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Modelling ¹⁴C transfer in terrestrial environments in response to chronic and accidental ¹⁴C releases

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Context & objective

Concern about the quantity of carbon-14 (¹⁴C) released for several decades from nuclear facilities has prompted several modelling approaches of ¹⁴C behaviour in the environment. The TOCATTA model aims at estimating ¹⁴C (and ³H) transfers in terrestrial ecosystems exposed to atmospheric ¹⁴C (and ³H) releases from nuclear facilities under normal operating or accidental conditions. The model belongs to the larger framework of the SYMBIOSE modelling and simulation platform that aims at assessing the fate and transport of a wide range of radionuclides in various environmental systems, and their impact on humans and/or biota. In this context, the conceptual and mathematical modelling in TOCATTA have been designed to be relatively simple, minimizing the number of compartments and input parameters required, for being used in an operational mode.

Model assumptions

The TOCATTA model has the following main characteristics:

- Based on a **daily time step**, and mainly driven by daily atmospheric ¹⁴CO₂ concentration and monthly meteorological data.
- Based on the assumption of an **isotopic equilibrium** between the net primary productivity flux assimilated by vegetation and the surrounding air at each time step of the simulation (e.g. 1 day); each step corresponding to a given period of time according to which atmospheric ¹⁴C in air was assumed to be constant.
- Implemented in the **conceptual** and **mathematic** frameworks of the SYMBIOSE modelling platform, i.e.:
 - Components and elementary processes of mass transfer defined in an Interaction Matrix
 - First-order differential equations defined for time-varying release conditions, expressing conservation of radionuclide mass activities for each component of the conceptual model. The change over time in the activity A_i or concentration [C]_i in a given pool or component i can be generally expressed as:

$$\frac{dA_i}{dt} = \frac{d\{\chi_i[C]_i\}}{dt} = \sum_{\substack{p \\ \text{input}}} TC_{j,k}^p - \sum_{\substack{p \\ \text{output}}} TC_{k,l}^p$$

$TC_{i,j}^p$ = the activity fluxes (e.g. mol.m⁻² s⁻¹) transferring from the component i to the component j via the effect of the processes p.

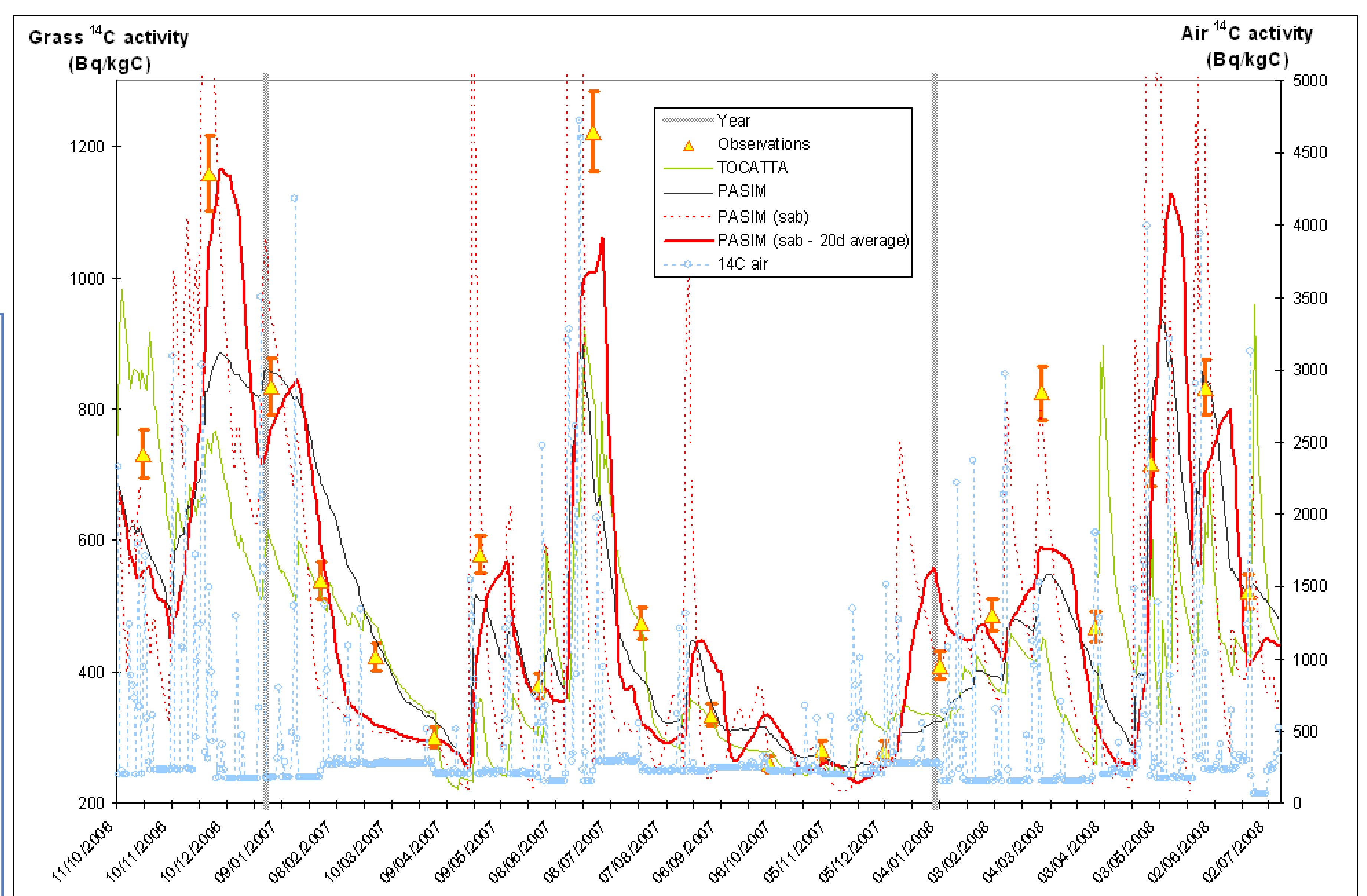
χ_i = plant dry density, derived from **time-dependant predefined growth curves** or **experimental data**

- Parameterized for various types of agricultural plants according to categories defined in SYMBIOSE (see poster 713: Gonze et al.): **annual crops**, **vegetable crops** and **pasture grass**. Two categories of soils were also considered by default: sandy soil and clay soil.
- Does not account for local meteorological conditions (e.g. light, temperature) or plant physiological parameters either (e.g. water and nutrient status, leaf photosynthetic characteristics)
- Does not take into account the day / night cycle of the plant physiological behaviour (photosynthetic uptake and respiratory loss)

Which model is the more suitable for representing ¹⁴C measurements in grassland near the AREVA-NC La Hague reprocessing plant ?

The TOCATTA model was tested against *in situ* data of ¹⁴C activities measured on a grassland ecosystem located 2 km downwind of the AREVA NC La Hague reprocessing plant between 2006 and 2009 (see methodology and experimental protocol in poster 632: Maro *et al.*)

- The model **is not sufficiently accurate** to reproduce the observed **month-to-month variability** and **is not suitable** to simulate **day-to-day variability** in grass ¹⁴C activity following intermittent releases from the AREVA NC that may occur indifferently either the day or night
- ➔ Hence the necessity to use an **hourly time step model** of ¹⁴C transfer – such as **PASIM** recently developed for radiocarbon - based more thoroughly on knowledge issued from plant physiology, soil science and local meteorology.
- ➔ The PASIM model [Riedo *et al.*, 1998 ;Vuichard *et al.*] :
 - a process-oriented pasture model simulating grassland C and N cycling, based on a **mechanistic** understanding of nutrient cycling between atmosphere, plant and soil
 - Simulates the ¹⁴C activity in two different compartments of the plant : the **shoot biomass** (i.e. substrate + structural) and the **substrate** only (i.e. the sab)
 - The sab ¹⁴C activity is highly variable and, in some points, closer to the observed variability than the ¹⁴C activity of the shoot biomass
 - The averaged sab ¹⁴C activity can be regarded as a **mean turnover time** – from the old, ageing structural dry matter to be gradually replaced by structural “fresh” matter
 - Both related curves, i.e. the shoot biomass ¹⁴C activity given by PASIM and the **moving average of the sab ¹⁴C activity**, can be considered a mean to represent the grass ¹⁴C activity
 - The grass ¹⁴C activity resulting from a **20-days moving average** of the sab ¹⁴C activity performs very well compared with observations, in particular for the peak in June 2007.



Conclusion & perspectives

- The TOCATTA model has voluntarily been designed to be simple enough to be used in an operational mode for environmental survey around nuclear facilities. However, it fails to represent the dynamics of ¹⁴C exchange at a high temporal resolution, showing smoother and less variable curves than what was observed. Consequently, it is not adapted to single (accidental) or intermittent releases such as those recorded by AREVA NRP.
- PASIM shows some interesting features to represent these dynamics, but is too complex for being used in an operational mode.
- Future work will focus on the implement of some key physiological processes of PASIM and make it evolved towards a new model: **TOCASIM**. The challenge of combining the two model is:
 - ✓ To reproduce the grass ¹⁴C activity as **realistic** as does the moving average of PASIM sab ¹⁴C activity,
 - ✓ To keep TOCASIM simple enough to be used in an **operational mode**, and in the future, maybe replace TOCATTA in the SYMBIOSE simulation platform.