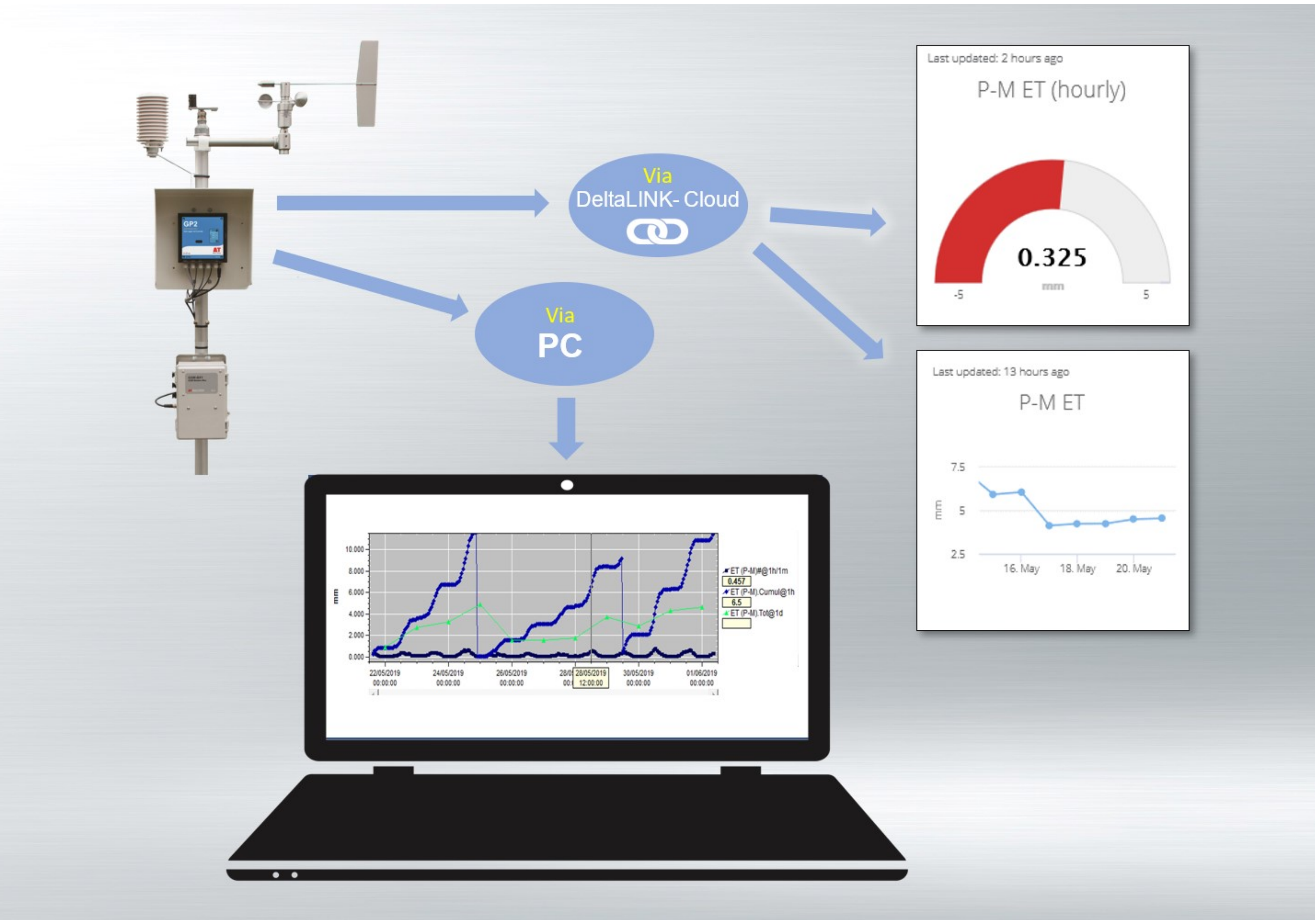
Penman-Monteith Evapotranspiration in GP2 logger controller

Delta-T Devices

Nick Webb v1 31/5/2019



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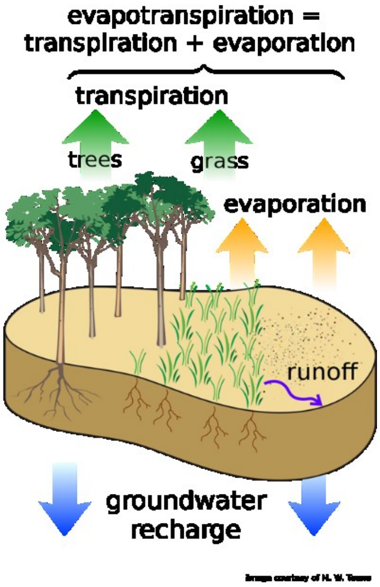
Introduction

The GP2 Data Logger and DeltaLINK software (versions 3.7 and later), in combination with relevant sensors, enables the full ASCE/FAO-56 Penman-Monteith equation for calculating crop reference evapotranspiration (ET_o).
ET_o calculated by the GP2 Data Logger uses measurements of relative humidity, wind speed, solar radiation, and air temperature, so sensors for these must be present.
This ET_o implementation includes the ability to vary crop albedo, Leaf Area Index (LAI), canopy resistances, crop height and sensor heights.
The functionality is easily accessed as a selectable recording option within DeltaLINK.
Calculated ET can be recorded as hourly and daily values – and may be used in further bespoke calculations or to guide field irrigation decisions.
ET dashboards and time series graphs can be viewed online if suitable internet connection to DeltaLINK Cloud exists.
This is all also available to the WS-GP2 Weather Station.

About Evapotranspiration - what is it and why does it matter?



It can be used to predict how much water to add to a crop.
Use of the ET_o calculation of water lost by evaporation and transpiration may significantly enhance the GP2 logger controller's capability as a precision irrigation controller.
One can envisage its use in a WS-GP2 weather station, with or without soil moisture or sap flow sensors, for irrigation control.

Used in combination with Delta-T soil, plant and weather sensors, ET_o may enhance the GP2's capability as a research and control tool in several areas: -

- Irrigation control
- Plant phenotyping trials
- Improving our understanding of the Soil–Plant-Air continuum
- Providing a reference point for satellite-based ET maps

Quick Start

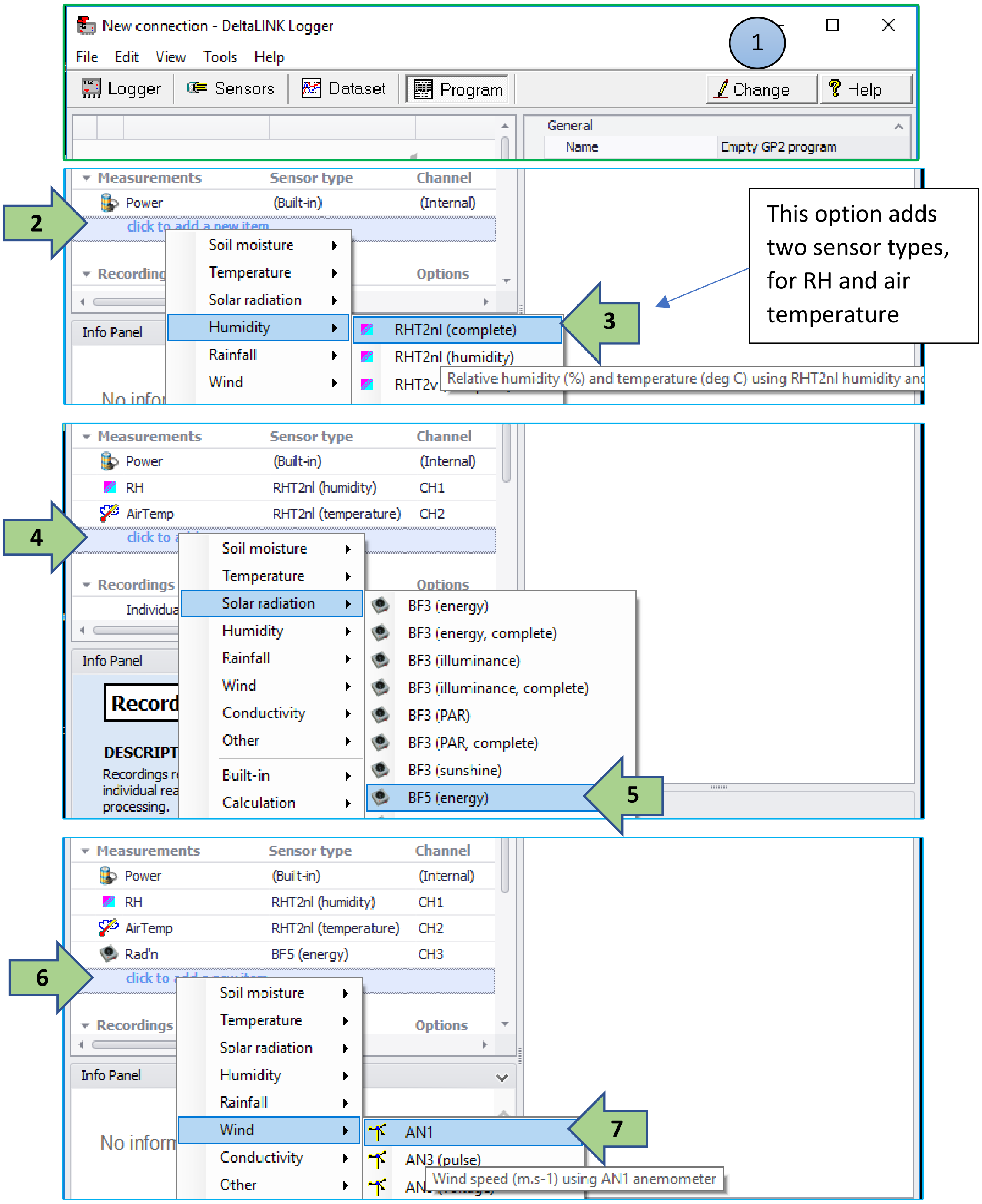
An example DeltaLINK program for a GP2 logger.

Readings from the following sensor types are required for Penman Monteith equation – relative humidity, air temperature, wind speed and solar radiation

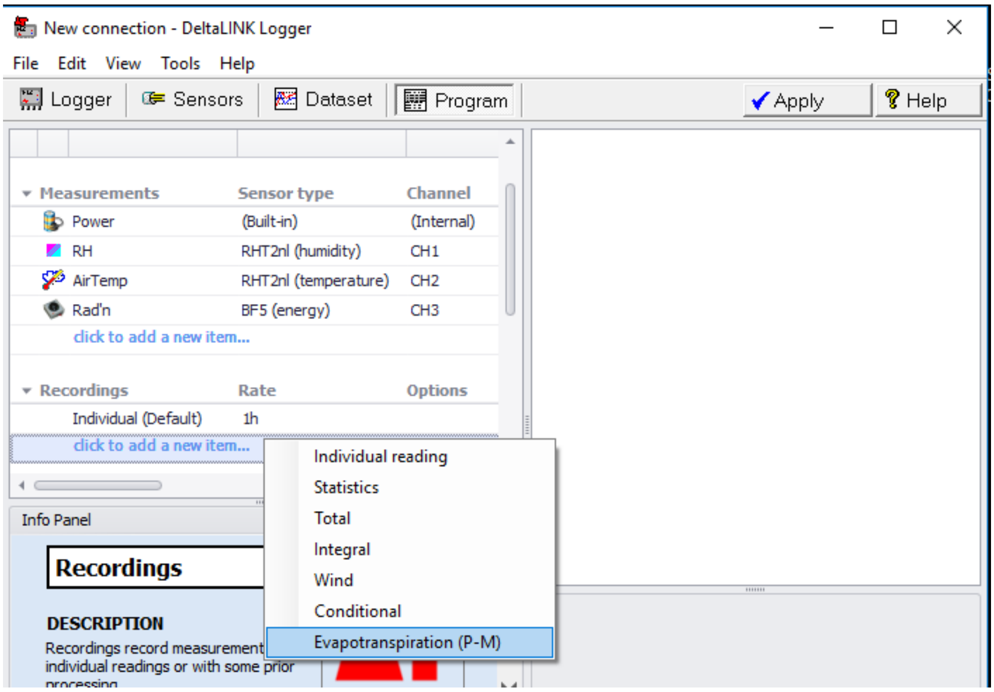
See also the GP2 User Manual and the individual sensor user manuals

1) Click on Change to modify a new or existing GP2 program

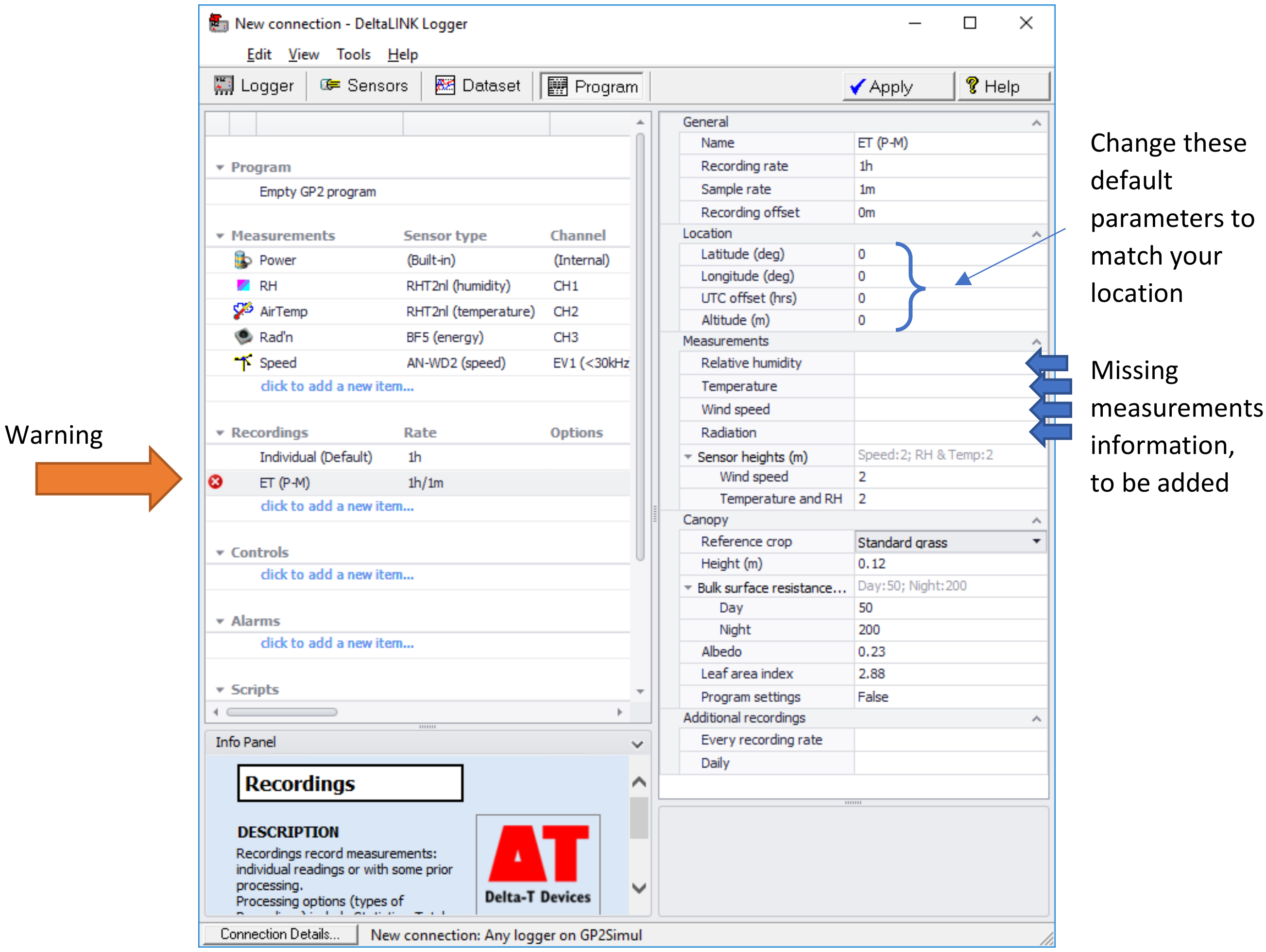
2) If these measurements do not already exist in your program, then using “Click to add a new item”, add the four sensor types measurements needed by the ET calculation to the GP2, as shown below. The GP2 provides more than one option for each sensor type



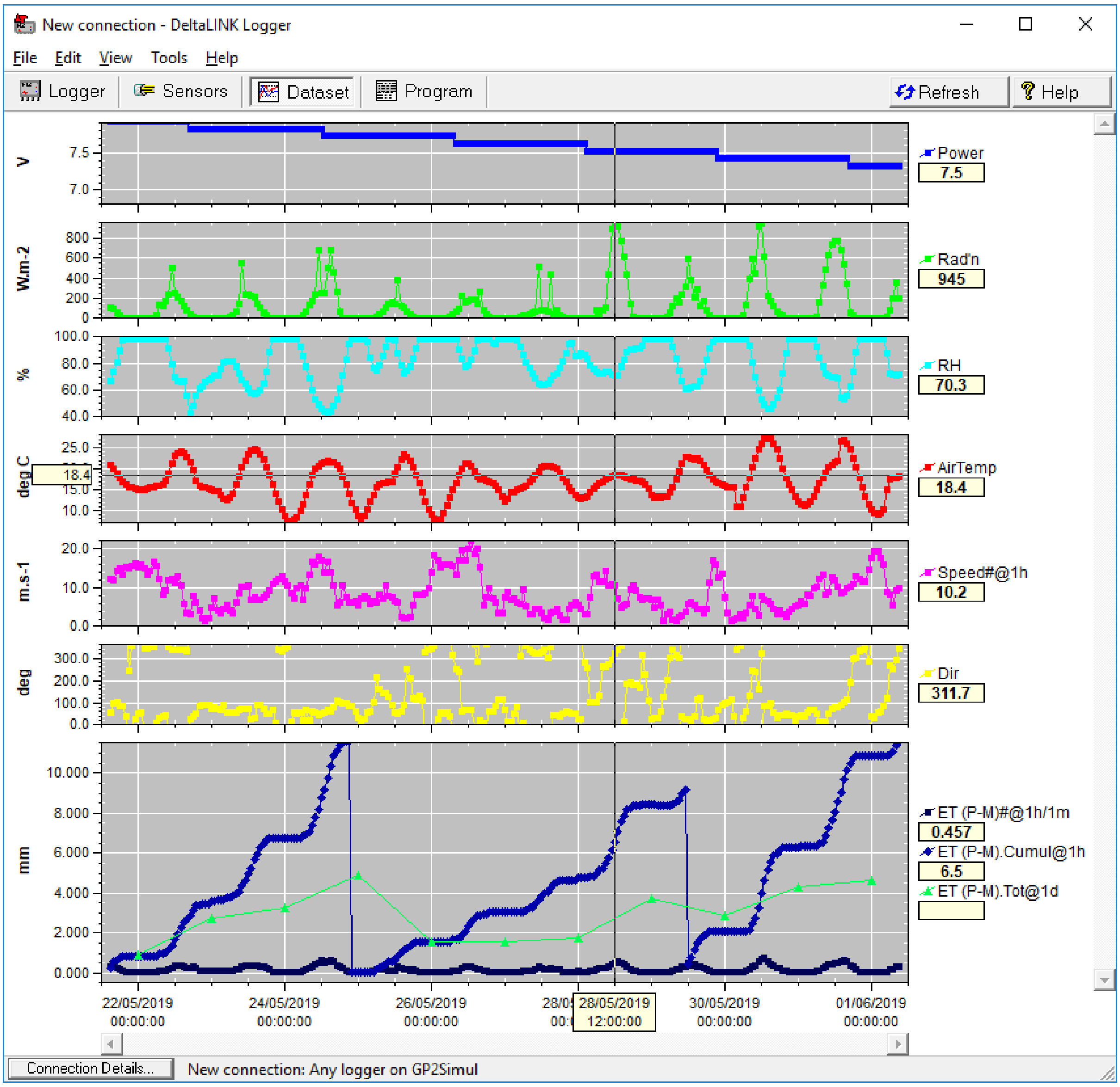
3) Click on “click to add new item” to Recordings and select Evapotranspiration (P-M)



On selecting the ET option DeltaLINK then displays the screen below.
Note the red cross to the left of the ET entry under Recordings. This indicates the program needs something more. Move the cursor over the red cross to see what the errors are.
– in this case the clue is the empty properties in the Measurement section on the right.
4) Place the cursor in each of the blank boxes to display a drop-down list of possible measurements and select the recommended one (with the gold star).



Example DeltaLINK dataset potential evapotranspiration ET graphed at bottom, along the with the sensor readings. This calculation uses the full ASCE/FAO-56 Penman-Monteith equation for calculating reference evapotranspiration (ETo). This data set was created with the DeltaLINK simulator.



DeltaLINK Properties and settings

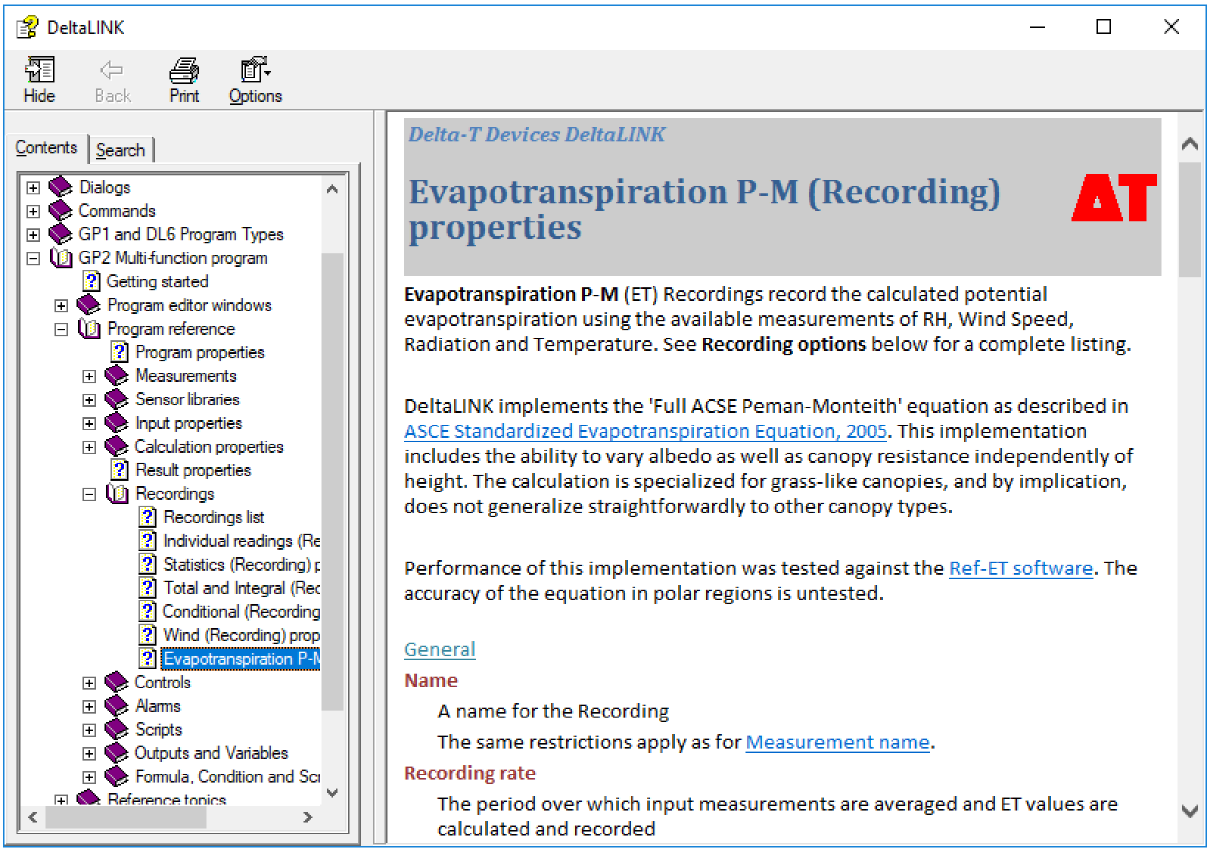
DeltaLINK implements the 'Full ACSE Penman-Monteith' equation as described in ASCE Standardized Evapotranspiration Equation, 2005. This implementation includes the ability to vary albedo as well as canopy resistance independently of height. The calculation is specialized for grass-like canopies, and by implication, does not generalize straightforwardly to other canopy types.
Performance of this implementation was tested against the Ref-ET software. The accuracy of the equation in polar regions is untested.

General	Name	A name for the Recording
	Recording rate	The period over which input measurements are averaged and ET values are calculated and recorded. Enter an exact multiple of the **Sample rate**
	Sample rate	The rate at which the input measurements are sampled. For example, you can sample the inputs every 1 minute and record ET every 1 hour. Enter an exact divisor of the **Recording rate**
	Recording offset	Delays the time of Recording from an exact multiple of Recording rate periods For example: if Recording rate = 1h and Recording offset = 10m then ET values are recorded at 00:10:00, 01:10:00, 02:10:00 … 23:10:00.
Location	Set the location details of the weather station.	
	Latitude (deg)	Enter the latitude of the station's location in degrees. -90 is south and +90 is north. Enter value as a decimal. e.g. 51.5
	Longitude (deg)	Enter the longitude of the station's location in degrees. -180 is west and +180 is east. Enter value as a decimal. e.g. -75.15
	UTC offset (hrs)	The offset from Coordinated Universal Time (UTC) in the logger's time zone. e.g. -5 in New York (Eastern Time Zone) with the logger's clock set to Eastern Standard (i.e. UTC-5) or -4 with the logger's clock set to Daylight Time (i.e. UTC-4). Note: Consider the logger's time zone and daylight saving.
	Altitude (m)	Enter the altitude of the station's location.
Measurements	Select the input measurements that will be used to calculate ET and give their height (where applicable)	
	Relative humidity	The relative humidity measurement. Select a Measurement from the drop-down list. Measurements belonging to the Humidity category are marked as preferred. The result units of this measurement must be "%".
	Temperature	The temperature measurement. Select a Measurement from the drop-down list. Measurements belonging to the Temperature category are marked as preferred. The result units of this measurement must be "deg C" or "deg F".

	Wind speed	The wind speed Measurement Select a Measurement from the drop-down list. Measurements belonging to the Wind speed category are marked preferred. The result units of this measurement must be "m.s-1", "m/s", "ft.ms-1", "ft/s", "kts", "knots", "mph" or "km/h".
	Radiation	The radiation Measurement Select a Measurement from the drop-down list, in which Measurements belonging to the Solar radiation category are marked as preferred. The result units of this measurement must be "W.m-2".
	Sensor heights (m)	The height in meters (above the ground) of the wind speed and temperature & RH sensors.
Canopy	These settings define the canopy that is used for calculating reference ET	
	Reference crop	Choose the reference crop. Standard grass is predefined with default values. For anything else select custom, or change the values of the subsequent properties.
	Height (m)	Specify the height of the reference crop in m
	Bulk surface resistance	Specify the day and night surface resistance of the reference crop in s.m-1.
	Albedo	Specify albedo at the given leaf area index (below) as a fraction.
	Leaf area index	Specify the leaf area index of the reference crop. If this value is changed at run time the albedo value is correspondingly updated
	Program settings	Specify whether the canopy parameters are exposed as program settings, if so then they can be updated throughout the season from the logger tab.
Additional recordings	Choose the summaries you want to record from the following options. In parentheses are the suffices applied to the Measurement name to generate data series names, for example (.Avg) means that the average of a Measurement 'Speed' will be recorded as Speed.avg.	
Every recording rate		
	Relative humidity (avg)	Average RH
	Temperature (avg)	Average temperature
	Wind speed (avg)	Average wind speed
	Radiation (avg)	Average solar radiation
	Cumulative daily ET	Continuously accumulating ET at the recording rate. The total is reset daily.
	Resettable cumulative ET	Continuously accumulating ET at the recording rate. The total can be manually reset (program settings)
Daily		
	Total daily ET	Daily accumulated ET. Recorded once a day.
	Resettable cumulative ET	Continuously accumulating ET, recorded once a data. The total can be manually reset (program settings)

Use of DeltaLINK Help

The P-M ET_o Properties and Setting section above is also available within DeltaLINK Help, as shown below: -



Use of alternative simpler ET equations

In *"A comparison of 4 empirical potential evapotranspiration (PET) equations performed with the DeltaLINK Simulator"* Goodchild describes four alternative approximations for calculating ET
See Goodchild et al https://www.delta-t.co.uk/wp-content/uploads/2016/10/ET-poster-ver-4-1.pdf

McCloud – Temperature-based PET model
Hargreaves – Solar radiation and temperature-based PET model
Turc – Solar radiation, temperature and relative humidity based PET model
Abtew – Solar radiation-based PET model

Whilst these reduced measurement methods of estimating potential ET are attractive from a cost point of view there is plenty of literature presenting their accuracy limitations with respect to reference Penman- Monteith ET_o (Irmak et al, 2003)

ET or soil moisture?

The FAO Penman Monteith equation estimates the amount of water lost by evaporation from the soil and by the transpiration from a crop. It is highly regarded and widely used.

Our soil moisture sensors directly measure how much water is in the soil. They too are highly regarded and widely used.

The volume sampled by our soil moisture sensors spans a few centimetres, whereas the evapotranspiration calculation is an estimate for a standard crop over a region and involves a range of empirically derived engineering constants. Which is better? Both have strengths and weaknesses.

If asked the question "At how many locations should soil moisture measurements be made?", I generally answer evasively, saying "as many as you can afford", and drop sinister hints about soil porosity being fractal so the averages do not scale the way you might expect, and that you might want to brush up on the dark arts of Bayesian statistics.

When asked how far from the weather station will the Penman Monteith equation be valid I become equally evasive, muttering about the need for a sensitivity analysis of the model based on the known accuracy of the sensors, the uniformity of the soil and of the environment, the effect of adjacent trees on wind, shade or RH, and any known limitations of the various empirical engineering corrections published in the FAO guidelines.

All of which amounts to saying I don't really know. (If you are a farmer you will know where the driest part of your field is, so if you only have one sensor, put it there!)

A benefit of the P-M ET_o equation is that it does not need a soil moisture sensor and can cover a wider area. Whilst it is just a model with built-in assumptions and limitations, it is widely used. It has some predictive power using crop coefficients that change according to the stage of growth. (Crop coefficient changes can be programmed into the GP2 via the script editor or entered manually without interrupting GP2 logging).

A review of all the large number of papers on the use, accuracy and limitations of the Penman Monteith equation is outside the scope of this document. It is a big subject - see References below.

One limitation of ET supplied from satellite data derives from the common assumption that the up and down-welling radiation occur at the same time. Goodchild has shown, with the use of heat flux measurements and a GP2, that a significant time-lag can exist between the two, resulting in calculation errors.

Doing both soil moisture and ET is simple and straight forwards on a GP2. It should be possible to integrate ET as feedback into a PID irrigation control algorithm, of the sort outlined by Goodchild (2015) for precision irrigation. One could envisage field-wide irrigation based on ET with soil moisture sensor readings used as set point limits – located at the known wettest and driest part of the field. (At the time of writing we have not tried this yet.

A WS-GP2 weather station plus soil moisture sensor may be used to ground-truth satellite data for both soil moisture and ET. The scale of satellite derived ET, weather station derived ET, and soil moisture sensor readings all being different, comparisons between them, of course, need care.

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Software

Ref-ET Software: https://www.uidaho.edu/cals/kimberly-research-and-extension-center/research/water-resources/ref-et-software