**Effect of averaging period of eddy-covariance fluxes on water use efficiency**

**README File**

* **Data conversion**

Software used : Loggernet version 4.7

Purpose : conversion of .dat format to ASCII format

* **Averaging and Data processing**

Software used : EddyPro version 7.0.8

Averaging periods considered in the study - 1, 5, 10, 15, 30, 45, 60, and 120 minutes.

* **Data plotting and representation**

Softwares used : Python

MS Excel 365

MS Excel (2016 version)

* **Results - Steps followed**

**Figure 1**: **Diurnal variations in energy balance components (available energy:**

**Rn-G and turbulent fluxes: H+LE) during the crop cycle with different**

**averaging periods. Inset: Scatter-plots between the two datasets.**

1. Calculating the EBR for all the averaging periods for entire crop period

using the formula

EBR= (H+LE) / (Rn-G)

1. Averaging the data of each averaging period by grouping it based on each time step for the entire crop season using python code so as to obtain diurnal values for the crop period.

Code :

*#Importing Packages*

import numpy as np

import pandas as pd

import os

*#reading the dataset*

data = pd.read\_excel(r'E:\phd\_course\IWM\filtered\figure1\fig\_fin\30min figure1.xlsx')

*#daily averaging*

k1 = data.groupby(['time']).mean()

*#changing the directory*

os.chdir(r'E:\phd\_course\IWM\filtered\figure1\fig\_fin')

*#Saving to excel file*

k1.to\_excel('30min\_fin.xlsx')

1. Plotting the graph showing diurnal variations in energy balance components

for each averaging period in python.

Code:

*#importing modules*

import pandas as pd

import numpy as np

import matplotlib.pyplot as plt

import time

*#reading the dataset*

data1=pd.read\_excel(r'E:\phd\_course\IWM\filtered\figure1\fig\_fin\30min\_fig1\_outputs1.xlsx')

*#plotting and formatting*

fig,ax = plt.subplots(1,1)

fig.set\_size\_inches(10,8)

#ax.plot(data1['time'],data1['H+LE'], data1['Rn-G'],lw=2)

ax.plot(data1['time'],data1['H+LE'], lw=1.5,color = 'black')

ax.plot(data1['time'], data1['Rn-G'],lw=1.5,linestyle='dashed',color = 'black')

plt.fill\_between(data1['time'],data1['H+LE'], data1['Rn-G'],where = (data1['H+LE'] > data1['Rn-G']),alpha = 0.5,color = 'grey',interpolate = True)

plt.fill\_between(data1['time'],data1['H+LE'], data1['Rn-G'],where = (data1['H+LE'] <data1['Rn-G']),alpha = 0.5,color = 'black', interpolate = True)

plt.xticks(rotation = 90)

start,end = ax.get\_xlim()

ax.xaxis.set\_ticks(np.arange(start,end,1))

ax.set(xlabel='Time(h)', ylabel='Energy fluxes[W+1M-2]');

plt.legend(['H+LE','Rn-G'])

plt.show()

1. **Inset:** Scatter plot of H+LE vs Rn-G is drawn for each averaging period with a 1:1 line.

**Figure 2**: **Variation in energy balance ratio (EBR) with averaging period for different growth stages**

1. EBR for all the averaging periods is calculated as accordingly

EBR= (H+LE) / (Rn-G)

1. In each averaging period the mean EBR for each crop stage (10am to 3pm) is calculated so that we obtain one mean EBR value for each stage in Microsoft Excel 365 using ‘Average’ function
2. Plotting the graph in Microsoft Excel 365 showing the mean EBR of each stage represented by different curves against the averaging period.

**Figure 3:** **Variation in mean carbon/water fluxes with averaging period for different growth stages**

1. The mean of carbon and water fluxes for each stage from 10 AM to 3 PM in each averaging period is calculated such that we obtain one mean CO2 flux value for each crop stage for all averaging periods in Microsoft Excel 365 using the ‘Average’ function.
2. Plotting the graph in Microsoft Excel 365 showing the mean of carbon/water fluxes of each stage represented by different curves against the averaging period.

**Figure 4:** **Whisker plots showing the distribution of error in estimating carbon fluxes with various averaging periods relative to the conventional 30-min. averaging.**

1. Mean of carbon and water fluxes for each day from 10am to 3pm in the entire crop season is calculated for all the averaging periods in python. Hence the sample size of carbon and water fluxes becomes equal for all averaging periods.

Code:

*#Importing Packages*

import numpy as np

import pandas as pd

import os

*#reading the dataset*

data=pd.read\_excel(r'E:\phd\_course\IWM\filtered\figure3\30min figure1.xlsx')

*#daily averaging*

k1 = data.groupby(['Month', 'Day']).mean()

*#changing the directory*

os.chdir(r'E:\phd\_course\IWM\filtered\figure4')

*#Saving to excel file*

k1.to\_excel('30min\_fin.xlsx')

1. Relative error of Carbon and water fluxes of all averaging periods is calculated with respect to the 30minute averaging period as accordingly

Relative error (%) = [{(CO2 flux)i - (CO2 flux)30}/(CO2 flux)30]\*100

Relative error (%) = [{(H2O flux)i - (H2O flux)30}/(H2O flux)30]\*100

Where *i* represents the averaging periods.

1. Plotting the graph in Microsoft Excel 365 showing relative error of carbon/water fluxes with different whisker bars representing different averaging periods for different growth stages represented by each subplot.

**Figure 5: Ogive plots of carbon/water fluxes for different growth stages of the Maize crop**

1. 2 hr time averaged Ogive data which is resulted from Eddypro Processing, was taken in a single day corresponding to each crop season i.e June 1st, June 25th, July 29th, 21st August in 2019 for 6th Leaf, Silking, Dough and Maturity stages respectively .
2. Then the median of day ogives were taken using MS-Excel (Version 2016) for plotting ogives.
3. Then the frequency is converted into Hz and the frequency vs median ogive values were plotted in each day in each crop season in a log-normal plot (Using MS-Excel 2016 version).
4. The vertical lines correspond to time averaging periods like 1 min, 5 min,10 min, 15 min, 30 min, 45 min and 60 min and 120 min were drawn Using MS-Excel 2016 version)

**Figure 6: Seasonal variations in daily mean WUE fluxes obtained with conventional 30-min (black) and optimal averaging periods (red) during the crop cycle.**

1. The conventional 30 min time averaged carbon dioxide and water fluxes were taken for calculation of ecosystem water use efficiency.
2. We consider the fluxes to correspond to an efficient day time (i.e 10:00 AM to 15:00 PM.)
3. Then the median values corresponding to the above mentioned time period in each day were taken using python script (As shown in below). Finally the median values of both CO2 and H2O values were calculated each day in the entire crop period.

Code:

*#Importing Packages*

import numpy as np

import pandas as pd

import os

*#reading the dataset*

data = pd.read\_excel(r'E:\phd\_course\IWM\filtered\figure1\fig\_fin\WUE')

*#daily averaging*

k1 = data.groupby(['time']).median()

#changing the directory

os.chdir(r'E:\phd\_course\IWM\filtered\figure1\fig\_fin')

*#Saving to excel file*

k1.to\_excel('WUE\_med\_fin.xlsx')

1. Then the ecosystem WUE was calculated using CO2 / H2O relation and its same plotted in a normal graph as the x axis corresponding to days after sowing and the y-axis corresponding to estimated WUEe values (Using MS-Excel 2016 version).
2. For the effective time average WUE plot, we took optimal time average periods from the ogive analysis results. The 15 min time average period is taken for 6th Leaf and Dough stages and the 45 min time average period was taken for Silking and maturity stages. The fluxes corresponding to these periods were taken and the above mentioned procedure was followed for calculating median values of CO2 and H2O fluxes. Then the water use efficiency was calculated based on CO2 and H2O fluxes ratio..
3. Finally,WUE for the effective time average period was plotted in the same normal plot using MS-Excel 2016 version.

**Figure 7:** **Whisker plots showing the distribution of error in estimating WUE fluxes with various averaging periods relative to the conventional 30-min. averaging.**

1. Mean of WUE fluxes for each day from 10am to 3pm in the entire crop season is calculated for all the averaging periods in python. Hence the sample size of carbon and water fluxes becomes equal for all averaging periods.

Code:

*#Importing Packages*

import numpy as np

import pandas as pd

import os

*#reading the dataset*

data=pd.read\_excel(r'E:\phd\_course\IWM\filtered\figure3\30min figure1.xlsx')

*#daily averaging*

k1 = data.groupby(['Month', 'Day']).mean()

*#changing the directory*

os.chdir(r'E:\phd\_course\IWM\filtered\figure3')

*#Saving to excel file*

k1.to\_excel('30min\_fin.xlsx')

1. Relative error of WUE fluxes of all averaging periods is

calculated with respect to the 30minute averaging period as accordingly

Relative error (%) = [{(WUE)i - (WUE)30}/(WUE)30]\*100

Where *i* represents the averaging periods.

1. Plotting the graph in Microsoft Excel 365 showing relative error of WUE fluxes with different whisker bars representing different averaging periods for different growth stages represented by each subplot

**Figure 8: Correlation charts showing the linear association of WUE, CO2 and H2O fluxes estimated with different averaging periods.**

Correlation chart for CO2, H2O fluxes and WUE are plotted in Python

1. WUE (water use efficiency) is calculated for time 10am to 3pm in entire

crop season for all averaging periods as accordingly

WUE = CO2 / H2O

1. Mean of daily CO2 fluxes, H2O fluxes and WUE for all averaging periods is calculated in python. Hence the sample size of each averaging period becomes the same.
2. The dataset is then read in python
3. Calculation of pearson coefficient of correlation using corr function in python
4. Plotting the correlation chart using corrplot package in Rstudio

Code :

*rm(list= ls())*

*graphics.off()*

*#CO2*

*setwd("D:\\MTECH IITH\\MTech 1st Sem\\IWM\\final plots\\figure-7")*

*#reading dataset*

*library(readxl)*

*data <- read\_excel("co2\_avgd\_all (1).xlsx")*

*#correlation*

*M<-cor(na.omit(data))*

*#plotting correlation chart*

*library(corrplot)*

*corrplot(M, method="circle",type="upper",tl.col = "black", COL2('PiYG', 10),*

*outline = TRUE, insig ='blank',, win.asp = 1, number.cex = 80, )*

**Table 1: Phenological growth stages and physical properties of the Maize crop**

1. Date of sowing : 25th May, 2019.
2. The phenological stages of the maize crop were classified as 6th leaf, silking, Dough, Maturity with a crop period of 104 days which ends in the 6th of september, 2019.

**Table 2: Summary of linear regression parameters in closing the energy balance with different averaging periods**

1. Table containing the columns named Averaging period, slope, R2, intercept, r, N, RMSE.

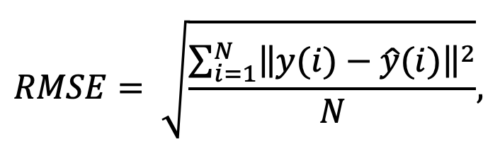
Where R2 - coefficient of determination

r - correlation coefficient

N - sample size of each averaging period

RMSE - root mean square error

1. Plot of H + LE versus Rn - G was drawn for all averaging periods. From the equation of best fit line, the values of slope and intercept are noted. Also R2 was taken from each plot.
2. RMSE value for each averaging period is calculated accordingly



where *N* is the number of data points, *y(i)* is the i-th measurement, and *ŷ(i)* is its corresponding prediction.