CRITERIA-3D

User manual

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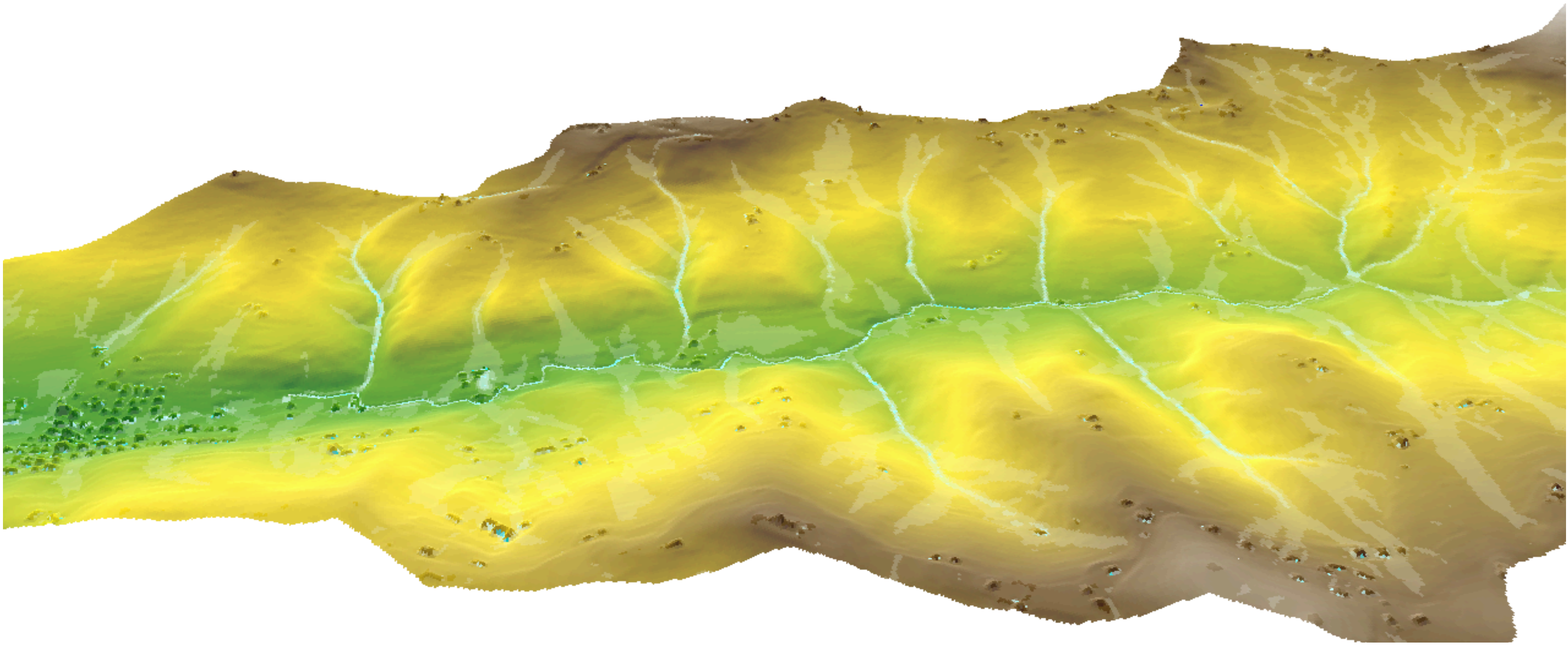

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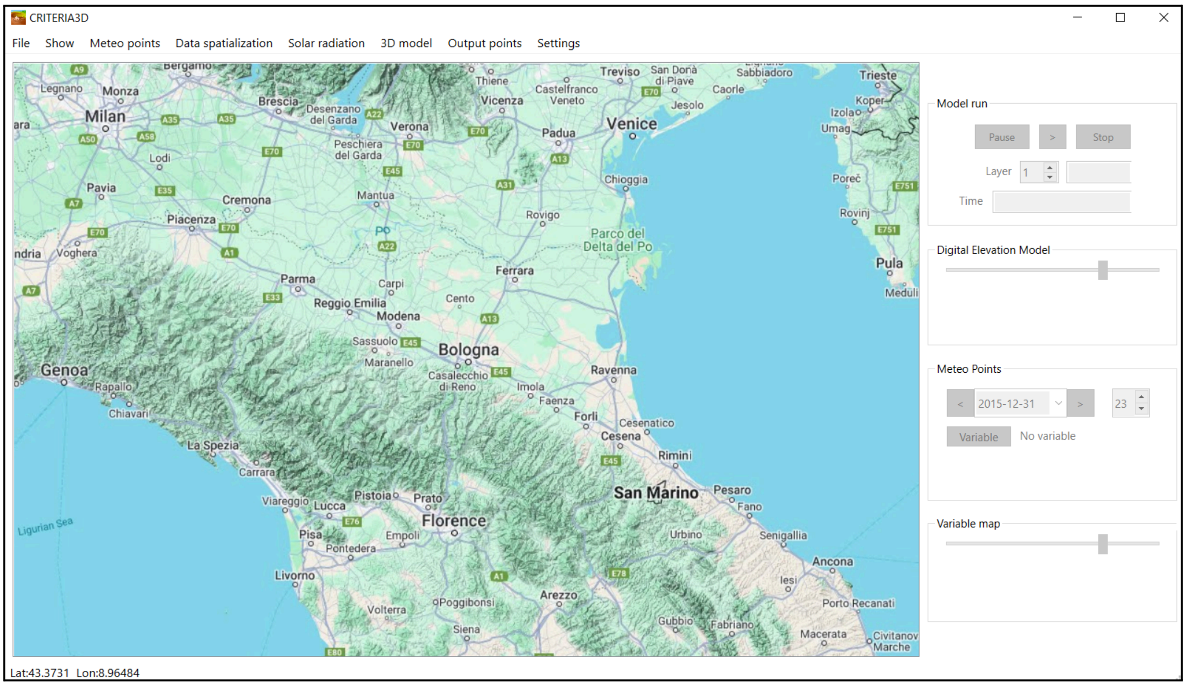


Fig. 1 CRITERIA-3D main window

Once launched, the CRITERIA-3D main window appears as represented in Fig. 1. In the upper part of the window, a menu is present. The different voices are:

- **File**: allows the user to upload an existing Project (through a text file with .ini extension), to manage input and output databases (see par. 1.1 *Menu File*);
- **Show**: allows visualizing different maps (soil, land use, crop etc.) and specific variables (water content, water potential, slope stability etc.). The 3D viewer is also present in this menu section, where it is possible to view the desired variable upon the real digital elevation model (DEM);
- **Meteo points**: allows to open a meteo points database and to deal with the different meteo stations;
- **Data spatialization**: allows to set the spatialization methods and to analyze data spatially, computing specific periods for meteorology;
- **Solar radiation**: allows to set the solar radiation conceptual model parameters;
- **3D model**: allows to set the 3D hydrological computation, selecting active processes (soil water flow, snow and crop model) and treating with model states;
- **Output points**: allows to create new output points, and to select where to save outputs;
- **Settings**: allows to choose the background map (Google Terrain is the default) and to set some parameters such as the time convention, the time zone, and some parameters about data quality and meteorology.

In the next sections the different voices are described in detail.

1.1 ‘File’ menu

The ‘file’ menu is composed by three voices:

- **Project**: allows to open or close a project. A project is represented by a text file (Fig. 2) where users need to define where the different databases and maps are located. A project is composed of a DEM, a meteorological database (`meteo_points`), a soil map and the related soil database, a land use map, and a crop database. Specific depths for the chosen outputs can be set. The structure of these files will be explained in Section 2;
- **Input**: in this menu it is possible to upload a DEM (if a project is already opened it will be replaced), a meteo points database, a soil map, a soil database, a land use map and a land unit and crop database. When a DEM is uploaded, the map centers on it automatically and new maps will be visualized only if overlaying the uploaded DEM. Some of the input can also be created through the Input menu voice;
- **Output**: allows to upload an output points list, where the points are defined in terms of id, latitude, longitude, height and a boolean (i.e., a 1 or 0 variable) that indicates if the point is active or not, and an output points database where to save outputs. The output database can be created directly from this voice menu.

Montue.ini - Blocco note di Windows

File Modifica Formato Visualizza ?

```
[software]
software=CRITERIA3D

[location]
lat=45.06
lon=9.275
utm_zone=32
time_zone=1
is_utc=true

[project]
name=Montue
dem=./MAPS/DEM_Montue.flt
meteo_points=./METEOPOINTS/Montue.db
soil_map=./MAPS/Soil_Montue.flt
soil_db=./DATA/soil_Montue.db
landuse_map=./MAPS/Landuse_Montue.flt
crop_db=./DATA/crop_Montue.db
output_points=./outputPoints/outPoints.csv

# 1D
db_meteo=./DATA/meteo1D.db
db_comp_units=./DATA/comp_units.db
db_output=./OUTPUT/montue1D.db

[settings]
parameters_file=./SETTINGS/parameters.ini
log_file=./LOG/Montue.txt
tile_map=GOOGLE

[output]
waterContent=20,40,60,100,120,140
waterPotential=20,60,120
factorOfSafety=1,3,5,10,20,60,100,120
```

Fig. 2 An example of a .ini file

1.2 ‘Show’ menu

This menu allows to visualize specific variables, both during a simulation and at the end of it. Subsurface variables (i.e., water content, factor of safety etc.) can be mapped for any computational layer depth.

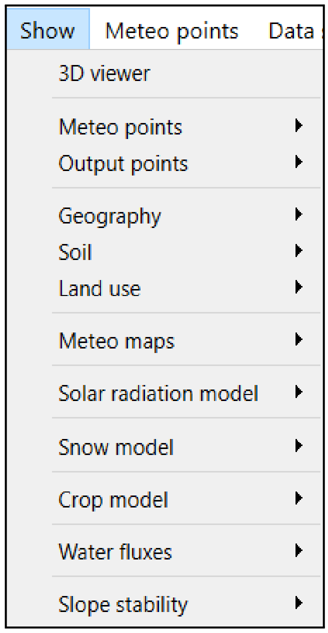


Fig. 3 The menu ‘Show’

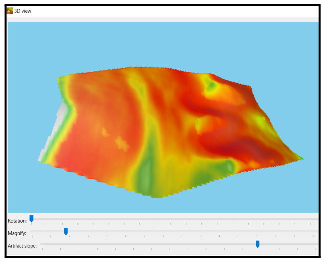


Fig. 4 The 3D viewer with minimum factor of safety visualized upon a DEM

- **3D viewer**: let the user to visualize the DEM in a 3D domain, in order to study the morphology of the study area. Variables that are shown can be represented in the 3D viewer as well (Fig. 4)
- **Meteo points**: allows to activate or deactivate meteo points, and to choose how to visualize points;
- **Output points**: allows to hide and view output points;
- **Geography**: let the user handle the DEM visualization. More particularly, slope, aspect and runoff boundaries can be mapped and visualized. It is possible to reverse these visualization and going back to the DEM with the ‘hide map’ voice;
- **Soil**: allows to show/hide the soil map;
- **Land use**: shows and hides the land use map;
- **Meteo maps**: this menu voice allows to visualize maps of air temperature, air relative humidity, precipitation, wind intensity and potential evapotranspiration. Through the voice ‘none’ of this menu, it is possible to remove any kind of map from the canvas;
- **Solar radiation model**: it allows to visualize the solar radiation outputs, namely: the global irradiance, the beam radiation, the diffuse radiation, the reflected radiation and the atmospheric transmissivity;
- **Snow model**: this voice is related to the snow processes. It is possible to visualize the snow water equivalent, the snowfall, the snowmelt, the energy content of snow (or soil), the energy content of the surface layer, the surface temperature, the sensible heat, the latent heat, the liquid water content and the age of the snow;
- **Crop model**: the crop processes produce as output the Leaf Area Index (LAI) and Degree Days maps. These two maps can be visualized through this menu voice;
- **Water fluxes**: it allows the user to visualize water content states, namely the surface water content, the surface water pond (that

is variable with LAI and slope), the volumetric water content, the degree of saturation and the water potential. Some of them can be visualized through a fixed color palette in order to compare the evolution of water fluxes during a simulation.

- **Slope stability**: through this voice it is possible to visualize the safety factor maps at a specific depth or the minimum value occurred over a simulation period.

1.3 'Meteo points' menu

Through this menu it is possible to handle the meteo points of the map, choosing which to delete, activate and deactivate. It is possible to select meteorological stations through a criterion (i.e., by name, by location) or by a .csv file containing the list of the target stations. The voices present in the meteo points menu are:

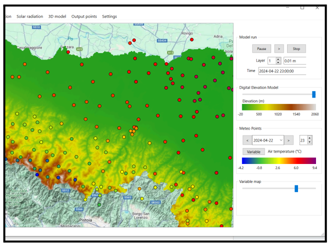


Fig. 5 An example of air temperature values visualized on meteo points

- **Clear selection**;
- **Activate**;
- **Deactivate**;
- **Delete points**;
- **Delete data**.

1.4 ‘Data spatialization’ menu

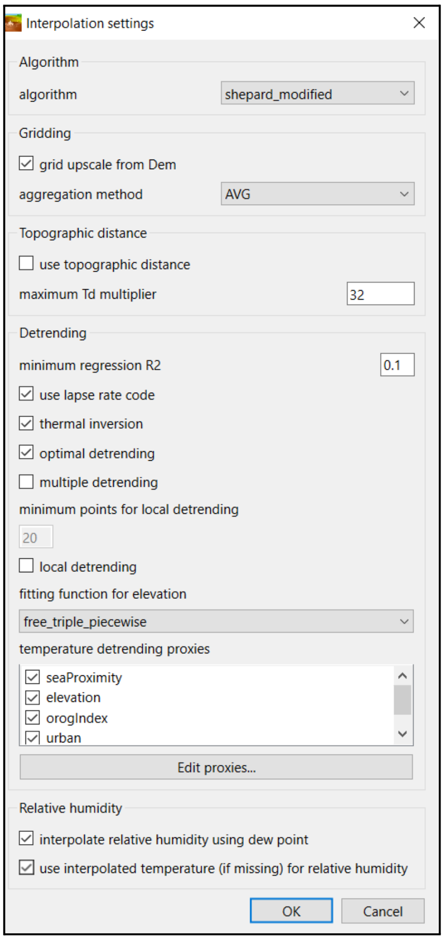


Fig. 6 Interpolation settings window

TODO

1.5 'Solar radiation' menu

In Fig. 7 the window corresponding to the '**Solar radiation settings…**' menu voice is shown.

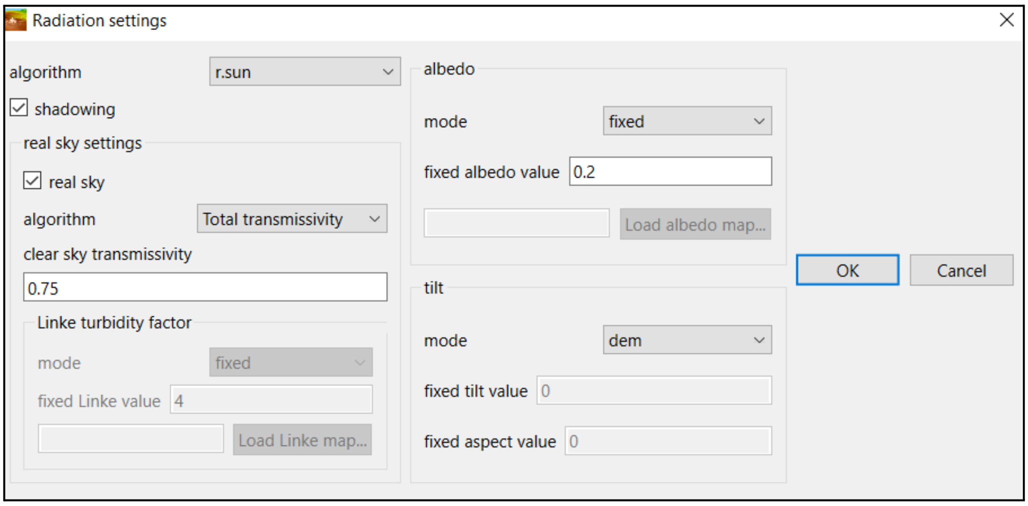


Fig. 7 Solar radiation settings window

The algorithm r.sun from the GRASS homonymous library is adopted in CRITERIA-3D to get the potential solar radiation. If the *shadowing* option is selected, reliefs as derived from the DEM will be considered to assign the radiation, based on the hourly position of the sun.
The '**real sky settings**' frame allows to set the atmospheric conditions that reduce the radiation at the earth's surface. More particularly, it is possible to choose between two algorithms:

- **Total transmissivity**: considers the maximum potential transmissivity, derived as the ratio between the real radiation and the extraterrestrial incoming radiation. This value is then reduced by the clear sky transmissivity value, which is a measure of the maximum transmissivity when the sky is not cloudy;
- **Linke turbidity factor**: the turbidity factor, that is a measure of the whole atmospheric absorption spectrum (due to its composition), can be assigned in three ways. Monthly, fixed or local values (through a map) can be associated to the DEM spatial domain.

The '**albedo**' frame allows setting the reflection surface conditions. It can assume fixed, monthly or map-derived values.
The '**tilt**' frame is used to assign the surface inclination and exposure direction. For each pixel, they can be derived from the DEM or fixed values can be given.

1.6 '3D model' menu

Through this menu voice, it is possible to set up the model simulation. The whole menu contains the voices represented in Fig. 8. When running a simulation, first of all, through the first voice '**Set active processes…**' (Fig. 9) the desired processes must be activated.
The other voices of the menu are:

- **Water fluxes settings…** (see Section 1.6.1);
- **Snow settings…** (see Section 1.6.2);
- **Load and save state** (see Section 1.6.3);
- **Initialize**: make CRITERIA-3D selected processes to be initialized;
- **Compute next hour**: allows the simulation of the next hour hydrology;
- **Run model…**: allows to set the computational running period (Fig. 10);
- **Update sub hourly**: allows to see the evolution of any selected variable not only at the end of the hour, but also during the hour. This can be useful when high rainfall are happening;
- **Automatic state saving (end of run)**: activates the automatic state saving at the end of the computational period;
- **Automatic state saving (daily step)**: activates the automatic daily state saving.

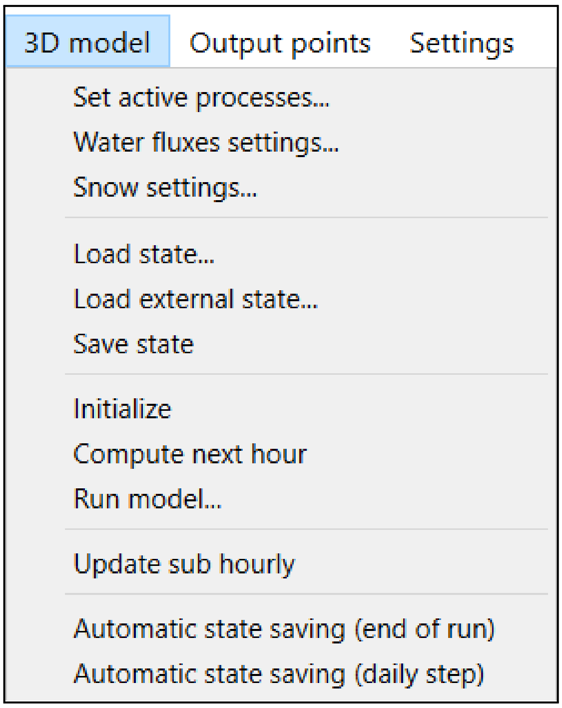


Fig. 8 3D model menu

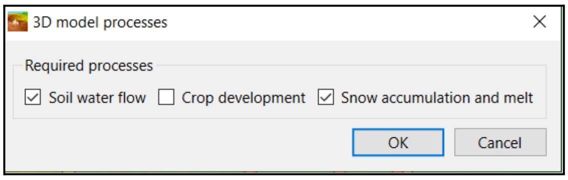


Fig. 9 The 'Set active processes…' window

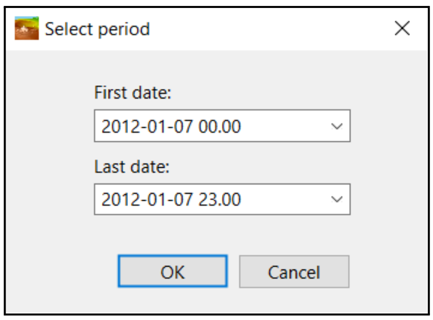


Fig. 10 The 'Run model…' window

1.6.1 Soil water flow process

After activating the soil water flow process, the specific settings can be determined through the voice '**Water fluxes settings…**' of the 3D model menu. As shown in Fig. 9, the first two menu items represent the initial condition of the simulation, that can be indicated through either the water potential or the degree of saturation at the beginning of the simulation.
The subsequent three items are related to the spatial extension of the computation; it is possible to choose if to compute only surface flows, the total soil depth fluxes or to consider a limited portion of soil (up to an imposed computation depth).
For what concerns the soil hydraulic behavior, the ratio between horizontal and vertical hydraulic conductivity can be imposed and it is possible to choose whether to use field water retention data.
The last item of Fig. 9 can be used to reduce or increase the model accuracy and eventually speed up the simulation.
These settings will be automatically saved in the project `parameters.ini` settings file. When the same project is opened again, the parameters will appear in the settings windows.

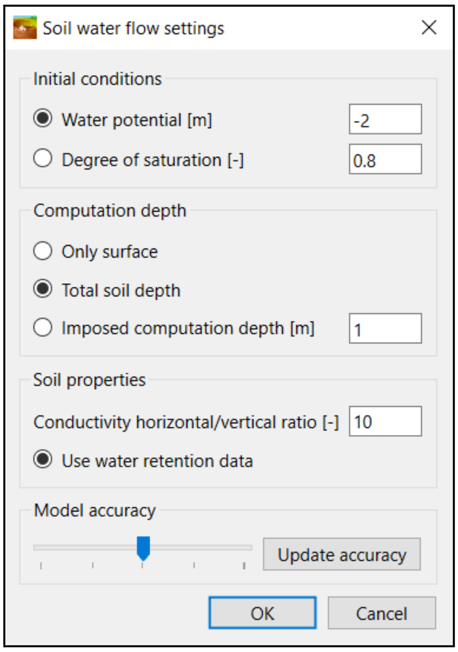


Fig. 9 Soil water flow settings window

1.6.2 Snow settings

TODO

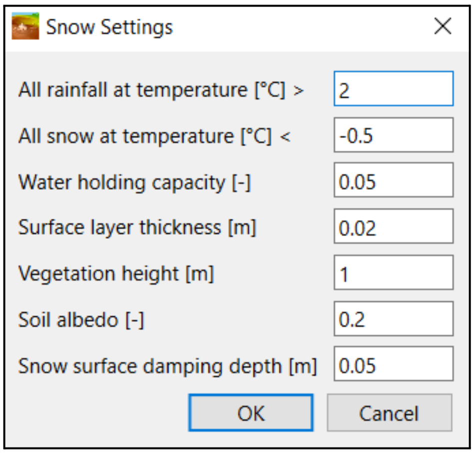


Fig. 10 Snow settings window

1.6.3 Load and save state

A state in CRITERIA-3D is a “package” of maps at all the different computational layer depths for a specific moment. Saving a state means freezing an instant of the computational domain. The variables that are saved in maps are the Degree Days for the crop (obviously, at the surface) and the water potential for the soil water flow (one map for each soil layer). Maps are singularly saved for each layer depth, but in the CRITERIA-3D all the maps related to a specific moment will be uploaded together.

States are normally saved at the end of a simulation. The automatic saving at the end of run has to be activated before the simulation starts, otherwise users can pause the simulation at any desired moment to save a specific state. After the pause, when the simulation starts over again, output will continue to be saved in the same output db.

If the automatic saving was not activated, at the end of the whole simulation states must be saved manually through the related voice in the ‘3D model’ menu.

Saving states can be really useful when large simulations are carried out. For example, if a user is studying landslide dynamics, or wants to study in detail the evolution of crops on the basis of certain meteorological conditions, saving different states and visualizing them can be really useful. States are saved as `.flt` and `.hdr` files and can be exported also in GIS environments.

1.7 'Output points' menu

After uploading or creating an output points list (a .csv file), through the voice '**Add new point…**', the window in Fig. 11 allows the user to create new points for which outputs want to be saved. In the same figure, on the left, some output points (in green) are displayed.

The other items of the output points menu, namely '**Clear selection**', '**Activate**', '**Deactivate**', '**Delete**', are useful to manage the output points. The last two items of the menu are '**Save output on points**' and '**Compute only points**'. The first one needs to be selected before the simulation run in order to save outputs in the related database (if the database has not been uploaded, an error message will appear); the second voice allows to compute unidimensional simulations on the desired output points.

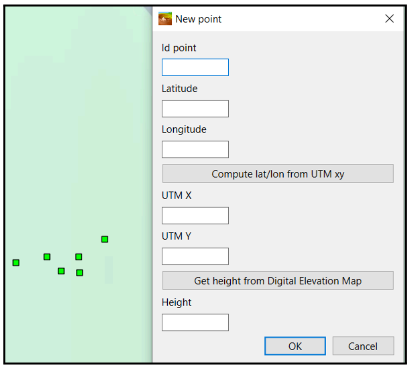


Fig. 11 Output points (on the left) and new output point creation window

1.8 'Settings' menu

Through the settings menu it is possible to change the background **map**. The possible choices are: OpenStreetMap, Google Satellite, Google hybrid satellite, Google terrain and ESRI world imagery.

The last voice of the settings menu, '**Project parameters…**' it is possible to change the framing location of the project (although when a DEM is uploaded, the project map will be centered on it), the time convention. The other two tabs, namely **QUALITY** and **METEO**, allow managing big meteorological databases and some basic computation settings (such as the Samani coefficient for reference evapotranspiration computation). The tabs' voices are represented in Fig. 12 and Fig. 13.

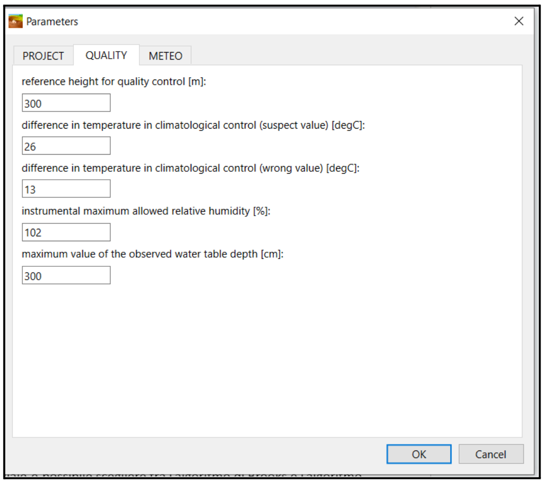


Fig. 12 'Quality' tabs

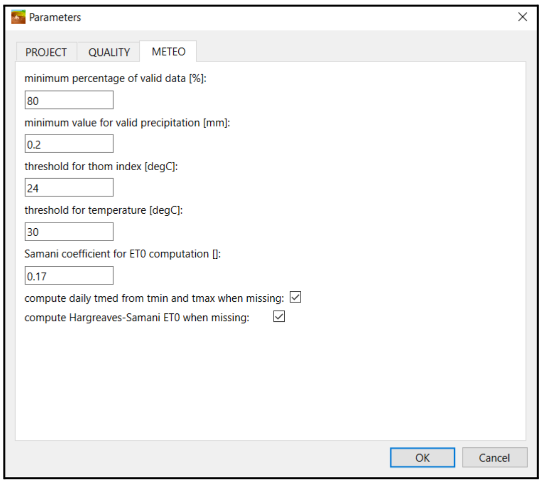


Fig. 13 'Meteo' tabs

2. Input databases (.db)

Both input and output CRITERIA-3D data are stored in databases (file .db), treatable through the open software DB Browser for SQLite. Basically a database (hereinafter, db) is a data structure organized in tables.
As already mentioned in section 1.1, CRITERIA-3D projects are composed of: a digital elevation model (DEM), a soil db, a crop db, a meteo db, a soil map, a land use map. All the different databases are connected in a single project through an initialization file (file .ini, see Fig. 2). In this section, only databases will be described. Input maps will be described in Section 3.

2.1 Crop db

In order to easily modify the crop related parameters, it is suggested to add in the .ini file a CRITERIA-1D computational units database (`comp_units.db`) and open the whole project through CRITERIA1D_PRO.exe, which can be downloaded from the related Github page. By doing so, it is possible to modify the crop/vegetation characteristics through the graphical interface as shown in Fig. 14. Actually, crop parameters cannot be changed through the CRITERIA-3D graphical interface, but only through the db handler, although in the CRITERIA-3D application it is possible to visualize the vegetation related data by right-clicking the crop map (or the DEM).
The vegetation type can be determined in the `comp_units.db` through the **ID_CROP** column (see Fig. 15) which must correspond to the **ID_CROP** of the ***crop*** table (Fig. 16), and also to the **ID_CROP** of the ***land_units*** table of the `crop.db`. The same name, comprising upper cases, must be typed in the three cited columns.
If the file .ini is properly written, the 3D project can be opened with CRITERIA1D_PRO as well.

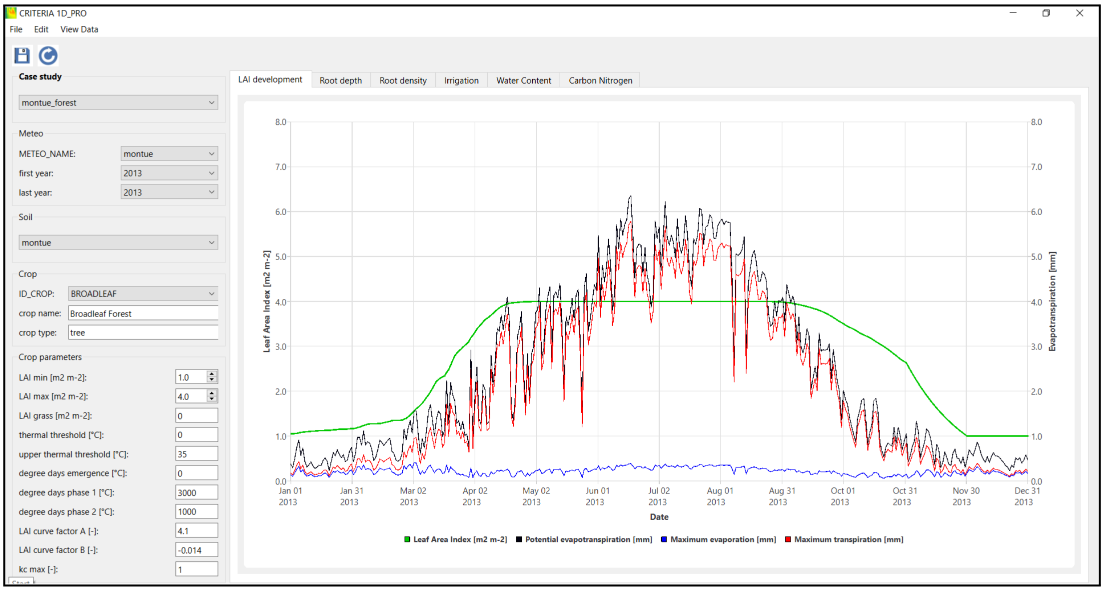
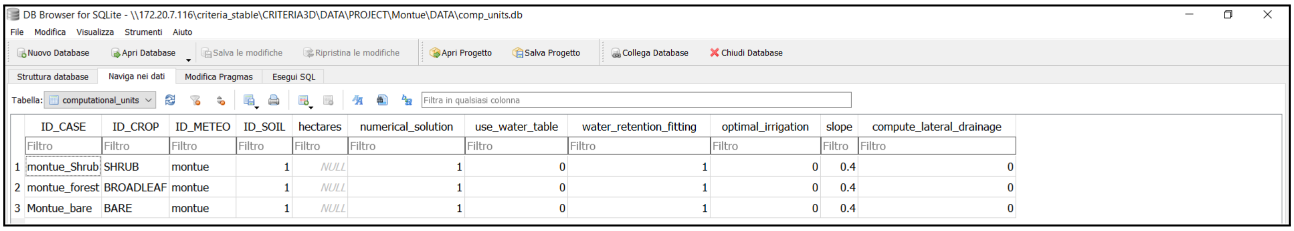


Fig. 14 CRITERIA1D_PRO graphical interface for crop modeling. The project opened is a CRITERIA-3D project as written in Fig. 2 (section 1.1)

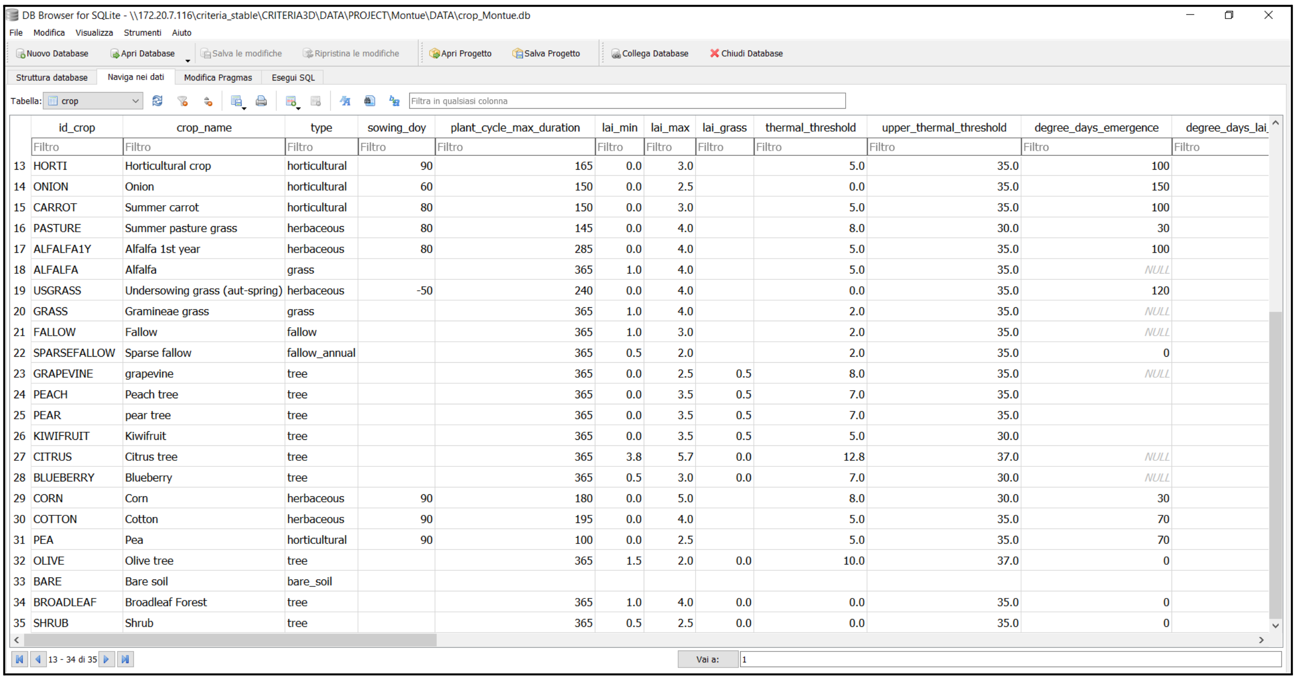


DB Browser for SQLite - \\172.20.7.116\criteria_stable\CRITERIA3D\DATA\PROJECT\Montue\DATA\comp_units.db

Tabella: computational_units

	ID_CASE	ID_CROP	ID_METEO	ID_SOIL	hectares	numerical_solution	use_water_table	water_retention_fitting	optimal_irrigation	slope	compute_lateral_drainage
1	montue_Shrub	SHRUB	montue	1	NULL	1	0	1	0	0.4	0
2	montue_forest	BROADLEAF	montue	1	NULL	1	0	1	0	0.4	0
3	Montue_bare	BARE	montue	1	NULL	1	0	1	0	0.4	0

Fig. 15 `comp_units.db` **for CRITERIA1D_PRO**



DB Browser for SQLite - \\172.20.7.116\criteria_stable\CRITERIA3D\DATA\PROJECT\Montue\DATA\crop_Montue.db

Tabella: crop

	id_crop	crop_name	type	sowing_doy	plant_cycle_max_duration	lai_min	lai_max	lai_grass	thermal_threshold	upper_thermal_threshold	degree_days_emergence	degree_days_lai_
13	HORTI	Horticultural crop	horticultural	90	165	0.0	3.0		5.0	35.0	100	
14	ONION	Onion	horticultural	60	150	0.0	2.5		0.0	35.0	150	
15	CARROT	Summer carrot	horticultural	80	150	0.0	3.0		5.0	35.0	100	
16	PASTURE	Summer pasture grass	herbaceous	80	145	0.0	4.0		8.0	30.0	30	
17	ALFALFA1Y	Alfalfa 1st year	herbaceous	80	285	0.0	4.0		5.0	35.0	100	
18	ALFALFA	Alfalfa	grass		365	1.0	4.0		5.0	35.0	NULL	
19	USGRASS	Undersowing grass (aut-spring)	herbaceous	-50	240	0.0	4.0		0.0	35.0	120	
20	GRASS	Gramineae grass	grass		365	1.0	4.0		2.0	35.0	NULL	
21	FALLOW	Fallow	fallow		365	1.0	3.0		2.0	35.0	NULL	
22	SPARSEFALLOW	Sparse fallow	fallow_annual		365	0.5	2.0		2.0	35.0	0	
23	GRAPEVINE	grapevine	tree		365	0.0	2.5	0.5	8.0	35.0	NULL	
24	PEACH	Peach tree	tree		365	0.0	3.5	0.5	7.0	35.0		
25	PEAR	pear tree	tree		365	0.0	3.5	0.5	7.0	35.0		
26	KIWIFRUIT	Kiwifruit	tree		365	0.0	3.5	0.5	5.0	30.0		
27	CITRUS	Citrus tree	tree		365	3.8	5.7	0.0	12.8	37.0	NULL	
28	BLUEBERRY	Blueberry	tree		365	0.5	3.0	0.0	7.0	30.0	NULL	
29	CORN	Corn	herbaceous	90	180	0.0	5.0		8.0	30.0	30	
30	COTTON	Cotton	herbaceous	90	195	0.0	4.0		5.0	35.0	70	
31	PEA	Pea	horticultural	90	100	0.0	2.5		5.0	35.0	70	
32	OLIVE	Olive tree	tree		365	1.5	2.0	0.0	10.0	37.0	0	
33	BARE	Bare soil	bare_soil									
34	BROADLEAF	Broadleaf Forest	tree		365	1.0	4.0	0.0	0.0	35.0	0	
35	SHRUB	Shrub	tree		365	0.5	2.5	0.0	0.0	35.0	0	

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Fig. 16 Crop table of the crop database `crop.db` **for CRITERIA-3D**

In Fig. 14 it can be seen that the crop related tabs in the CRITERIA-1D interface are:

- **LAI development;**
- **Root depth;**
- **Root density;**
- **Irrigation.**

The following two tables (Water Content and Carbon Nitrogen) are instead related to the soil.

The **LAI development** tab allows the user to modify the canopies development throughout the year, by changing the thermal threshold for heat accumulation, the LAI min and LAI max, the degree days needed to change phenological stage (i.e., growing phase, maturity stage, decaying phase), and the LAI curve factors (i.e. determining the behavior of ascending and descending branches of the curve over the year).
Through the **root depth** tab and the **root density** tab it is possible to modify parameters conceiving the root development with depth. It is possible to choose a root architecture shape (i.e., cardioid, conoid or cylindric) and to modify it in order to approximate the real root architecture system that the user is trying to reproduce, depending on the type of vegetation present.
The tab **irrigation** allows to set the crop irrigation programme and to define the leaves suction, i.e. the suction that the plant is able to counteract for pulling water out from the soil.
For technical details about how crop modeling works, please refer to the CRITERIA_2016 technical manual and the CRITERIA1D_technical_manual.

2.2 Meteo db

A CRITERIA-3D meteorological database is composed of three tables: ***point_properties*** (Fig. 17), ***variable_properties*** (Fig. 18) and the ***meteo*** records table (Fig. 19). In the CRITERIA-3D format the meteorological records are characterized by a numerical code that corresponds to a specific variable in the ***variable_properties*** table. CRITERIA-3D accepts hourly data as meteorological input. The meteo records table can be created through a text editor or Excel.
In the ***point_properties*** database, the geographical information of the meteo station are present (latitude, longitude and height), as well as the time convention (whether the time series adopts UTC time convention or not). In this table it is possible to indicate whether the meteo point is active or not, and to describe the meteo point through some master data such as the municipality, the region, the dataset the station belongs to, etc. It is possible to create new description columns in the **point_properties** table.

Struttura database | Naviga nei dati | Modifica Pragmas | Esegui SQL

Tabella: point_properties

	id_point	name	dataset	latitude	longitude	latInt	lonInt	utm_x	utm_y	altitude	state	region	province	municipality	is_active	is_utc	orog_code
1	MONTUE_ERG5	MONTUE_ERG5	NULL	NULL	NULL	NULL	NULL	521701	4989696	182.5	NULL	NULL	NULL	NULL	1	1	0

Fig. 17 point_properties table of the meteo database

Tabella: variable_properties

	id_variable	variable	description	frequency	height	resolution	unit	min	max
1	101	TAVG	hourly average air temperature at 2 m	3600	2.0	0.1	°C	-50.0	60.0
2	102	PREC	hourly cumulated precipitation	3600	2.0	0.1	mm	0.0	200.0
3	103	RHAVG	hourly average relative air humidity a...	3600	2.0	1	%	0.0	100.0
4	104	RAD	hourly average global radiation flux	3600	2.0	1	W m-2	0.0	1360.0
5	105	W_SCAL_INT	hourly scalar average wind intensity ...	3600	10.0	0.1	m s-1	0.0	100.0
6	106	W_VEC_DIR	hourly prevailing wind direction at 10 m	3600	10.0	1	°	0.0	360.0
7	151	DAILY_TMIN	daily minimum air temperature at 2 m	86400	2.0	0.1	°C	-50.0	60.0
8	152	DAILY_TMAX	daily maximum air temperature at 2 m	86400	2.0	0.1	°C	-50.0	60.0
9	153	DAILY_TAVG	daily average air temperature at 2 m	86400	2.0	0.1	°C	-50.0	60.0
10	154	DAILY_PREC	daily cumulated precipitation	86400	2.0	0.1	mm	0.0	1000.0
11	155	DAILY_RHMIN	daily minimum relative air humidity a...	86400	2.0	1	%	0.0	100.0
12	156	DAILY_RHMAX	daily maximum relative air humidity a...	86400	2.0	1	%	0.0	100.0
13	157	DAILY_RHAVG	daily average relative air humidity at ...	86400	2.0	1	%	0.0	100.0
14	158	DAILY_RAD	daily average global radiation	86400	2.0	0.1	MJ m-2	0.0	50.0
15	159	DAILY_W_SCAL_INT_AVG	daily scalar average wind intensity at...	86400	10.0	0.1	m s-1	0.0	100.0
16	160	DAILY_W_VEC_DIR_PREV	daily previling wind direction at 10 m	86400	10.0	1	°	0.0	360.0
17	161	DAILY_W_SCAL_INT_MAX	daily maximum wind intensity at 10 m	86400	10.0	0.1	m s-1	0.0	200.0
18	107	W_VEC_INT	hourly vector average wind intensity ...	3600	10.0	0.1	m s-1	0.0	100.0
19	108	LEAFW	hourly leaf wetness	3600	2.0	1	-	0.0	1.0
20	109	ET0	hourly potential evapotranspiration	3600	2.0	0.1	mm	0.0	10.0
21	110	NET_RAD	hourly average net radiation flux	3600	2.0	1	W m-2	-1000.0	1360.0

Fig. 18 variable_properties table of the meteo database

Tabella: MONTUE_ERG5_H

	date_time	id_variable	value
1	2012-01-01 00:00:00	101	0.8
2	2012-01-01 00:00:00	102	0.0
3	2012-01-01 00:00:00	103	66.2
4	2012-01-01 00:00:00	104	0.0
5	2012-01-01 00:00:00	105	0.5
6	2012-01-01 01:00:00	101	4.0
7	2012-01-01 01:00:00	102	0.0
8	2012-01-01 01:00:00	103	52.8
9	2012-01-01 01:00:00	104	0.0
10	2012-01-01 01:00:00	105	1.3
11	2012-01-01 02:00:00	101	3.2
12	2012-01-01 02:00:00	102	0.0
13	2012-01-01 02:00:00	103	54.9
14	2012-01-01 02:00:00	104	0.0
15	2012-01-01 02:00:00	105	1.0
16	2012-01-01 03:00:00	101	1.9
17	2012-01-01 03:00:00	102	0.0
18	2012-01-01 03:00:00	103	59.0
19	2012-01-01 03:00:00	104	0.0
20	2012-01-01 03:00:00	105	0.8
21	2012-01-01 04:00:00	101	2.1
22	2012-01-01 04:00:00	102	0.0
23	2012-01-01 04:00:00	103	58.0
24	2012-01-01 04:00:00	104	0.0

Fig. 19 Example of a meteo records table

2.3 Soil db

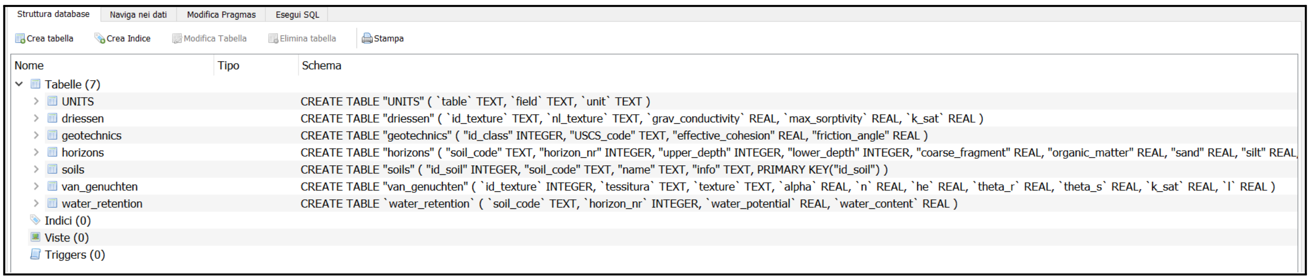

Fig. 20 Variable properties table of the meteo database

A soil database should be composed of seven tables (Fig. 20). The tables are:

- **UNITS**: this table stores the variables unit of measurement that CRITERIA-3D uses for the computation;
- **driessen**: this table stores reference values of saturated hydraulic conductivity, gravimetric conductivity and maximum sorptivity as depicted by Driessen (1992)[1] for the USDA textural classes;
- **geotechnics**: this table contains reference values of effective cohesion (c') and friction angle (φ') as depicted by Garcìa-Gaines and Frankenstein (2015)[2] for the USDA textural classes;
- **horizons**: this table contains the specific data for each horizon of the soils present in the studied area. Through the **soil_code** column each horizon is assigned to a soil. The columns that store quantitative data are: upper and lower depth of the horizon [cm], coarse fragment [%], organic matter content [%], sand, silt and clay content [%], soil bulk density [g/cm^3], water content at saturation θ_{sat} [m^3/m^3], the saturated hydraulic conductivity K_{sat} [cm/day], effective cohesion c' [kPa] and friction angle φ' [°];
- **soils**: this table contains the **id_soil**, the **soil_code**, **name** and **info** of the soils present in the computational domain;
- **van_genuchten**: this table contains reference data for the Van Genuchten curve fitting parameters (namely α, n, m [-]), the air entry value h_e [kPa], the water content at saturation (θ_{sat}) and at the wilting point (θ_{res}) [m^3/m^3], the saturated hydraulic conductivity K_{sat} [cm/day], the Mualem tortuosity parameter l [-] for each USDA textural class. CRITERIA-3D uses the Mualem model[3] as hydraulic conductivity function and the Ippisch modification of the Van Genuchten model as water retention curve[4].

---

[1] Driessen, P. M., & Konijn, N. T. (1992). *Land-use systems analysis*. WAU and Interdisciplinary Research (INRES).

[2] García-Gaines, R. A., & Frankenstein, S. (2015). USCS and the USDA soil classification system: Development of a mapping scheme.

[3] Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water resources research*, *12*(3), 513-522.

[4] Ippisch, O., Vogel, H. J., & Bastian, P. (2006). Validity limits for the van Genuchten–Mualem model and implications for parameter estimation and numerical simulation. *Advances in water resources*, *29*(12), 1780-1789.

- **water_retention**: in this table, field derived points for the soil water retention curve can be provided. It is possible to provide specific water content-water potential values.

Major details are provided in the CRITERIA_2016 technical manual.

2.3.1 Soil editor

CRITERIA-3D can handle soil data not only through the DB Browser for SQLite, but also through the graphical interface. By right clicking on the DEM map or the soil map (Fig. 21), through the appearing menu it is possible to open the soil editor (Fig. 22).

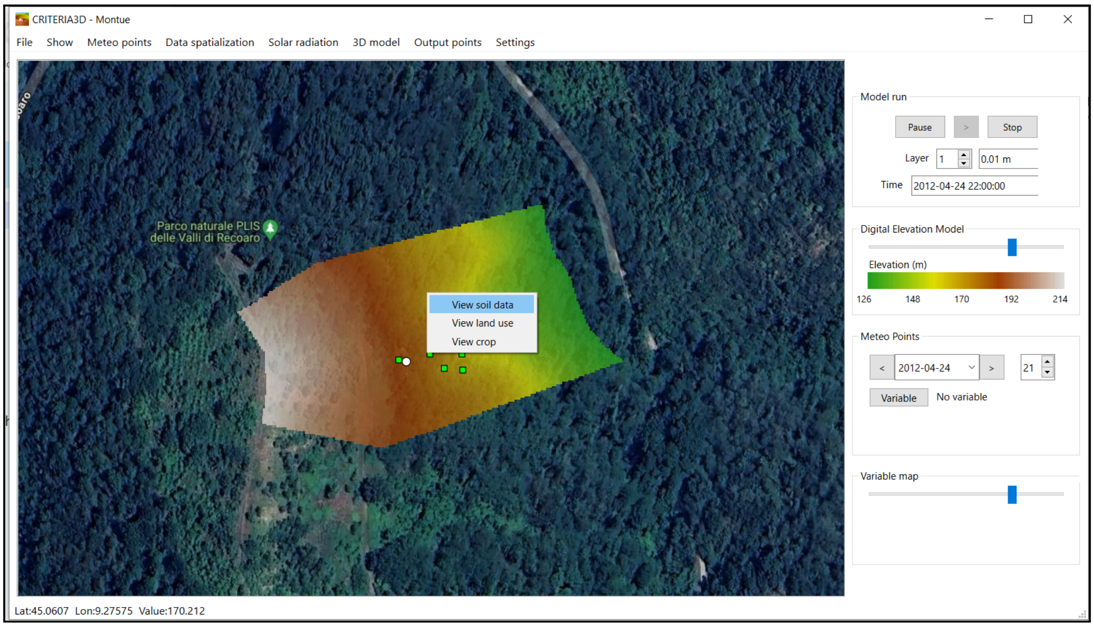

Fig. 21 The available options when right clicking on the DEM

Through the soil editor, horizons parameters and water retention curves can be changed. The tabs present are:

- **Horizons**: through this tab it is possible to modify horizons parameters (Fig. 22). The tab is composed of two tables: the upper one represents the soil database as uploaded by the user, while the one below shows the parameters as estimated by CRITERIA-3D when db records are missing;
- **Water Retention Data**: through this tab it is possible to add, change or delete characteristic points of the water retention curve;
- **Water Retention Curve**: allows the user to visualize the water retention curves of the different horizons (Fig. 23);
- **Hydraulic Conductivity Curve**: allows the user to visualize the hydraulic conductivity function of the different horizons (Fig. 24).

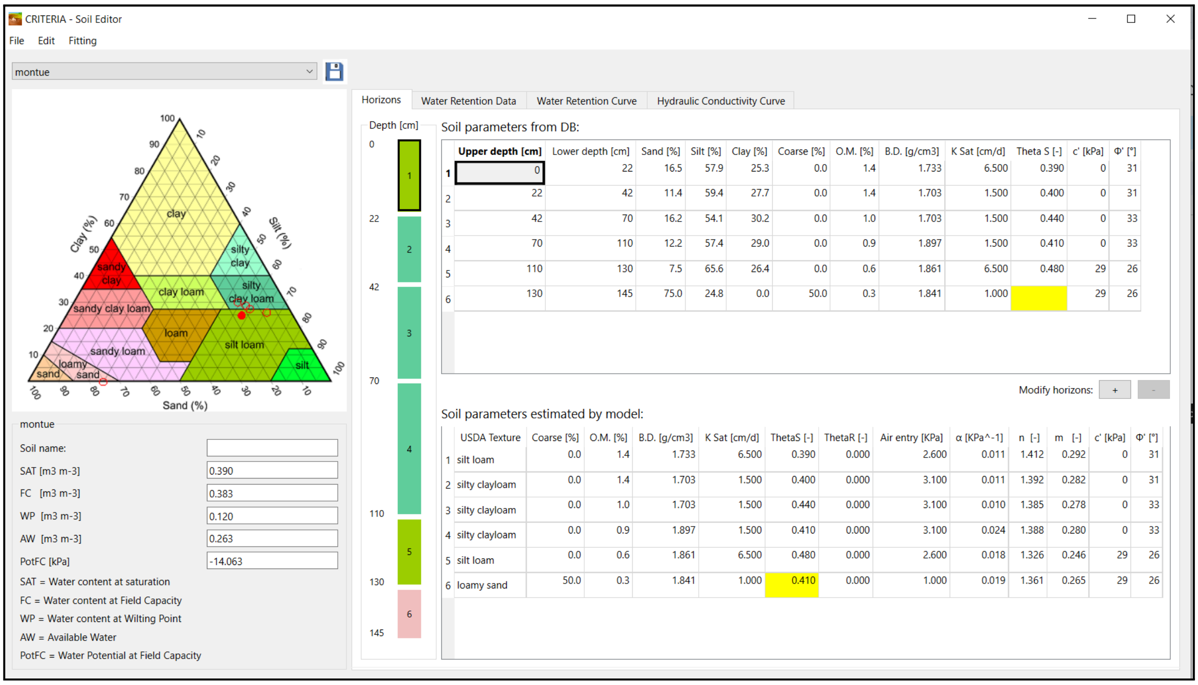

Fig. 22 CRITERIA-3D soil editor main window

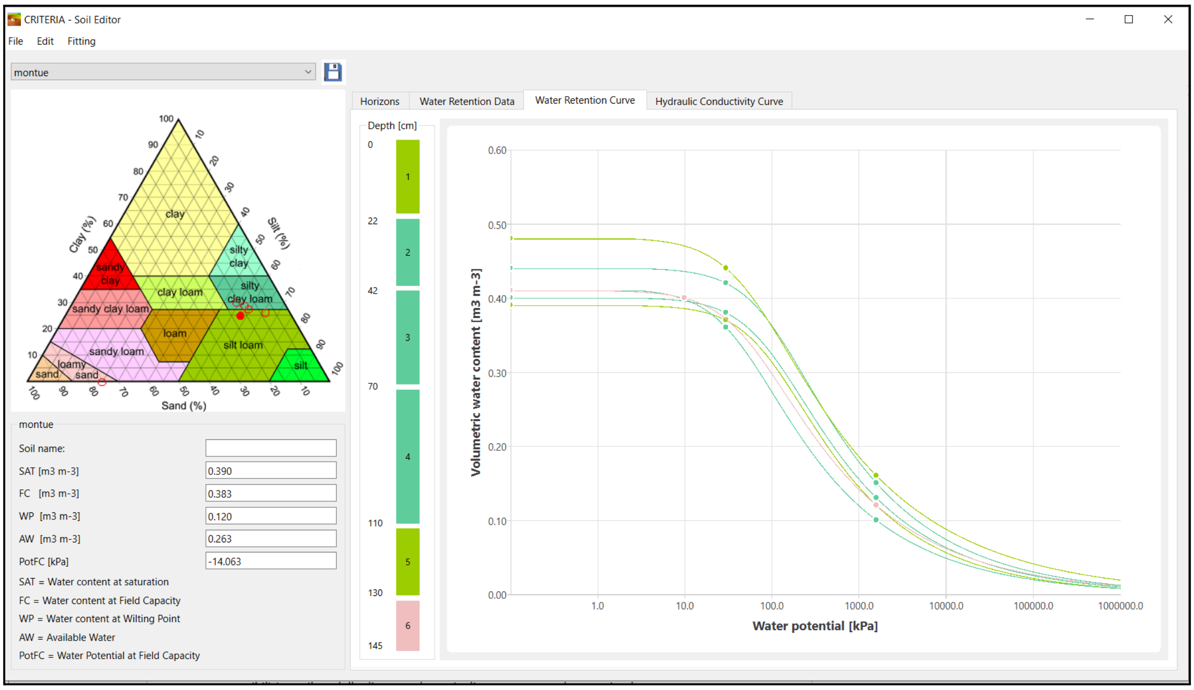

Fig. 23 Soil editor Water Retention Curve tab

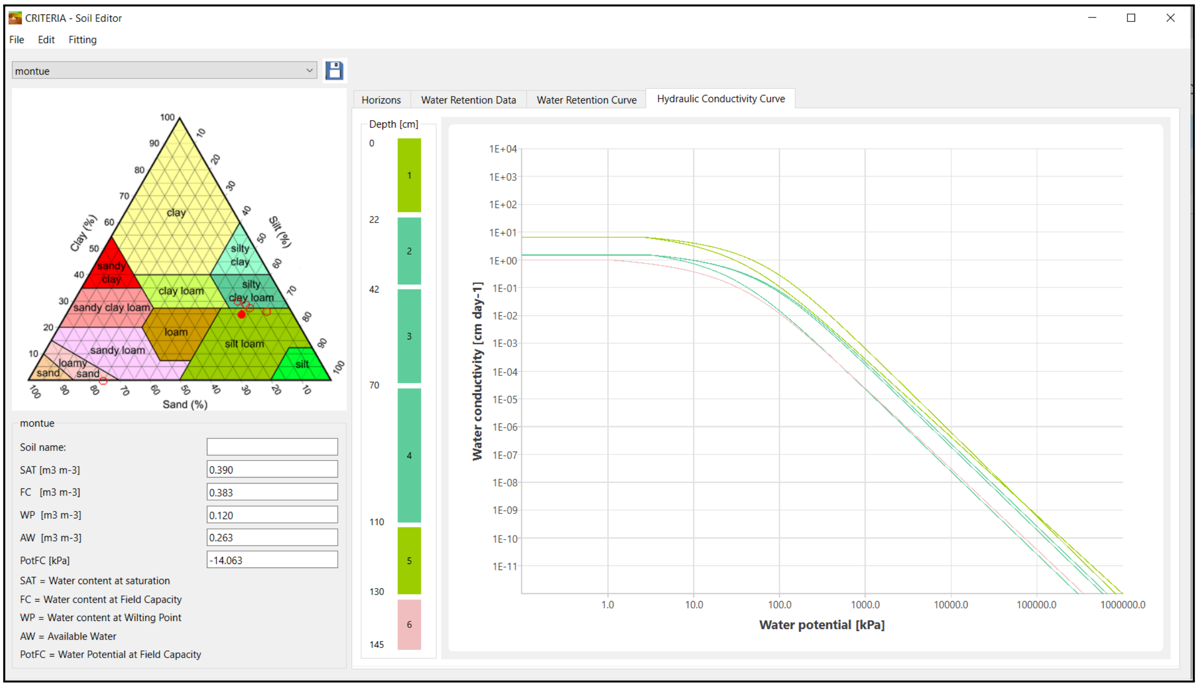

Fig. 24 Soil editor Hydraulic Conductivity Curve tab

When an horizon parameter from the database is missing, as in Fig. 22, the correspondent cell in the soil editor will be yellow coloured; in the table below, the estimated parameter will appear.

3. Input maps

In CRITERIA-3D, land use and soil maps can be provided. In order to show the maps, the menu 'show' can be used (see Section 1.2). The CRITERIA-3D model will compute the domain hydrology considering the actual vegetation and soil characteristics of each node.
Maps can be created through any GIS system and must have the ESRI float format (`.flt` extension). Each .flt file is coupled with a .hdr file that, normally, is automatically created with a `.flt` map. CRITERIA-3D also accepts ENVI image format files (`.img` extension).
It is very important that when the maps are created, the pixel values correspond to the related id in the databases. It means that soil maps must have the same soil code of the soil database (**id_soil** in the *soils* table of the soil `.db`) and the land use map must have the same land unit code of the crop database (**id_unit** in the *land_units* table of the crop `.db`).
An example of a soil map is provided in Fig. 25. By right-clicking any of the present polygon, the related soil editor will be activated. It is worth highlighting that the soil editor will be opened on the soil it was clicked on, but all the soils present in the database are accessible through the same soil editor. Thus, it is better to reopen it if a specific soil wants to be viewed in order to avoid confusion when big soil databases are present in a project.

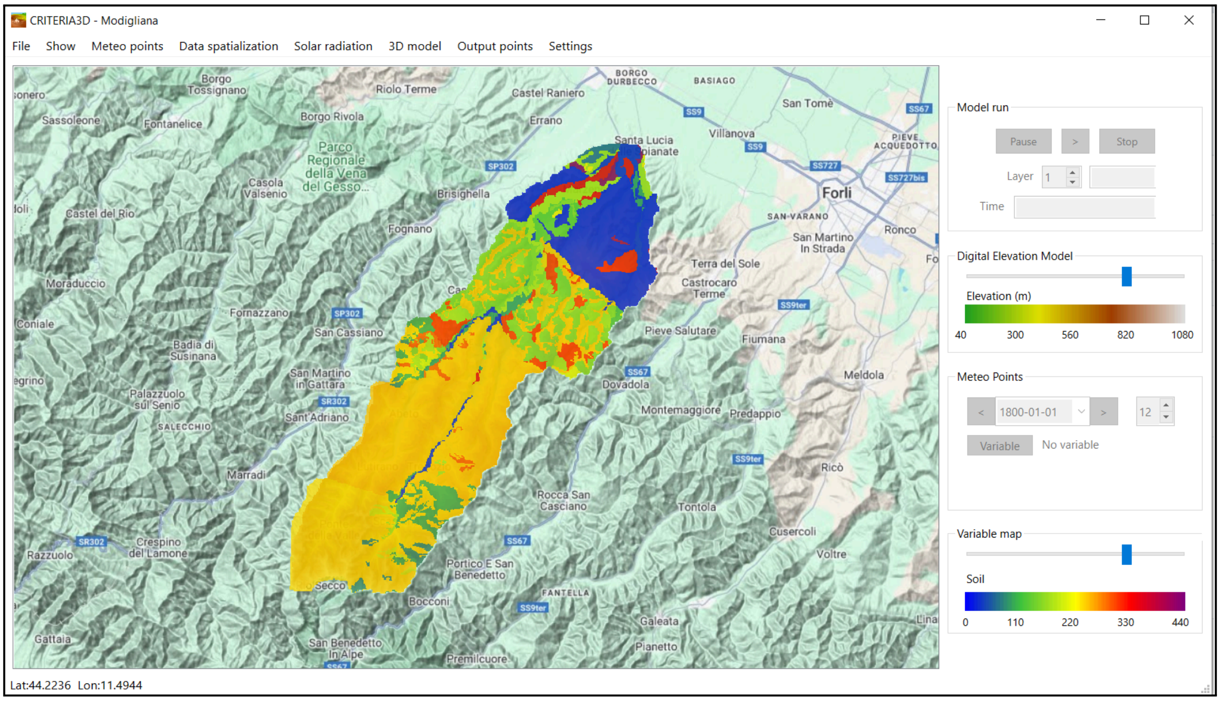

Fig. 25 An example of soil map

For what concerns the land use map, as already discussed in Section 2.1, in CRITERIA-3D only a pop-up window with the related information will be visualized when right-clicking on it (Fig. 26).

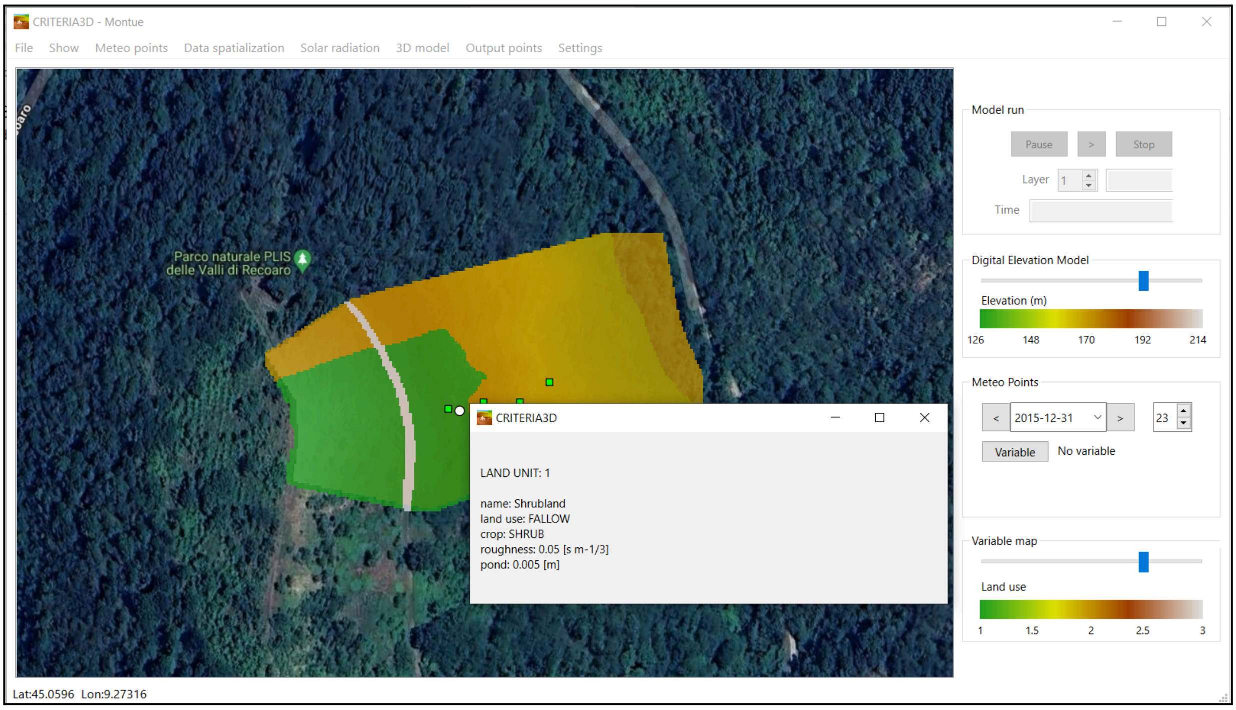

Fig. 26 An example of querying a land use map. The map was right-clicked in the green part. The other colors indicate different land uses.

The crop map can instead be visualized in terms of LAI or Degree Days map. Anyway, by right-clicking the DEM, crop related information can be visualized, if present (Fig. 27).

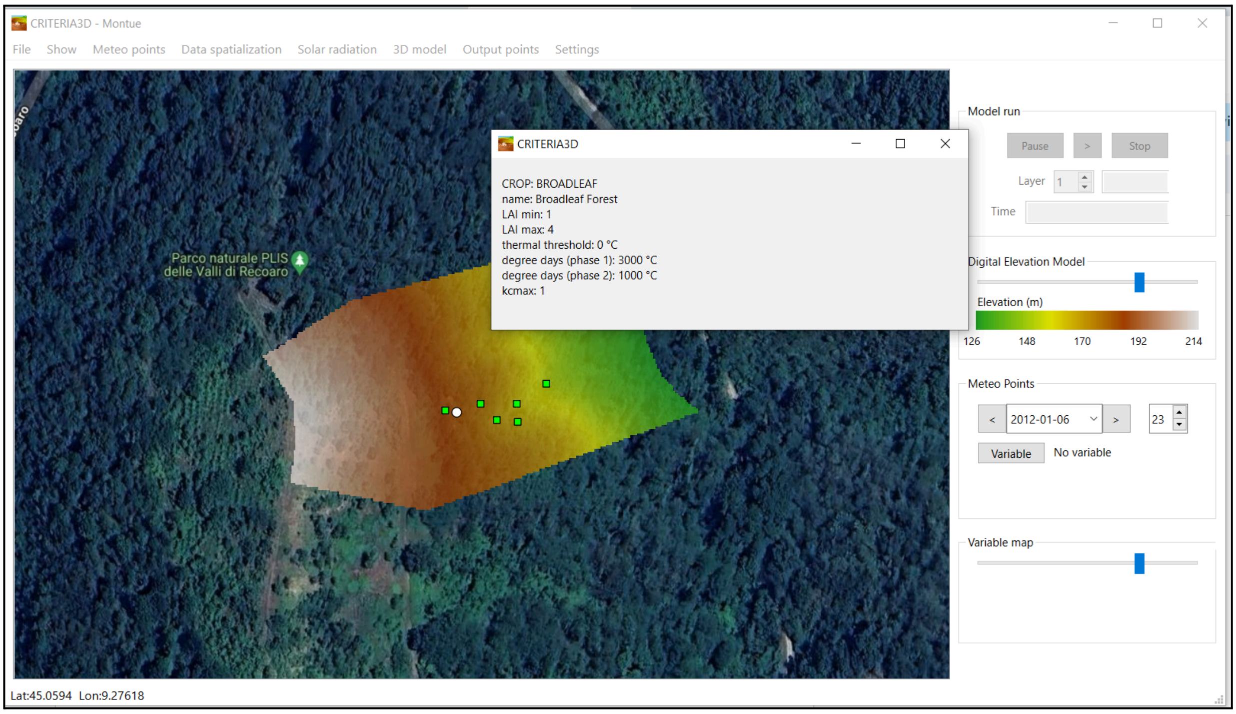

Fig. 27 An example of querying a crop map. The map was right-clicked in correspondence with the orange part of Fig. 25

After initializing the crop model (first, the process must be selected in the '**3D model**' menu, voice '**Set active processes…**') the crop state in terms of both Leaf Area Index (LAI) and Degree Days can be visualized. In Section 1.6.3, the states functioning were explained in detail.

4. CRITERIA-3D output

4.1 Output db

Nome	Tipo	Schema
Tabelle (6)		
TDR		CREATE TABLE 'TDR' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_RAD
landSlide1		CREATE TABLE 'landSlide1' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_
landSlide3		CREATE TABLE 'landSlide3' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_
landSlide4		CREATE TABLE 'landSlide4' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_
landSlide5		CREATE TABLE 'landSlide5' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_
landslide2		CREATE TABLE 'landslide2' (DATE_TIME TEXT, TAVG REAL, PREC REAL, RHAVG REAL, W_SCAL_INT REAL, ATM_TRANSMIT REAL, RAD REAL, DIRECT_RAD REAL, DIFFUSE_RAD REAL, REFLEC_
Indici (0)		
Viste (0)		
Triggers (0)		

Fig. 28 An example of output db. The output points in this specific case are: TDR (where a Time Domain Reflectometer was installed) and 5 control points of a real shallow landslide

A CRITERIA-3D output database consists of as many tables as the output points are (Fig. 28). Each table will report the selected output variables at the chosen depths. Users can indicate the desired outputs in the `.ini` project file (see Section 1.1). At the moment, the possible variable outputs are: the factor of safety (indicated as FOS), the volumetric water content (indicated as VOL_WC), the water potential (indicated as WP) and the degree of saturation (indicated as SATDEG) at any desired computational layer depth. If the vertical discretized node series doesn't contain the specified depth, CRITERIA-3D will automatically consider the nearest point and save the related outputs in the output db. The name of the output column will be composed by the variable name abbreviation in capital letters (i.e., FOS, VOL_WC, WP or SATDEG), an underscore (_) and the computation depth in cm (i.e. FOS_20 will be the factor of safety at 20 cm, WP_100 the water potential at 100 cm, and so on).
From the database, a whole output table can be copied including the headers as well if desired. Data can then be pasted in excel or Google Sheets for rapid graphic visualization. Otherwise, from the .db data can be exported as .csv, .json or SQL file. Users can choose how to handle them.

4.2 Output maps

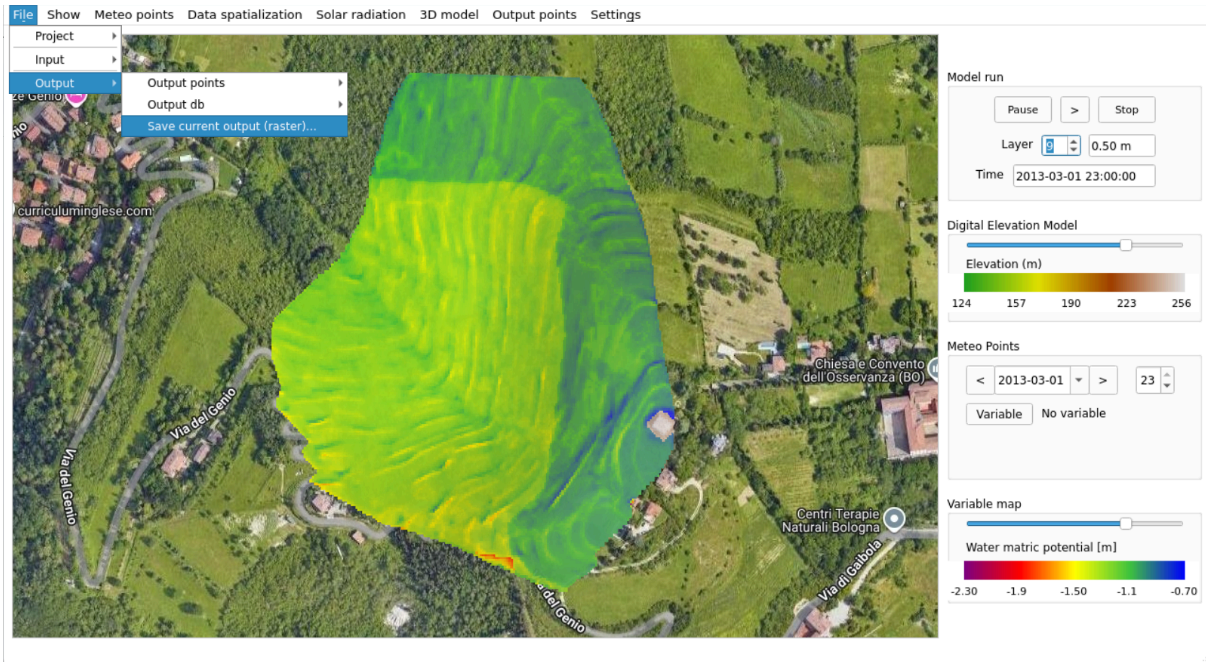

Fig. 29 An example of how to save a raster map from the CRITERIA-3D environment

The CRITERIA-3D model allows users to save any desired map. A map can be selected for a chosen depth and a chosen time step. The map can be saved as raster with .flt extension, with its related header file (.hdr) through the menu shown in Figure 29.

5. How to

5.1 How to install CRITERIA-3D

To install CRITERIA-3D for Windows OS the Github page with the latest release can be used. After unzipping the downloaded folder, the user can follow the instructions in the **readme.txt** file to install the software. If the executable software wants to be launched directly, it is enough to: unzip `CRITERIA-3D_WIN64.zip`; copy CRITERIA-3D directory in a local path of your choice (for example `C:\myApps\CRITERIA-3D`); run the file `\BIN\CRITERIA-3D.exe`.
In the folder DATA > TEMPLATE, users can find the templates for the input databases, namely the crop, the meteorological and the soil templates.

If a user wants to read and access the code locally, the Qt Creator must be installed. Qt is also the recommended environment to develop new code within CRITERIA-3D.
It is also necessary to download the GitHub prompt, Git Bash, in order to be able to eventually download all the code updates. In fact, GitHub is an online cloud where code repositories can be uploaded and merged when more than one person is working on the same project.
It is advisable to create a folder in the local disk (C:) named GITHUB, where different Git repositories can be cloned. After downloading and launching the GitHub prompt, it will appear as in Fig. 30.

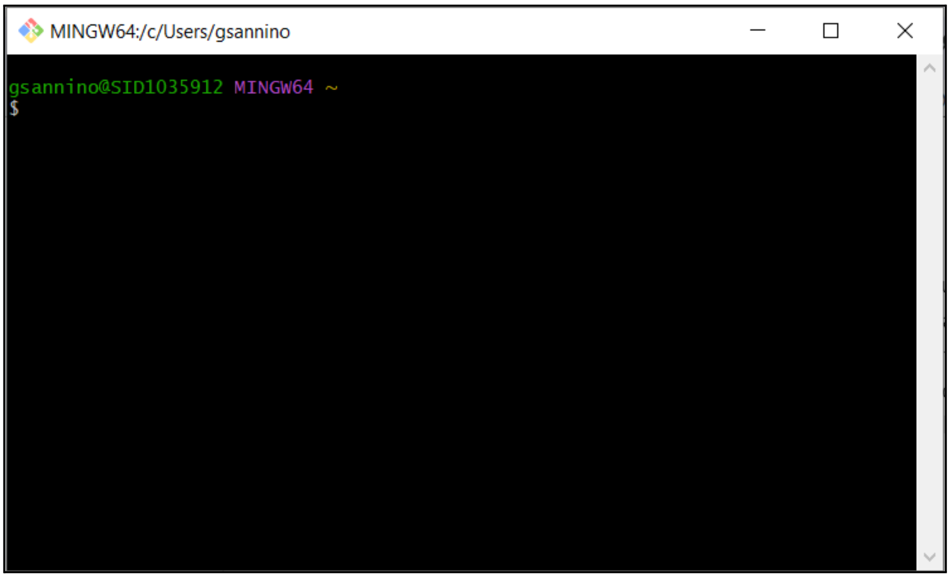

Fig. 30 Git Bash main window; gsannino is the username that will be different for each user.

In order to clone an online repository in local memory, the GITHUB directory created in the local disk C: must be accessed. To do so, this command must be typed in GitBash:

```
cd C:/GITHUB
```

By doing so, users are now inside the empty folder that was just created. The next step consists in cloning the repository, and the following command is needed:

```
git clone https://github.com/ARPA-SIMC/CRITERIA-3D
```

Be aware that the link can be copied and pasted by using the mouse or must be handwritten. When the cloning process is finished, users will have a new folder inside the GITHUB one (that, by the way, can be named as wished). The new folder will have the name of the project (Fig. 31).

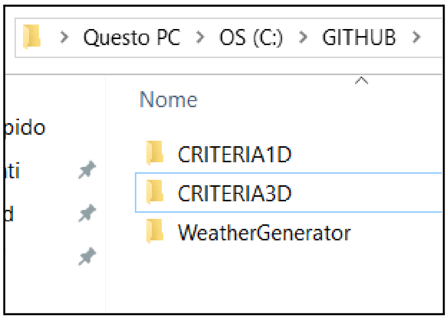

Fig. 31Example of cloned GitHub repositories in the local folder called GITHUB

Now, to compile and run the CRITERIA-3D code to get the application, the Qt Creator must be opened. Two files must be opened as projects and then build in Qt: first,

```
C:\GITHUB\CRITERIA-3D\mapGraphics\mapGraphics.pro
```

and then

```
C:\GITHUB\CRITERIA-3D\bin\Makeall_CRITERIA-3D\Makeall_CRITERIA-3D.pro
```

In order to avoid unnecessary creation of folders, in the section “Project” of the Qt Creator interface, the option “Shadow build” can be unchecked before building a project, both for debug and release builds, selectable through the wrench symbol in the left vertical menù (Fig. 32).

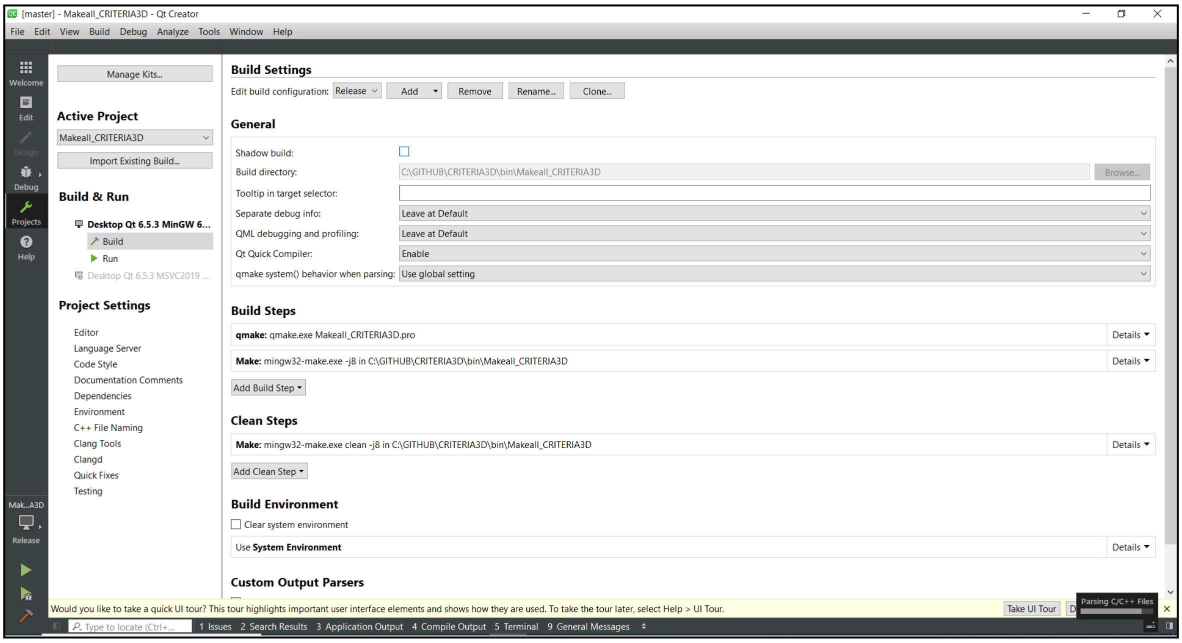

Fig. 32 Qt build settings window

5.2 How to create a project

Together with the CRITERIA-3D executable file, within the release folder, some projects are available at the following path: `CRITERIA-3D_WIN64\CRITERIA-3D\DATA\PROJECT`. The `PROJECT` folder is also present in the GitHub repository. As an example, in Fig. 33 the folders related to the project ‘Montue’ are shown.

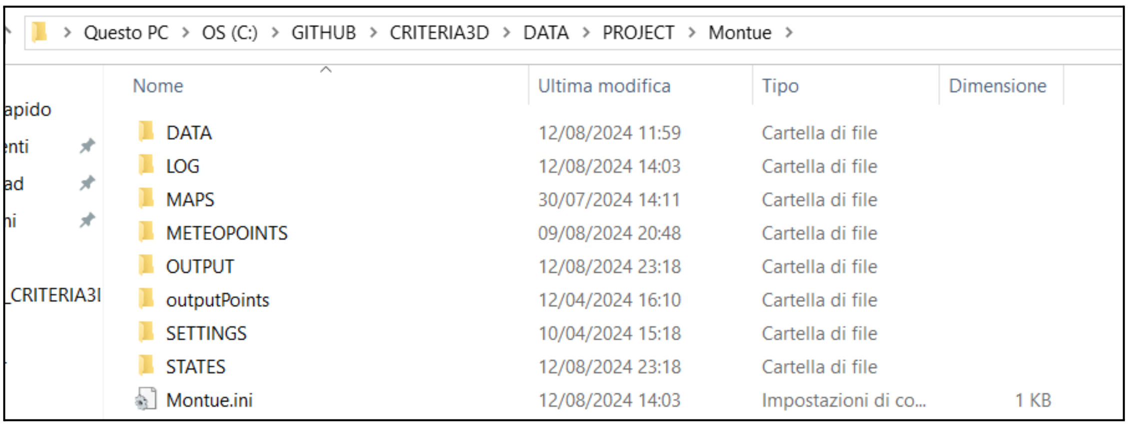

Fig. 33 Example of cloned GitHub repositories in the local folder called GITHUB

The easiest way to create a new project could be to make a copy of this project (as it is composed of customized and local databases) and to fill the databases with needed information related to the new project (i.e., modifying meteo, soil and crop databases). Moreover, inserting the right

DEM in the `MAPS` folder is required, together with the deleting of all the files contained by the `STATES` folder and the `OUTPUT` folder. The empty folders `STATES` and `OUTPUT` are to be left, as they will be filled by CRITERIA-3D itself when new simulations are run, if the user set up the project correctly. In fact, when opening the project in CRITERIA-3D, the output db can be easily created through the interface (through **File > Output > Output db > New...**). To handle the databases, [DB Browser for SQLite] is the recommended tool. Soil and land use maps must be created, and doing it through external software such as QGIS is recommended. The `outputPoints` folder has also to be emptied and, if desired, new output points can be created through the model graphical interface or modifying the .csv file of the folder.
The initialization file (`Montue.ini` in Fig. 33) must be modified, providing the right paths for the input databases and the desired output variables. Input can also be created through the templates provided within the release. The `LOG` folder can be deleted directly: CRITERIA-3D will automatically create it during simulations, filling the folder with a log .txt file that will have the name indicated in the .ini file.

5.3 How to set map boundary conditions

For the moment, spatial boundary conditions in CRITERIA-3D are fixed. They can be visualized through the menu voice **Show > Geography > Runoff boundaries**. The default boundary conditions are runoff at the surface, and the free drainage at the bottom layer. If in a specific project, the contact with an impermeable layer is present (for example, if the lithological contact is present), this condition can be reproduced by inserting a thin layer with low hydraulic conductivity.

5.4 How to set the initial hydrological state

For what concerns the initial hydrological state, it is suggested to model soil water fluxes for one year before the interested period, by using real or spatialized meteorological data. By doing so, the initial water content state will be more accurate. At the initial moment, i.e. when setting the soil water fluxes parameters, the soil is assigned with a water potential of -2 m and a degree of saturation of 0.8. This condition may not be the real one at the start of a project period of interest. Moreover, it is advisable to start the simulation on the 1st of January of the antecedent year: by doing so, the heat accumulation and subsequent growth of the vegetation will be more accurate.

5.5 How to set the meteorological points

Through the menu voice **File > Input > Meteopoints > New (from csv)...** it is possible to create both the meteorological database and to upload the list of meteo stations that want to be used in the project. The list can be created through any text editor and must be saved as a .csv file. It must contain the voices represented in Fig. 34.

FIGURA 34

The meteorological database must be filled up with hourly time series. The required hourly records are: average air temperature, precipitation, average relative humidity, solar radiation, average wind intensity. If some hourly records are missing in the time series, CRITERIA-3D will not accept it as it cannot handle missing values (the so called NA or NAN). The missing values must be replaced with the default no value amount (that is -9999) or with a time interpolated value.

For what concerns air temperature, missing hourly records can be derived through a linear interpolation (if few) or by copying the days before (if entire days are missing). Wind records can be replaced with an average area value derived from antecedent records. The average relative humidity and the solar radiation can be linearly interpolated or replaced with records from the day before. The radiation must be zero before the sunrise and after the sunset and its maximum must be reached at noon and 1pm. Rainfall amount, which is the most important variable for the soil hydrological balance in CRITERIA-3D, should be derived from nearby stations if several subsequent records are missing. If a single hourly record is missing, a zero amount can be assigned if the hours around it don’t log rainfall amounts; otherwise, by comparing to other records, a similar precipitation amount can be assigned. CRITERIA-3D can interpolate data from nearby stations automatically (see Section 1.4).

5.6 How to set the output points

In Fig. 35 an example of an output points registry .csv file is provided.

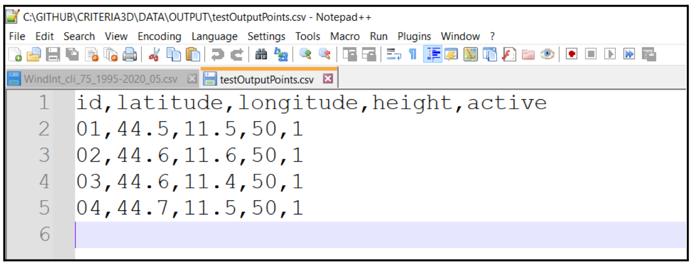

Fig. 35 Example of an output points .csv file

It is suggested to provide more decimal numbers (at least four positions) in order to get more accurate positions if a specific geographic position wants to be analyzed. The example provided in Fig. 34 is a test file, thus the precision is not so important.

After creating the .csv file, it is possible to upload it in the project by selecting the menu voice **File > Output > Output points > Load list…**. If the file was correctly set up, the points should appear in the map, as represented in Fig. 36.

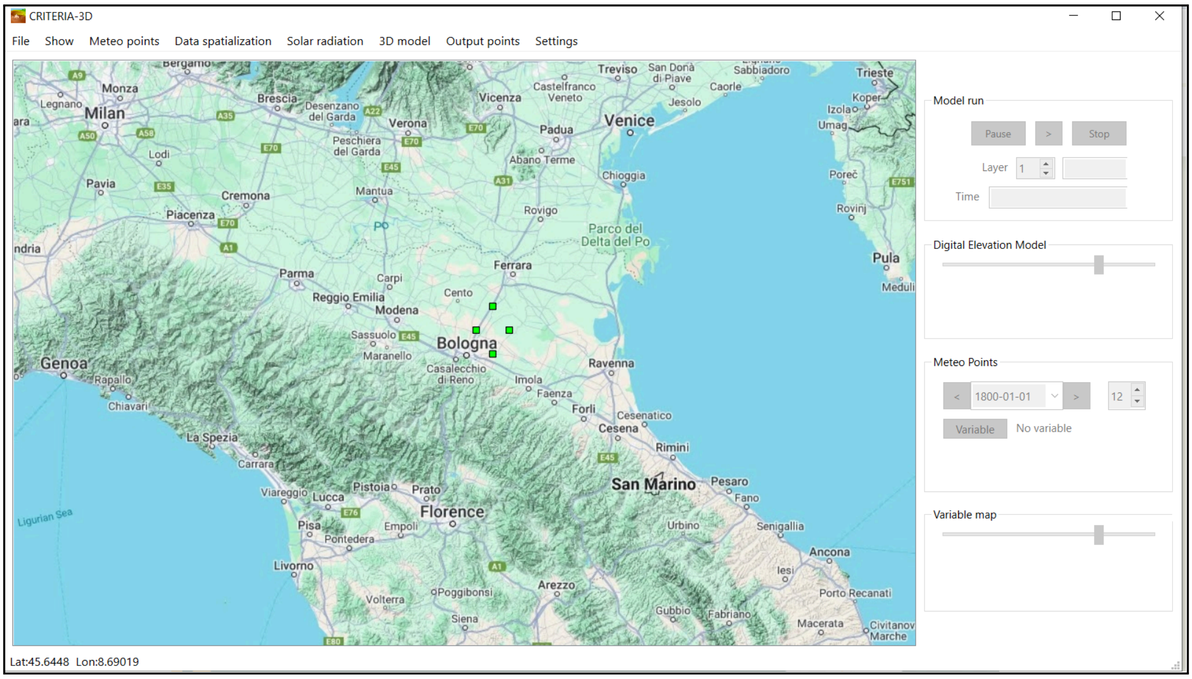

Fig. 36 Output points as uploaded by a .csv list (green points)

The .csv file can be prepared through any text editor. An output related db can be created through the voice **File > Output > Output db > New…** and it will be empty at the beginning. When running a simulation, if the voice '**Save output on points**' of the menu '**Output points**' is selected, the .db will be automatically filled in with the related tables.

5.7 How to prepare an input .flt map

In order for the CRITERIA-3D model to run properly, the input maps must be prepared in a specific format. The format has to be a `.flt` raster map.

The maps can be prepared in any GIS environment also starting from a shapefile (`.shp`), that is often the format of geographical open data available online, using a conversion function of a GIS. Before converting it, however, it is important to create in the shapefile one new column, if not present, that reports an id numerical code that will be used as the new raster pixel values.

As an example, if there is a shapefile map containing all the parameters of a database (that is the case for example here), the shapefile and the database (that may be an excel, and it has to be converted in a file `.db`) will have an identifier in common. Normally, in a shapefile with its attribute table, it is a text identifier with the name of the soil. For CRITERIA-3D it is **necessary** to have a numeric identifier. So, in the database and in the shapefile it is needed to enumerate the soils with unique numbers in a column called, for example, "id_soil"; when converting the shapefile in a raster, it must be selected this column to fill the new pixels with an amount. In this way, the new raster will recall the shapefile polygons based on the id_soil.

The same approach applies to the preparation of input land use maps. In this case, the database containing the crop parameters and the land units provided within the CRITERIA-3D distribution contains a numeric id for each land use type; this classification must be reported in the shapefile containing the land cover (for example, this), creating a specific column in the attributes table. The use of a shapefile format in the first step will be also useful to manually redefine the different land uses based on the real case study under exam.