SUEWS, is not supported yet.
  3. Simulation in parallel mode is NOT supported on Windows due to system limitation.

5.2 Version 2020.2.2

- **New**
  1. A checker to validate input `DataFrame`s. See option `check_input` in *run_supy*.
  2. Utilities to generate forcing data using ERA-5 data. See *download_era5* and *gen_forcing_era5*.

- **Improvement**
  1. Improved performance of the parallel mode.
- **Changes**

  None.
- **Fix**

  None.
- **Known issue**
  1. ESTM is not supported yet.
  2. BLUEWS, a CBL modules in SUEWS, is not supported yet.
  3. Simulation in parallel mode is NOT supported on Windows due to system limitation.

5.3 Version 2019.8.29

- **New**
  1. added WRF-SUEWS related functions.
  2. added diagnostics of canyon profiles.
- **Improvement**

  None.
- **Changes**
  1. synchronised with v2019a interface: minimum supy_driver v2019a2.
- **Fix**

  None.
- **Known issue**
  1. ESTM is not supported yet.
  2. BLUEWS, a CBL modules in SUEWS, is not supported yet.
  3. Performance in parallel mode can be worse than serial mode sometimes due to heavy (de)-serialisation loads.

5.4 Version 2019.7.17

- **New**
  1. added OHM related functions.
  2. added surface conductance related functions.
- **Improvement**

  None.
- **Changes**

  None.

- **Fix**

  1. Fixed a bug in unit conversion for TMY data generation.

- **Known issue**

  ESTM is not supported yet.

5.5 Version 2019.6.8

- **New**

  None.

- **Improvement**

  None.

- **Changes**

  None.

- **Fix**

  1. Fixed a bug in rescaling Kdown when loading forcing data.

- **Known issue**

  ESTM is not supported yet.

5.6 Version 2019.5.28

Spring house cleaning with long-await command line tools (more on the way!).

- **New**

  1. Added version info function: `show_version`.
  2. Added command line tools:

  - *suews-run*: SuPy wrapper to mimic SUEWS-binary-based simulation.
  - *suews-convert*: convert input tables from older versions to newer ones (one-way only).

- **Improvement**

  None.

- **Changes**

  None.

- **Fix**

  1. Fixed a bug in writing out multi-grid output files caused by incorrect dropping of temporal information by pandas .

- **Known issue**

  ESTM is not supported yet.

5.7 Version 2019.4.29

Parallel run.

- **New**

  Added support for parallel run on the fly.

- **Improvement**

  None.

- **Changes**

  None.

- **Fix**

  None.

- **Known issue**

  None

5.8 Version 2019.4.17

UMEP compatibility tweaks.

- **New**

  None.

- **Improvement**

  None.

- **Changes**

  `Error messages: problems.txt` will be written out in addition to the console error message similarly as SUEWS binary.

- **Fix**

  Incorrect caching of input libraries.

- **Known issue**

  None

5.9 Version 2019.4.15

ERA-5 download.

- **New**

  Added experimental support for downloading and processing ERA-5 data to force supy simulations.

- **Improvement**

  Improved compatibility with earlier `pandas` version in resampling output.

- **Changes**

  None.

- **Fix**

  None.

- **Known issue**

  None

5.10 Version 2019.3.21

TMY generation.

- **New**

  Added preliminary support for generating TMY dataset with SuPy output.

- **Improvement**

  None.

- **Changes**

  None.

- **Fix**

  None.

- **Known issue**

  None

5.11 Version 2019.3.14

This release improved memory usage.

- **New**

  None.

- **Improvement**

  Optimised memory consumption for longterm simulations.

- **Changes**

  None.

- **Fix**

  None.

- **Known issue**

  None

5.12 Version 2019.2.25

This release dropped support for Python 3.5 and below.

- **New**

  None.

- **Improvement**

  None.

- **Changes**

  Dropped support for Python 3.5 and below.

- **Fix**

  None.

- **Known issue**

  None

5.13 Version 2019.2.24

This release added the ability to save output files.

- **New**

  1. Added support to save output files. See: `supy.save_supy()`
  2. Added support to initialise SuPy from saved `df_state.csv`. See: `supy.init_supy()`

- **Improvement**

  None.

- **Changes**

  None.

- **Fix**

  None.

- **Known issue**

  None

5.14 Version 2019.2.19

This is a release that improved the exception handling due to fatal error in `supy_driver`.

- **New**

  Added support to handle python kernel crash caused by fatal error in `supy_driver` kernel; so python kernel won't crash any more even `supy_driver` is stopped.

- **Improvement**

  None.

- **Changes**

  None

- **Fix**

  None.

- **Known issue**

  None

5.15 Version 2019.2.8

This is a release that fixes recent bugs found in SUEWS that may lead to abnormal simulation results of storage heat flux, in particular when `SnowUse` is enabled (i.e., `snowuse=1`).

- **New**

  None.

- **Improvement**

  Improved the performance in loading initial model state from a large number of grids (>1k)

- **Changes**

  Updated `SampleRun` dataset by: 1. setting surface fractions (*`sfr`*) to a more realistic value based on London KCL case; 2. enabling snow module (`snowuse=1`).

- **Fix**

  1. Fixed a bug in the calculation of storage heat flux.
  2. Fixed a bug in loading `popdens` for calculating anthropogenic heat flux.

- **Known issue**

  None

5.16 Version 2019.1.1 (preview release, 01 Jan 2019)

- **New**

  1. Slimmed the output groups by excluding unsupported ESTM results
  2. SuPy documentation
     - Key IO data structures documented:
     - *df_output variables* (GH9)
     - *df_state variables* (GH8)
     - *df_forcing variables* (GH7)
     - Tutorial of parallel SuPy simulations for impact studies

- **Improvement**

  1. Improved calculation of OHM-related radiation terms

- **Changes**

  None.

- **Fix**

  None

- **Known issue**

  None

5.17 Version 2018.12.15 (internal test release in December 2018)

- **New**

  1. Preview release of SuPy based on the computation kernel of SUEWS 2018b

- **Improvement**

  1. Improved calculation of OHM-related radiation terms

- **Changes**

  None.

- **Fix**

  None

- **Known issue**

  1. The heat storage modules AnOHM and ESTM are not supported yet.

Index

Symbols

A

B

C

D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U