The VSoil modelling software platform

Nicolas Beudez, Nathalie Moitrier, Nicolas Moitrier,
Cédric Nouguier, Stéphane Ruy
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INRAE, UMR EMMAH, Avignon

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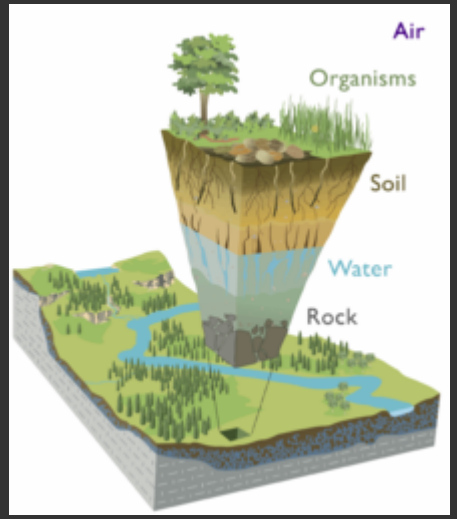
1) Context: the soil

The soil is at the heart of the ‘critical zone’.

Critical zone:

- extends from the atmosphere to the unaltered rock;
- is the site of numerous exchanges: water, solutes, gas, solids, energy, organisms;
- is the place where processes that sustain life on Earth take place.



The ‘critical zone’

It is essential to understand how the soil functions and predict its evolution for:

- sustainable agriculture,
- biodiversity preservation,
- water resource management,
- climate change mitigation,
- ...

2) Need to create models of soil functioning

Digital models: powerful tools for reproducing and studying soil functioning

Survey (2006 – 2008) conducted within the 'Environment and Agronomy' department of INRA to identify the needs in terms of soil functioning modelling.

→ Scientists want:

- to develop models that couple mechanisms:
  - of different natures: water, solute, gas and heat transfers, earthworm dynamics, particle transport, …;
  - at different time and space scales;

- models to be developed easily and quickly: use available and / or new codes;

- the development of models to be accessible to all: coding reduced as much as possible.

3) Technical barriers

Need for assistance in the modelling chain:

experiments → model conceptualisation → computer code → analysis of results

Different computer languages (Fortran, C, C++, Java, Python, R, …) for programming whose lack of standards restrains the coupling of existing models.

Lack of assistance and support for computer programming of simple and complex models.

4) VSoil: a powerful software platform to develop soil models

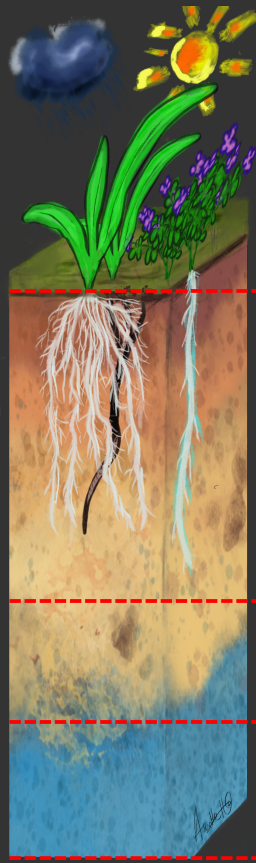
VSoil: a modelling software platform for developing digital 1D models describing the physical, chemical and biological processes of soil in interaction with climate, plants and human actions.

VSoil facilitates coupling between these processes.

Creation of models of varying complexity from the assembly of existing or new computer codes.

VSoil is developed since 2009 at EMMAH (INRAE / Avignon University, France).

4) VSoil: a powerful software platform to develop soil models



ground surface

root zone

deep vadose zone

groundwater table

interest zone
in VSoil

Soil pedon considered in VSoil:

- local scale (a few m^2);

- soil profile from the surface to the groundwater table including the root exploration zone.

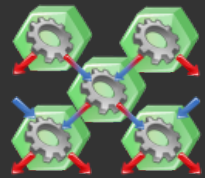
4) The architecture of VSoil

From concepts…

Phenomena (physical, chemical, biological) are called processes and are characterised by their inputs and outputs.

A module is a computer implementation of a process.

Processes and their inputs / outputs produce graphs called skeletons.

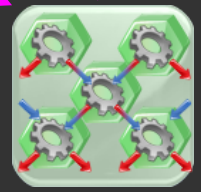


A model is an ordered set of modules.

A numerical simulation.

vsoil-processes

vsoil-modules



vsoil-models

vsoil-player

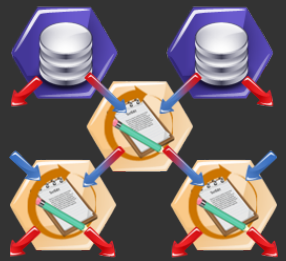
… to software.

4) The VSoil software components: vsoil-processes

Phenomena are called processes (examples: bioturbation, evapotranspiration, heat transport and balance, organic matter dynamics, water flow and balance, …). They are characterised by their inputs and outputs .

Some processes are external.

Interactions between processes are detected using inputs and outputs .



Processes with their inputs and outputs produce graphs: skeletons.

vsoil-processes

Open lists of variables and processes

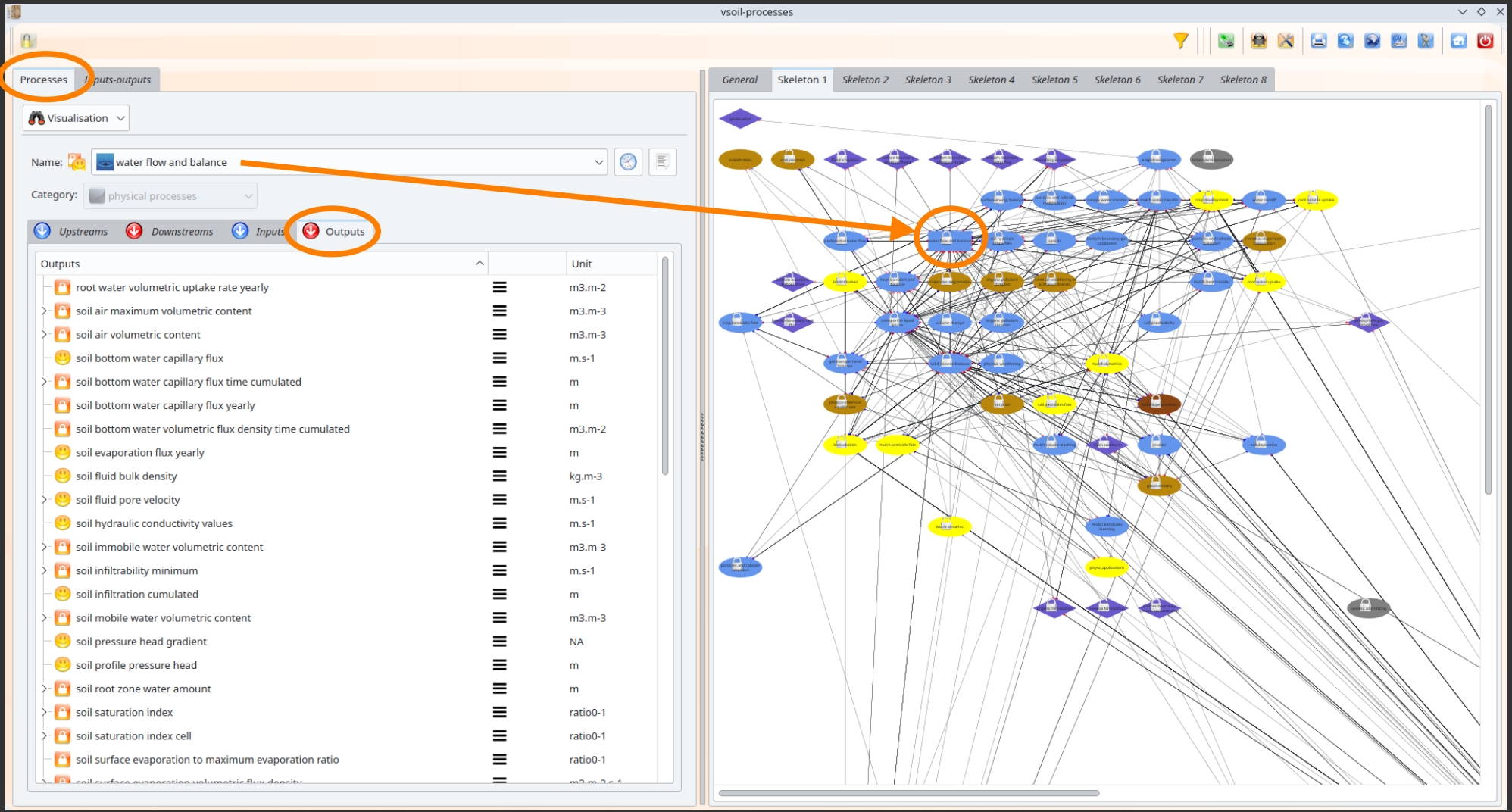
Guide for naming variables

Automatic creation of skeletons

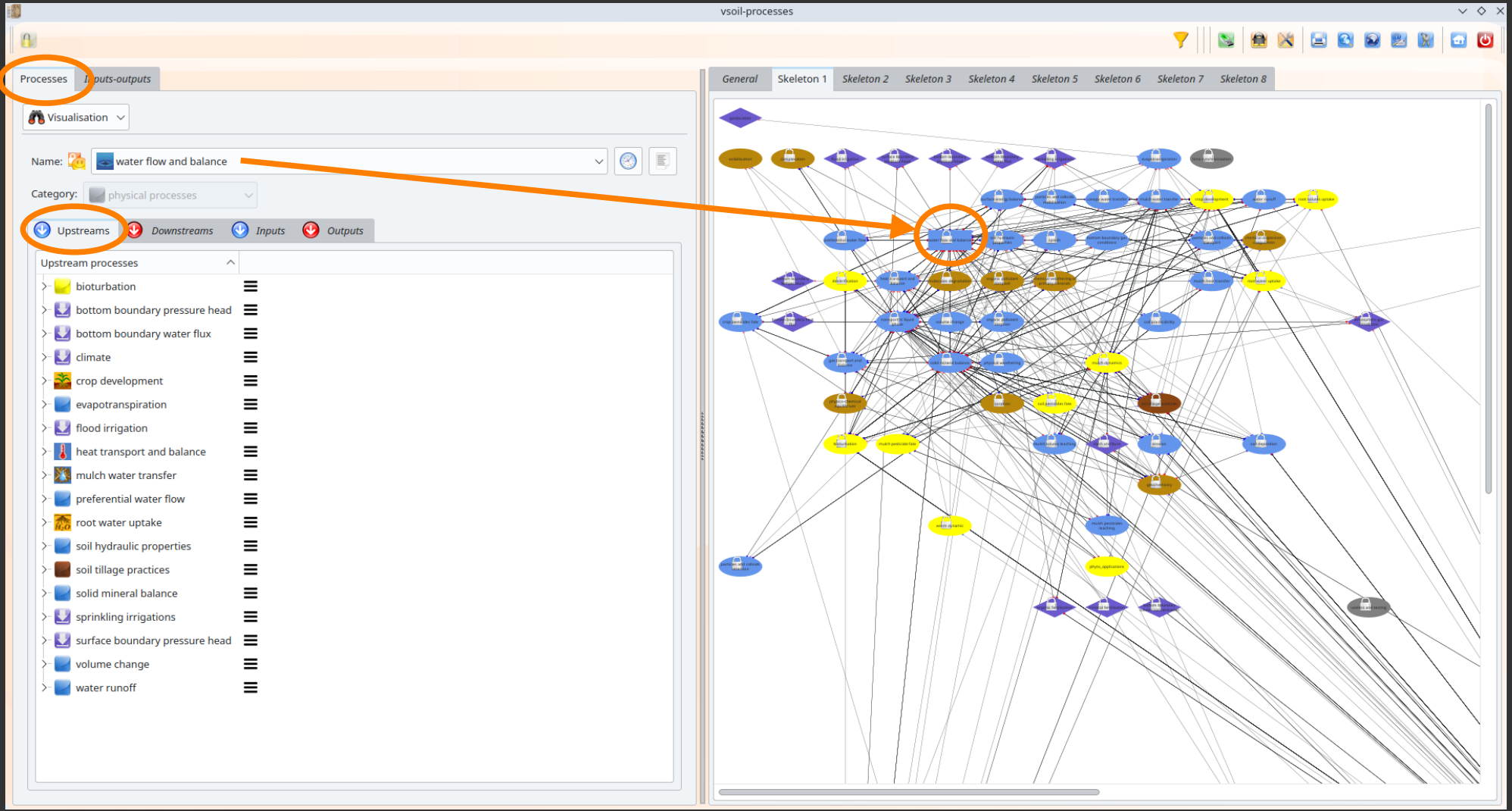
Provides information for coding and assembly of modules

60 official processes

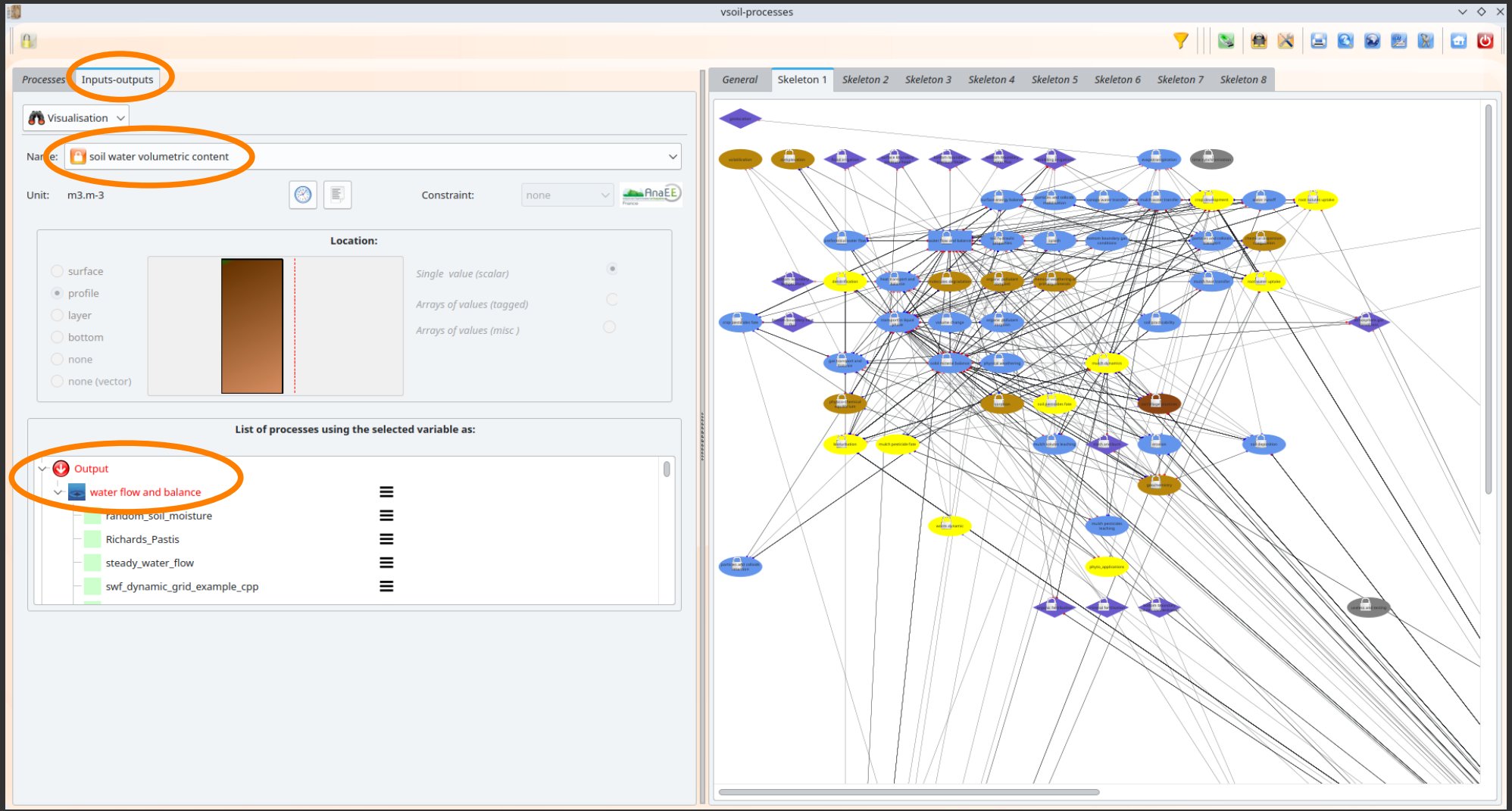
4) The VSoil software components: vsoil-processes



4) The VSoil software components: vsoil-processes



4) The VSoil software components: vsoil-processes



4) The VSoil software components: vsoil-modules

A module corresponds to a modelling, a numerical method, …

It is a computer code (Fortran, C++).

A module is linked to a process.

Several modules may be available for a process.

A module uses some of the inputs ↘ of its process and must produce at least one output ↘.

vsoil-modules

Parameters

Coding assistance

Compilation

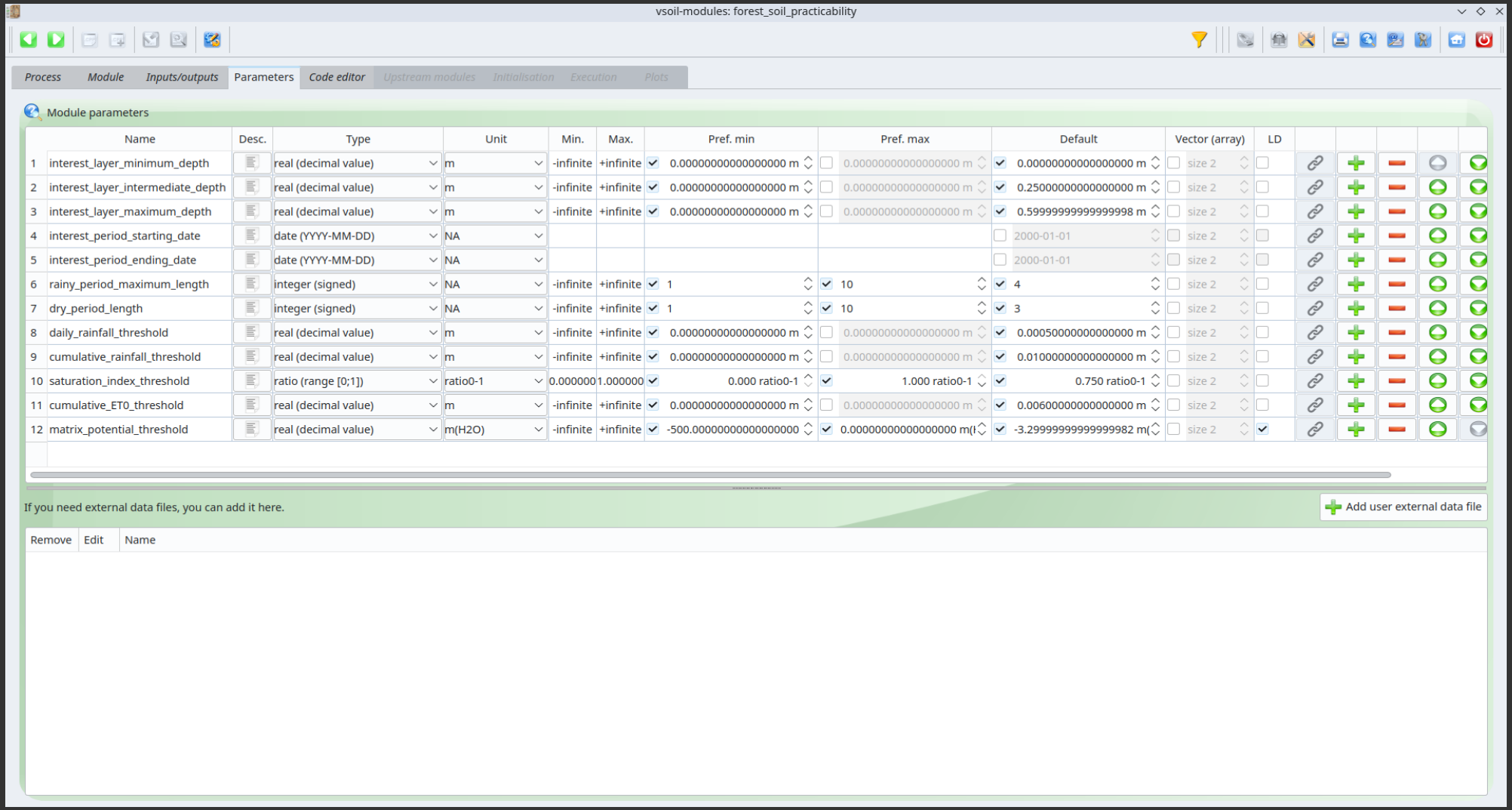
Tests

Graphs

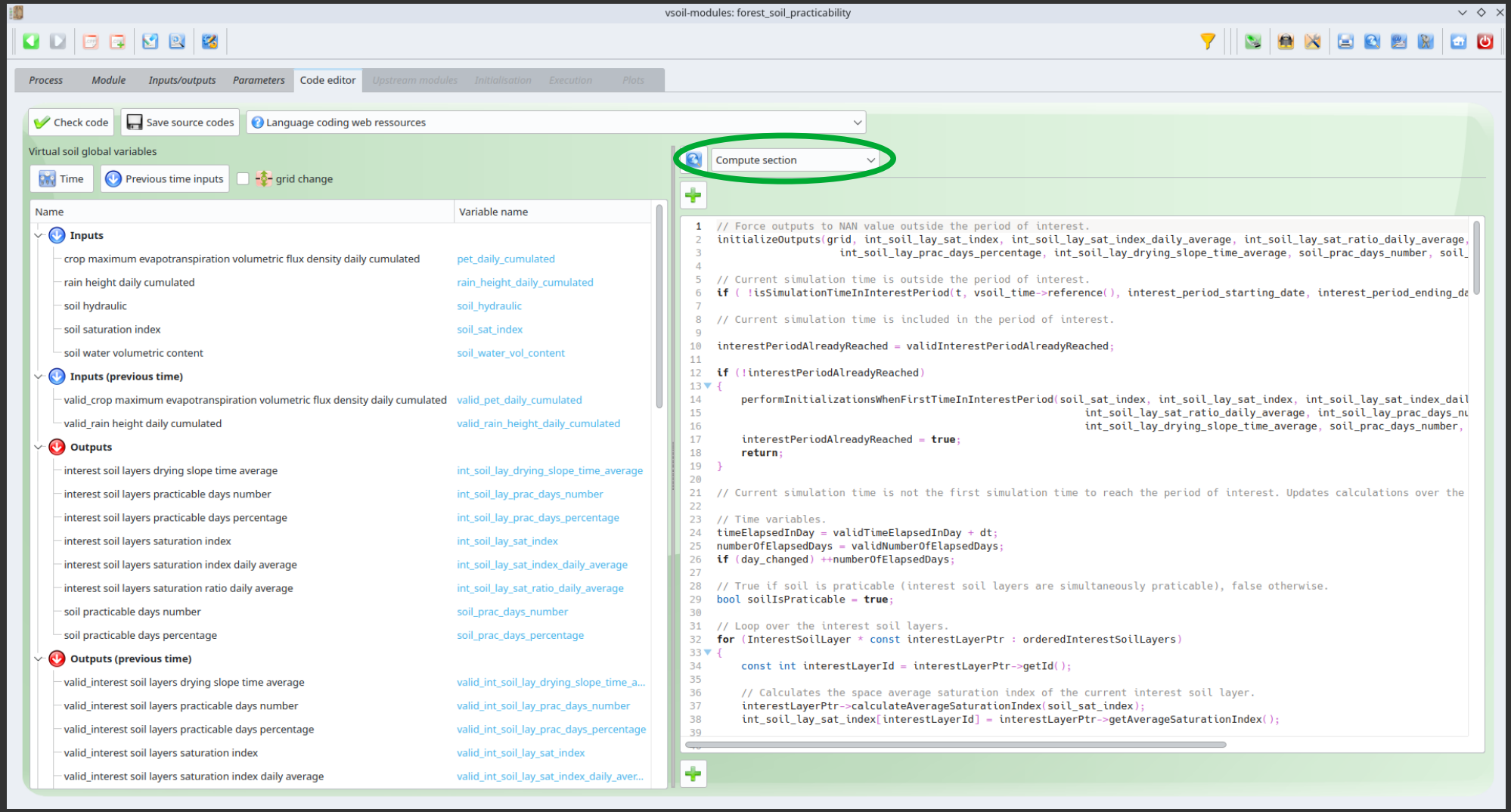
Standardised languages: Fortran / C++

148 official modules

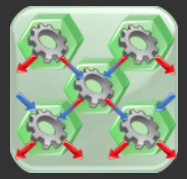
4) The VSoil software components: vsoil-modules



4) The VSoil software components: vsoil-modules



4) The VSoil software components: vsoil-models



For each process...

… a module is selected.

A model is an ordered set of modules.

vsoil-models

Module selection

Generation of the main

Generation of the GUI

Execution

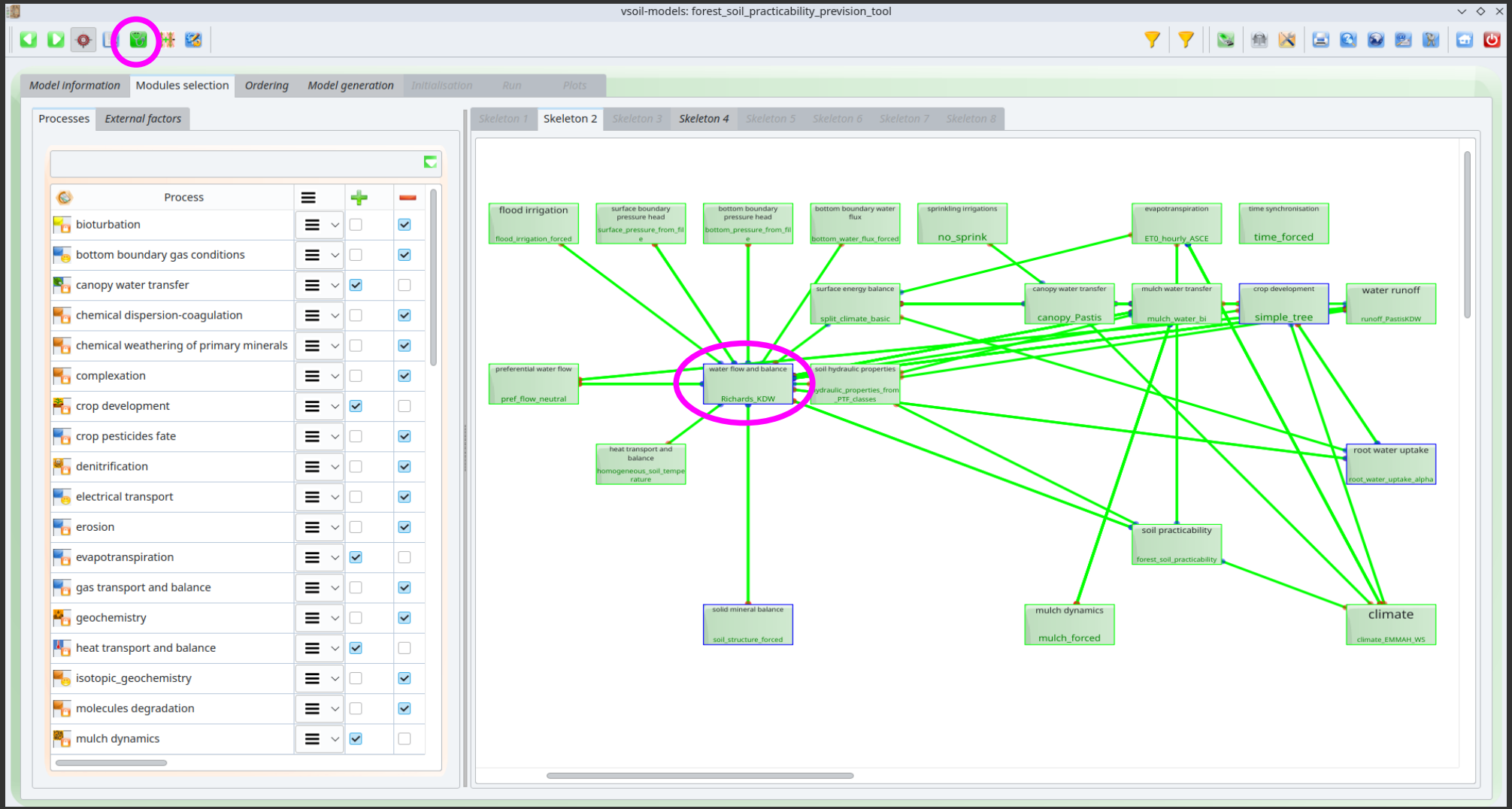
Visualisation

Backup

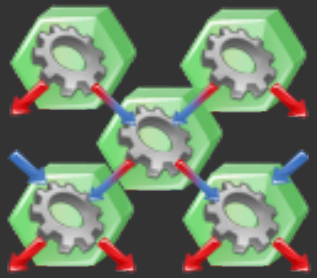
Modification

20 official models

4) The VSoil software components: vsoil-models



4) The VSoil software components: vsoil-player



A model already built.

Simulations, visualisation of results, ...

vsoil-player

Use available models

Run simulations

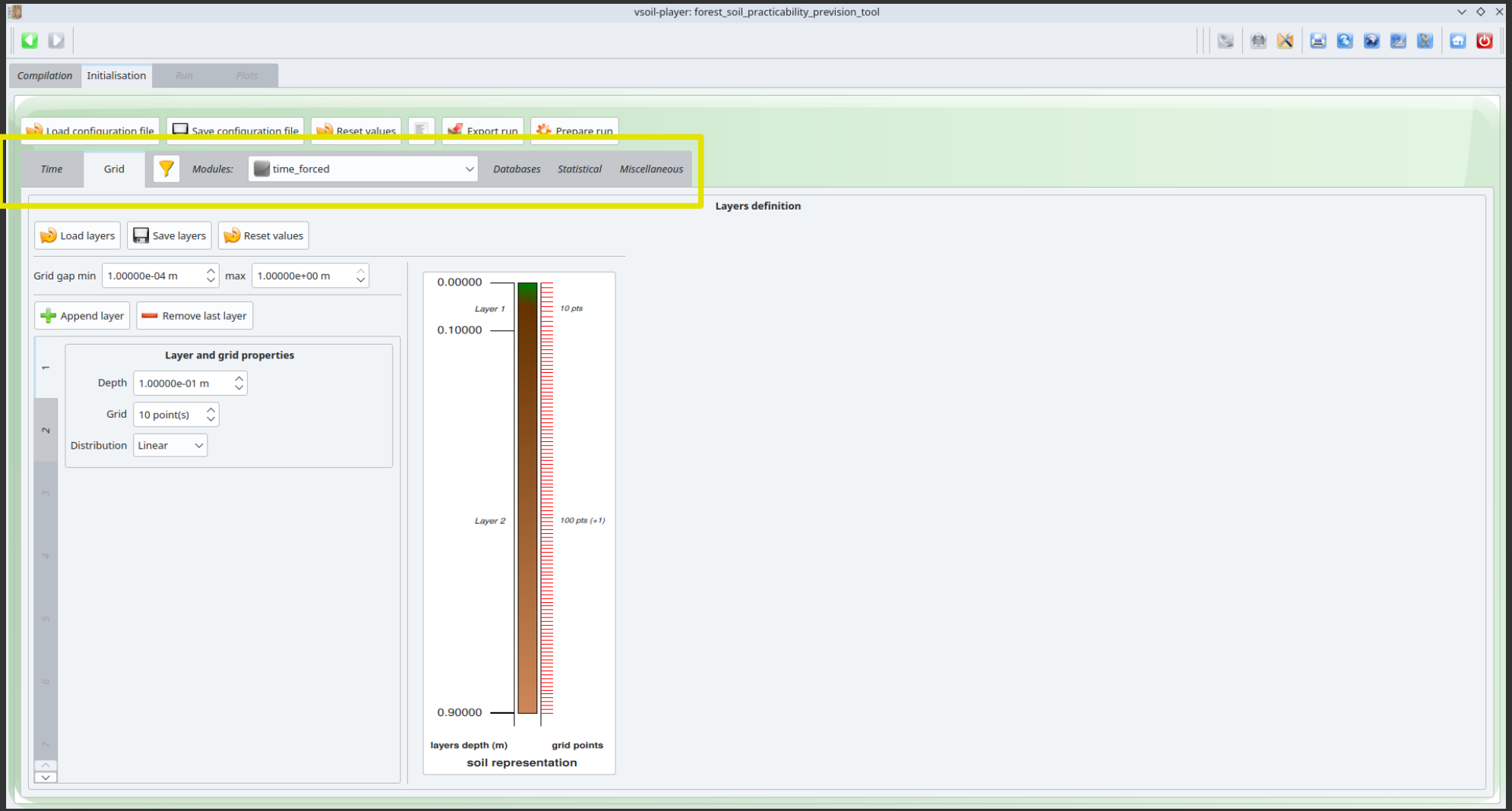
Archive simulations

View saved results

Compare simulation results

Perform sensitivity analysis and parameter estimation

4) The VSoil software components: vsoil-player



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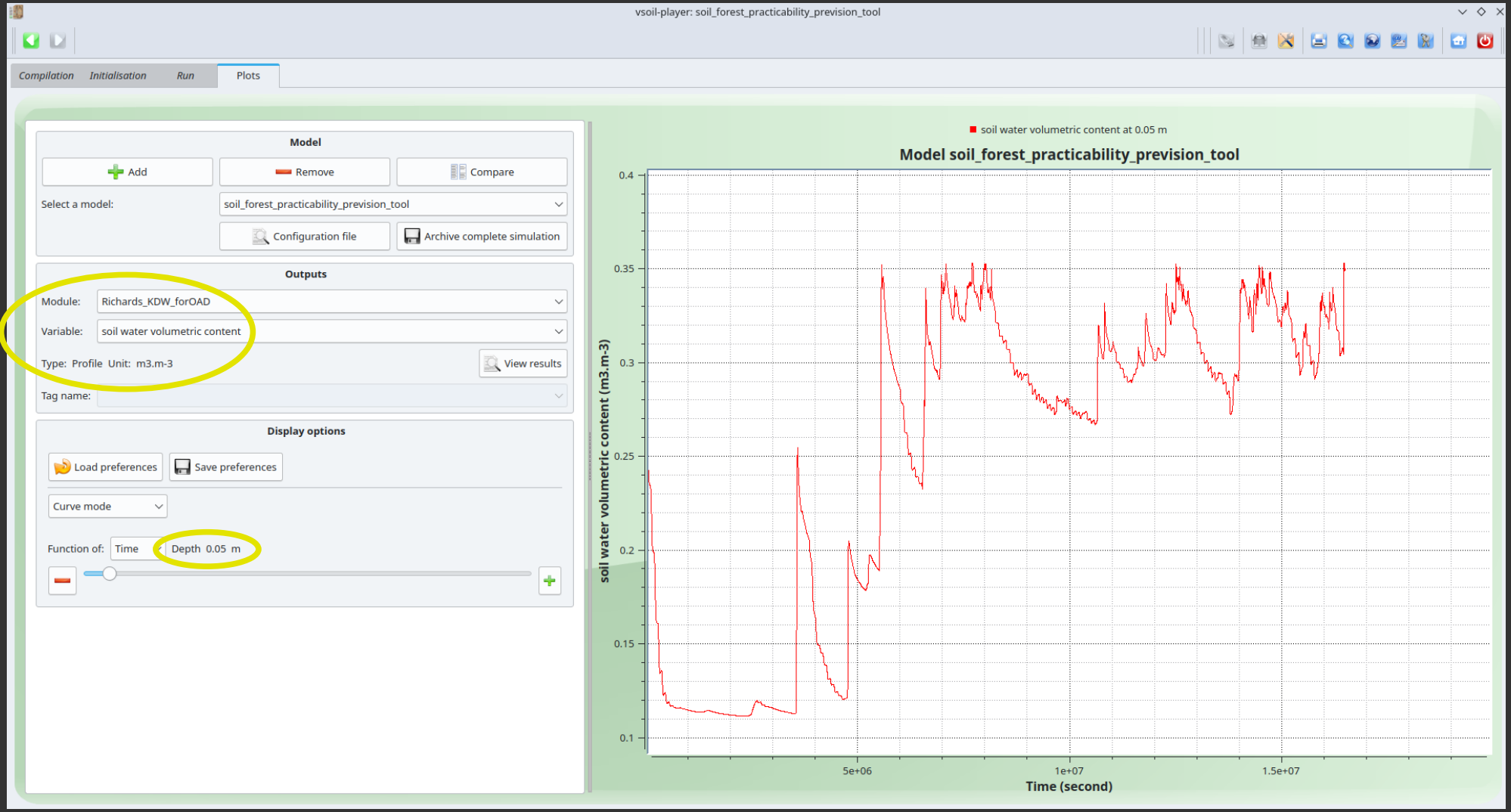


6) Particular features of VSoil

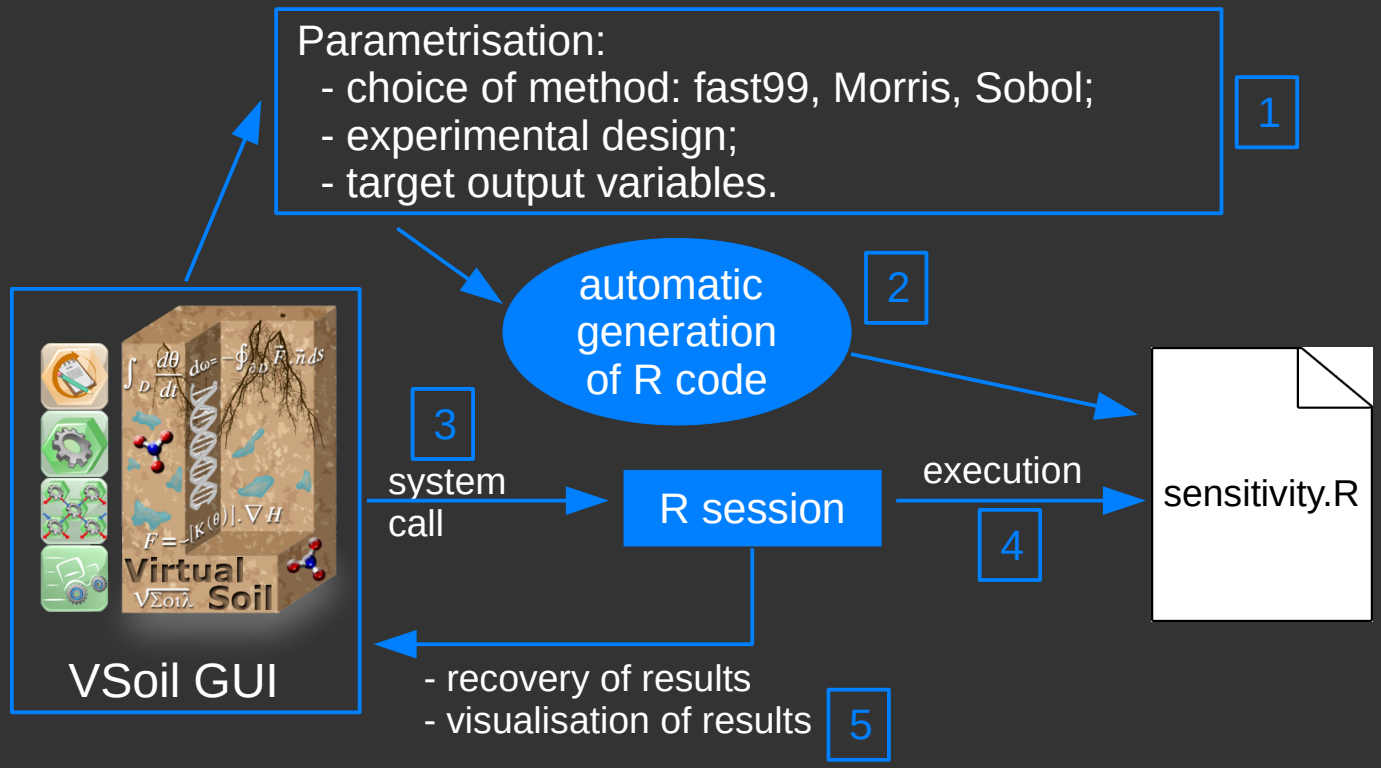
6.1) Interfacing with R software environment

- For using model exploration tools:
  - several sensitivity analysis methods: fast99, Morris, Sobol (*sensitivity*);
  - various algorithms for parameter estimation:
    - Levenberg-Marquardt (*minpack.lm*);
    - SCE-UA (Shuffle Complex Evolution – Uncertainty Analysis) (*rtop*);
    - DREAM (DiffeRential Evolution Adaptative Metropolis) (*dream*);
    - DREAMzs (Differential Evolution Adaptative Metropolis) (*BayesianTools*).
- For running multi-simulations.

6) Particular features of VSoil

6.1) Interfacing with R software environment

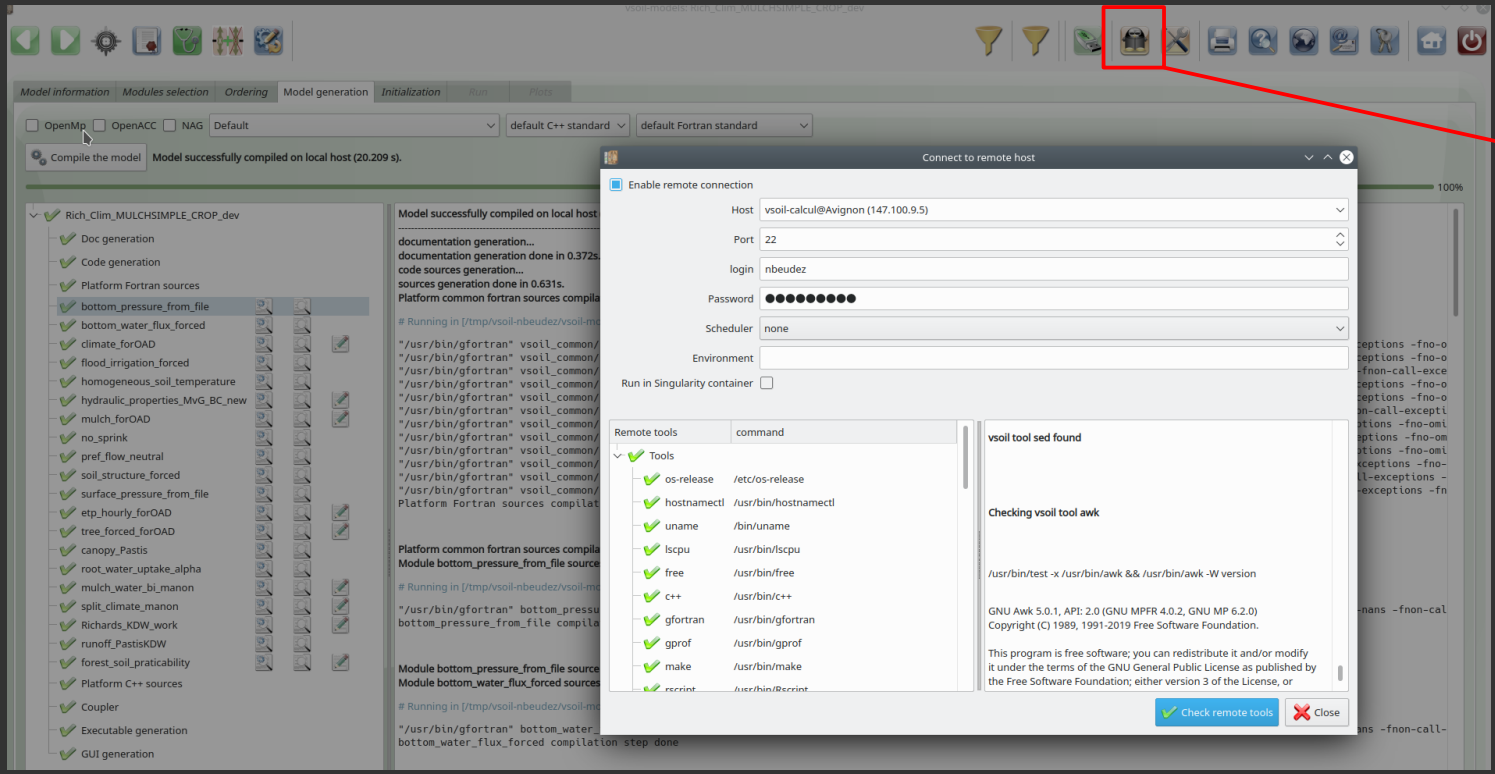
- Example of scenario: sensitivity analysis



6) Particular features of VSoil

6.2) Ability to run calculations on remote servers

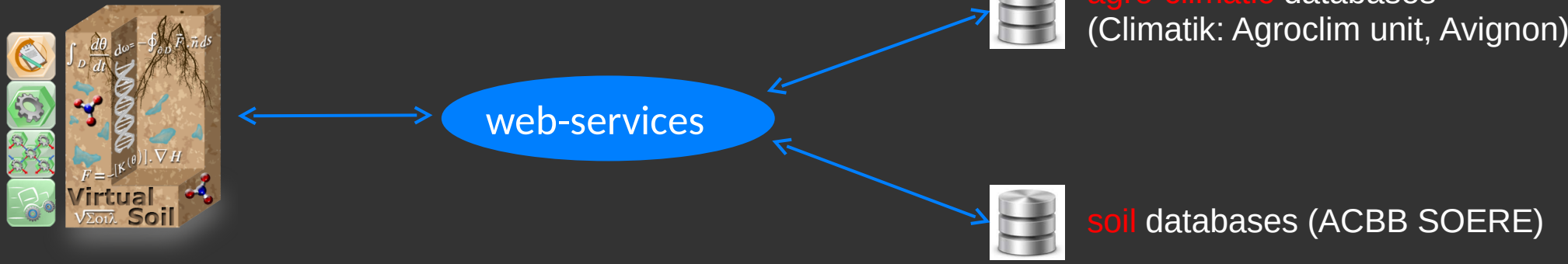
- Linux server ‘vsoil-calcul’: Ubuntu 24.04, 56 cores, 92 GB RAM;
- compatible with clusters;



remote connection activation

6) Particular features of VSoil

6.3) Connecting to databases

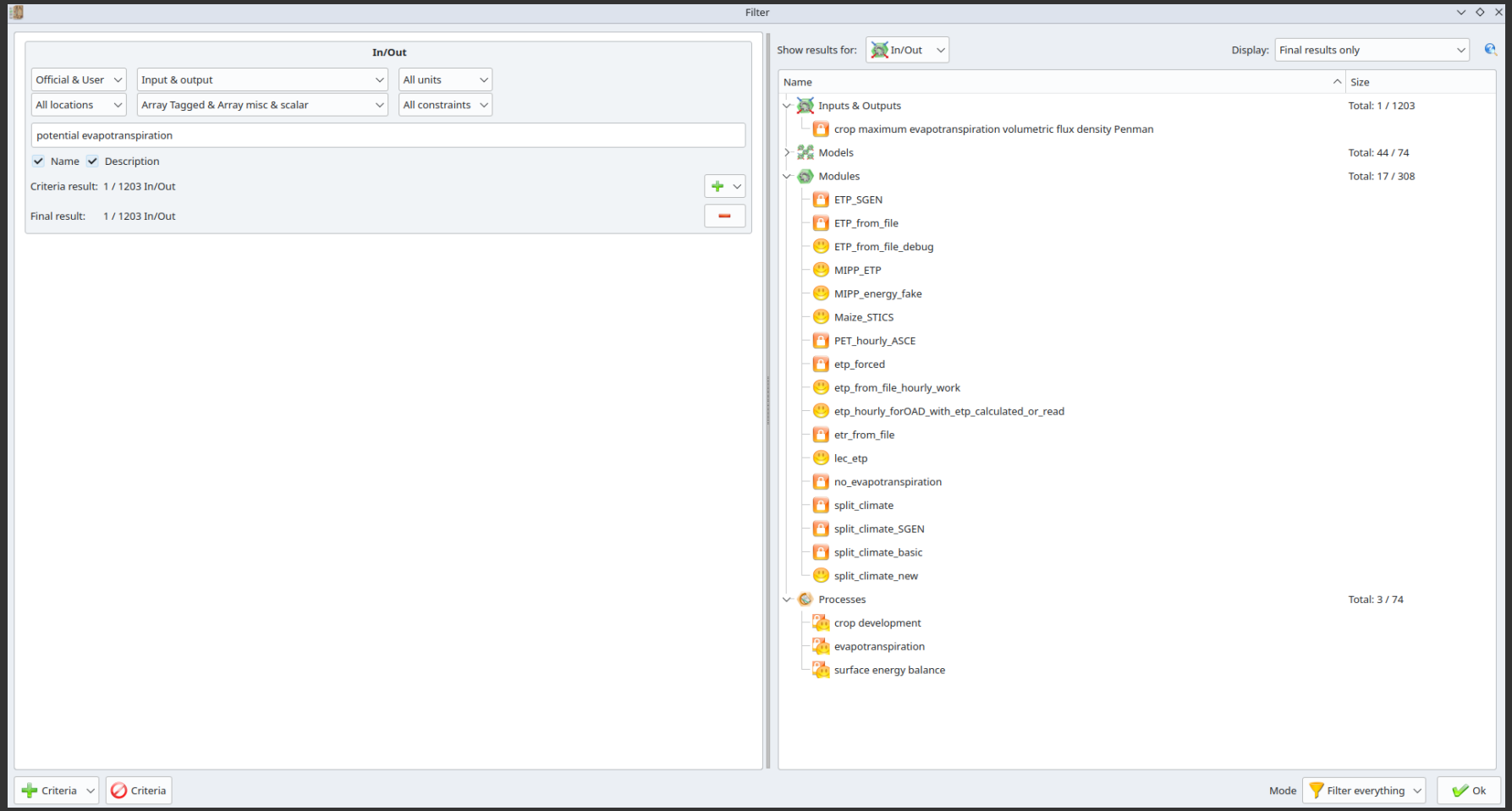


SOERE: Long-term Observation and Experimentation System for Environmental Research (« Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement »)

ACBB: Agro-ecosytem, Bio-geochemical Cycle and Biodiversity (« Agro-écosystème, Cycle Bio-géochimique et Biodiversité »)

6) Particular features of VSoil

6.4) Filter for exploring VSoil objects



7) Additional information

- Some technical specifications:
    - Linux / Windows support;
    - Apache 2 licence (open source);
    - software versioning: Apache subversion;
    - continuous integration tool: Jenkins;
    - languages: C++ / Qt (software) and C++ / Fortran (modules);
    - 728 variables, 60 processes, 148 modules and 20 models;
    - naming of variables: OBOE ontology;
    - files format: XML (configuration files) and CSV (output files);
    - external libraries used in modules: Gimli (geophysics), LAPACK (numerical computation).

- Distribution strategy: 2 to 3 stable versions per year.

7) Additional information

- Examples of collaborations:

  - INRAE: EMMAH (Avignon), CEREGE (Aix-en-Provence), LISAH (Montpellier), FARE (Reims), ECOSYS (Palaiseau), Info&Sols (Orléans);

  - ONF (Chambéry);

  - Gustave Eiffel University (Champs-sur-Marne), Ghent University (Belgium), National Autonomious University of Mexico (Mexico);

  - Groupe Roullier (Saint-Malo).

8) VSoil in summary

1. VSoil makes modelling accessible to people who are not comfortable with computer programming. The modeller:

focuses on his core business:
- manufacturing bricks (modules);
- assembling bricks graphically;
- analysing simulation results.

→ is relieved of all technical tasks that do not fall within his area of expertise.

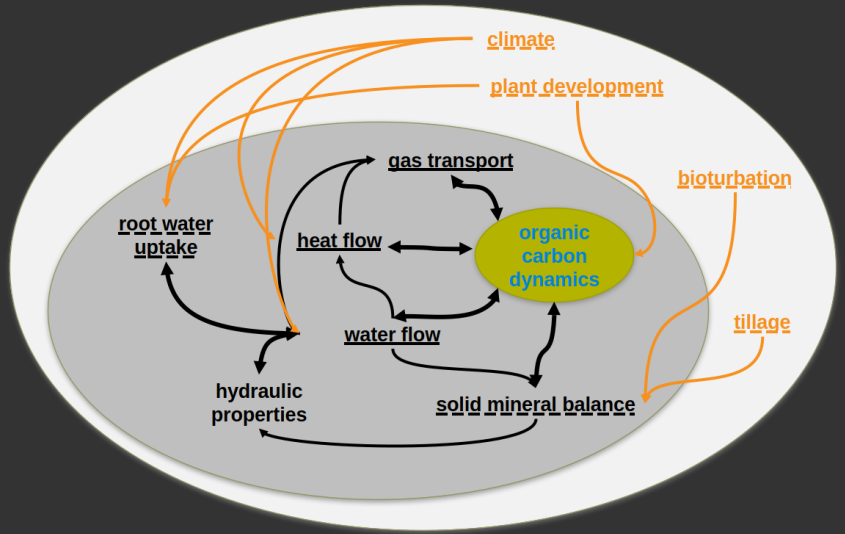
2. VSoil facilitates the sharing and reuse of new developments within the platform's user community (new features, distribution of VSoil objects, import / export system).

3. VSoil encourages collaborations between scientists from different fields.

9) Examples of realisations

- OC_VGEN (Keyvanshokouhi et al., 2019 and Chaif et al., 2025): model for simulating the evolution of soil properties at the century scale in a vertical soil profile.

Funding: INRAE, ADEME, partners: INRAE, ARVALIS.



Processes involved in the OC_VGEN model (H. Chaif)

Several processes are represented into dedicated modules adapted from SoilGen (Finke and Hudson, 2008) and PASTIS (Lafolie, 1991 and Findeling et al., 2007) models.

References:

- Lafolie (1991), DOI: 10.1007/bf01051129
- Findeling et al. (2007), DOI: 10.1111/j.1365-2389.2006.00826.x
- Finke and Hudson (2008), DOI: 10.1016/j.geoderma.2008.01.017
- Keyvanshokouhi et al. (2019), DOI: 10.1016/j.scitotenv.2018.10.236
- Chaif et al. (2025), DOI: 10.1016/j.geoderma.2025.117228

9) Examples of realisations

- forest_soil_practicability_prevision_tool (Martin et al., 2024 and Pousse et al., 2025): model for predicting the risk of rutting in forest soils.
Funding: ADEME, partners: ONF, CNPF-IDF, FCBA, INRAE.

Ruts in Grand-Pays national forest (Meuse, France) – March 2021

Forestry machinery traffic test - 2018

Forestry machinery travels on dedicated tracks known as skid trails, whose practicability must be maintained over the long-term.

References:
- Martin et al. (2024), DOI: 10.1186/s13595-024-01265-4
- Pousse et al. (2025); https://hal.science/hal-05198975

Development of a climate service prototype for real-time prediction of the water status of skid trails over the next 14 days:

observed and forecast weather data (ECMWF) + model to simulate the degree of water saturation of skid trails + ask minimum information to forestry operator = predicting the risk of rutting

9) Examples of realisations

- MIPP ('Integrated Modelling of the fate of Pesticides in agricultural Landscapes'): model for predicting pesticide concentrations in soil, water and air compartments (Voltz et al., 2019):

  - one brick = a mechanistic 1D VSoil model: transfers of water, heat and pesticides + fate of pesticides on leaves + penetration of pesticides into plant + partitioning of pesticide in soil (liquid, solid and gas phases);

  - integrative MIPP model implemented in OpenFLUID modelling platform: pesticide transport in soil, air and surface waters over all units of a discretised landscape;

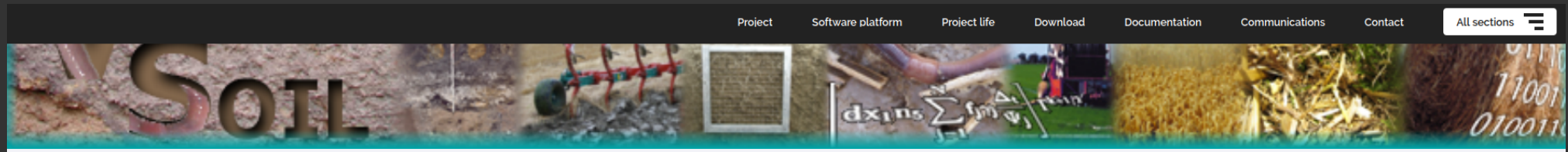
  - Ecophyto RIPP-Viti project: adaptation to take into account intra-field heterogeneities encountered in vineyards (Dagès et al., 2024a et 2024b).

References:
- Voltz et al. (2019), https://hal.inrae.fr/hal-02962223v1
- Dagès et al. (2024a), https://hal.inrae.fr/hal-04695079
- Dagès et al. (2024b), https://hal.inrae.fr/hal-04719108

Funding: INRA département Environnement et Agronomie, Ecophyto Recherche & Innovation, OFB, partners: INRAE, Institut Agro, Agence de l'Eau Rhône-Méditerranée-Corse, Chambre Régionale d'Agriculture Occitanie, FREDON captages d'eau Occitanie, IFV, Réseau DEPHY-Vigne, EPT de bassin Orb et Libron, OFB

10) Resources

Website: https://vsoil.hub.inrae.fr/



Welcome to the VSoil project!

VSoil (for Virtual Soil), is a **modelling software platform** supported by the **"Agroécosystèmes" division of INRAE** and developed and hosted by **EMMAH laboratory**. It is a tool to **help develop numerical models** describing the **physical, chemical and biological processes of the soil** in interaction with the **climate**, **plants** and **anthropic actions**. By **facilitating the coupling between these processes**, the platform makes it possible to **develop complex models from assemblies of existing or new codes**.

We advise you to read the **What you can do with VSoil** page before using VSoil in order to know more about what VSoil is, the capabilities it has and the functionalities it offers.

Look also at the top of this page to access more informations about the VSoil project: description of the **project** and the **software platform**, informations about the **project life**, procedures to **download** the VSoil software suite (on Linux and Windows), access to **documentations** of the VSoil software suite (including some tutorials) and how to **contact** us.

You can find below all the **news about the VSoil project**: new stable versions of VSoil software suite, new collaborations (projects, thesis, ...), ...

News

- A **new stable version** of VSoil software suite (VSoil 20250929) is available. The main changes introduced in this version are: (1) several **modules** were translated into **C++ language**, (2) when a model is detected to need **time synchronisation** with calendar dates, then the **vsoil-models** software adds automatically the default time synchronisation module (that can be removed or changed), (3) modules can now ask **programatically** to **save outputs** on current time step and (4) '**soil practicability**' was added to the list of available processes. See the Technical news page for more details about this version and the Download page to download and install it. *29/09/2025*
- An article written by **Hamza Chaif *et al.*** was recently published in ***Journal of hydrology***. See the Communications page for more details. *08/07/2025*
- **Claude Doussan** (INRAE, EMMAH, Avignon) presented a poster entitled "**Caractérisation des propriétés hydrauliques du sol par inversion jointe électrique-hydrique**" at the GEOFCAN 2025 symposium (4-6 June 2025, Avignon, France). This poster illustrates the work done by **Ismail Djellouli** (Sorbonne University, Paris) and **Julien Ardouin** (Savoie Mont Blanc University) during 2 master's internships he supervised and involving the VSoil platform (see here for more details about Ismail's and Julien's work). *10/06/2025*
- **Nicolas Beudez** (VSoil team, INRAE, EMMAH, Avignon) presented the VSoil modelling software platform in a **poster** at the **EGU General Assembly 2025** (Vienna, Austria, 27 April to 2 May 2025). **Cécile Dagès** (INRAE, LISAH, Montpellier) also presented a **poster** illustrating the **MIPP model** and its application to estimate the environmental impact of pesticides in a Mediterranean wine-growing watershed. See the Communications page for more details. *06/05/2025*

11) The VSoil team

Team members:

- scientific team:

Nicolas Beudez
scientific computing engineer
scientific co-director

Stéphane Ruy
research fellow
scientific co-director

- software team:

Nicolas Moitrier
research software engineer –
IT project manager

Nathalie Moitrier
software design
engineer

Cédric Nouguier
software design
engineer

To contact us:

- vsoil@inrae.fr ==> scientific team
  vsoil-support@inrae.fr ==> software team
- Discord server

Thank you for your attention