Establishing and Operating a Regional Network for Field Measurement of Actual Crop Water Consumption (Evapotranspiration)

NENA Regional ET-Network

Output 2: Standards, Protocols and Methods for Instrument Operation & Maintenance and for Field Measurements

Activity 2.1: Detail Description of the technical specifications of the Instruments, Maintenance Standards and Calibration Protocols.

submitted by
International Center for Agricultural Research in the Dry Areas (ICARDA)

to
The United Nations Food and Agriculture Organization (FAO)

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The Project

Establishing and Operating a Regional Network for Field Measurement of Actual Crop Water Consumption (Evapotranspiration)

There are several conventional field methods used to determine ETa, including: 1) the Eddy covariance/energy balance method; 2) the Bowen-ratio/energy balance method; 3) Weighing lysimeters; 4) Soil-moisture depletion method; 5) Large Aperture Scintillometer; and 6) the Penman Monteith method. These methods have their own specific advantages and limitations based on the theory behind and on the instrumentation requirements. However, what they have in common is, among others, the restricted sampling area and the complexity and extremely high costs when attempting to scale-up to larger areas. For large scales (e.g., irrigation schemes, watershed, sub-national, national and basin scales) the only feasible and affordable methods for ET determination are through satellite Remote Sensing (RS), due to progress and advances in space science in recent years. There are several well-established RS-based algorithms for the determination of ET_a, including SEBAL (Surface Energy Balance Algorithm for Land), METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration), SEBS (Surface Energy Balance System), ETLook, ETMonitor, etc. Unfortunately, also these methods have their own specific advantages and limitations and are all suffering from a generally limited and scattered field validation. Virtually no validations are systematically carried out in the NENA Region. Therefore, the ET_a field measurements established through this ET-Network could effectively be used to validate and calibrate the remote sensed based estimations.

In this regional ET-Network (having Egypt, Jordan, Lebanon, Morocco, and Tunisia as initial countries), the overarching objective is to establish and operate a NENA Regional Network of specialized Institutions, within the countries of reference, to conduct field measurements of actual ET, over selected crops, in order to evaluate the accuracy of existing RS based ET estimates. The Network has been named NENA-ETNet. This regional network was established by ICARDA and financially supported by FAO.

Keywords: Evapotranspiration, ET network, water productivity, water management

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Table of Contents

1. Theoretical Basis and Protocols

The uniqueness of this project is in the adoption of a standardized methodology for field determination of ET_a, the modality of data collection and sharing with a consistent protocol for data measurement, quality control, and database management. In this section the measurement methods are described in enough details of their underlying principles and theory.

1.1 Surface Energy Balance

Many ET estimation methods are based on the classical surface energy balance approach. The energy balance concept describes the processes of radiation interaction in the atmospheric boundary layer and how the incoming short wave (SW) and the long wave (LW) radiation is partitioned in the boundary layer. The incoming shortwave and longwave radiation are either reflected or absorbed by the surface of the ground or/and plant canopy. The net radiation (Rn) is the amount of radiation absorbed by the earth's surface and is measured by subtracting the overall reflected and re-emitted radiation from the total incoming radiation. The absorbed radiation contributes to soil heat flux (G), sensible heat flux (H), and latent heat flux (LE). All these energy variables are expressed in wats per square meter (W m^{-2}). G is the amount of radiation gained or lost by the soil surface through conduction. H is the energy that increases the temperature of the atmosphere, and LE is the energy available for the evaporation of water. Due to the theory of thermodynamics, the net radiation must be distributed among the other three fluxes. This yields the basic energy balance equation:

$$Rn=LE+H+G \qquad (1)$$
$$LE=Rn-H-G \qquad (2)$$

Rn can be measured by a variety of instruments where the incoming solar radiation is measured in addition to the reflected and re-emitted radiation. *G* is measured by soil heat flux plates which measure the amount of energy gained or lost by the soil. *H* requires advanced instruments and methods for its measurement. Since LE is the energy used for evaporating water, it can be converted to ET (in mm) dividing it by the latent heat of vaporization (λ).

1.1.1 CORDOVA-ET station

The CORDOVA-ET station is a prototype developed by the University of Cordoba, Spain. It yields ET_a measurements based on the surface energy balance principles. Its complete functionality, along with hardware specifications, is well described in the UCO CORDOVA-ET report (Berni et al., 2018). This station consists of multiple sensors which communicate via wireless connections. There are multiple micro-meteorological stations which are called 'nodes' that integrate the sensors required for measuring the components of the energy balance. These nodes are powered with solar photovoltaic cells and related batteries. Along with nodes, there is a base station which receives the data from the nodes and forwards them to a main server through Internet. A server-based software stores and manages the data from the nodes and helps their visualization to the users.

The CORDOVA-ET station (Fig. 1) makes use of the surface energy balance approach to derive ET_a, through Equation (2), where *Rn* and *G* are measured, and *H* ($W\ m^{-2}$)is calculated as

$$H = \rho Cp \frac{(Tc - Ta)}{ra} \qquad (3)$$

where: ρ is the air density (kgm^{-3})

$C_p$is the air specific heat capacity ($Jkg^{-1}\ {}^oC^{-1}$)

Tc and Ta are the canopy and air temperature, respectively (^oC)

r_a is the aerodynamic resistance ($m\ s^{-1}$).

The main issue is that net radiometers are expensive and not commonly available in most weather stations. Following what proposed in the FAO-56 publication, approaches for estimating *Rn* from measurements of solar radiation (*Rs*) can be adopted, as *Rs* is most commonly measured in agrometeorological weather stations.

The other critical parameter is r_a which depends mainly on the wind speed and on canopy attributes (height and roughness). There are multiple formulations for estimating r_a. However, being a critical variable in the calculation of *H*, and therefore for estimating *LE*, the assumptions behind its calculation can have very important impacts on the results of the surface energy balance. For a detailed sensitivity analysis of the estimation of *LE* from canopy temperature measurements, see (Leinonen et al., 2006; and Maes and Steppe, 2012). The methodology used to calculate r_a in the CORDOVA-ET station is based on Berni et al. (2009) and the model of Viney (1991) has been used given the simplicity of that parameterization and good results.

Fig. 1 – Illustration of a typical CORDOVA-ET station (Figure Courtsey: José A. Jiménez-Berni, personal communication)

1.2. Eddy covariance

Eddy covariance (EC) systems are based on the theory that wind moves in three dimensional circular patterns, or eddies. In addition, as the air moves, it carries with it molecules of water vapor and other gases such as carbon dioxide, methane, and others, as well as heat. If the speed of these eddies can be determined in all three directions, then also the movement of the other molecules (and heat) can be determined. A gas analyzer can be used to measure the amounts of water vapor (or other gases) the air contains at that moment in time. The covariance between the movement of the air mass and the composition of that same air mass can be used to determine the water flux (or fluxes of carbon dioxide and methane). In mathematical terms, "eddy flux" of any entity is computed as a covariance between instantaneous deviation in vertical wind speed (w') from the mean value (w-overbar) and instantaneous deviation in gas concentration i.e. mixing ratio (s'), from its mean value (s-overbar), multiplied by mean air density (ρa).

$$F = \overline{\rho_a}.\ \overline{w'.s'} \quad (4)$$

In the case of latent heat flux, the eddy flux is calculated as

$$F_{latent} = \overline{\rho_a}\ .L_v.\overline{w'\rho'_v} \quad (5)$$

In the case of sensible heat flux, the eddy flux is calculated as

$$F_{sensible} = \overline{\rho_a}\ .C_p.\overline{w'T'} \quad (6)$$

where: ρ_a is the mean dry air density (kgm^{-3})
C_p is the specific heat of air at constant pressure ($J\ kg^{-1}\ {}^{\circ}C^{-1}$)
Lv is the Latent heat of vaporization ($J\ kg^{-1}\ {}^{\circ}C^{-1}$)
w' Fluctuation about the mean of vertical wind speed
ρ_a' Fluctuation about the mean of density of water vapor in air
T' Fluctuation about the mean of air temperature

The Eddy covariance approach used in the NENA-ETNet in some cases measure ET_a directly as water vapor transfer (latent heat flux) but in some cases indirectly through the surface energy balance methods, i.e., through Eq. (2) where *H* is measured through the eddy covariance method (with a high-frequency sonic anemometer to measure wind speed and a fine-wire thermocouple to measure temperature), *Rn* and *G* are measured through net radiometer and soil heat plate, respectively. An example of sensors and power set up for an eddy covariance equipment in the field is reported in Fig. 2

Fig. 2 – Typical example of ICARDA's setup of eddy covariance (in this picture, the crop is sugar beet grown in old land of the Nile delta, Egypt). Courtesy: A. Swelam, personal communication.

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1.2.1. Processing of Eddy Covariance Data

The Eddy Covariance method is one of the most direct ways to measure and calculate turbulent fluxes within the atmospheric boundary layer. However, the method is mathematically complex, and requires significant care to set up and process data. The main challenge of the method for a non-expert is the complexity of system design, implementation, and processing of the large volume of data. In the past several years, efforts of the flux networks (e.g., FluxNet, Ameriflux, CarboEurope, Fluxnet-Canada, Asiaflux, etc.) have led to progress in unification of the terminology and general standardization of processing steps. The methodology itself, however, is difficult to standardize, because various experimental sites and different purposes of studies dictate different treatments, and site-, measurement- and purpose specific approaches.

Because EC is more of a modeling activity using the measurement of parameters in the turbulent boundary layer, a series of calculation steps are involved that includes a lot of corrections and quality control protocols to retrieve the ETa as reported in Fig. 3. Thus, it is recommended that all the sites within a network use the same standardized EC data processing and quality control protocol using the ECPACK software (Van Dijk et al., 2004). This ensures that all the EC sites follow the same approach of processing EC data.

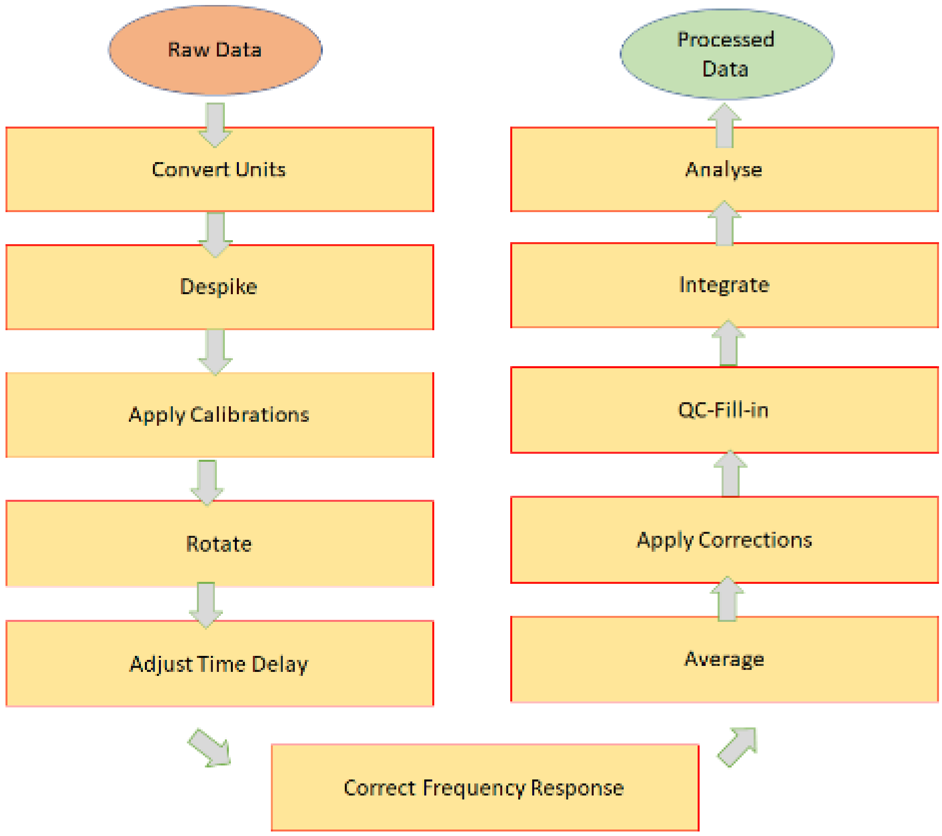

Fig. 3 – Typical workflow of an eddy covariance data to retrieve a desired flux such as E

1.3. Lysimeter Method

A lysimeter is a long-standing and ultimate approach of ET_a direct measurement in agricultural systems. A lysimeter consists of a mass of soil in an enclosed container which can be weighed to determine the amount of water lost or gained over time. Lysimeters can be very complex and expensive to install and operate but are a direct measurement of soil water storage. Thus, lysimeters are often used widely for ET_a validations against all other methods.

Lysimeters are considered 'point' measurements determined by the surface area of the container. However, if the surrounding field is properly managed to match the lysimeter, the ET data can represent field conditions. The optimal surface area and shape of a lysimeter (e.g., square, rectangular, circular) depend mainly on the crop to investigate, the soil type and filling procedure, and the location of installation. Lysimeters with crop stands should represent the natural crop status of the surrounding field, including the maximal root penetration depth. The demanding installation, operation and management of lysimeter is typically only possible at research locations.

Two weighing lysimeters (one in Jordan and one in Lebanon) are used by the NENA-ETNet. The lysimeter in Jordan measures 3 m by 2.4 m on the surface and by 2.5 m deep over a fine sand drainage base (see Fig. 4). It contains an undisturbed monolithic soil profile.

The soil container rests on a large agronomic scale equipped with a counterbalance and load cell system. Calculating ET in units of equivalent depth of water requires that the change in lysimeter mass be divided by the effective evaporating and transpiring area of the lysimeter. The crop inside the lysimeter should be of the same density, height, growth-stage and health of the surrounding field crop in order to minimize micro-advective energy exchange and, therefore, affect the ET_a determinations. The space between the lysimeter vessel and the surrounding soil should be minimized to reduce artificial temperature gradients within the soil block. The lower section of the lysimeter is often segmented to obtain information on the spatial heterogeneity of the water and solute fluxes.

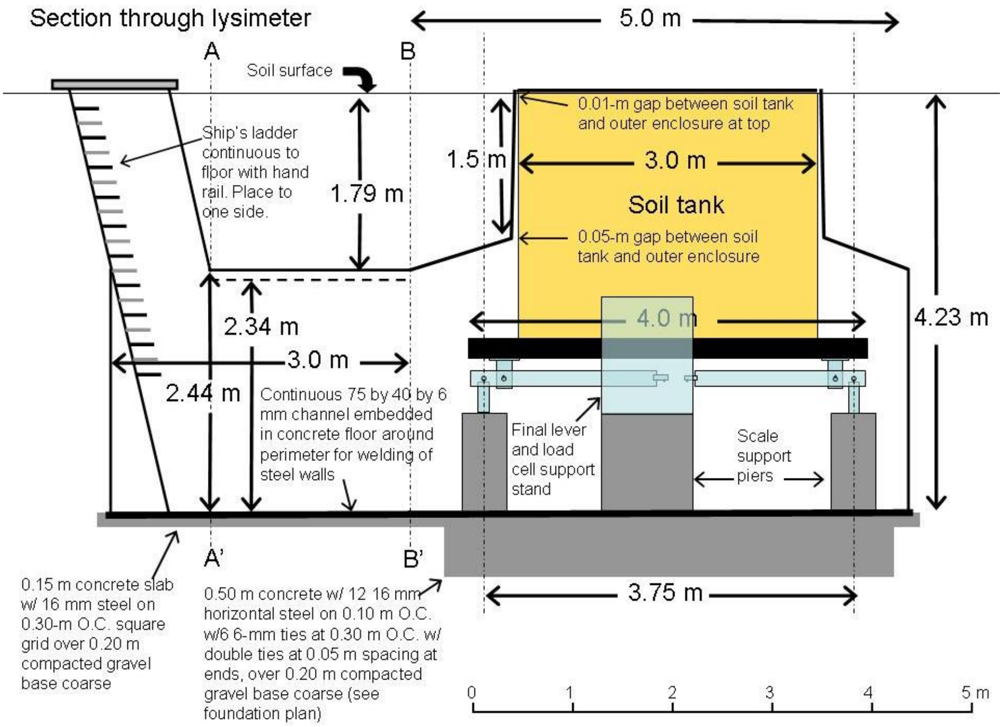

Fig. 4 – Weighing lysimeter installed in Dar Al'a, Jordan Vally and used for NENA-ETNet (Evett, et. Al, 2009)

A lysimeter is most accurate when vegetation is grown in a large soil tank which allows the rainfall input and water lost through the soil to be easily calculated. The amount of water lost by evapotranspiration (or gained by precipitation or irrigation) can be worked out by calculating the difference between the consecutive weighing. For trees, lysimeters can be expensive and not recommended as often poorly represent the actual field conditions.
The LARI installed a weighing Lysimeter (9 m^2) in 1972 as one of the most mechanical precision part, comparable to the unit of UC-Davis (Aboukhaled, 1982). This Lysimeter had a buffer area of 2 ha, but this area shrunk to about 10 ha during the civil war in Lebanon and between 2010 and 2018. According to Aboukhaled (1998), very limited measurements were possible before the war crashed and LARI equipment largely stolen and broken.

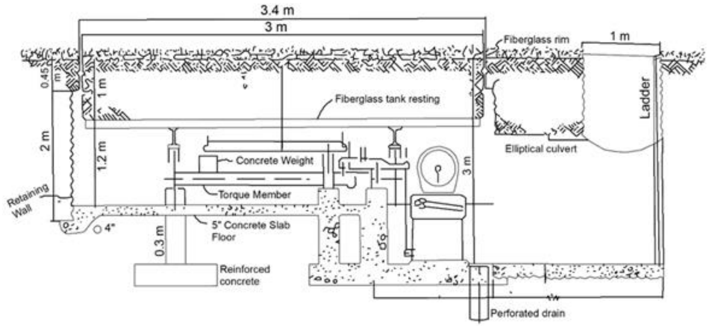

Fig. 5 Weighing lysimeter installed in Tel Emara Beqaa Valley and used for NENA-ETNet. Lefy shows the scheme and the right panel shows the field deployment (Ihab Jomaa, et. Al, 2009).

1.4. Soil Moisture Depletion

The soil moisture depletion method is usually employed to determine the consumptive use of irrigated field crops grown on fairly uniform soils when the depth to the ground water is such that it will not influence the soil moisture fluctuation within the root zone. This technique involves the measurement of soil moisture at various depths of the effective root zone and at a number of times throughout the crop growth period. The greater the number of measurements the higher the accuracy.

The water use from the root zone for successive sampling periods or within one irrigation cycle (WR, in mm) can be calculated according to following equation

$$WR = \sum_{i=1}^{n} \frac{M_{1,i} - M_{2,i}}{100} \rho_i D_i \qquad (7)$$

where: n is the number of soil layers sampled in the root zone depth D *(m)* ; M_{1i} and M_{2i} are the soil moisture percentage at the time of the first and second sampling in the i^{th} layer respectively; ρ_i is the bulk density *(kg m^{-3})* of the i^{th} layer of soil; and D_i is the depth of the i^{th}layer of soil (in mm).

A wide range of tools are available for determining soil moisture, and the devices mentioned here are typically used for irrigation management purposes. They are not much more expensive than simple soil probes (but are much more accurate) and are straightforward to operate.

[1] Tensiometers are devices that measure soil moisture tension. They are sealed, water-filled tubes with a porous ceramic tip at the bottom and a vacuum gauge at the top. They are inserted in the soil to plants' root zone depth. Water moves between the tensiometer tip and surrounding soil until equilibrium is reached, and moisture tension registers on the gauge at the top of the unit. Readings indicate water availability in the soil. Tensiometers operate best at soil moisture tensions near field capacity and need to be serviced before reuse if they dry out. Average cost for a tensiometer is $50-$100 (and generally more than one is installed at a location).

[2] Electrical resistance blocks, also known as gypsum blocks, measure soil water tension. They consist of two electrodes embedded in a block of porous material, usually gypsum; the electrodes are connected to lead wires that extend to the soil surface for reading by a portable meter. As water moves in or out of the porous block in equilibrium with the surrounding soil, changes in the electrical resistance between the two electrodes occur. Resistance meter readings are converted to water tension using a calibration curve. Gypsum blocks operate over a wider range of soil moisture tensions than tensiometers but tend to deteriorate over time and may even need to be replaced yearly (Werner, 2002). Individual blocks can cost as little as $1.25 each and the meter is around $300 (Cregg, 2003). Granular matrix sensors are newer devices that are similar to gypsum blocks but are less susceptible to degradation. The sensors are more expensive than gypsum blocks, in the $30 range.

[3] Time Domain Reflectometry (TDR) is a newer tool that sends an electrical signal through steel rods placed in the soil and measures the time for the signal to return which is correlated to the soil water content. Wet soil returns the signal more slowly than dry soil. This type of sensor gives fast, accurate readings of soil water content, and requires little to no maintenance. However, it does require more work in interpreting data, and may require special calibration depending on soil characteristics. The cost ranges from $100 to $500.
Examples of this sensor include the Campbell Scientific CS650 and the IMKO Trime-Piko 32 (Fig. 6). TDR probes are repeatable and do not require a large amount of maintenance. Since soil dielectric properties are affected by salt content, their readings can be affected by salinity. However, many probes independently measure EC and use this to compensate for the effect of salinity on moisture readings. TDR probes respond quickly to varying soil moisture. Similar to capacitance and frequency domain sensors, TDR sensors must have good contact with the soil, because any air gaps will lead to erroneous measurements. The measurement volume of TDR sensors depends on the length of the rods. The probability of air gaps forming during installation increases with longer rods. Additionally, longer rods will measure a greater length of the soil profile and moisture content can vary significantly from shallow to deeper depths making interpretation of data difficult. TDR sensors should not be used in high saline soils or soils with high bulk electrical conductivity or high attenuation. In soils with high EC values, the voltage pulse is not reflected back along the rod and, therefore, is not measured. The pulse is attenuated beyond the length of the rod. TDR probes have been found to have errors in soils with EC values of 1.32 dS/m.

An additional drawback of the TDR is the disturbance of the soil to insert the rods. In fact, as the rods are inserted horizontally at different depths, space is needed to operate the installation of the rods (see Fig. 6). The longer the rods, the higher the soil disturbance.

Fig. 6– Typical TDR instrument being inserted to a soil pit at a given depth. (Courtesy: Atef Swelam)

2. Integrating various Approaches in the NENA_ET Network

Due to the high cost and required expertise needed to maintain the routine standard ET measurement approaches, such as the eddy covariance-based flux towers, lysimeters, and gravimetric approaches which not all locations in all countries can afford to have, the energy balance-based methodology protocol using CORDOVA-ET station, which was recently developed by Cordova University, Spain will be used to measure ETa in all participating countries and tested for its robustness in selected countries of the NENA Region. The eddy covariance, lysimeters and soil moisture depletion methods will be also used as benchmarks to validate the CORDOVA-ET station.

2.1. Data collection and archiving

After installed and operating the various instrumentations, a data collection procedure is established. The data collection protocol ensures the timely collection of data in a standardized way in all countries with high accuracy. Data archiving is an important component, especially when dealing with different countries and institution on large datasets. While archiving the data, a brief analysis will be conducted to identify outliers. On-the-spot instruments calibration will be conducted so that the project team can correct for space and time. Following this, quality analysis and quality control will be performed. The data collection from different platforms and instruments will be collected, processed and archived following a strict and consistent protocol across all the teams in the network. The responsible national institutions of each country will be responsible for this task and report the collated data in a consistent format to a central archive located in ICARDA Cairo.

2.2. Raw ET and Related Data Archival from CORDOBA Platform

Climatic data and ET data from CORDOVA-ET stations from all five countries is retrieved directly in real time at Grafana interface hosted by Cordoba University. All the data is available at http://iocrops.csic.es/. The Grafana interface is useful to analyses the data in real time, find the missing data and also d-loading the data for analysis in different programs. The data can be shown in hourly, daily and monthly time steps. The Granfa interface has not only data from weather stations but also has real time data for the nodes installed to estimate actual evapotranspiration. This data can be analyzed in Grafana by simple interface as well (see Fig. 7).

Figure 7. Retrieval of raw data from Grafana Interface developed by the University of Cordoba.

Python directly download the data from the above website and use FAO-56 methodology to estimate the reference evapotranspiration. The data from nodes for estimating actual evapotranspiration is also downloaded from the above website to calculate the actual evapotranspiration. The codes prepared at Cordoba University can be downloaded from the library using the following links:

ETo: https://colab.research.google.com/drive/1yFy88W45mCXX_Os3C399yQtTdO900E2w
ETa: https://colab.research.google.com/drive/1wDMdyyqPKC20_ikoxxTajTL4xJnqK2SV

An example of such code, for the calculation of ET_O is reported in Fig. 8.

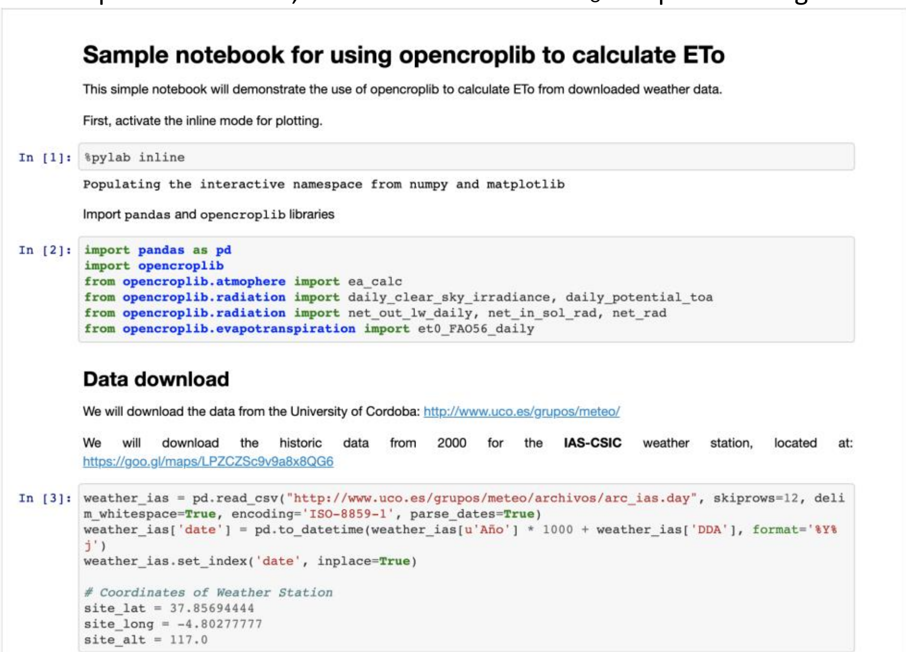

Fig. 8. Open croplib interface to calculate ETo (https://pypi.org/project/opencroplib/)

The country contact person will adopt a systematic data archival, along with the team members, following an agreed protocol. For instance, the original raw files obtained from the different methods should be named as "***COUNTRY_SiteName_METHOD_Year_Month_DOY_RAW.csv***", and saved in multiple copies in separate folders.

Examples of RAW file naming convention, in the case of Egypt, are:

EGYPT_Sharkhia_Cordoba_2019_May_215_RAW.csv

EGYPT_Sharkhia_Lysimeter_2019_May_215_RAW.csv

EGYPT_Sharkhia_EnergyBalance_2019_May_215_RAW.csv

Subsequently, a copy of these files will be used to do follow the steps.

3. Processed ET and Related Meteorological Data (L1, L2 and L3 files)

Depending on the level of processing, temporal resolution and units of the RAW files, new files are generated and categorized in 3 so-called L-type file, and specifically indicated as L1, L2 and L3 files.

Unlike the RAW files, L-type files are aggregate files that combine various information obtained from various sources (RAW files) but put together on a monthly basis. For example, the RAW files are kept separated in different files according to the data sources (e.g., CORDOVA-ET station, Lysimeter, etc.), while L-type files will be having all the information in a single file.

If any of the variables are not monitored at a site, it is reported as NaN, and if it is missing (e.g. instrument failure) it gets reported as -9999.

Their characteristic features of L-type files are reported in table 1.

Table 1. Difference between L1, L2 and L3 files.

Feature	**L1 File**	**L2 File**	**L3 File**
Temporal Resolution	Daily	Daily	Daily
Data Gaps (-9999)	Possible	Not possible	Not possible
Day Stamp	1, 2,..365	1, 2,..365	1, 2,..365
Unavailable Data (NaN)	Possible	Possible	Possible
Gap Filling	Not Mandatory	Mandatory	Mandatory
Units	Original	See Table 2	See Table 2
Auxillary Data (LAI, NDVI)	NA	NA	If available, can be reported
Reporting and Transmitting to ICARDA	Mandatory	Optional	Mandatory
Attestation requirement	Country manager	Technician Country manager	Technician Country manager
File Naming convention	*COUNTRY_SiteName_Year_Month _L1.csv*	*COUNTRY_SiteName_Year_Month _L2.csv*	*COUNTRY_SiteName_Year_Month _L3.csv*

Table 2. Description of Common Variables Used to Report L1, L2 and L3 files along with their acronyms and units

Description of Variable	Variable Shortname	Units used
Year	YEAR	YYYY
Month	MONTH	MM
Julian Day of the Year	DOY	DDD
Local Time (2400hr format)	TIME	2330
Potential ET (ETo) by CORDOVA method	ETo_COR	mm/day
Potential ET (ETo) by other methods	ETo_SELF	mm/day
Actual ET (ETa) measured by CORDOVA method	ETa_COR	mm/day
Actual ET (ETa) measured with Lysimeter	ETa_Lysi	mm/day
Actual ET (ETa) measured with EB Method	ETa_EB	mm/day
Actual ET (ETa) measured with EC Method	ETa_EC	mm/day
Actual ET (ETa) measured with SM Depletion	ETa_SMD	mm/day
Sensible Heat Flux	H	W/m2
Ground Heat Flux	G	W/m2
Latent Heat Flux	LE	W/m2
Precipitation	Precip	mm/day
Air Temperature	A_Temp	oC
Soil Temperature at 10cm	S_Temp	oC
Plant Canopy Temperature	Canopy_Temp	oC
Incoming SW Radiation Flux	SW_In	W/m2
Outgoing SW Radiation Flux	SW_Out	W/m2
Incoming LW Radiation Flux	LW_In	W/m2
Outgoing SW Radiation Flux	LW_Out	W/m2
Net Radiation Flux	NetRad	W/m2
Relative Humidity	RH	%
Volumetric Soil Water Content	VSMC	fraction
Wind Speed at 2m	WS	m/sec
Normalized Difference Vegetation Index (optional)	NDVI	-1 to +1
Canopy Height (optional)	Cnpy_Ht	m
Runoff from the Field (optional)	Runoff	mm/day
Capillary Rise (optional)-estimated	Capillary	mm/day
Air Pressure- measurement height	Pressure	mbar
Leaf Area Index	LAI	m2/m2
Irrigated Water	Irrigation	mm/day
Method used for Gap Filling	Gap_Method	Regression
Person who prepared the file	Prepared By	Initials of Technician
Date of this dataset preparation	Date of Prep	24/2/2020
Attested By	CountryManager	Initials of CM

The temporal resolution of L1 and L2 file is daily. The difference between L1 and L2 is that L1 files will NOT have gap filled. Hence missing values will have -9999 and unavailable values will be depicted
as NaN. L1 files are subjected to rigorous quality checks and then gap filled, leading to the L2 level of processing. The type of gap filling method and the date of processing and details of processing should be explained in the L2 file (e.g. regression based, or interpolation based). Thus, in L2 there are NO -9999 values. However, NaN values may still exist if that site do not measure a variable. A typical L1 and L2 files are created for each month of a year.The L3 files are gapfilled (i.e. no -9999 values) and are at daily time step. A typical L3 file represents a monthly file with daily values reported. However, for L3 files, daily values (average or sum, depending on the variable, of 48 half hourly values which includes both daytime and nighttime) need to be reported and be consistent with the units used. Some biometric variables such as LAI or NDVI if collected at the site can also be included in this file that may be useful for data interpretation and further synthesis. In order to create L3 files, it is mandatory to create L2 files to do the averaging (or summing) correctly. Typical variables recorded in L-type of files are reported in table 2.

The L1-file naming convention is "*COUNTRY_SiteName_Year_Month_L1.csv*". An example for the case of Egypt would be "*EGYPYT_Sharkhia_2019_May_L1.csv*". Each L1 file will have 48 x number of days in a month time steps.

The L2-file naming convention is "*COUNTRY_SiteName_Year_Month _L2.csv*". An example for the case of Egypt would be "*EGYPYT_Sharkhia_2019_May_L2.csv*". Each L2 file will have 48 x number of days in a month time steps.

The L3-file naming convention is "*COUNTRY_SiteName_Year_Month _L3.csv*". An example for the case of Egypt would be "*EGYPYT_Sharkhia_2019_May_L3.csv*". Each L3 file will have only the number of days in a month time steps.

Examples of files structure for L1, L2 and L3 are shown in table 9, 10 and 11, respectively.

Because we report half-hourly data which demands 48 entries in a given day, we have 48 x number of days in a month in L1 or L2 files. Because daily average values are reported in L3 file, we will have 28, 29, 30 or 31 entries per file, depending on the month and leap year.

Excel Rows

Excel Columns

	1	2	3	4	5
A	YEAR	2009	2009	2009	
B	MONTH	7	7	7	
C	DOY	345	346	347	
D	ETo_COR	3	3.1	4	
E	ETo_SELF	3.1	2.8	3.3	
F	ETa_COR	2	-9999	3	
G	ETa_Lysi	NaN	NaN	NaN	
H	ETa_EB	NaN	NaN	NaN	
I	ETa_EC	NaN	NaN	NaN	
J	ETa_SMD	NaN	NaN	NaN	
K	H	500.3	400.5	452	
L	G	21.9	19.8	22.8	
M	LE	154.7	150.7	-9999	
N	Precip	1.2	0	0	
O	A_Temp	27	24.8	27.9	
P	S_Temp	20.5	20.5	20.5	
Q	Canopy_Temp	15.5	15.7	14.6	
R	SW_In	400.5	-9999	500.7	
S	SW_Out	300.6	360.4	393.7	
T	LW_In	234.7	234.7	-9999	
U	LW_Out	145.7	145.7	145.7	
V	NetRad	34.6	56.6	45.5	
W	RH	78.2	-9999	-9999	
X	VSMC	0.27	0.27	0.27	
Y	WS	6.73	6.73	6.73	
Z	Irrigation	0	1.2	1.2	
AA	Pressure	1013.25	1014.76	1013.2	
AB	GapFill_Mthd	NaN	NaN	NaN	
AC	PreparedBy	SH	SH	SH	
AD	Date of Prep	24/9/2019	24/9/2020	24/9/2021	
AE	CountryManager	BF	BF	BF	
AF					
AG					

Fig. 9. Typical format of an L1-level file (the rows and columns of the Excel sheet are transposed for easy of presentation). Note the highlighted areas that are characteristic of L1 file with data gaps (-9999) and unmeasured datasets (NaN). Note the Column AB where the Gap Filling method is represented as NaN because no Gap Filling exists in this file.

Excel Rows

Excel Columns

	1	2	3	4	5
A	YEAR	2009	2009	2009	
B	MONTH	7	7	7	
C	DOY	345	346	347	
D	ETo_COR	3	3.1	4	
E	ETo_SELF	3.1	2.8	3.3	
F	ETa_COR	2	1.5	3	
G	ETa_Lysi	NaN	NaN	NaN	
H	ETa_EB	NaN	NaN	NaN	
I	ETa_EC	NaN	NaN	NaN	
J	ETa_SMD	NaN	NaN	NaN	
K	H	500.3	400.5	452	
L	G	21.9	19.8	22.8	
M	LE	154.7	150.7	143.7	
N	Precip	1.2	0	0	
O	A_Temp	27	24.8	27.9	
P	S_Temp	20.5	20.5	20.5	
Q	Canopy_Temp	15.5	15.7	14.6	
R	SW_In	400.5	450.2	500.7	
S	SW_Out	300.6	360.4	393.7	
T	LW_In	234.7	234.7	222.6	
U	LW_Out	145.7	145.7	145.7	
V	NetRad	34.6	56.6	45.5	
W	RH	78.2	77.2	79.6	
X	VSMC	0.27	0.27	0.27	
Y	WS	6.73	6.73	6.73	
Z	Irrigation	0	1.2	1.2	
AA	Pressure	1013.25	1014.76	1013.2	
AB	GapFill_Mthd	Multi.Reg	Multi.Reg	Multi.Reg	
AC	PreparedBy	SH	SH	SH	
AD	Date of Prep	24/9/2019	24/9/2020	24/9/2021	
AE	CountryManager	BF	BF	BF	
AF					
AG					

Figure 10. Typical format of an L2 level file (the rows and columns of the Excel sheet are transposed for easy of presentation). Compare the highlighted cells with the L1 data to see how L2 is different from L1 due to Gapfilling of -9999 values. NaN values remains as it is as these variables are not measured at this site. Note the Column AB where the Gap Filling method (in this case Multiple Regression) is entered by the country manager.

Note that L1 is a consolidated file that contains various datasets obtained from various instruments and methods. In addition to ET, allied meteorological variables are also reported. Note that data reported is in half hourly temporal resolution. A given L1 file represents a particular month containing all the days within that month and half-hourly measurements within each day of the month. L1 is not gap filled. Thus, it has -9999 (e.g. due to instrument error or power failure) or if no specific instruments or methods are used at that site, we still use the file template and report it as not measured (using the "NaN" tag). Note the red coloured variables are mandatory variables to be reported and are available at each site irrespective of what method is employed at the site. Other variables if available at the station has to be reported, otherwise left as NaN. The format of this file remains unchanged. The rows and columns are transposed for the ease of presentation

Note that L2 is a consolidated file that contains various datasets obtained from various instruments and methods. In addition to ET, allied meteorological variables are also reported. Note that this is half hourly temporal resolution. One L2 file represents one month containing all the days within a month and half-hourly measurements within each day of the month. L2 is gap filled by a methodology determined by the country manager. Thus, it will not have any -9999 (no values / erroneous values). Note the red colored variables that are mandatory to be reported. Other variables if available at the station has to be reported otherwise left as NaN. The format of this file remains unchanged.

Note that L3 is a consolidated file that contains various datasets obtained from various instruments and methods. In addition to ET, allied meteorological variables are also reported. Note that this is DAILY temporal resolution. One L3 file represents one month containing all the days within a month. L3 is also gap filled by a methodology determined by the country manager. Thus, will not have any -9999 (no values / erroneous values). Note that also in this case the red coloured variables are mandatory to be reported. Other variables if available at the station has to be reported otherwise left as NaN. The format of this file remains unchanged.

Templates of these L1, L2, L3 files will be provided to the country managers by ICARDA (filed with dummy values) with clear guidelines. The red items are essential variables that has to be reported even if other variables are reported as NaN. If the sites have data on the other parameters, they are encouraged to report them too without altering the excel sheet format. If these datasets are not available, the variables should be reported as NaN without changing the structure of the file. It is also important to report the variables in the appropriate units as described below.

		Excel Rows				
		1	2	3	4	5
Excel Columns	A	YEAR	2009	2009	2009	
	B	MONTH	7	7	7	
	C	DOY	345	346	347	
	D	ETo_COR	3	3.1	4	
	E	ETo_SELF	3.1	2.8	3.3	
	F	ETa_COR	2	1.5	3	
	G	ETa_Lysi	NaN	NaN	NaN	
	H	ETa_EB	NaN	NaN	NaN	
	I	ETa_EC	NaN	NaN	NaN	
	J	ETa_SMD	NaN	NaN	NaN	
	K	H	500.3	400.5	452	
	L	G	21.9	19.8	22.8	
	M	LE	154.7	150.7	143.9	
	N	Precip	1.2	0	0	
	O	A_Temp	27	24.8	27.9	
	P	S_Temp	20.5	20.5	20.5	
	Q	Canopy_Temp	15.5	15.7	14.6	
	R	SW_In	400.5	450.7	500.7	
	S	SW_Out	300.6	360.4	393.7	
	T	LW_In	234.7	234.7	234.7	
	U	LW_Out	145.7	145.7	145.7	
	V	NetRad	34.6	56.6	45.5	
	W	RH	78.2	78.2	78.2	
	X	VSMC	0.27	0.27	0.27	
	Y	WS	6.73	6.73	6.73	
	Z	LAI	1.21	1.23	1.34	
	AA	NDVI	0.65	0.66	0.66	
	AB	Cnpy_Ht	0.4	NaN	NaN	
	AC	Irrigation	0	1.2	1.2	
	AD	Runoff	NaN	NaN	NaN	
	AE	Capillary	NaN	NaN	NaN	
	AF	Pressure	1013.25	1014.76	1013.2	
	AG	GapFill_Mthd	MultiReg.	MultiReg.	MultiReg.	
	AH	PreparedBy	SH	SH	SH	
	AI	Date of Prep	24/9/2019	24/9/2020	24/9/2021	
	AJ	CountryManager	BF	BF	BF	
	AK					
	AL					

Figure 11. Typical format of an L3 level file (the rows and columns of the Excel sheet are transposed for easy of presentation). Compare the highlighted cells with the L1 and L2 data to see how L3 is different from L1 due to the inclusion of some auxiliary variables that are not mandatory to report. NaN values remains as it is as these variables are not measured at this site. Also there is absolutely no data gaps shown as -9999.

4. Submitting Data and Archiving in the Central Database

The data from the CORDOVA-ET station located at the five country sites is automatically transferred to the cloud system under supervision of UCO. The data can be downloaded and analyzed at the GRAFANA and Python interface. The website for GRAFANA interface is already circulated among all partners. Each country representative can visualize the data and download it for different analysis. The country managers should retrieve this data and merge it with other data sets (e.g. Lysimeter, eddy covariance, etc.) and make a consolidated file as L1, L2 and L3, as described in the previous sections. It is the responsibility of the country manager to ensure that the L1, L2 and L3 data quality and presentation comply with the suggested protocols.

It is the responsibility of the country managers to retrieve various datasets from the stations and servers and prepare the L1, L2 and L3 files on a monthly basis and transmit it to the central database in ICARDA. Country representatives are free to submit the revised versions of the historical datasets after consulting with ICARDA and central database manager.

A draft of connectivity between measuring sites, countries and central databases is reported in Fig. 12

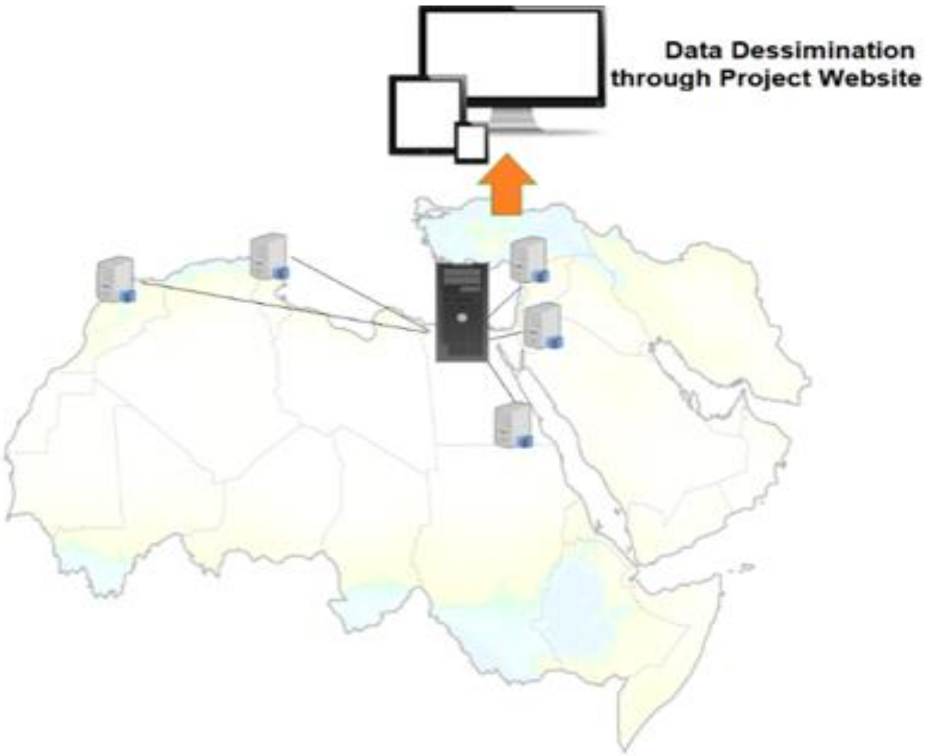

Figure 12. The envisaged flow of measured data from site level to country level to the central database.

The site level technicians ensure that data are properly transmitted and archived at the country level archive. It is assumed that the country partners ensure the transmission of quality-controlled data to the central database. From the central database located in ICARDA, various analysis and graphics will be made available and/or disseminated to different end users via a web-based interface (e.g. knowledge platform), but the dissemination of the data for research will be done on a fair-use policy. The same data will be used for capacity development when comparing them with Remote Sensing ET determinations.

The following description shows the database structure that will be developed at ICARDA. The users and contributors should be aware of this file architecture. The folders often have metadata file that contains additional information about the remaining files and sub folders.

ET-Network

Announcements	6/27/2019 6:40 AM	File folder
Contact List	6/27/2019 6:40 AM	File folder
CountriesData	6/27/2019 6:49 AM	File folder
Protocols	6/27/2019 6:40 AM	File folder
Publications	6/27/2019 6:40 AM	File folder
Reports	6/27/2019 6:40 AM	File folder
Site Photos	6/27/2019 6:40 AM	File folder

ET-Network\\CountriesData

Egypt	6/27/2019 6:48 AM	File folder
Jordan	6/27/2019 6:49 AM	File folder
Lebanon	6/27/2019 6:48 AM	File folder
Morocco	6/27/2019 6:48 AM	File folder
Tunisia	6/27/2019 6:48 AM	File folder

ET-Network\\CountriesData\\Lebanon

Site-1	6/27/2019 6:51 AM	File folder
Site-2	6/27/2019 6:51 AM	File folder
Site-3	6/27/2019 6:51 AM	File folder
Site-4	6/27/2019 6:51 AM	File folder
Site-5	6/27/2019 6:51 AM	File folder
CountryManager-METAFILE.docx	6/27/2019 7:05 AM	Microsoft Word Doc...

ET-Network\\CountriesData\\Lebanon\\Site-1

Data	6/27/2019 7:10 AM	File folder
Maps and other data	6/27/2019 7:10 AM	File folder
SiteMetaData_Lebanon_Site1.docx	6/27/2019 7:11 AM	Microsoft Word Doc...

The site level metadata file contains a detailed description of the site documented by a person knowledgeable in this area. This file includes information on crops and the management practices followed at these sites in different periods. Any relevant information that is missing in the data files should be documented here and attested by the country coordinator with the date.

ET-Network\\CountriesData\\Lebanon\\Site-1\\Data

L1	6/27/2019 9:47 AM	File folder
L2	6/27/2019 7:16 AM	File folder
L3	6/27/2019 7:16 AM	File folder
RAW	6/27/2019 7:16 AM	File folder

ET-Network\\CountriesData\\Lebanon\\Site-1\\Data\\L1

This folder contains the real L1 or L2 or L3 data as applicable. There is also a metafile for reporting any additional details if needed.

An example of a typical file content of a folder of a given site in a country is reported in Fig. 13.

L1-MetaFile_Lebanon_Site1.docx	6/27/2019 9:47 AM	Microsoft Word Doc...
Lebanon_Site1_2019_APR_L1.csv	6/27/2019 9:40 AM	Microsoft Excel Com...
Lebanon_Site1_2019_AUG_L1.csv	6/27/2019 9:44 AM	Microsoft Excel Com...
Lebanon_Site1_2019_DEC_L1.csv	6/27/2019 9:45 AM	Microsoft Excel Com...
Lebanon_Site1_2019_FEB_L1.csv	6/27/2019 7:17 AM	Microsoft Excel Com...
Lebanon_Site1_2019_JAN _L1.csv	6/27/2019 7:17 AM	Microsoft Excel Com...
Lebanon_Site1_2019_JUL_L1.csv	6/27/2019 9:44 AM	Microsoft Excel Com...
Lebanon_Site1_2019_JUN_L1.csv	6/27/2019 9:41 AM	Microsoft Excel Com...
Lebanon_Site1_2019_MAR_L1.csv	6/27/2019 7:17 AM	Microsoft Excel Com...
Lebanon_Site1_2019_MAY_L1.csv	6/27/2019 9:40 AM	Microsoft Excel Com...
Lebanon_Site1_2019_NOV_L1.csv	6/27/2019 9:45 AM	Microsoft Excel Com...
Lebanon_Site1_2019_OCT_L1.csv	6/27/2019 9:45 AM	Microsoft Excel Com...
Lebanon_Site1_2019_SEP_L1.csv	6/27/2019 9:44 AM	Microsoft Excel Com...
Lebanon_Site1_2020_FEB_L1.csv	6/27/2019 9:46 AM	Microsoft Excel Com...
Lebanon_Site1_2020_JAN_L1.csv	6/27/2019 9:46 AM	Microsoft Excel Com...

Figure 13. Typical file contents of a Site level Folder

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