The VSoil modelling software platform

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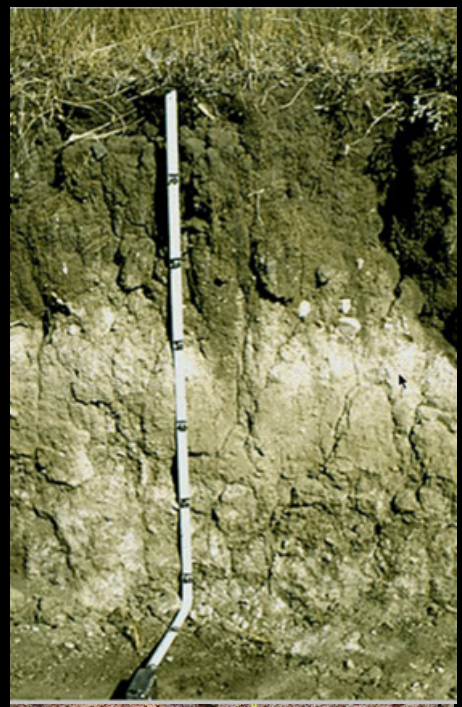
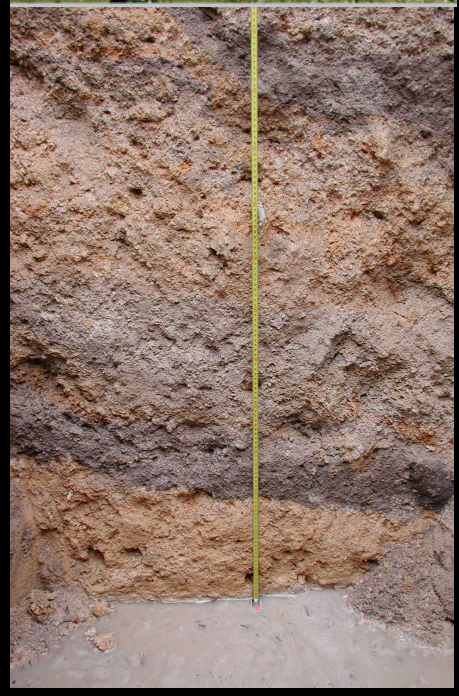
15 January 2025

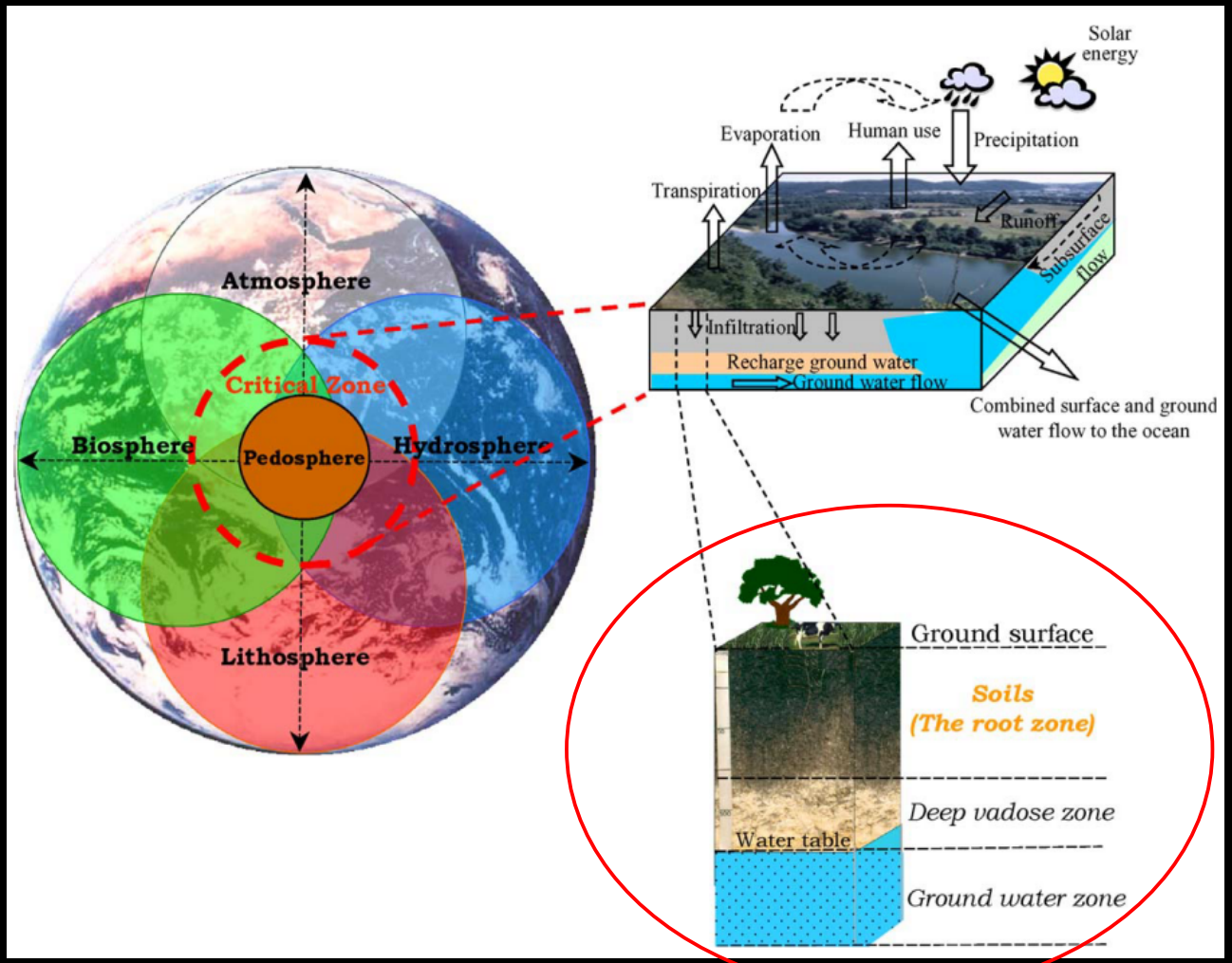


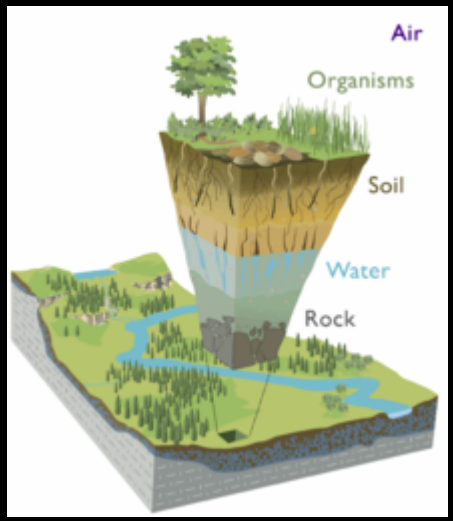


INRAE AVIGNON UNIVERSITÉ EmmaH

Context: soil

The soil is at the heart of the "critical zone" of exchange of water and solutes, gases, solids, energy and organisms that extends from the atmosphere to the unaltered rock.





The "critical zone"

Context:
- climate change;
- change of use;
- evolution.

Pedon:
- local scale (a few m²);
- soil profile from the surface to the groundwater or bedrock including the root exploration zone.

Modelling requirements

A **survey** conducted between 2006 and 2008 within the Environment and Agronomy department of INRA to **identify the needs in terms of soil functioning modelling**. It concluded that:

- scientists want to develop models that **couple mechanisms**:

  - of different natures (water / solutes / gaz / heat transfer, earthworms, particle transport, …);

  - at different scales of time and space;

  ➡ key point to **understand the functioning** and **predict the evolution of soils**;

- models should be developed **easily** et **quickly**: use what is available and / or develop new parts;

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

Technical barriers

Difficulties in appropriating the **modelling**:

chain: experiments → model → computer code

➡ **need for support**

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.

Objectives

Create a structure to:

- **host** and **share** models;
- **assist** in the development of new models;
- **facilitate** the use of existing tools;
- **reuse** and **capitalise** on the existing;
- have a **modular modelling** approach;
- accept **several representations** of a phenomenon;
- **manage the coupling** of mechanisms;
- **facilitate interactions** between « modellers » and « experimenters »;
- **facilitate communication** between scientists from different fields;
- **share** and **make** innovations **« immediately » usable** for all users of the structure.

The VSoil software platform

VSoil is a **modelling software platform** supported by the INRAE Agroecosystems department and hosted in EMMAH unit on the Avignon site (developed since 2009).

It is a tool to **assist in the development of numerical models** describing the **physical, chemical and biological processes** of the soil in interaction with climate, plants and human actions.

VSoil **facilitates the coupling** between these processes and makes it possible to develop complex models from the **assembly of existing or new source codes**.

Space for **animation** and **scientific collaborations**.

Basic concepts

The **processes** take place in the soil (physical, chemical or biological), can be described (example: water transfer) and have **input / output variables**.

A **module** is a computer representation of a process. Several representations of the same process are possible.

A **model** is an assembly of modules.

The modeller / user must be able to **concentrate on his core business**:

- making bricks (the modules);
- assembling the bricks;
- analysing the results.

➡ Modeller / user should be **relieved** of all tasks that are not its speciality.

Architecture

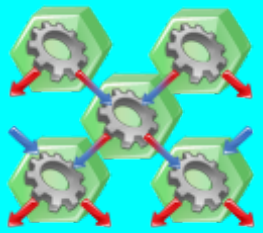
From concepts...

Processes

...encoded in modules,

...form squeletons,

...to create models



...and run simulations

vsoil-processes

vsoil-modules

vsoil-models

vsoil-player

...to softwares

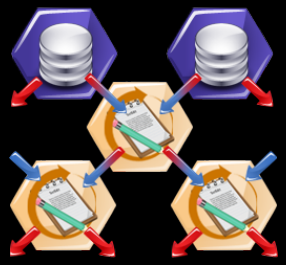
The VSoil software components (1/4)

1) vsoil-processes:

Phenomena are called **processes** (examples: bioturbation, evapo-transpiration, 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**.

demonstration!

vsoil-processes

Open lists of variables and processes

Guide for naming variables

Tool for exploring content

Automatic creation of skeletons

Provides information for coding and assembly of modules

58 official processes

The VSoil software components (2/4)

2) 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 .

demonstration!

vsoil-modules

Parameters

Coding assistance

Compilation

Tests

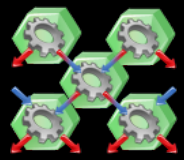
Graphs

Standardised languages: Fortran / C++

141 official modules

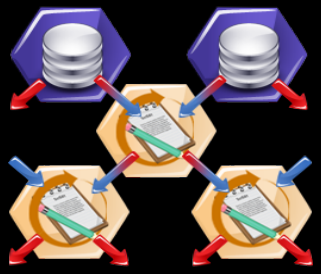
The VSoil software components (3/4)

3) vsoil-models:

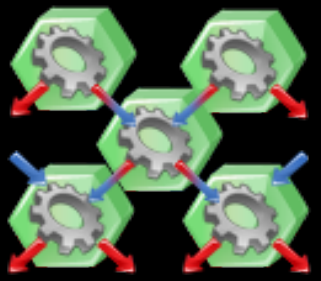


For each process...

... a module is selected.



A **model** is based on a skeleton.



A **model** is an ordered set of modules.

vsoil-models

Module selection

Generation of the main

Generation of the GUI

Execution

Visualisation

Backup

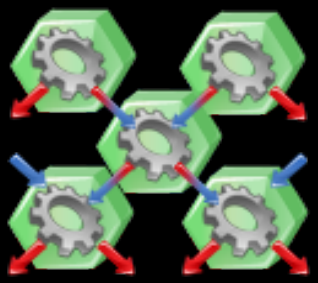
Modification

20 official models

demonstration!

The VSoil software components (4/4)

4) vsoil-player:



A model already built.

Simulations, visualisation of results, ...

demonstration!

vsoil-player

Use available models

Run simulations

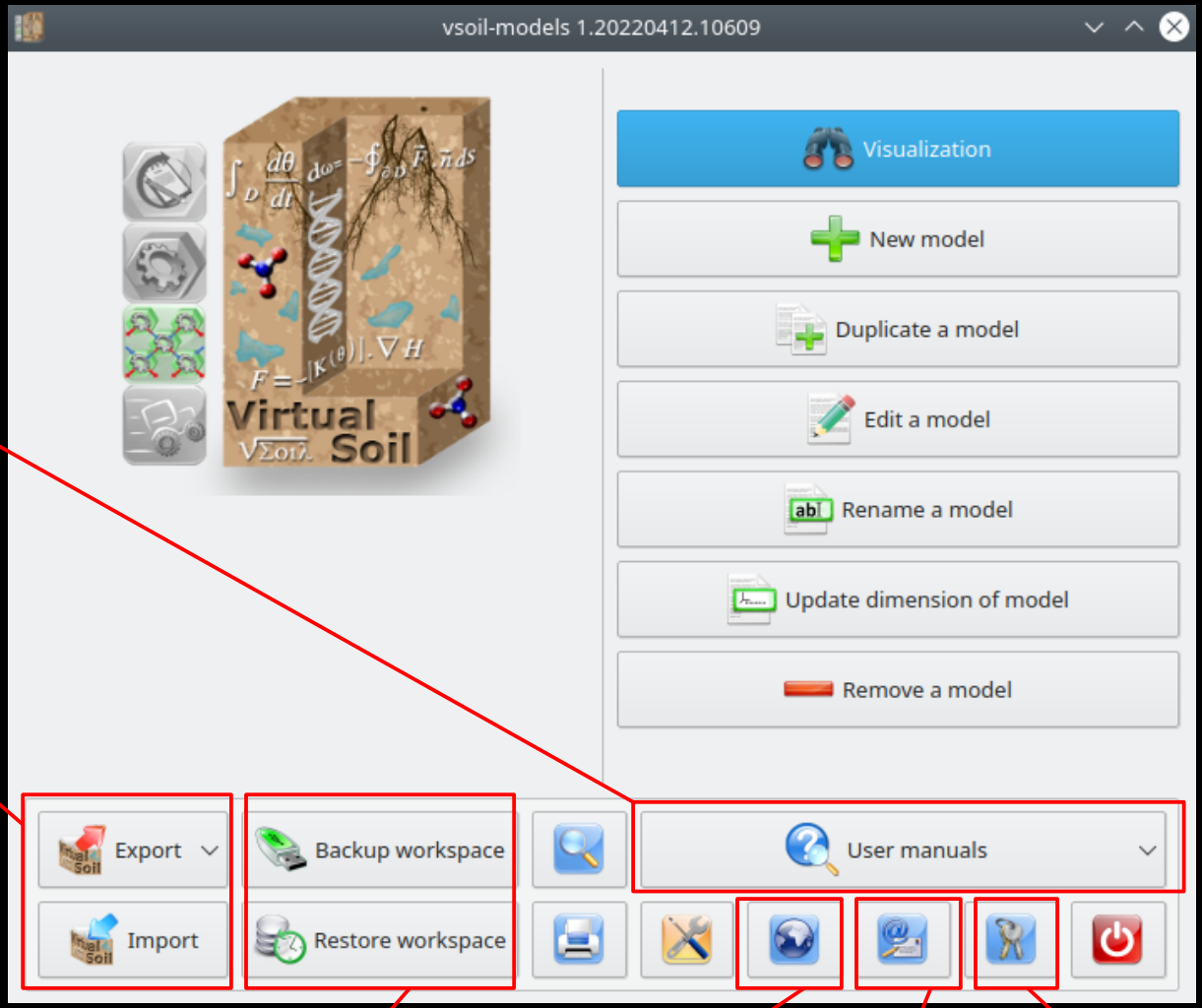
Archive simulations

View saved results

Compare simulation results

Perform sensitivity analysis and parameter estimation

A collaborative tool



online documentations (softwares and tutorials)

exchange of « user » objects

backup and restoration

access to the website

contact and support

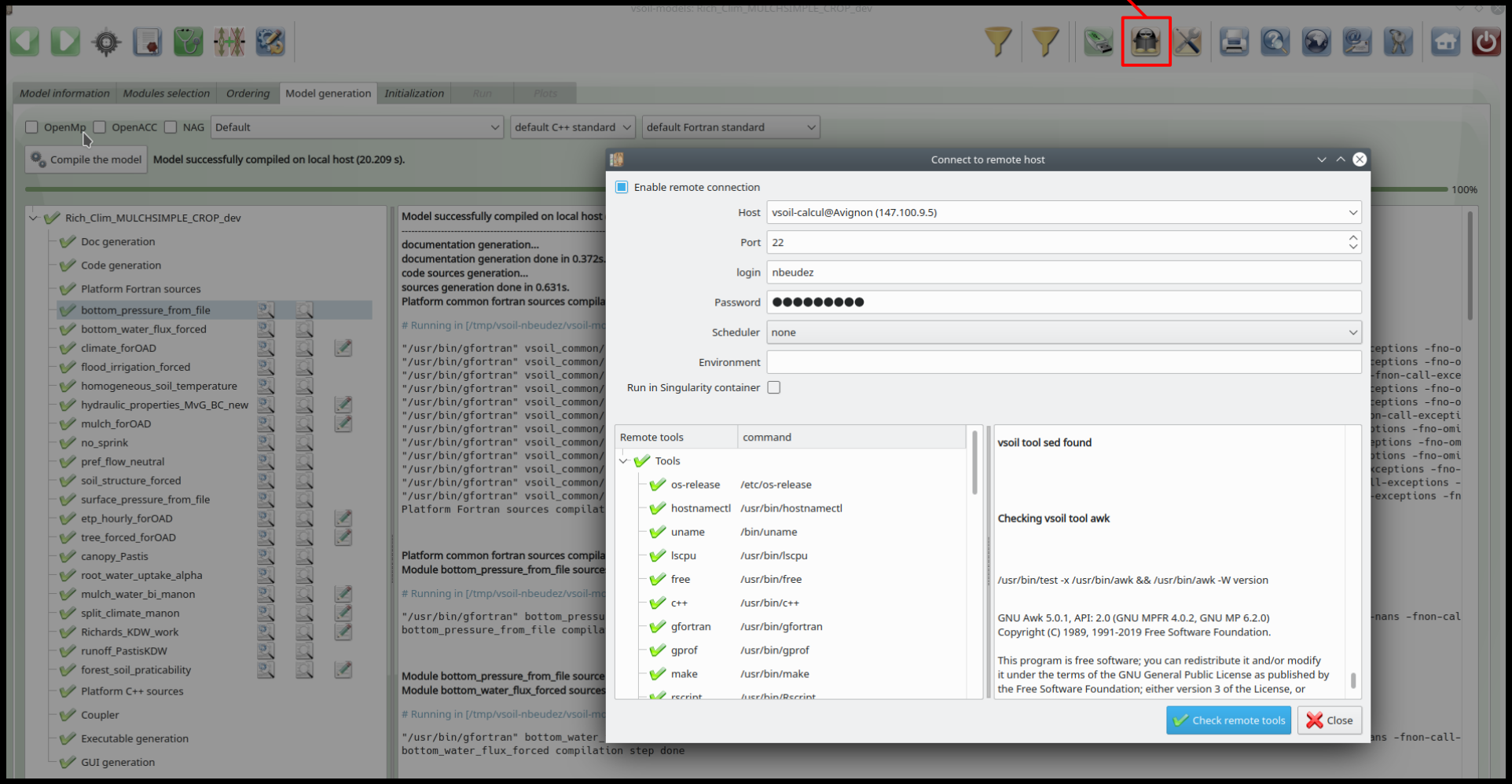
license and charter

Advantages of VSoil (1/3)

1) Ability to **run calculations** on **remote** servers:

- « vsoil-calcul » Linux server: Ubuntu 22.04, 56 cores, RAM 92 Go;
- compatible clusters.

activation of remote connection



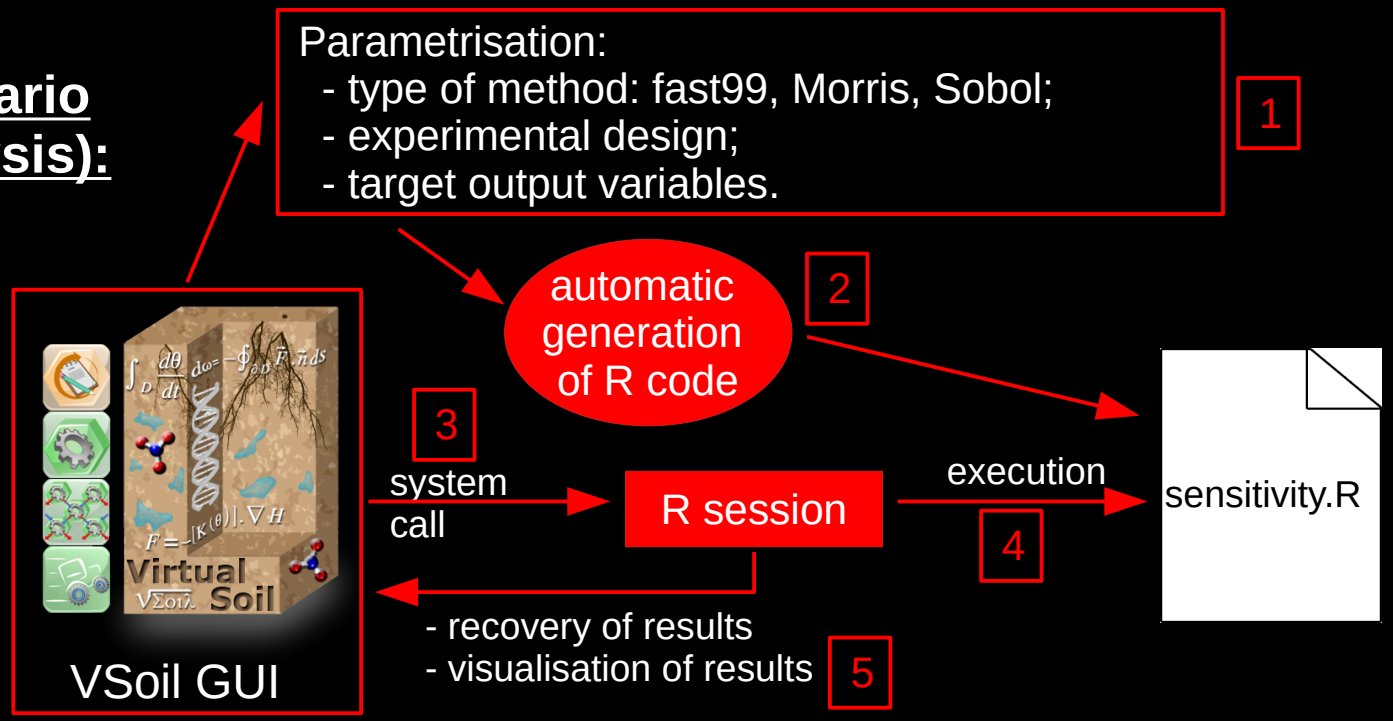
Advantages of VSoil (2/3)

2) **Model exploration** tools: VSoil models interfaced to dedicated **R packages**

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

⇒ different 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*).

Example of scenario (sensitivity analysis):



Advantages of VSoil (3/3)

3) Connections to **databases**

web-services

agro-climatic databases
(Climatik: Agroclim unit, Avignon)

soil databases (ACBB SOERE)

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 »)

Additional information

- **Technical characteristics**:

  - software versioning: Apache Subversion;
  - continuous integration tool: Jenkins;
  - source codes of software: C++ / Qt (~ 300,000 lines);
  - source codes of modules: C++ / Fortran (~ 3,000 lines);
  - naming of variables: OBOE ontology;
  - files format: XML (configuration files) and CSV (output files);
  - external libraries used in modules: Gimli (geophysics), LAPACK (numerical linear algebra);
  - ...

- Distribution strategy: 2-3 releases per year.

- Examples of collaborations:

  - INRAE: EMMAH (Avignon), CEREGE (Aix-en-Provence), LISAH (Montpellier), FARE (Reims);
  - ONF (Chambéry);
  - Ghent University, Gustave Eiffel University (Champs-sur-Marne), National Autonomous University of Mexico.

Examples of realisations using VSoil

1) **OC_VGEN** model: to simulate the soil carbon dynamics over long periods of time with the aim of moving towards a model of soil evolution in response to anthropogenic actions and climate change.
Saba Keyvansokouhi, Sophie Cornu (CEREGE, Aix-en-Provence), 2019

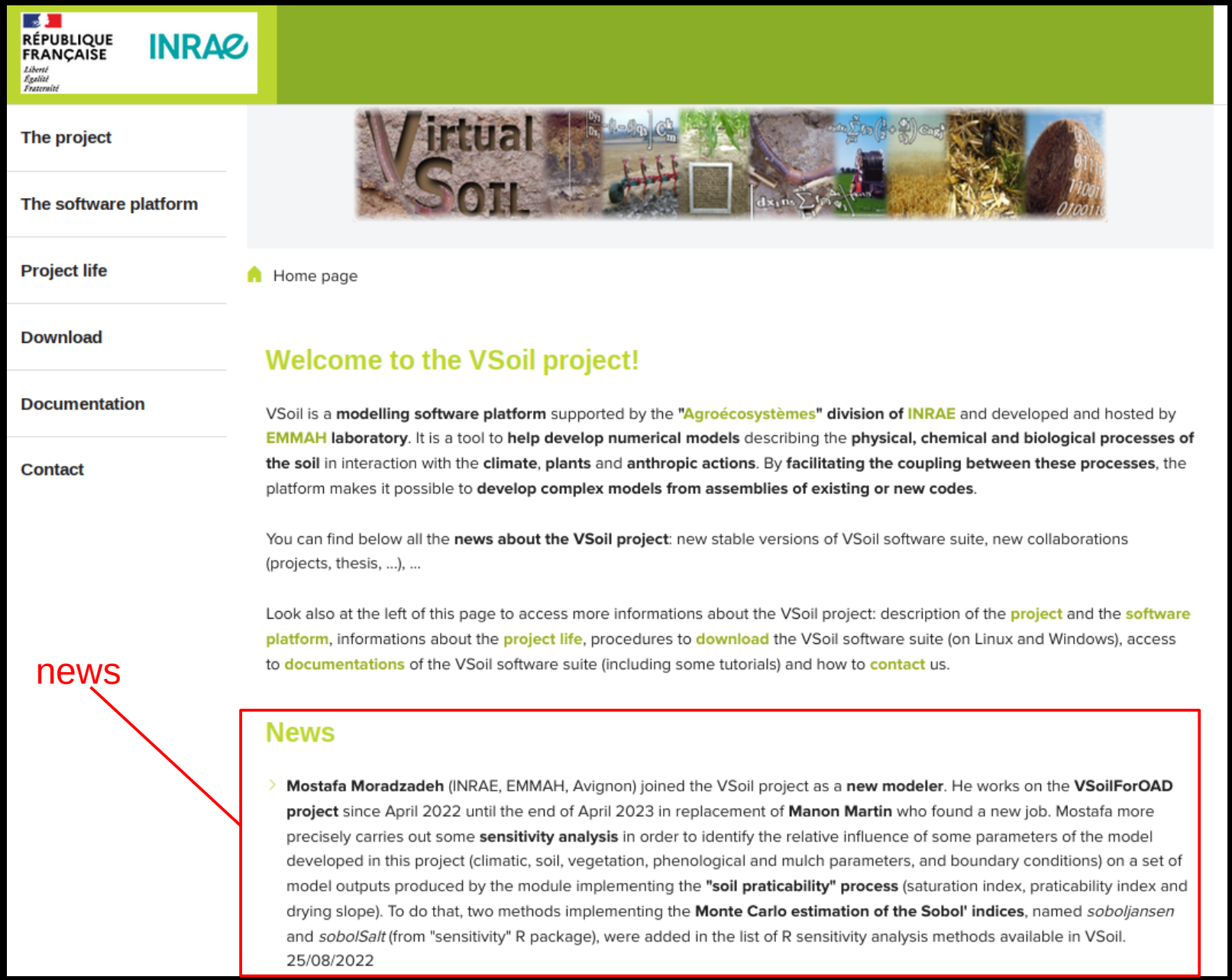
2) **ForestOAD** model: to predict the humidity of a layer of soil on the surface according to weather predictions in order to optimise forestry machine operations and avoid problems of soil degradation and compaction. This model will be used in a **decision-making tool for forestry professionals** (work in progress).

Manon Martin and Mostafa Moradzadeh (EMMAH, Avignon), Emma Schmitt (ONF, Chambéry) since 2016

3) **MIPP (2015-2017)** and **RIPP-Viti (since 2020)** projects: modelling of pesticide fate at the landscape scale to aid decision making.
⇒ **Communication** between:
- **OpenFLUID**: works on transfers at the level of the catchment area;
- **VSoil**: builds a local model;
- **FIDES**: simulates the air transport of molecules.

Resources (1/3)

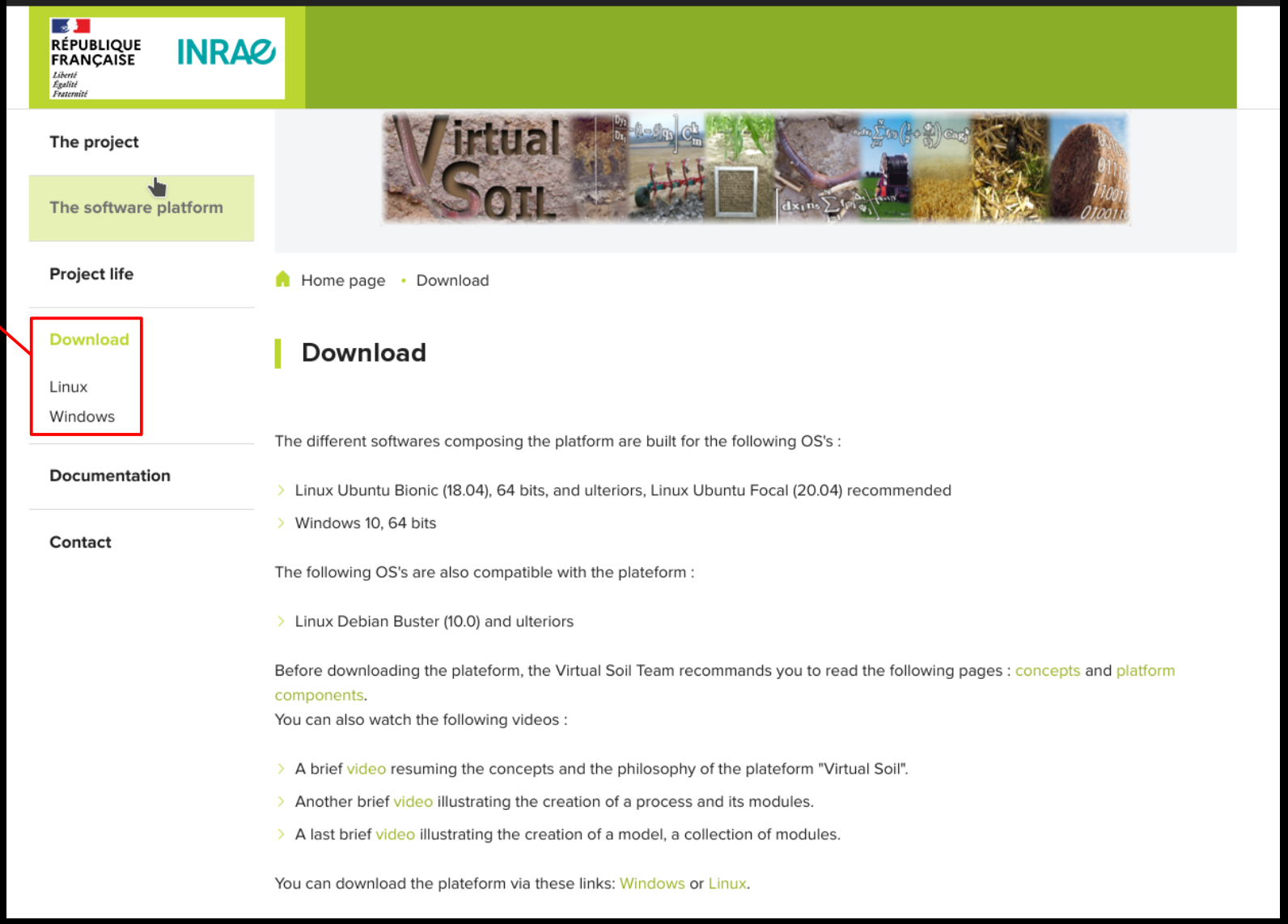
Website: https://vsoil.hub.inrae.fr/



Resources (2/3)

Website: https://www6.inrae.fr/vsoil/

download



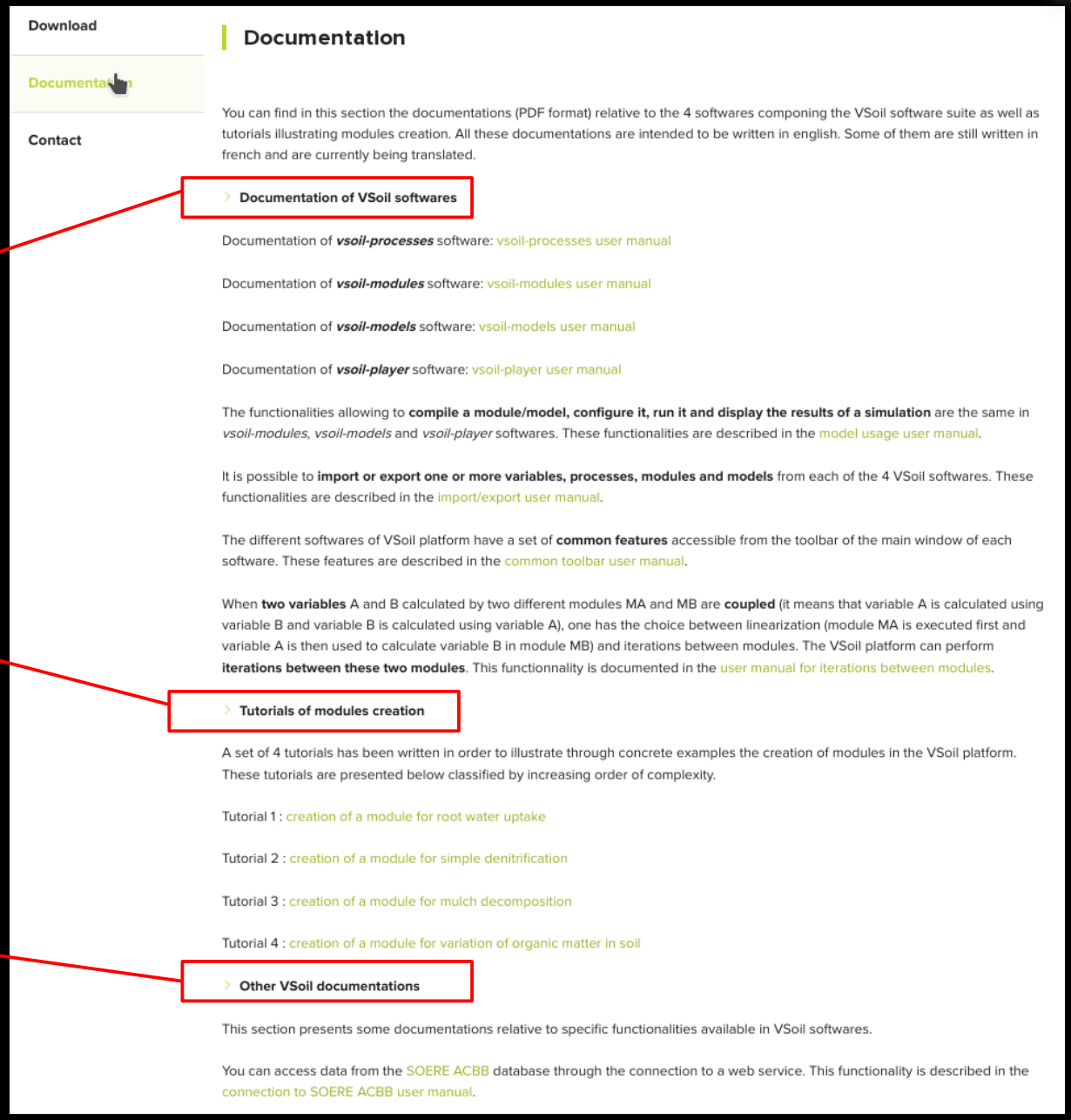
Resources (3/3)

Website: https://www6.inrae.fr/vsoil/

documentations of the different softwares:
- vsoil-processes
- vsoil-modules
- vsoil-models
- vsoil-player

tutorials for creating modules

other documentations: connection to databases



The VSoil team

Team members:

- scientific team:

Stéphane Ruy
(research fellow – scientific leader of the project)

Nicolas Beudez
(design engineer – scientific computing)

- development team:

Nicolas Moitrier
(research engineer – IT project manager)

Nathalie Moitrier
(design engineer – software engineering)

Cédric Nouguier
(design engineer – software engineering)

To contact us:

- vsoil@inrae.fr → scientific team
  vsoil-support@inrae.fr → development team

- Discord server

Thank you for your attention