Evapotranspiration forecast using SWAT model and weather forecast model

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SWAT calculates reference evapotranspiration (ETo) using three different methods: i) Priestley-Taylor ii) Hargreaves and iii) Penman-Monteith (P-M). All the methods use meteorological measurements for this calculation. However the P-M method is the most intensive in terms of meteorological measurements but is also considered the most accurate one.

SWAT uses ETo to estimate actual evapotranspiration (AET). For that it takes in consideration water availability in the soil, as well as the development stage of the plant. Water availability depends on soil properties and irrigation practices while plant development depends on agriculture practices and meteorology. This variables accuracy is very much dependent on input.

Traditionally farmers estimate a crop evapotranspiration (ETc) which is calculated by multiplying the reference evapotranspiration ETo, by a crop coefficient (Kc). The calculation of these variables has been standardized by FAO using a set of tables with successive corrections to Kc to obtain AET. These corrections have a correspondence to the SWAT plant stresses and Kc has correspondence to SWAT plant module.

An accurate estimation of AET is very important for farmers, because it allows them to better estimate the amount of water that is being removed from the soil. With this they can better estimate how much water they must use in irrigation.

In this perspective SWAT model is running in forecast mode using meteorological data from the previous week and forecasts for the next week. The weather data is from the closest station of each field (precipitation, temperature, relative humidity, wind speed and solar radiation). The weather forecasts come from a weather forecast model that is running for Portugal. This service is running for Sorraia Valley which is located in Portugal and is a typical irrigated agricultural area, mainly corn crops.

The SWAT model results were sent by mobile phone messages to the corn producers in the Valley Sorraia every week during the irrigation season of 2010 (May-September). Farmers received the temperature, precipitation and actual evapotranspiration data measured last week and the forecast for next week.

This study was developed in AquaPath-Soil project and supported by the European Space Agency (ESA).

This presentation will show the implemented service but will also show the accuracy of AET estimations using meteorology from weather forecast model.

Keywords: SWAT model, evapotranspiration, Penman-Monteith, Irrigation

Introduction

SWAT is a watershed model that can calculate reference evapotranspiration (ETo) with three different methods: i) Priestley-Taylor ii) Hargreaves and iii) Penman-Monteith (P-M). All methods use meteorological measurements for this calculation with P-M being the most intensive one. However, it is considered the most accurate one (Monteith, 1965; Allen, 1986; Allen et al., 1989). SWAT uses ETo to estimate actual evapotranspiration (AET). For that it takes in consideration water availability in the soil, as well as the development stage of the plant. Water availability depends on soil properties and irrigation practices while plant development depends on agriculture practices and meteorology. This accuracy of these variables is very much dependent on input data Traditionally farmers estimate crop evapotranspiration (ETc) by multiplying the reference evapotranspiration ETo, by the crop coefficient (Kc). These variables are standardized by FAO using a set of tables with successive corrections to Kc to obtain AET. These corrections have a correspondence to the SWAT plant stresses and Kc has correspondence to SWAT plant module.

An accurate estimation of AET is very important for farmers, because it allows to better estimate the amount of water that is being removed from the soil which dictates the amount of water needed in irrigation. This study was developed in AquaPath-Soil project and supported by the European Space Agency (ESA).

The study area is located in the Sorraia Valley in Portugal considering the famers field area with irrigated agriculture (Figure 1). Sorraia Valley has about 15500 ha being the largest area of irrigated agriculture in Portugal, especially corn, tomatoes and rice. The growing season starts at about 23 May and ends at about 15 October. In 2010, mean annual temperature and mean annual precipitation at Sorraia 16.2 °C and 953 mm, respectively. The mean temperature in the period between May and October was 19.9 ºC.

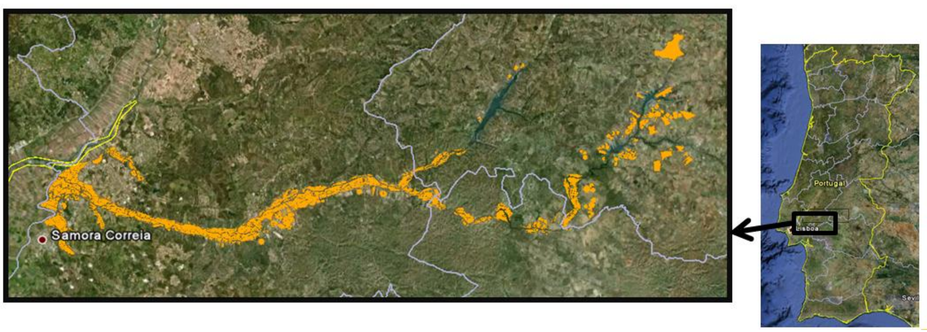


Figure 1- Study area location with farmer's fields selected

This paper shows the implemented service but will also show the accuracy of AET estimations using meteorology from weather forecast model.

Operational Forecast Service

SWAT model was setup in forecast mode using meteorological data from the previous week and forecasts for the next week (Figure 2). Weather data from the previous week are taken from the closest station for precipitation, temperature, relative humidity, wind speed and solar radiation. Weather forecasts are produced by the numerical model MM5 running at IST for Portugal in a 9 km2 grid (Sousa, 2002) and converted to a format that can be read by MOHID and SWAT model. .

SWAT forecasting system is implemented for Sorraia Valley (Portugal) which is a typical irrigated agricultural area with mainly corn crops.

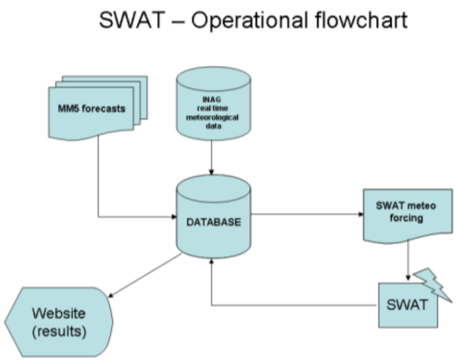


Figure 2 – Flow chart and hardware setup for operational model

SWAT model results are sent every week during the irrigation season of 2010 (May-September) to the corn producers in the Valley Sorraia, by mobile phone messages containing temperature, precipitation and actual evapotranspiration data measured last week and the forecast for next week. Figure 3 shows the workflow and hardware setup of the complete service. Daily forecasts for the next 6 days are also shown in the internet (Figure 4) according to the AquaPath-Soil project guidelines.

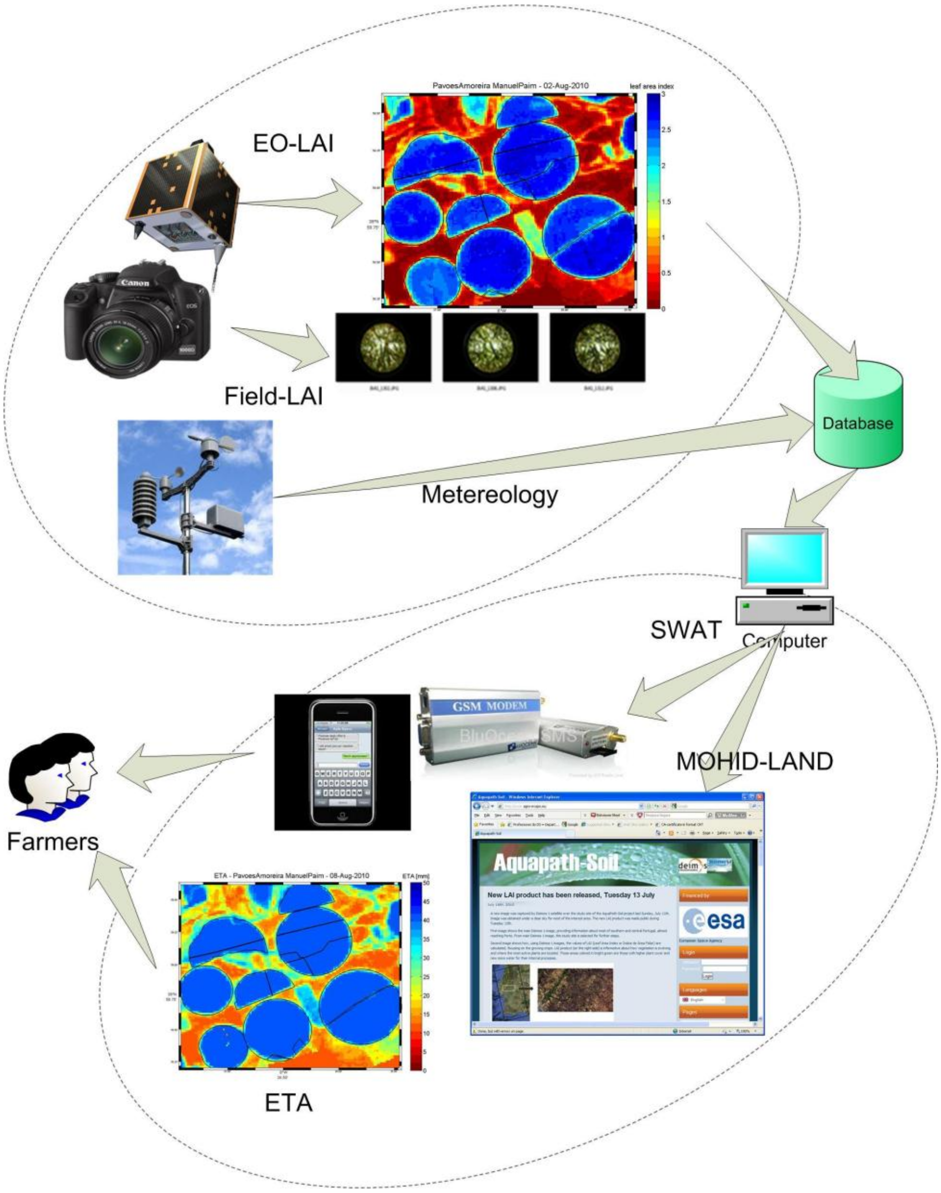


Figure 3– Work flow of Aquapath-Soil Project

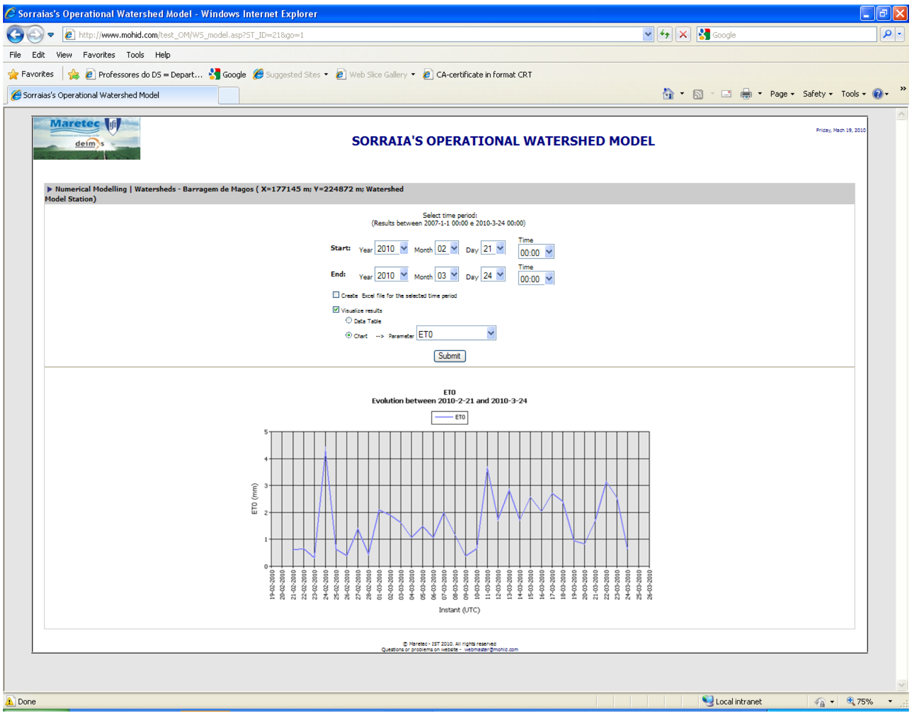


Figure 4 – SWAT forecast mode available in the internet (www.agro-evapo.eu)

SWAT forecast modeling

The system is contained in one main working folder. This folder then contains 7 folders: MEASUREMENTS, MM5, METEO, SMS, SWAT, BACKUP, LOGS.

The MEASUREMENTS folder contains the GetMeteoFromNet executable that downloads via HTTP the data from the ARBVS (Famers Irrigation association: www.arbvs.pt) or INAG-SNIRH (national water information system: snirh.pt) online meteorological data databases.

The MM5 folder contains 2 folders: GetMM5TimeSeries and UploadToDatabase. The GetMM5TimeSeries folder contains the program (GetMM5TimeSeries) that directly extracts time series from the Mesoscale Meteorological Model, Version 5 (**MM5**) results (day before and next 6 days) for the designated meteorological stations. The UploadToDatabase folder contains the program (TimeSeriesManager) that uploads the meteo extracted time series to the database.

The METEO folder contains the files responsible to generate digested meteo time series for each local station, using a combination of at least 2 different data sources already in the database: forecast data from MM5 forecasts (added to database in the previous step with UploadToDatabase folder) and measured data (added to database in the MEASUREMENTS folder) for each station.

The SWAT folder contains 3 standard folders: txtinout, res and database folders. Txtinout and res folders are the 2 standard folders to run the SWAT model, has in standard SWAT-Mohid version of SWAT model described in Chambel-Leitão et al (2007) and decribed in Mohid wiki available in the internet. In txtinout one can find all the input data files that are daily updated by the operational system, namely the file.cio (containing the initial and final dates for the simulation) and the meteorological forcing files (pcp1.pcp, tmp1.tmp, slr.slr, wnd.wnd and hmd.hmd). The database folder is the place where SWAT results are uploaded to database.

The Upload is made to 2 different database tables: one will have only the best available forecast (only forecasted data), and the other table will have the best available simulation (including hindcast – using measured data).

The SMS folder contains the SMSGenerator executable, responsible for generating the sms text that will be sent to the users of the service. The SMSGenerator.exe runs once a day, after all the simulations and needed database operations are done.

The BACKUP folder is the folder where all the results and input files of one daily simulation are stored. Each day a new folder is created inside BACKUP named with the initial and final date of that simulation. This folder is subdivided into 2 folders:

- Meteo (contains the best time series used for the day's simulation, both hourly and daily)
- Swat (contains the SWAT input files in the input folder; and SWAT results, in Results folder)

The LOGS folder contains daily generated log files with details of the operational tool tasks running evolution

SWAT forecast database

All the data involved in the SWAT-Operational is stored in a single database in MS ACCESS 2007. Data is stored in different tables, each one corresponding to a different data source and a specific local point (time series).

So, the database is composed by different tables:

- The "TimeSeries" table with metadata and details of each time series found in the database (name, geographical coordinates, etc)
- The "TimeSeriesTypes" table, with description of the different types of time series that can be found in the database
- Many timeseriestables (data sources for each local point):
    - Meteorological measured data from SNIRH-INAG or ARBVS
    - Meteorological predictions (from MM5);
    - SWAT Best available simulations (hindcast + forecast);
    - SWAT Best available forecasts (only forecasts)

To add new local stations to the system, database tables must be created, as well as new rows must be added to Metadata table describing new tables names, geographical locations, etc.

To the SMS service, another set of tables exists in the database.

System validation

Reference Evapotranspiration

The first step in modeling validation was focused in potential evapotranspiration. For this, SWAT results were compared with the Penman-Monteith formulas in FAO56 (Allen et al., 1998). These equations were used with data from the ARBVS meteorological station for the year 2009.Figure 5 compares both time series and it can be seen that results are very consistent. This was expected because SWAT and FAO56 use the same formula for evapotranspiration.

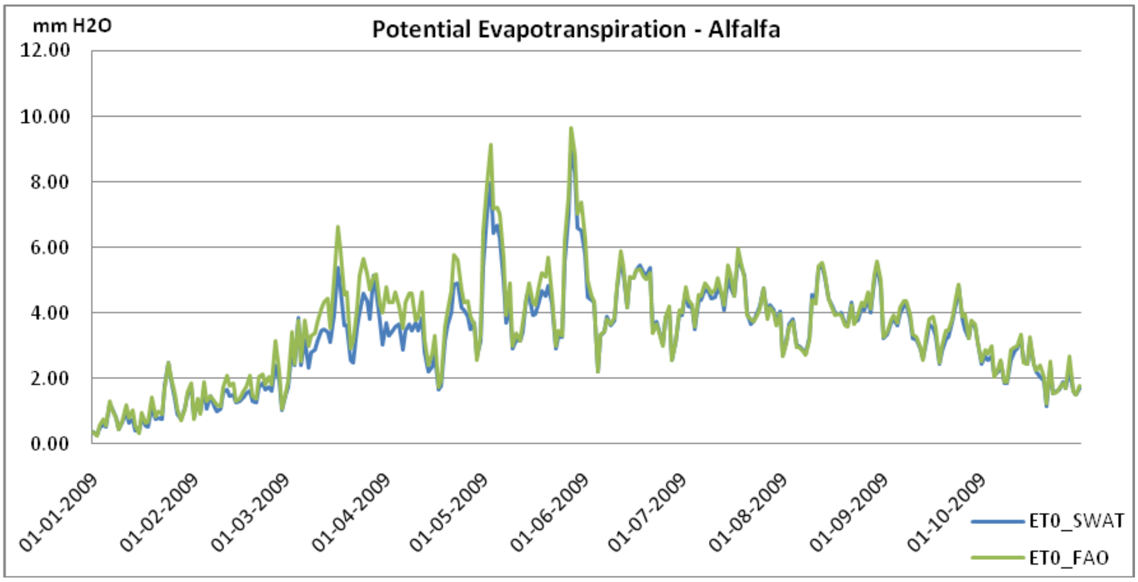


Figure 5 - SWAT evapotranspiration results compared with standard FAO56 paper calculation

Secondly, it was study the impact of using different meteorological stations on evapotranspiration calculation. It was used temperature (maximum and minimum), wind speed and humidity relative data from Barragem de Magos of SNIRH and Paul de Magos of ARBVS stations (Figure 6). These two stations are nearby but from different institutions.

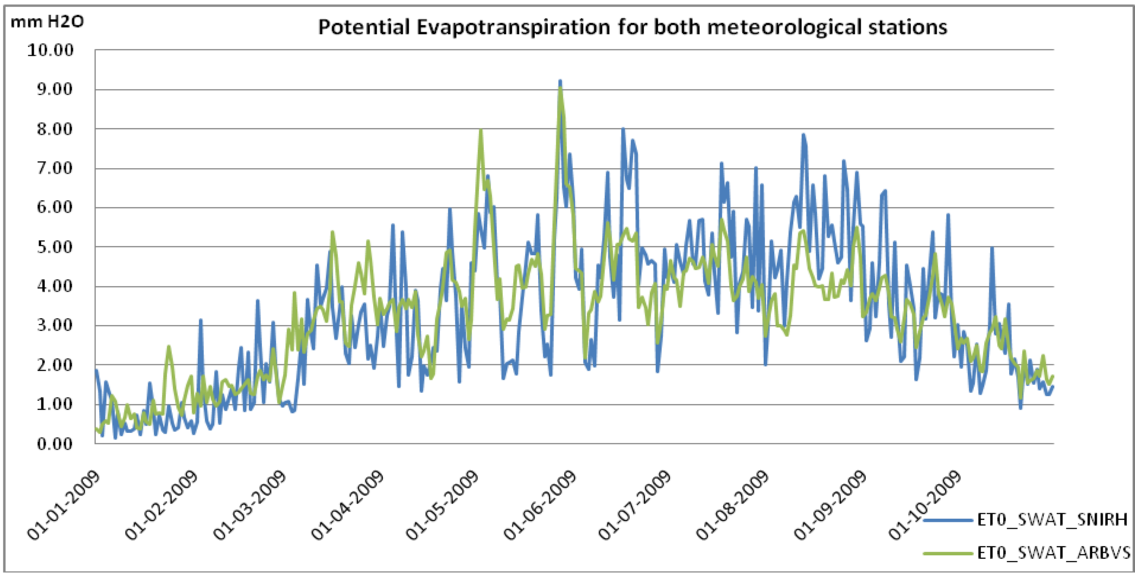


Figure 6 - Potential evapotranspiration results using different meteorological stations

Graphic shows that different meteorological stations represent different results in potential evapotranspiration values. The reason for this difference is wind and relative humidity. In fact when we use the same wind and relative humidity, both meteorological stations return similar potential evapotranspiration (Figure 7).

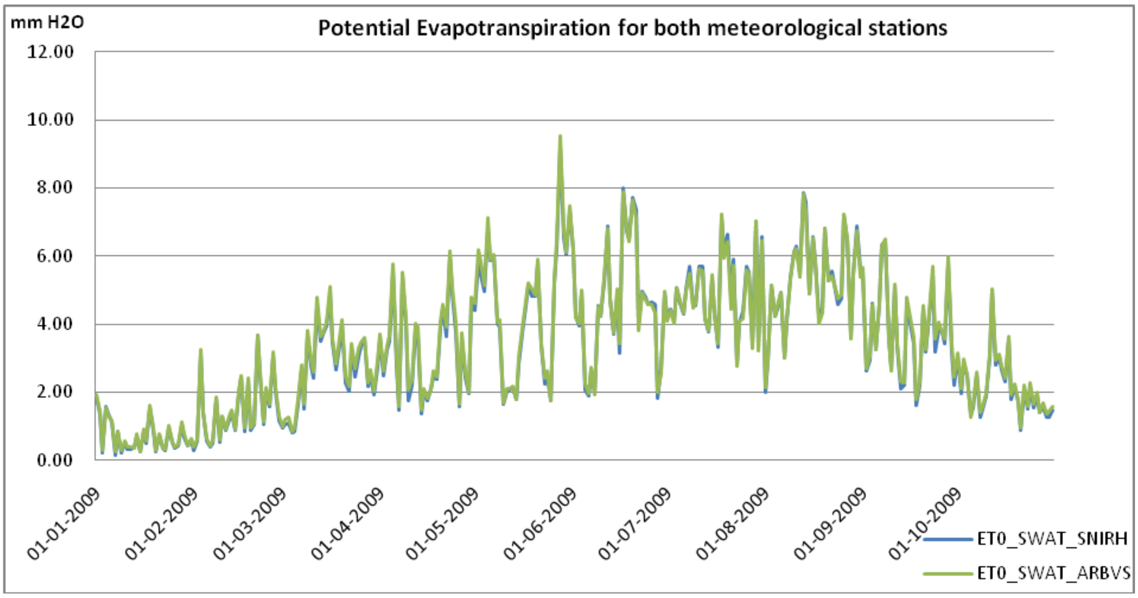


Figure 7 - Comparison of evapotranspiration values for both stations, with equal wind and humidity values

The effect of using different reference crops in the values of reference evapotranspiration was also investigated Figure 8 shows the potential evapotranspiration for Grass and Alfafa in Barragem de Magos, where it can be seen differences between crops are mainly in the irrigation season. The Alfalfa crop has always higher evapotranspiration values because the canopy resistance of this crop is higher than Grass crop. Also, Alfafa crop height can be 40 cm at plant's maximum growth, while grass plants only achieve 12 cm.

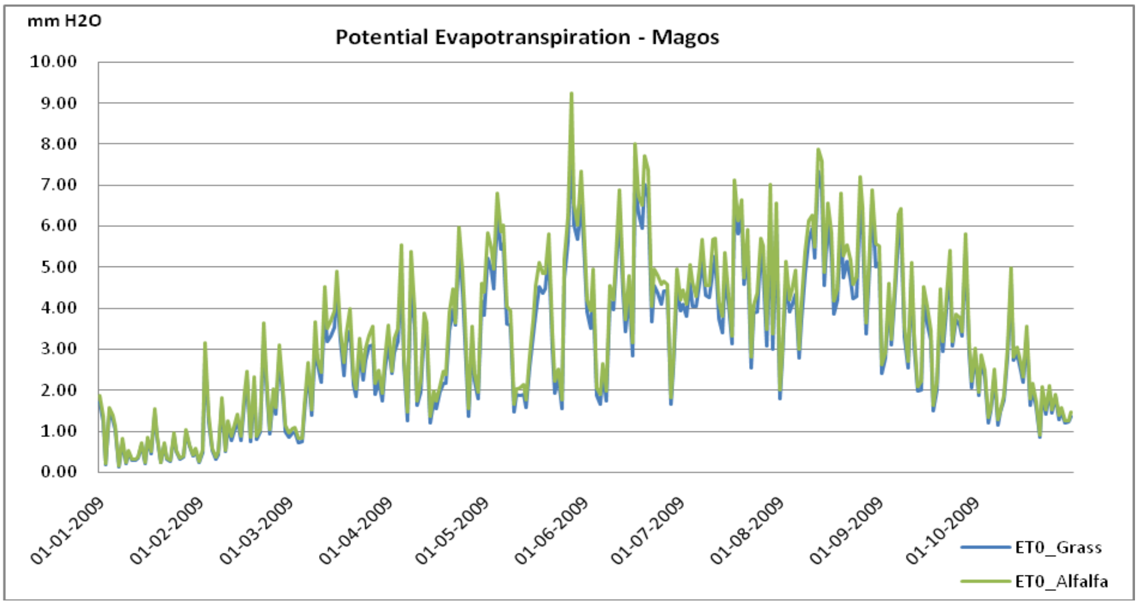


Figure 8 - Evapotranspiration calculated for Grass and Alfalfa crops.

Evapotranspiration

In Figure 9it can be observed the leaf area index curve, crop transpiration and soil evaporation (evapotranspiration components). In initial period only soil evaporation is represented because crops not yet started their growth. When crops begin grow it can be observed the transpiration and LAI increase. With this increase, it can be observed the soil evaporation decrease, because part of water initially in the soil is consumed by crops and then transpired. So it can be concluded that is possible to obtain the evapotranspiration from LAI values.

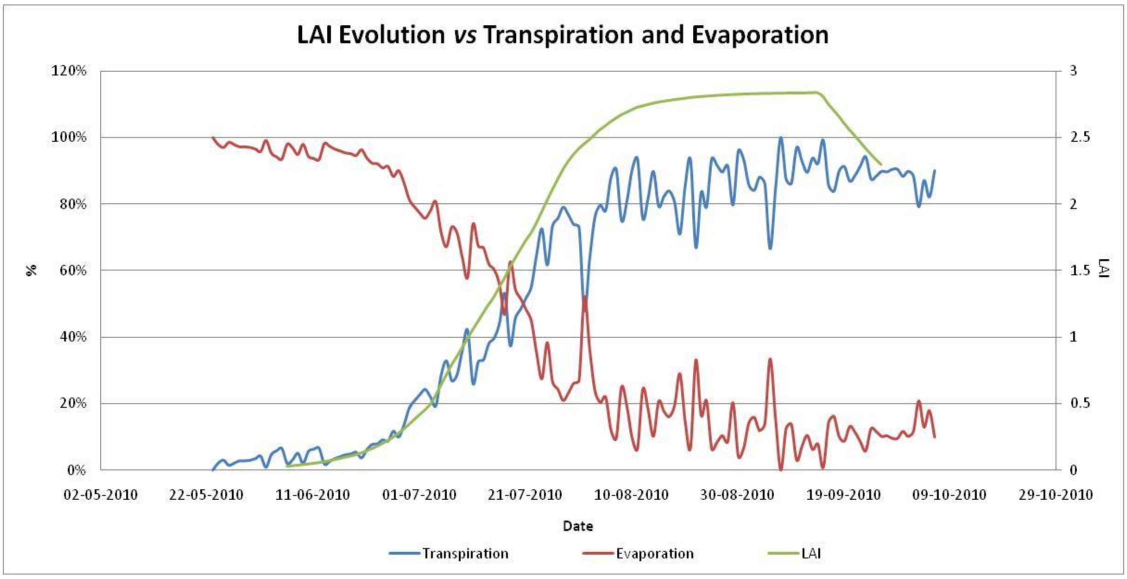


Figure 9 LAI, evaporation and transpiration in SWAT model

Cultural evapotranspiration results from both models were compared with the results measured at the meteorological station's ARBVS (Figure 10). It was concluded that the models results simulated a consistent behavior.

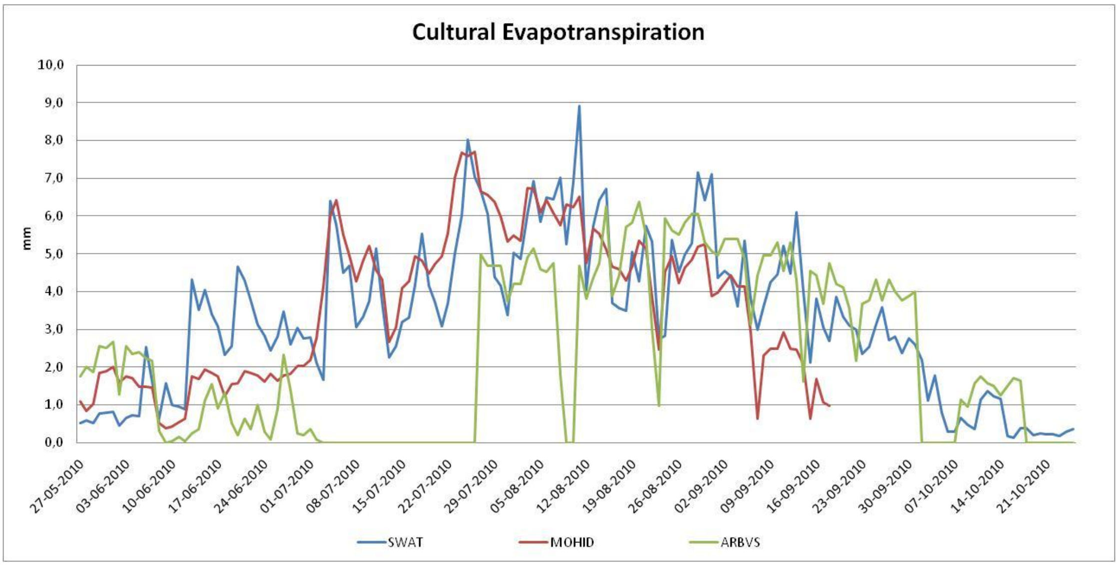
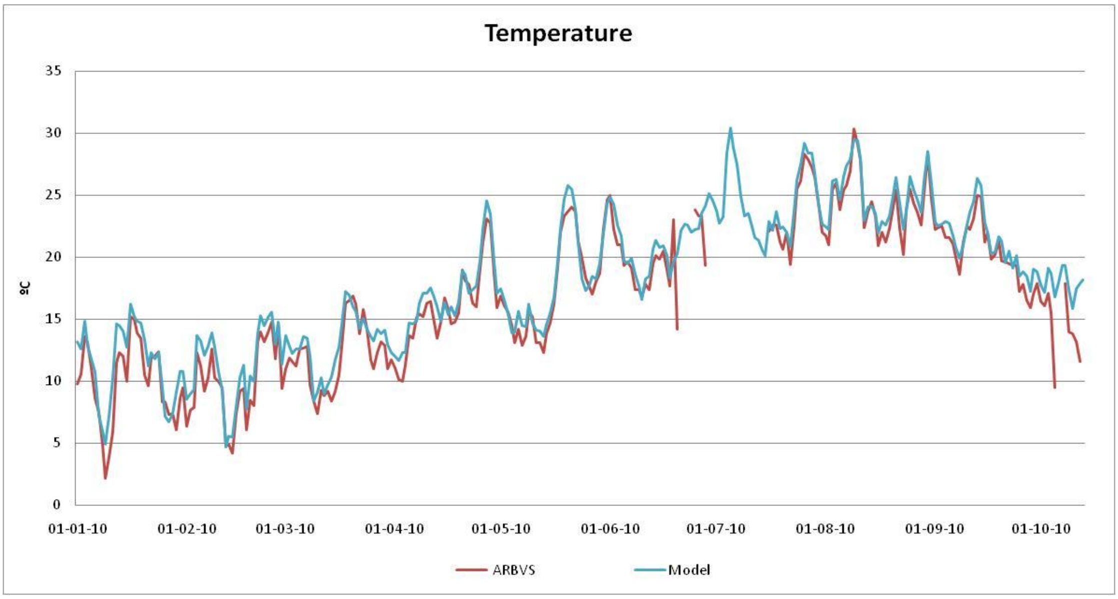


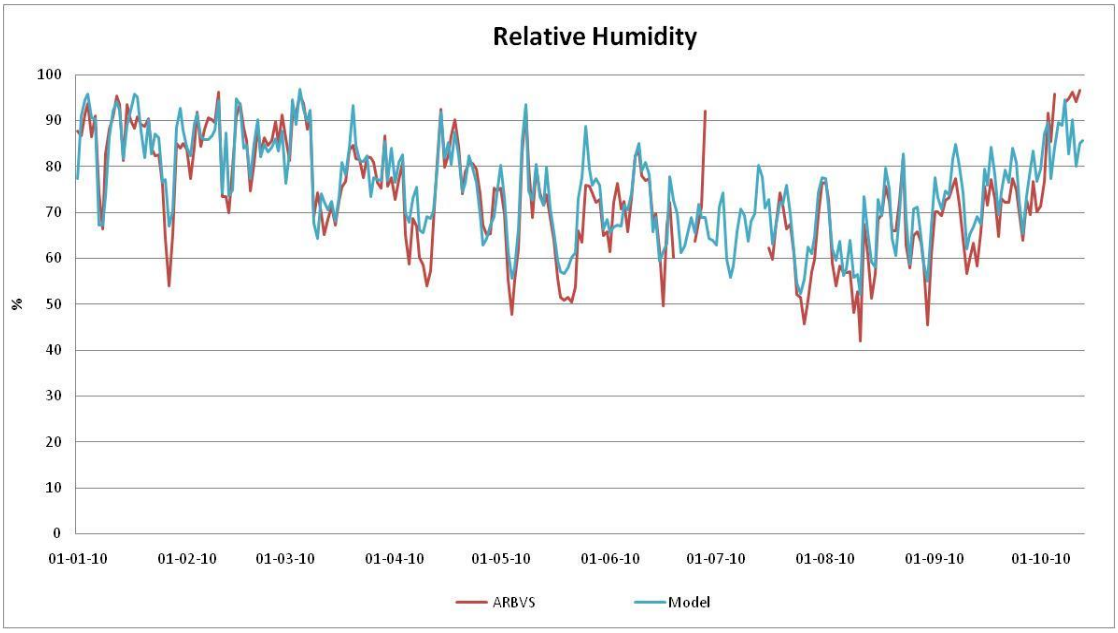
Figure 10 Cultural evapotranspiration comparison: meteorological station data (ARBVS), SWAT and Mohid model results

Weather Forecasts Validation

SWAT forecasts use both measured and forecasted meteorological data and the consistency between these is important for proper ETA forecasts. This is investigated by comparing the numerical forecasts with measured values in APBVS station. Figure 11 (a) to (c) show that temperature, relative humidity and precipitation forecasts are similar to those measured in the APBVS station, with slight overestimation of daily maxima temperature. Figure 11 (d) shows that wind speed forecasts are not very consistent with observations in the small fluctuations. However, the daily behavior is quite similar.



(a)



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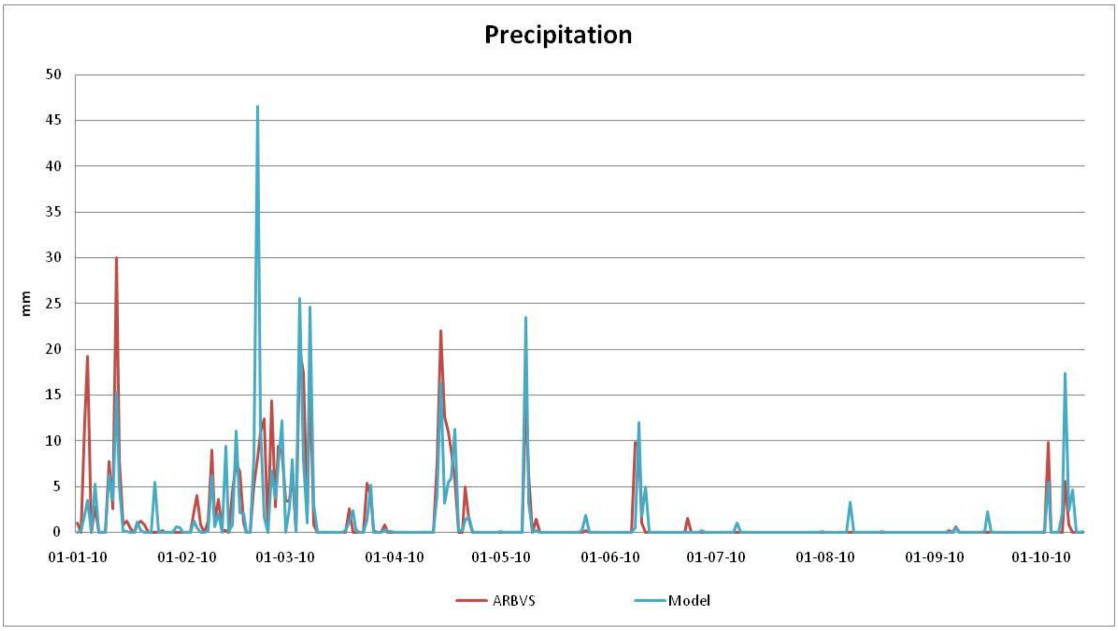
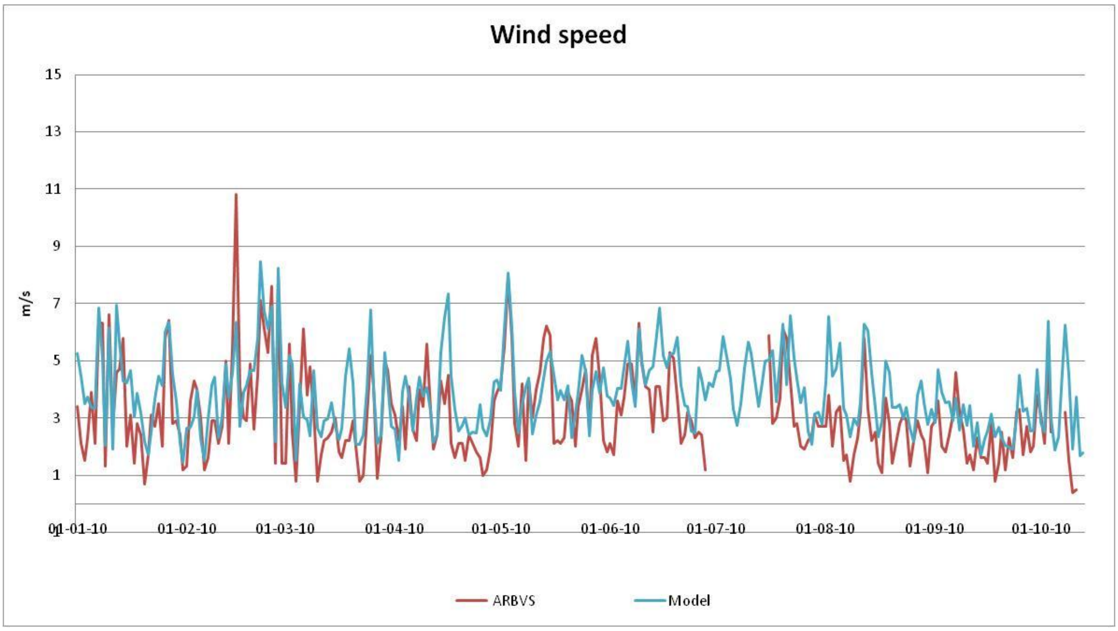


(c)



(d)

Figure 11 – Measured and forecasted 2 meter temperature (a) and relative humidity (b), precipitation (c) and 10 meter wind speed (d) at APBVS station.

AET Forecast Validation

AET forecasts and measured values in the previous week were send by SMS to the farmers. Table 1 shows an example of the information sent in each week, with forecasts in the second column, but with correspondent measured AET (previous week in the message of next week) in the third column, the difference between these two in the third column and the error in the last column. It can be seen that only week 2 and 4 have higher discrepancies between forecasts and observations.

Week	Initial Date	Next Week (model forecasts)	Previous Week (user estimations)	Error	% of Error

1	19-07-2010	30	38	-3	-8%
2	26-07-2010	41	60	13	22%
3	02-08-2010	47	50	-2	-4%
4	09-08-2010	52	51	8	16%
5	16-08-2010	43	32	-1	-3%
6	23-08-2010	33	31	1	3%
7	30-08-2010	30	36	-2	-6%
8	06-09-2010	38	24	-5	-21%
9	13-09-2010	29	25	-1	-4%
10	20-09-2010	26	15	-6	-40%
11	27-09-2010	21	14	-4	-29%
12	04-10-2010	18	8	3	38%
13	11-10-2010	5	6	-	-

Table 1 – Comparison example of previous week and next week ETA estimation for one of the users

Conclusions

Mesoscale Meteorological Model, Version 5 (MM5) temperature, precipitation and relative Humidity is consistent with local meteorology

ETo values estimated with data from meteorological stations close by were compared. Values of wind and humidity in two close by stations was different enough to change the result of ETo significantly.

SWAT, MOHID and FAO56 return similar evapotranspiration values for the present study site.

SWAT model was setup successfully to run in a forecast mode using meteorological data from the previous week and forecasts for the next week.

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