The VSoil modelling platform

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

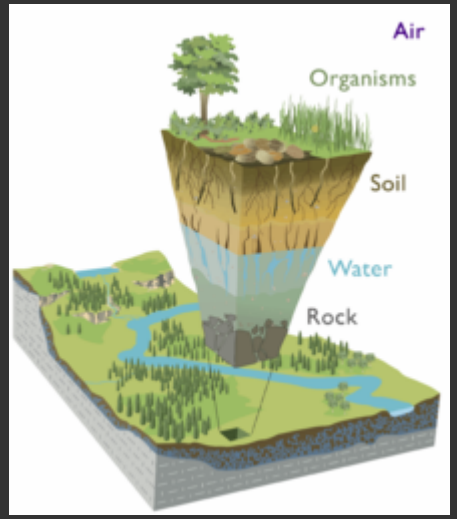
26 March 2026

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

ground surface

root zone

deep vadose zone

groundwater table

interest zone in VSoil

scale: soil pedon (a few m^2)

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 the 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).

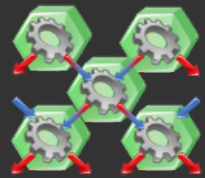
5) The architecture of VSoil

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.

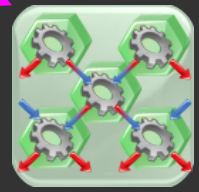


A model is an ordered set of modules.

A numerical simulation.

vsoil-processes

vsoil-modules



vsoil-models

vsoil-player

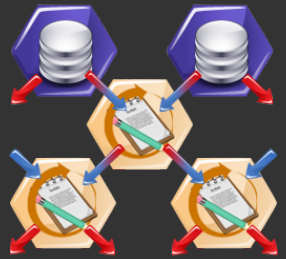
… to software.

6) 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

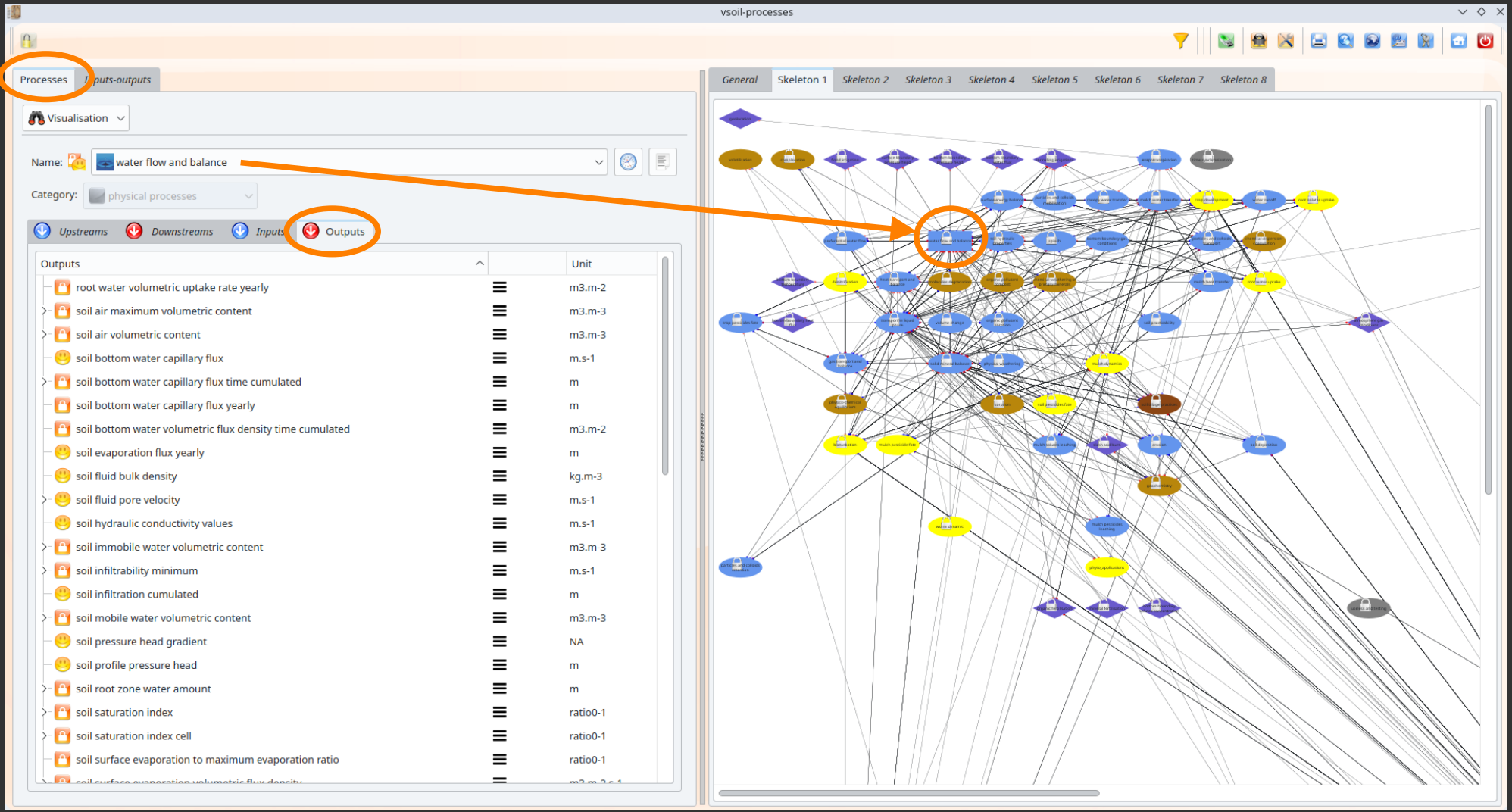
Guide for naming variables

Automatic creation of skeletons

Provides information for coding and assembly of modules

60 official processes

6) The VSoil software components: vsoil-processes



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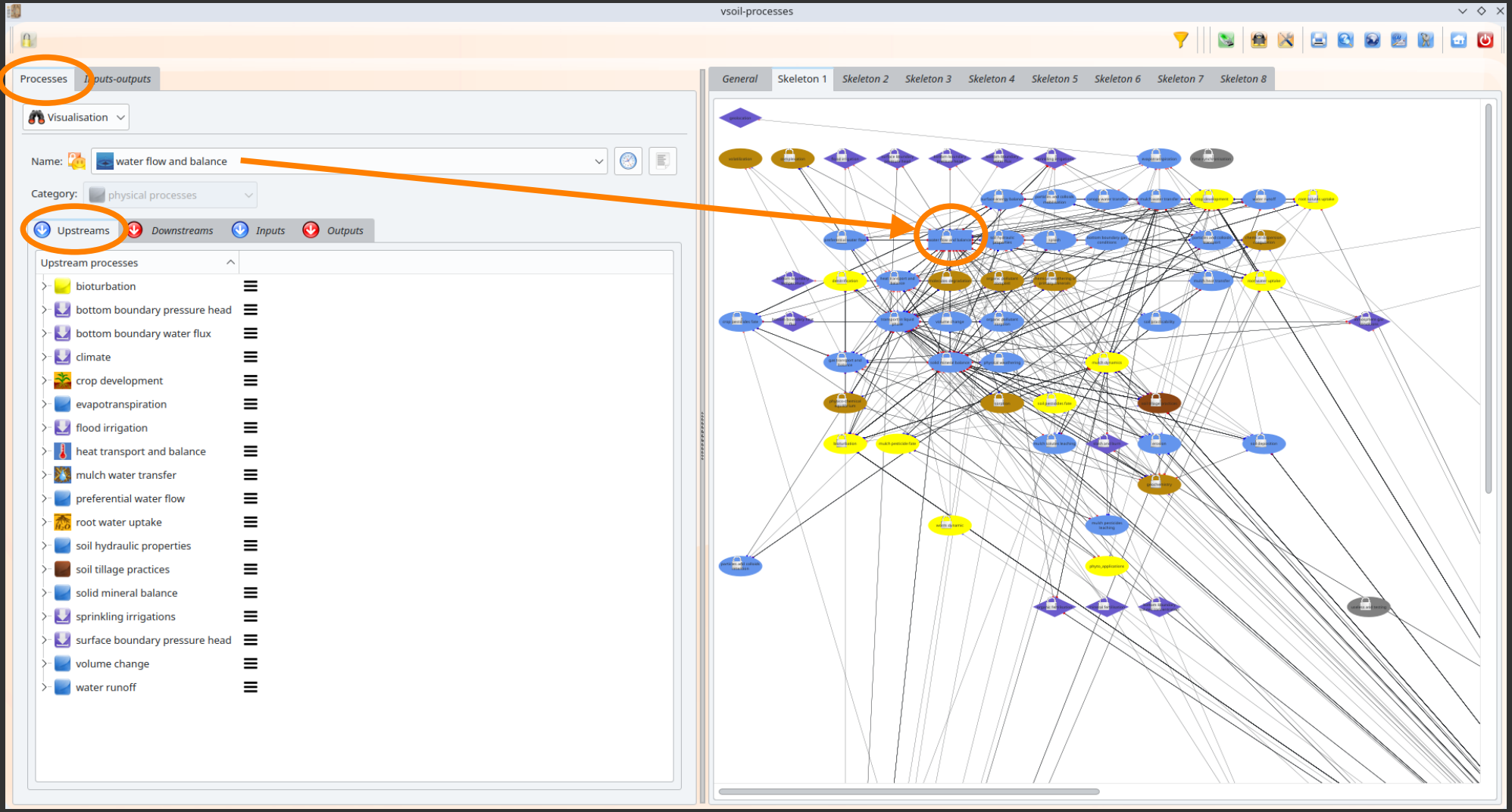

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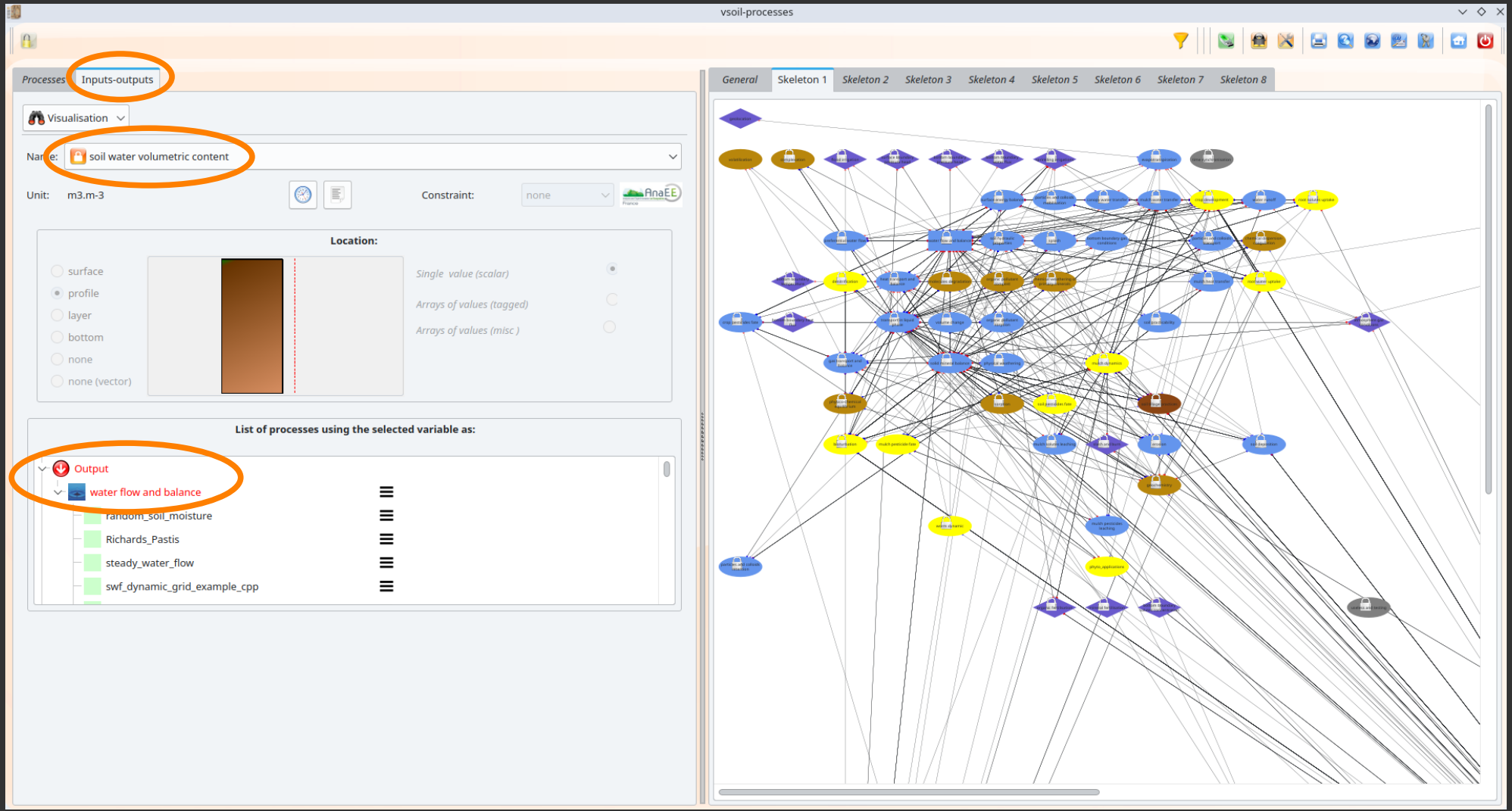


6) The VSoil software components: vsoil-modules

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

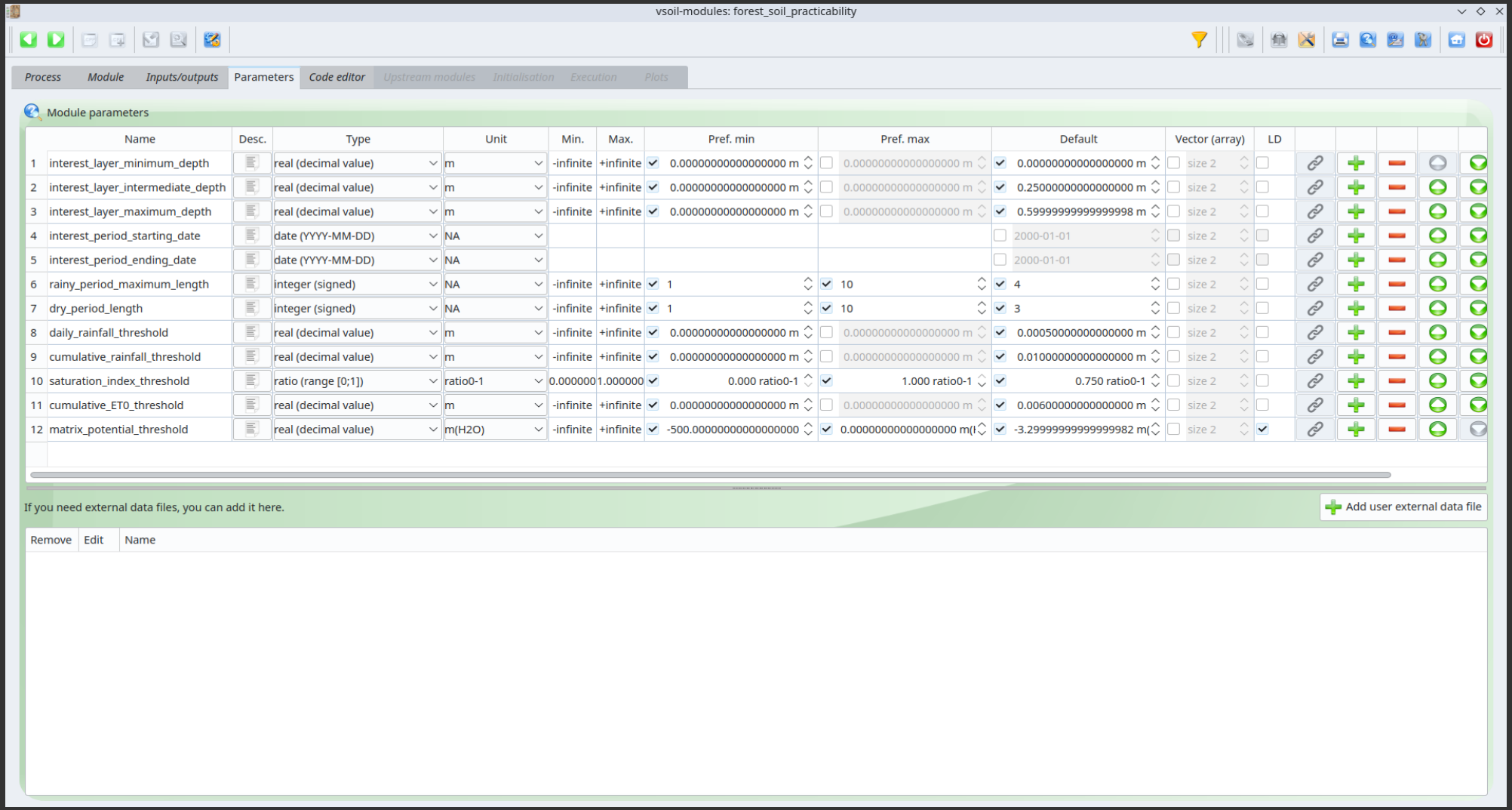
Tests

Graphs

Standardised languages: Fortran / C++

148 official modules

6) The VSoil software components: vsoil-modules



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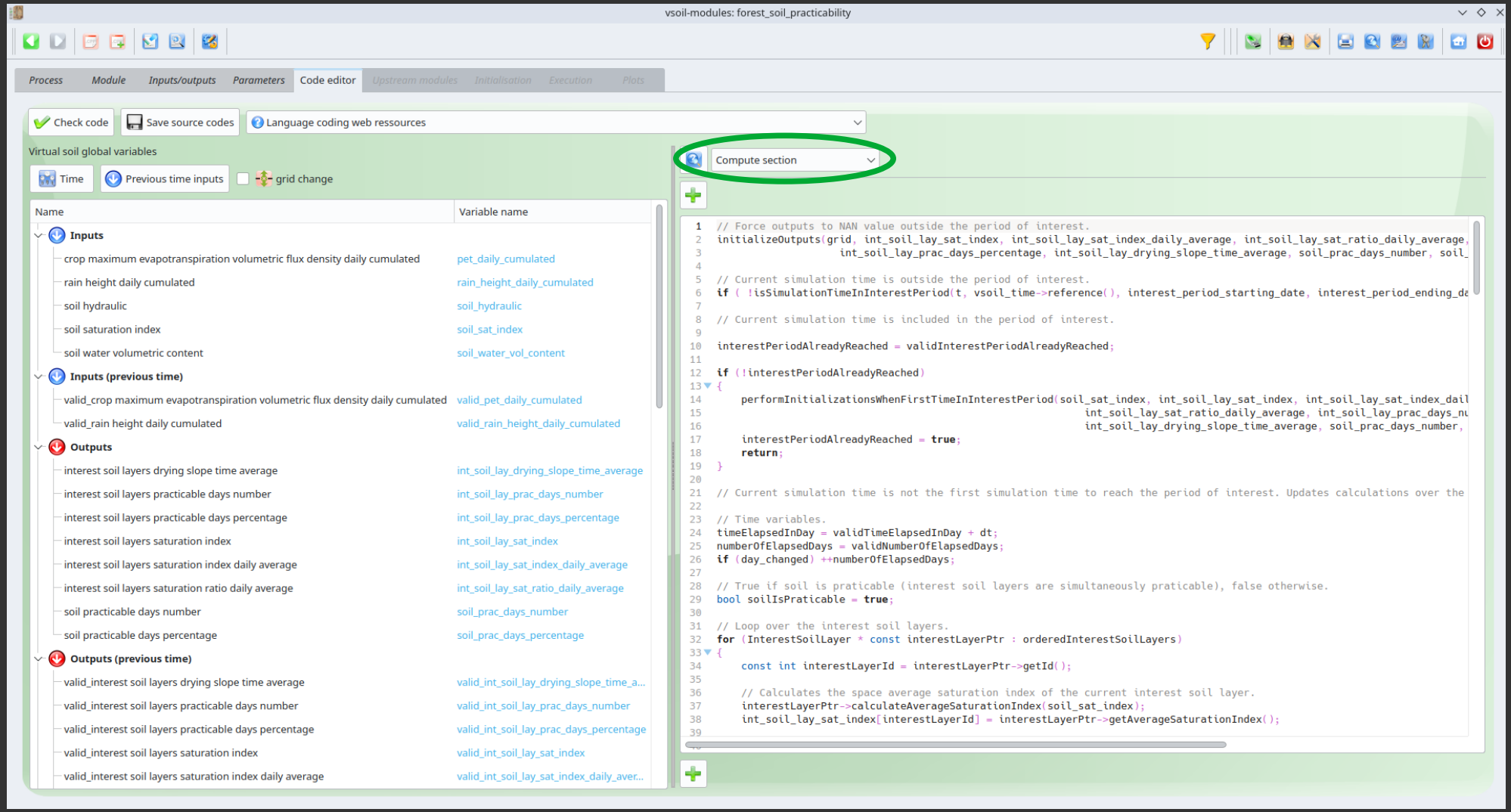
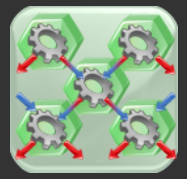
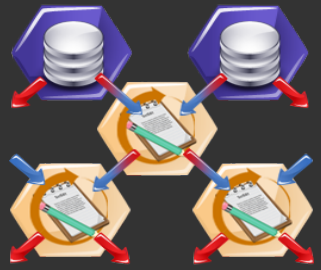


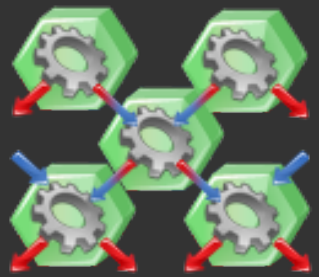
6) The VSoil software components: vsoil-models



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

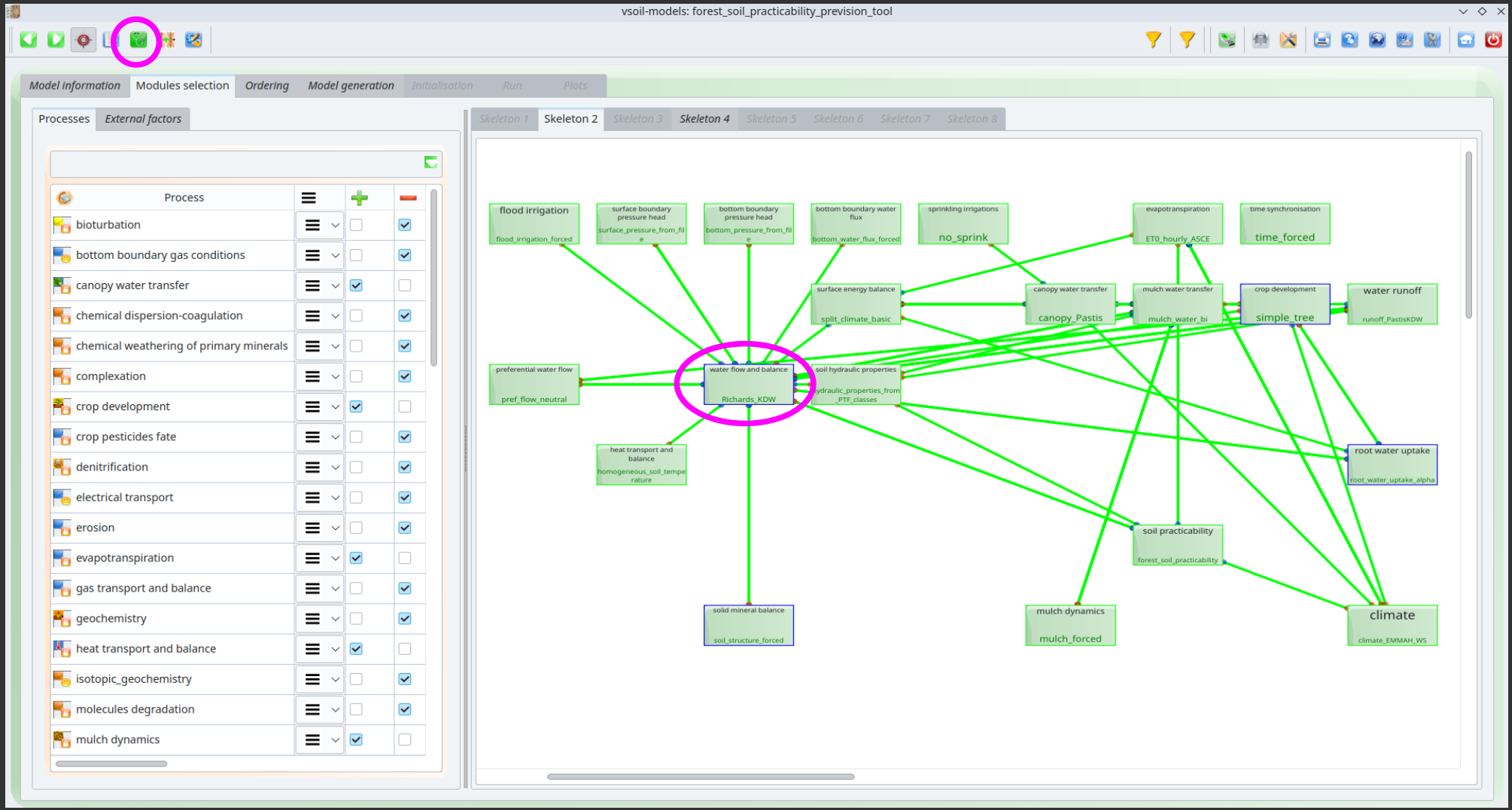
Visualisation

Backup

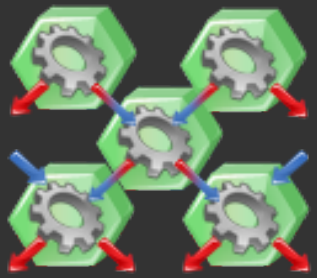
Modification

20 official models

6) The VSoil software components: vsoil-models



6) The VSoil software components: vsoil-player



A model already built.

Simulations, visualisation of results, ...

vsoil-player

Use available models

Run simulations

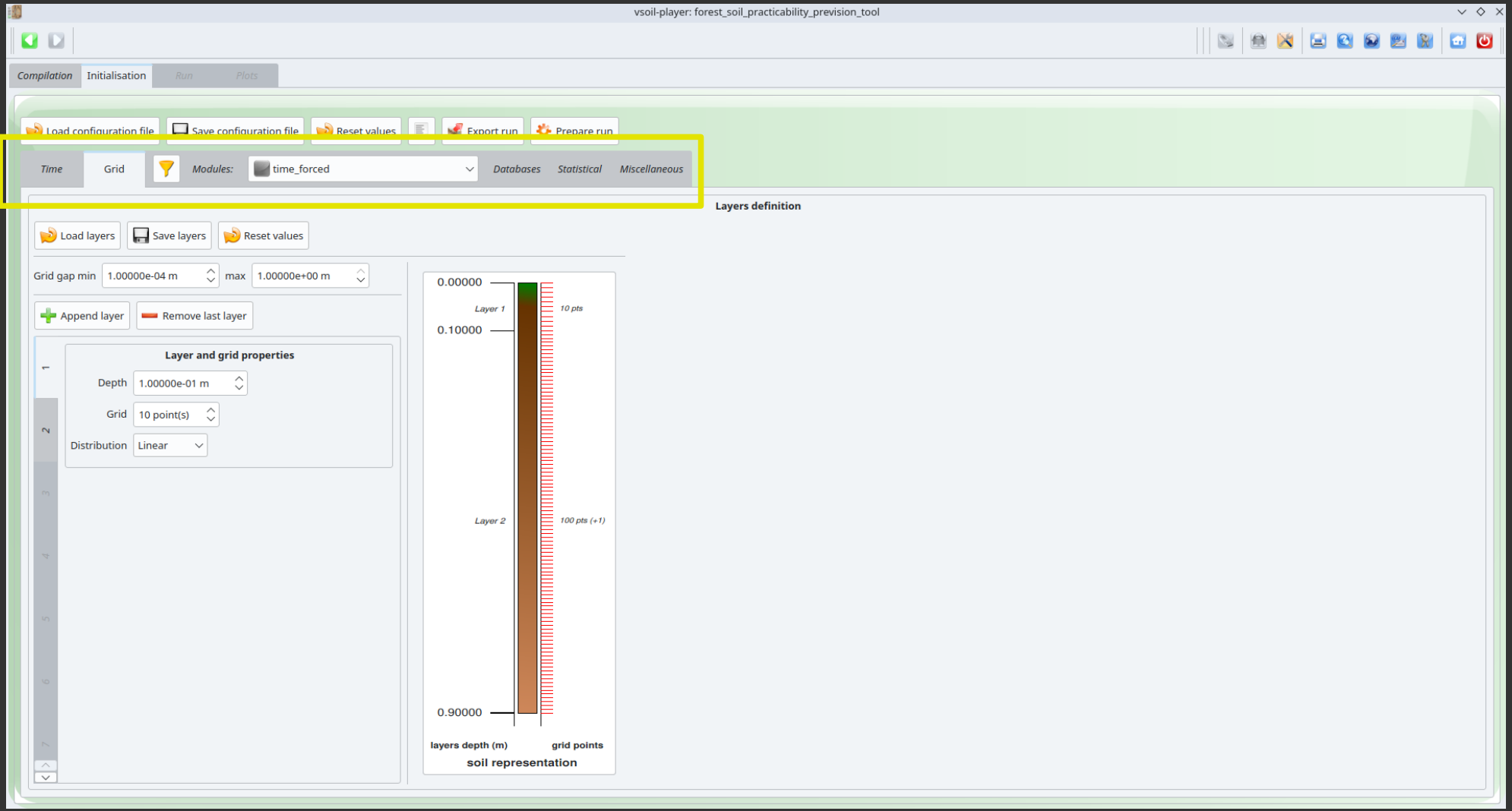
Archive simulations

View saved results

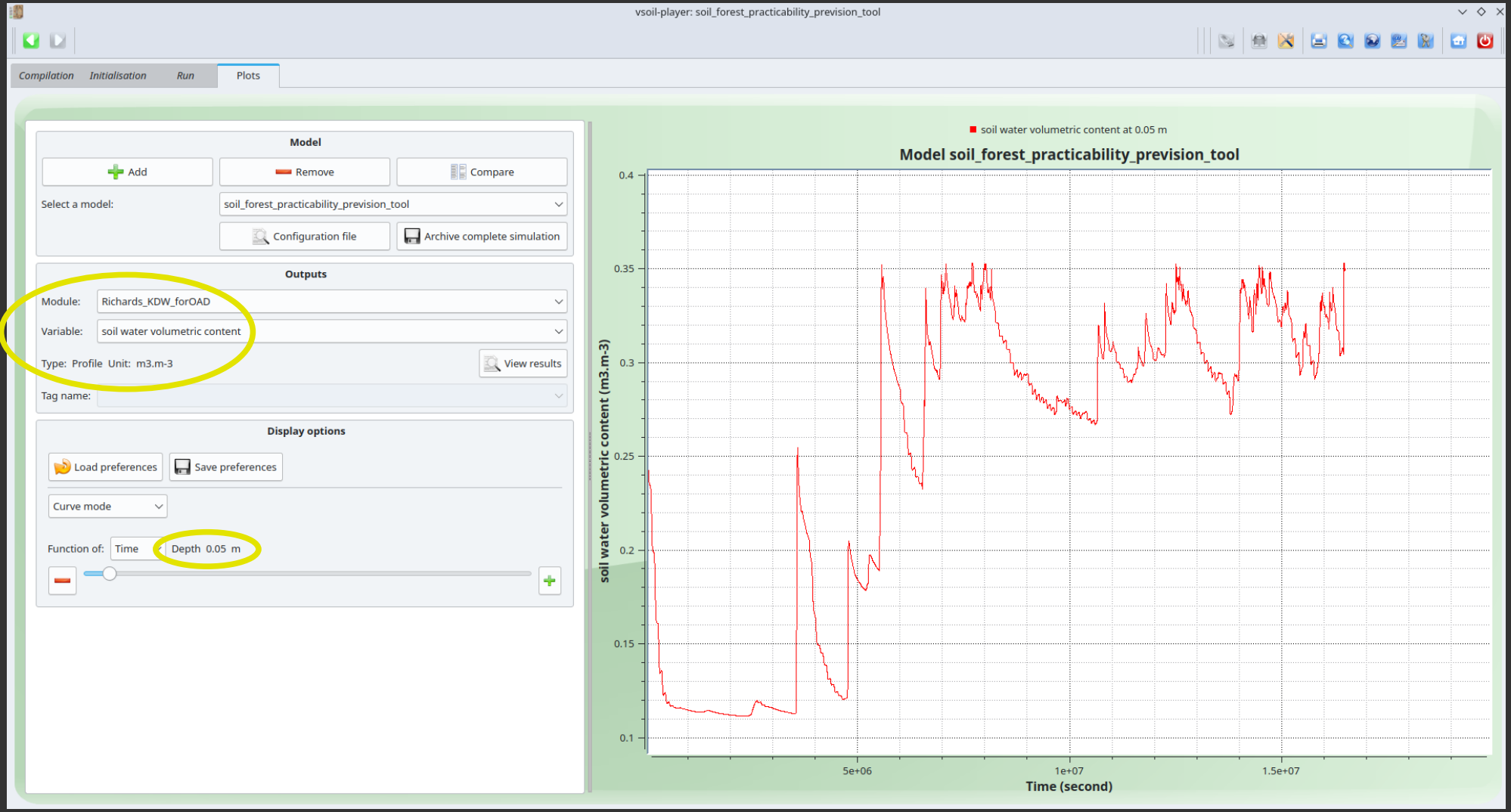
Compare simulation results

Perform sensitivity analysis and parameter estimation

6) The VSoil software components: vsoil-player



6) The VSoil software components: vsoil-player



7) Particular features of VSoil

7.1) Interfacing with R software environment

- For using model exploration tools:

  - several sensitivity analysis methods: fast99, Morris, Sobol (*sensitivity*);

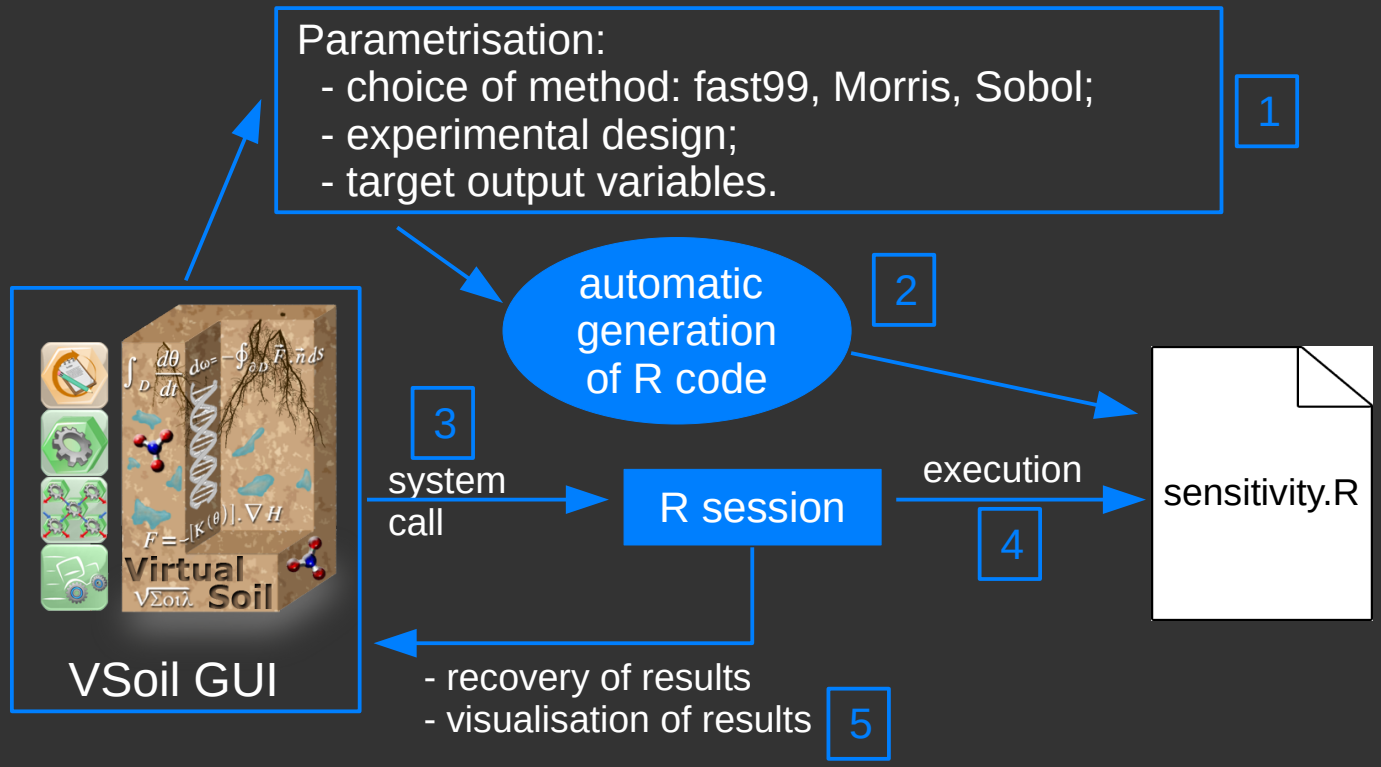
  - various algorithms for parameter estimation:
    - Levenberg-Marquardt (*minpack.lm*);
    - SCE-UA (Shuffle Complex Evolution – Uncertainty Analysis) (*rtop*);
    - DREAM (DiffeRential Evolution Adaptative Metropolis) (*dream*);
    - DREAMzs (Differential Evolution Adaptative Metropolis) (*BayesianTools*).

- For running multi-simulations.

7) Particular features of VSoil

7.1) Interfacing with R software environment

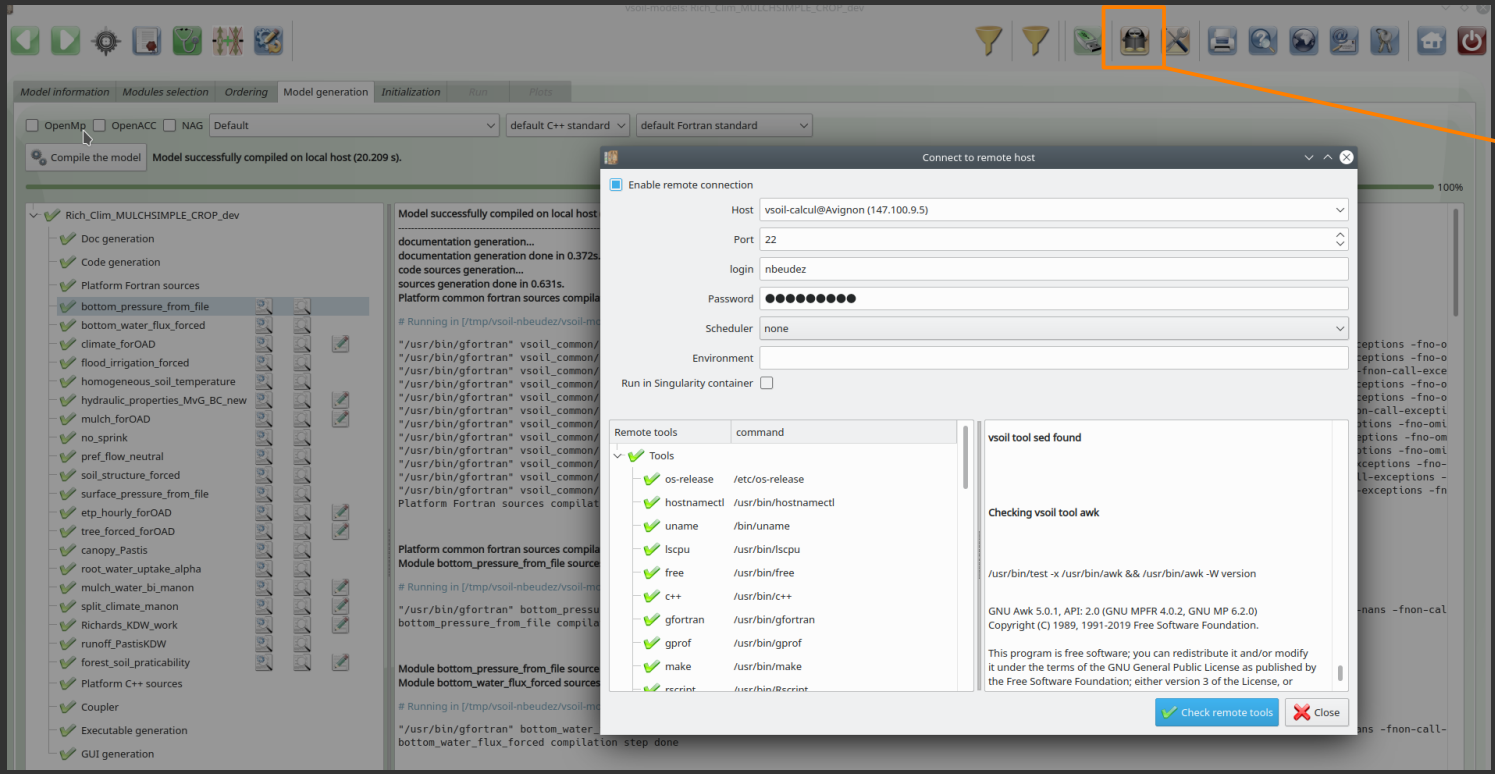
- Example of scenario: sensitivity analysis



7) Particular features of VSoil

7.2) Ability to run calculations on remote environments

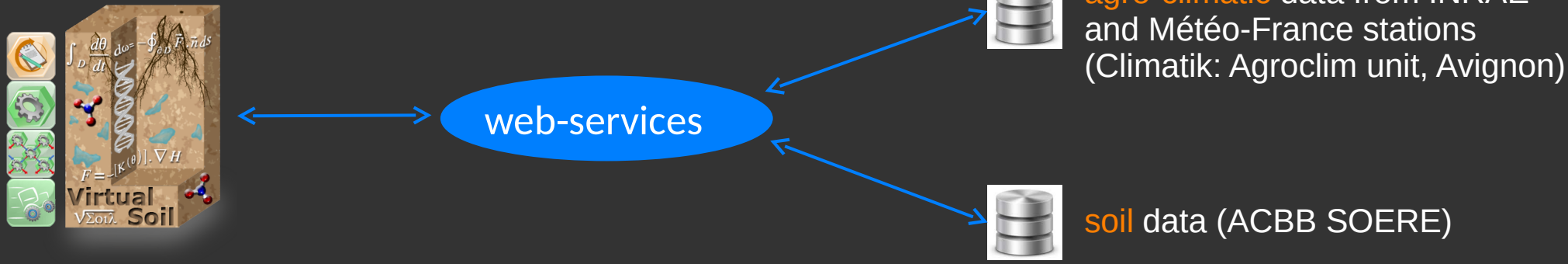
- Linux server ‘vsoil-calcul’: Ubuntu 24.04, 56 cores, 92 GB RAM.
- Compatible with clusters.



remote connection activation

7) Particular features of VSoil

7.3) Connecting to databases

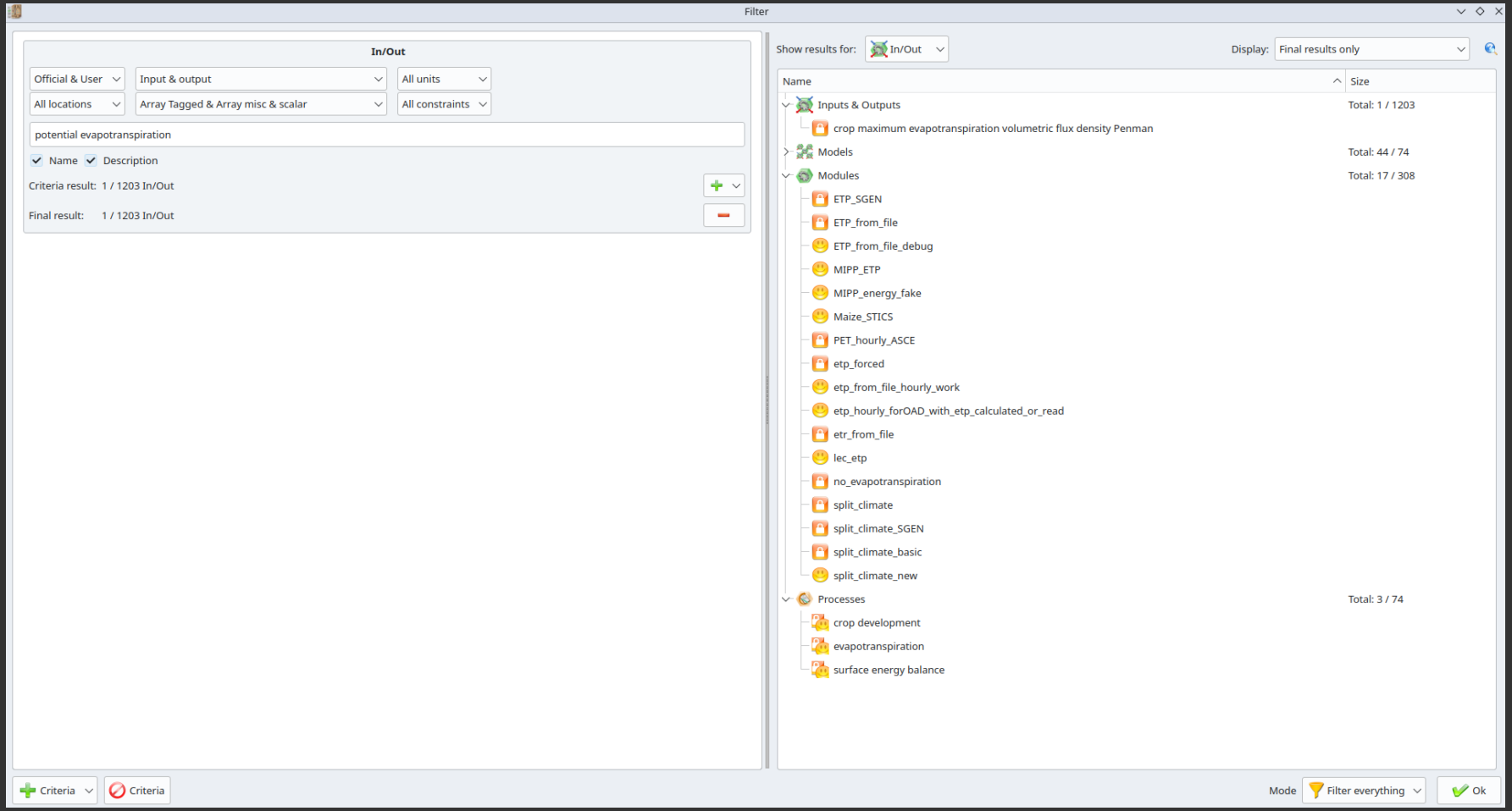


SOERE: Long-term Observation and Experimentation System for Environmental Research (« Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement »)

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

7) Particular features of VSoil

7.4) Filter for exploring VSoil objects



8) New features (since October 2024)

- Windows applications based on WSL (Windows Subsystem for Linux):

  - access to R-based tools (model exploration + multi-simulations) on Windows;

  - faster calculations.

- Simplified import function.

- ‘Stop and resume’ function: stop a simulation, save its state and restart with different datasets.

- ‘time_forced’: a new module for forcing simulation times on calendar dates (hour, day, month, year) or dates read from file.

- Identification of referent scientists for modules and models.

9) Work in progress

- Web-service providing access to weather data:

  - forecasts: 7-day, historical, seasonal, climate change scenarios, other scenarios, etc.;

  - unrestricted, direct (live) access via VSoil models.

- Online demo versions of models:

  - with extremely user-friendly interfaces;

  - daily forecasts for different types of soil and locations, for various purposes: drying rates, vehicle accessibility.

10) 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.

10) 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).

→ Examples of realisations in upcoming presentations!

11) 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.

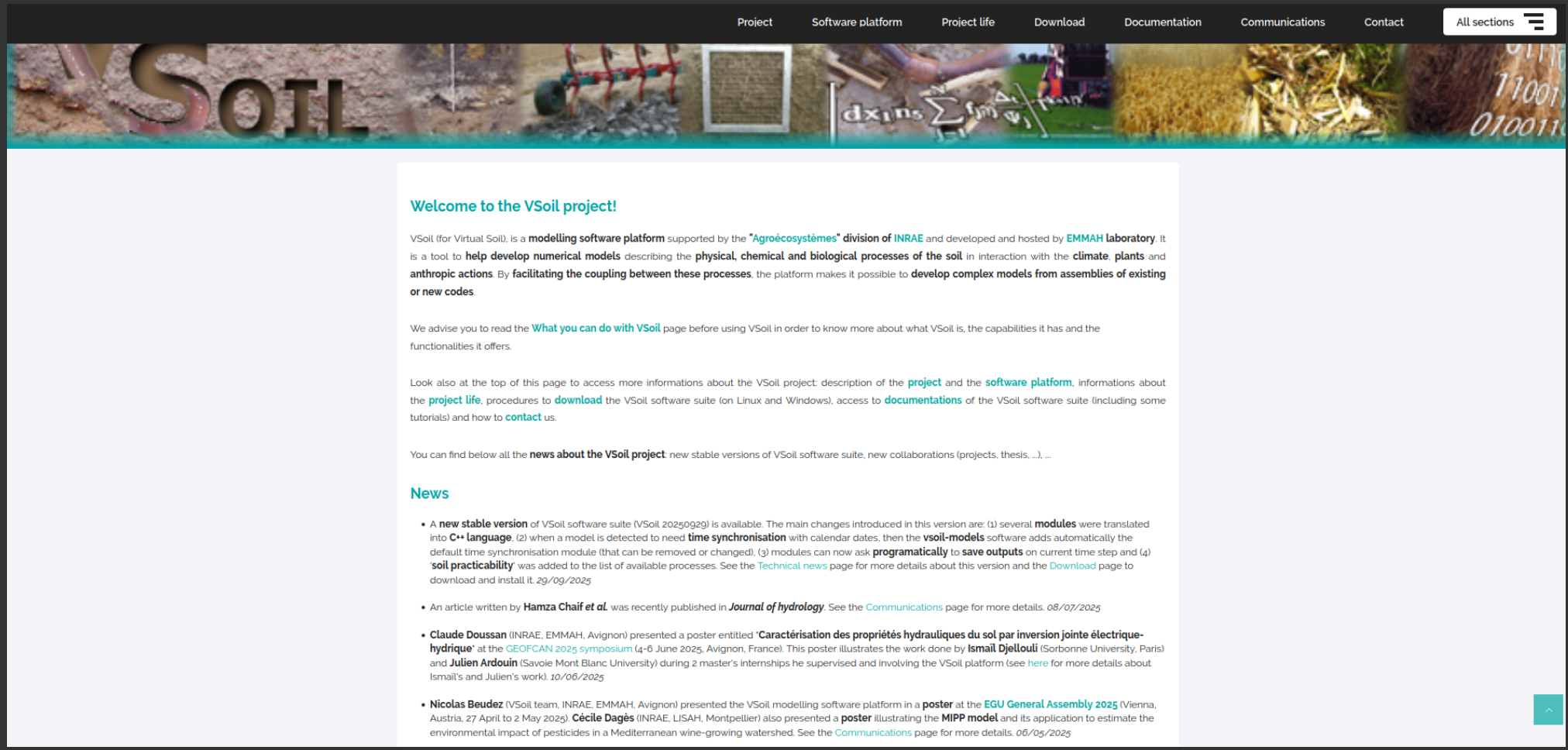
→ is relieved of all technical tasks that do not fall within his area of expertise.

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.

12) Resources

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



13) The VSoil team

Team members:

- scientific team:

Nicolas Beudez
scientific computing engineer
scientific lead

- software team:

Nicolas Moitrier
research software engineer – operational 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