Modelling and validation of tritium uptake, re-emission and OBT formation in tomato and potato plants at CRL

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September 8, 2010, Aix-en-Provence

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Objective

Modelling of airborne tritium in **plants** with emphasis on partitioning between organically bound tritium (OBT) and tissue free water tritium (HTO).

Issue

Long term models consider Plant on SA grounds (OBT ~ HTO ~ Air HTO), while **OBT/HTO ratios** collected in numerous experiments span the range of 0.2-40.0 and are rarely seen = 1.0 (as SA concept would suggest).

Predictions of short-term (dynamical) models start scattering far from observations in a **long term**.

Uncertainties in modelling of Plant compartment directly affect total tritium dose.

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* IAEA EMRAS I, Tritium WG, S-Scenario

Terrestrial Tritium Transfer: Key reasons for uncertainly

- Assumptions behind modelling of HTO re-emission from plant and retained amount of HTO are not fully understood;

- Theory of OBT formation in plants and its validation is incomplete;

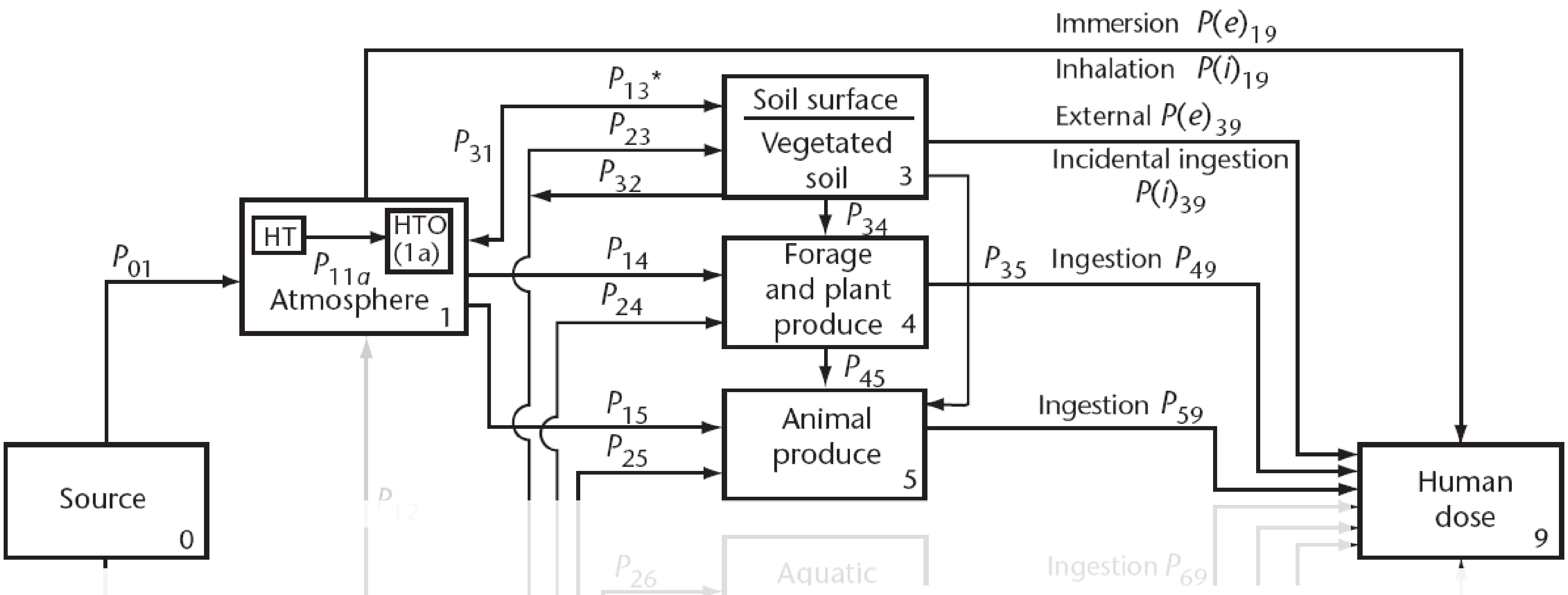
- Fractionation of OBT into exchangeable (like HTO) and non-exchangeable (like carbon) forms is important and needs more research;

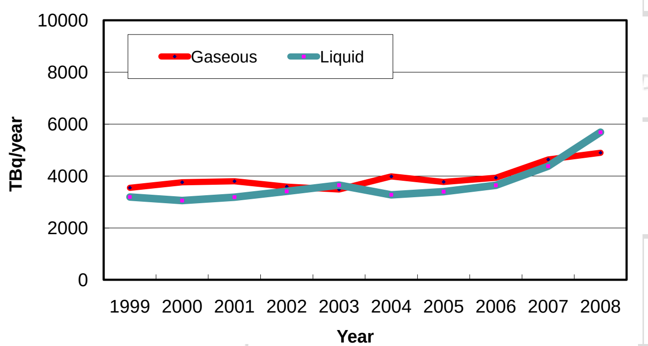
- Further OBT translocation via roots and decomposition both in roots and within soil in the first place) is insufficiently studied.

CANADIAN STANDARDS ASSOCIATION

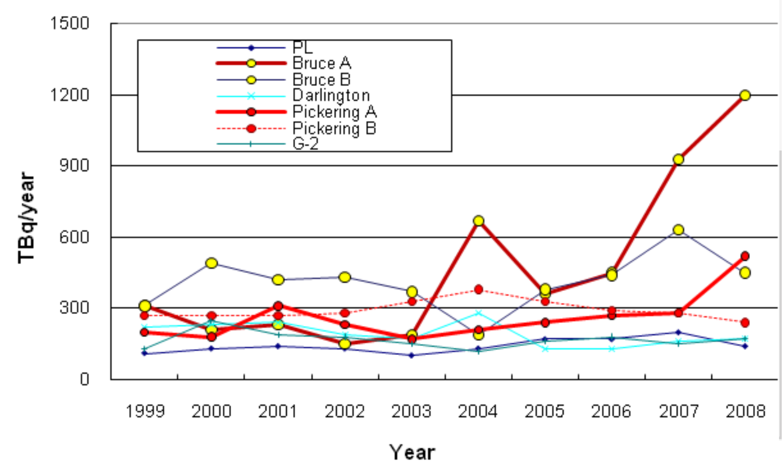
Tritium Pathways (this study)

N288.1-08





Source: CNSC



Tritium Pathways (this study)

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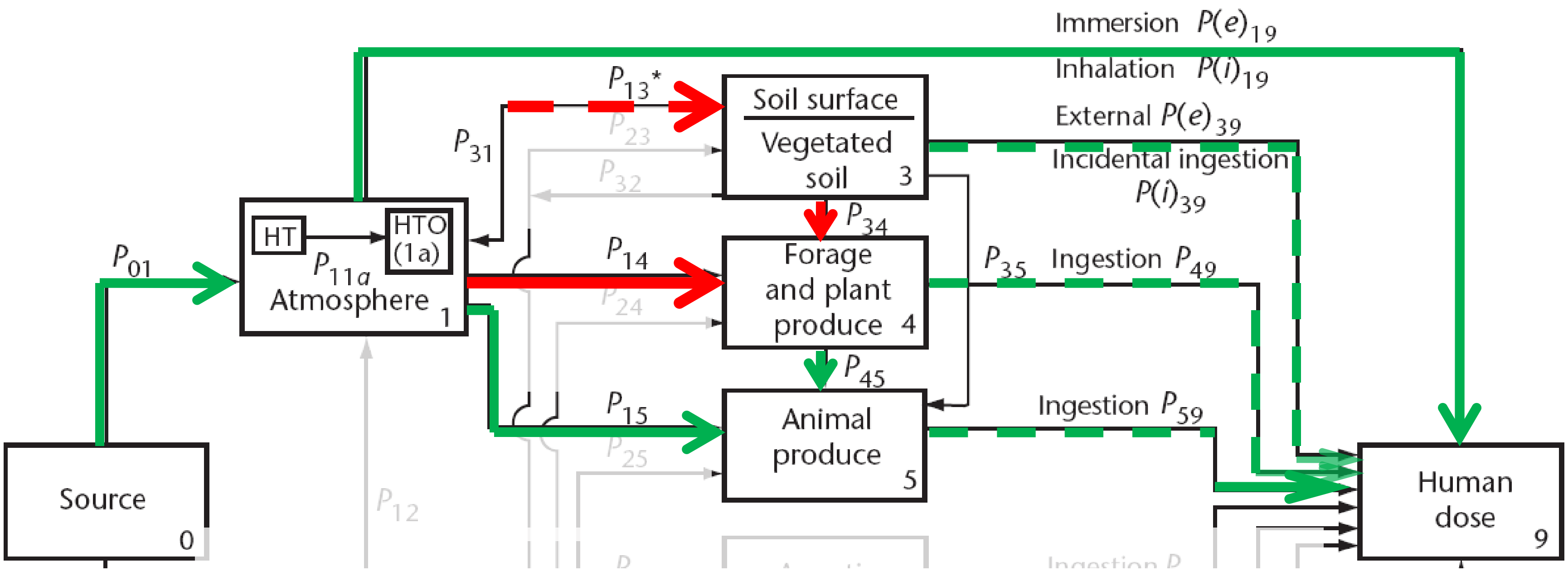
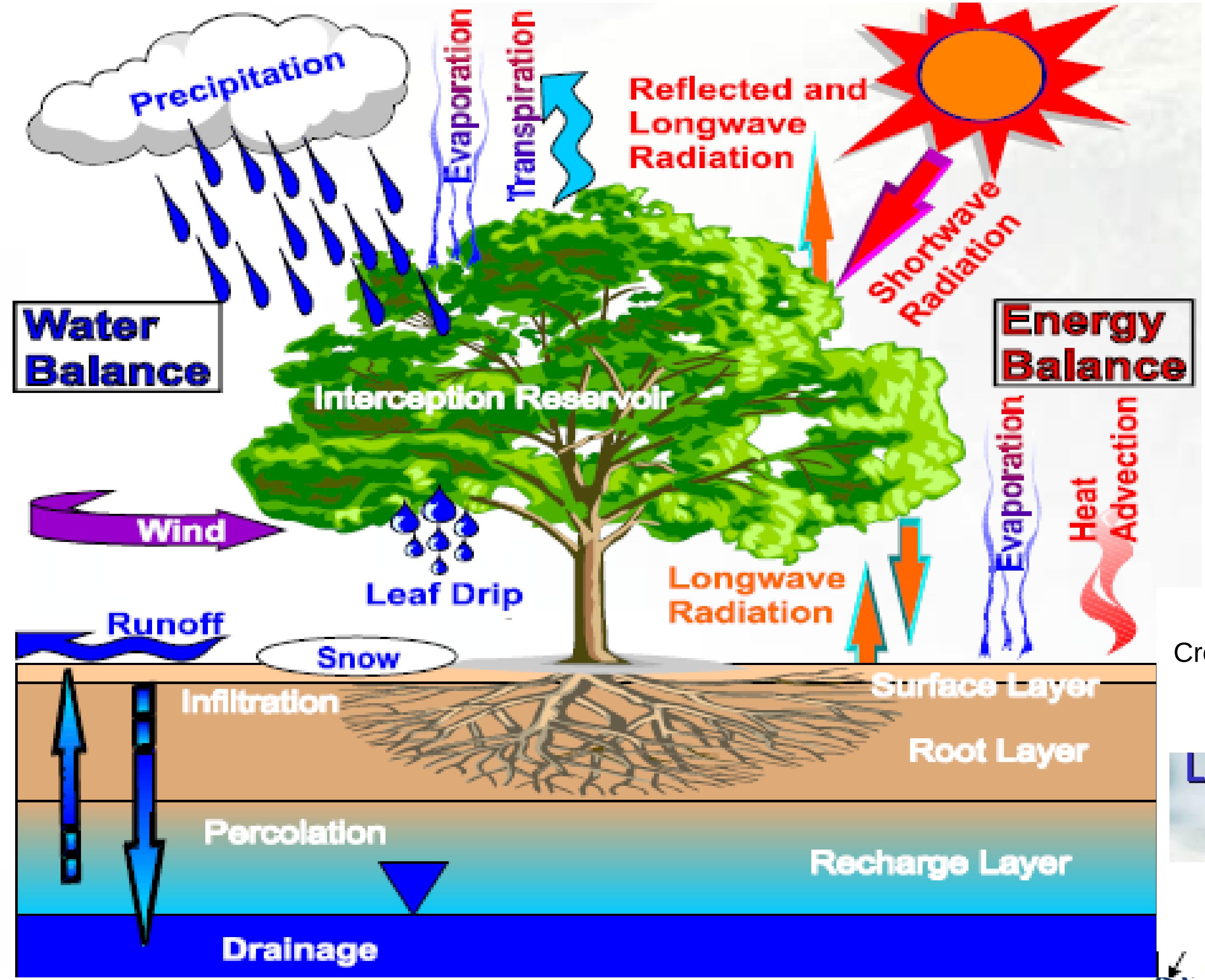


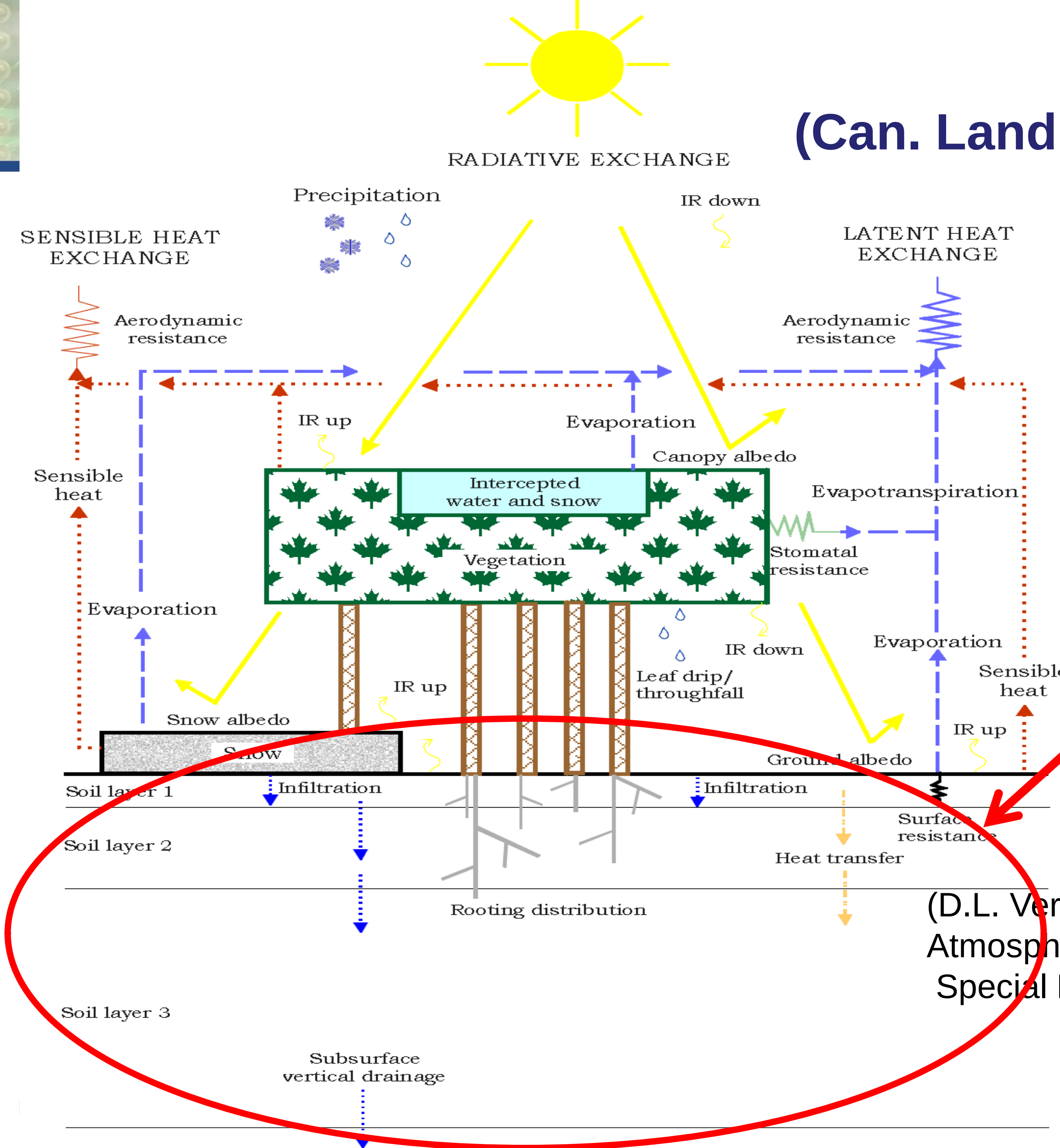
Tritium Pathway via Plant Water and its Ambient Drivers (modelling)



Credits: http://crew.iges.org

CLASS

(Can. Land Surface Scheme)



2000 ~2007

(D.L. Verseghy et al.
Atmosphere-Ocean, V38, N1, 2000
Special Issue, 269 p.)

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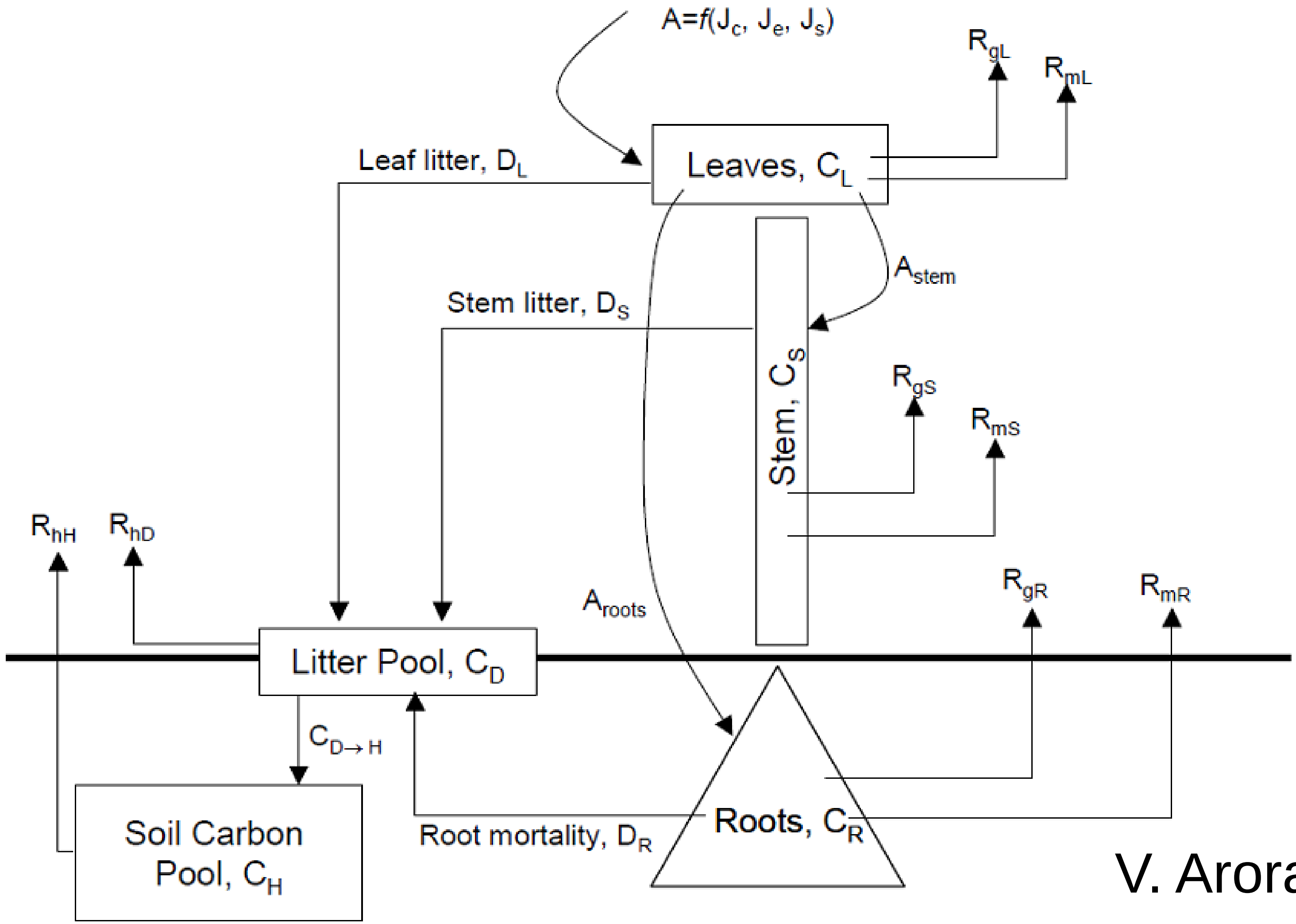
CTEM
(Can. Terrestrial Ecosystem Model)



V. Arora, 2007

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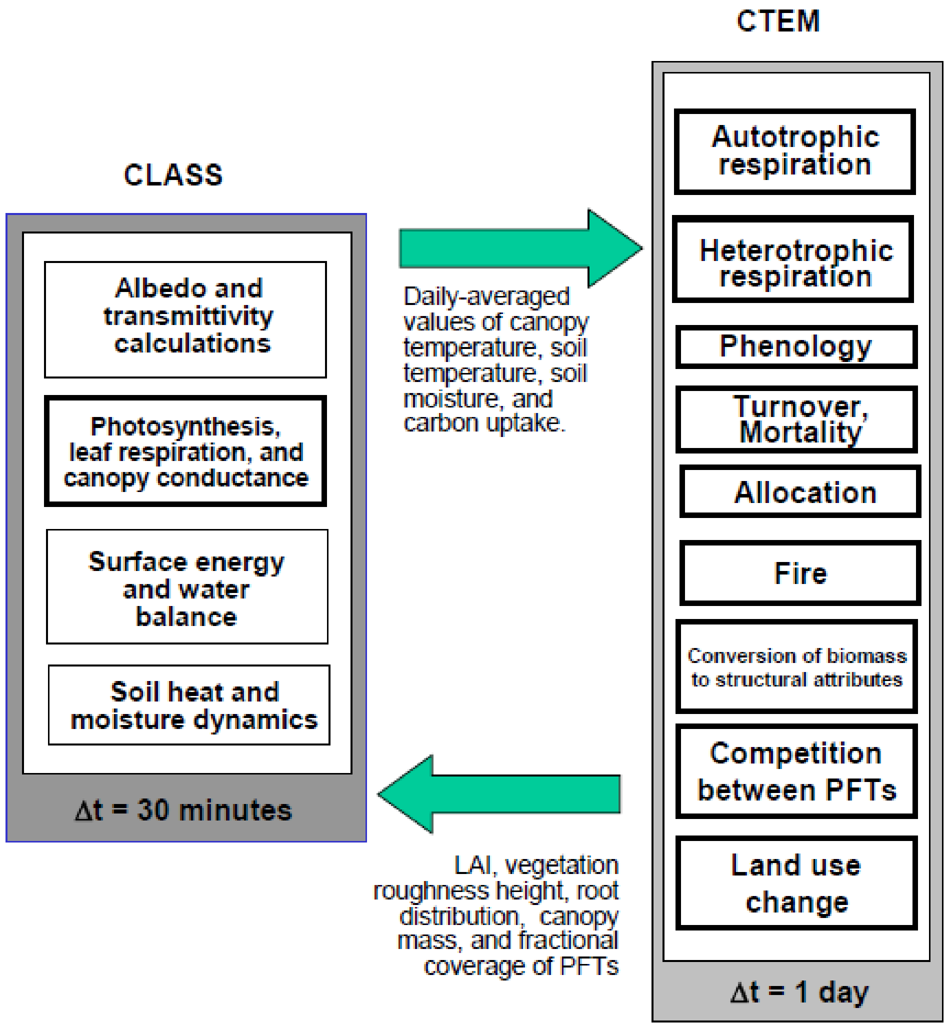
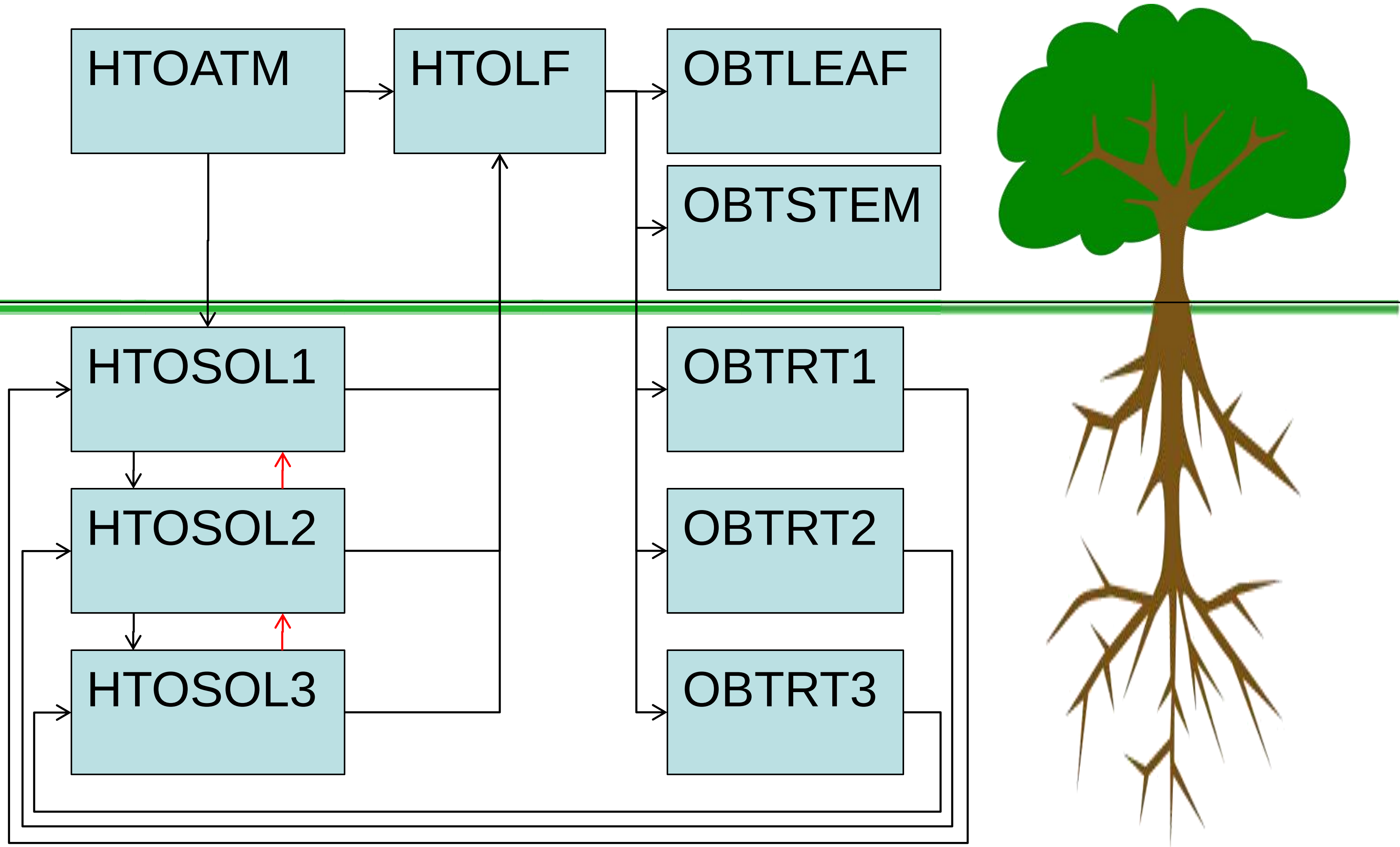
CTEM+CLASS



Source: CTEM manual v1.1

Tritium Translocation in CTEM+CLASS framework



AECL Model

Diffusion (V_{ex}), C_{atm} → **Plant tritium:** C_{leaf}, $\boldsymbol{C}_{OBT}$ → Diffusion (V_{ex}), C_{leaf}

Advection $(\boldsymbol{E})$, C_{soil} → **Plant tritium:** C_{leaf}, $\boldsymbol{C}_{OBT}$ → Advection $(\boldsymbol{E})$, C_{leaf}

$$dC_{leaf}/dt = \rho_w M_{leaf}^{-1}(V_{ex}(C_{atm} - C_{leaf}) + \boldsymbol{E}(C_{soil} - C_{leaf})) \quad (1)$$

$$d(M\boldsymbol{C}_{OBT})/dt = ID_p \, dM/dt \, C_{leaf} \quad (2)$$

$$C_{soil} = \gamma \, \mathbf{C}_{atm}$$

C_{atm} is the HTO concentration in the atmospheric moisture (Bq/L),
$\mathbf{C}_{atm}$ is the weighted time-average of atmospheric HTO concentration (Bq/L),
C_{leaf} is the HTO concentration in the plant water in leaf (Bq/L),
M is the whole plant dry matter water equivalent (d.m.w.e. kg/m^2),
M_{leaf} is the mass of a leaf part of the plant per surface area, fresh water equivalent (f.w.e., kg/m^2),
V_{ex} is exchange velocity in units converted to atmospheric water flux similar to that of ET (mm/s),
C_{soil} is the HTO concentration in the soil moisture (Bq/L),
E denotes ET (mm/s) and ρ_w is the water density; ID_p =0.8.

AECL Model

Diffusion (V_{ex}), C_{atm} → **Plant tritium** (C_{leaf}, $\boldsymbol{C}_{OBT}$) → Diffusion (V_{ex}), C_{leaf}

Advection $(\boldsymbol{E})$, C_{soil} → **Plant tritium** (C_{leaf}, $\boldsymbol{C}_{OBT}$) → Advection $(\boldsymbol{E})$, C_{leaf}

$$dC_{leaf}/dt = \rho_w M_{leaf}^{-1}(V_{ex}(C_{atm} - C_{leaf}) + \boldsymbol{E}(C_{soil} - C_{leaf})) \quad (1)$$

$$d(M\boldsymbol{C}_{OBT})/dt = ID_p \, dM/dt \, C_{leaf} \quad (2)$$

ETMOD

Added to ETMOD formulation: $(- \boldsymbol{E}C_{leaf})$

Off-line defined values:

V_{ex}, $\boldsymbol{E}$, M, C_{atm}, C_{soil}

AECL Model

The HTO concentration in the leaf is determined by tritium diffusion from the air and mass transfer from the soil. These two processes are parameterized separately via V_{ex} and $\boldsymbol{E}$

Aggregation of $\mathbf{C}_{atm}$ driving C_{soil} is based on deposition (dry and wet) and "reference crop" evapotranspiration $\boldsymbol{E}$ in modified PM formulation, which is based on surface $\boldsymbol{T}$ and $\Delta \boldsymbol{T}_s$ in soil.

$$C_{Soil}(t) = {}_0\int^t [\alpha_2 \exp(\alpha_1 \tau) C_{atm}(\tau)] d\tau \;/ \exp(\alpha_1 t),$$

$$\alpha_1(t) = \rho_w M_s^{-1}(t) E(t), \alpha_2(t) = M_s^{-1}(t)\, \rho_w V^s_{ex}(t)$$

$$E = a_1(R_n - G) + a_2\, 900/(T + 275)\, \boldsymbol{u} D$$

$$a_1 = \Delta/(\Delta+\gamma*), \quad \gamma* = \gamma\,(1 + 0.33\, \boldsymbol{u}), \quad a_2 = \gamma\,/(\Delta+\gamma*)$$

$G = 0.38c\,(\Delta T_s)/\lambda$ $\quad \Delta T_s$ as per (Killey, 1996; Wildsmith, 1976)

HTO Night Exposure Experiments

- **Germany**, 1996. Wheat, open field + exposure chamber
- **Korea**,1998. Rice pots, exposure chamber
- **Canada**

  - CRL, Perch Lake 2001. Tomato pots, open field

  - CRL, 2004. Tomato, Radish and Lettuce pots, exposure chamber

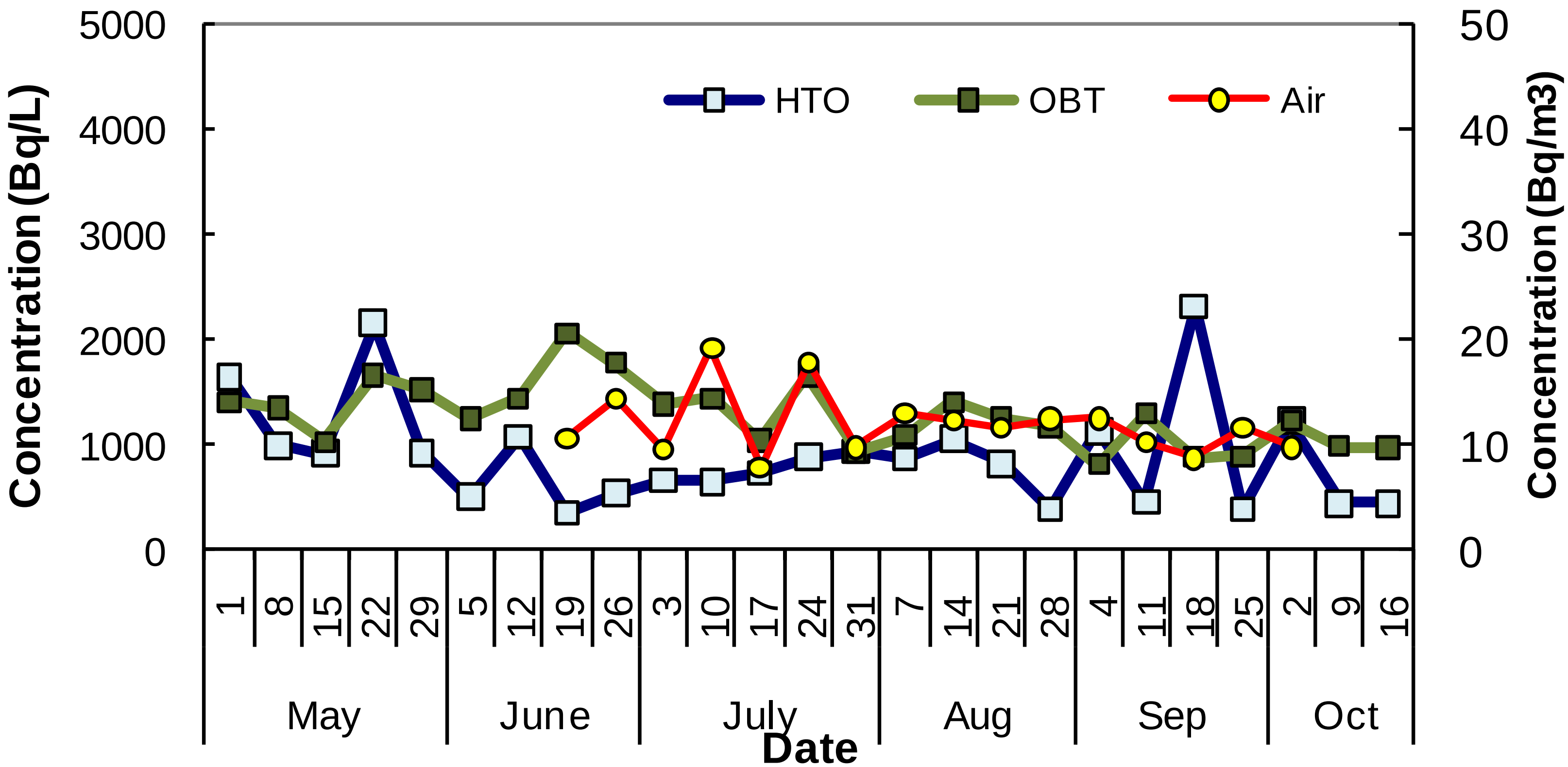
  - CRL, 2009. Tomato and potato, open field

CRL'2009 Details

Fig.1 Acid Rain Site dedicated to atmospheric uptake of tritium (tarp-covered clean soil)

Fig.2 Perch Lake Site dedicated to re-emission of tritium and its final retention in OBT form

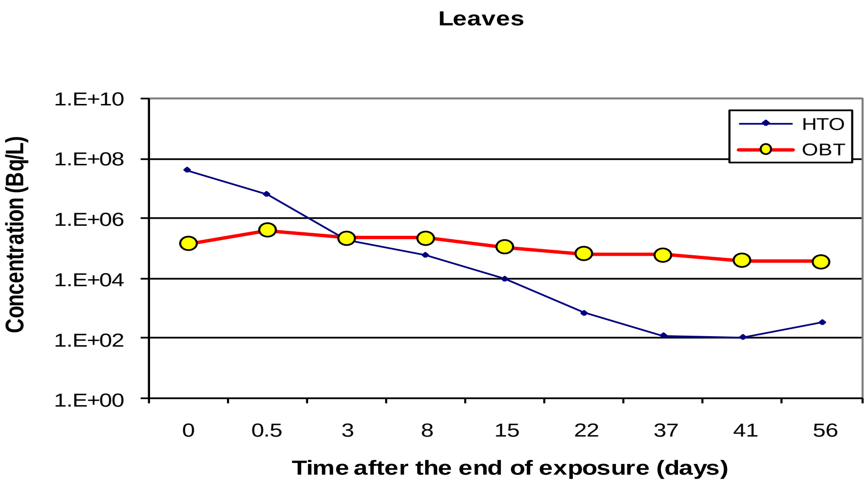
HTO and OBT Dynamics

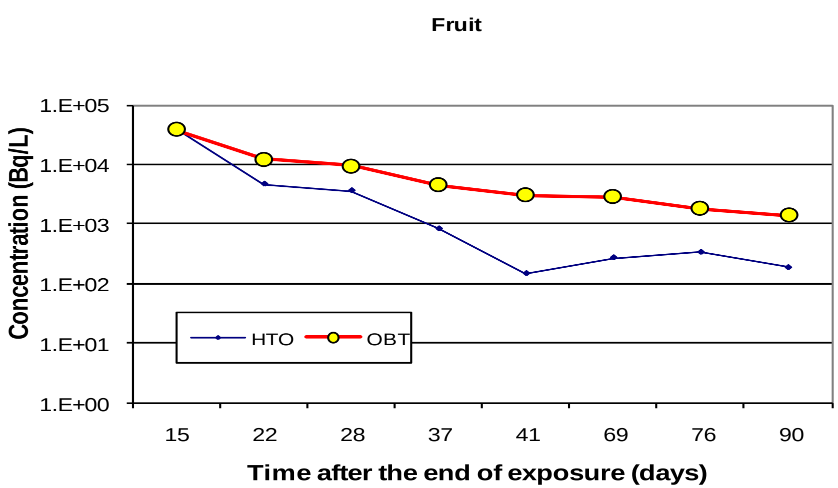


HTO and OBT measurements in tree leaves (B513):

Deviation from SA-based CSA N288.1 Tritium DRL procedure on all aggregation intervals

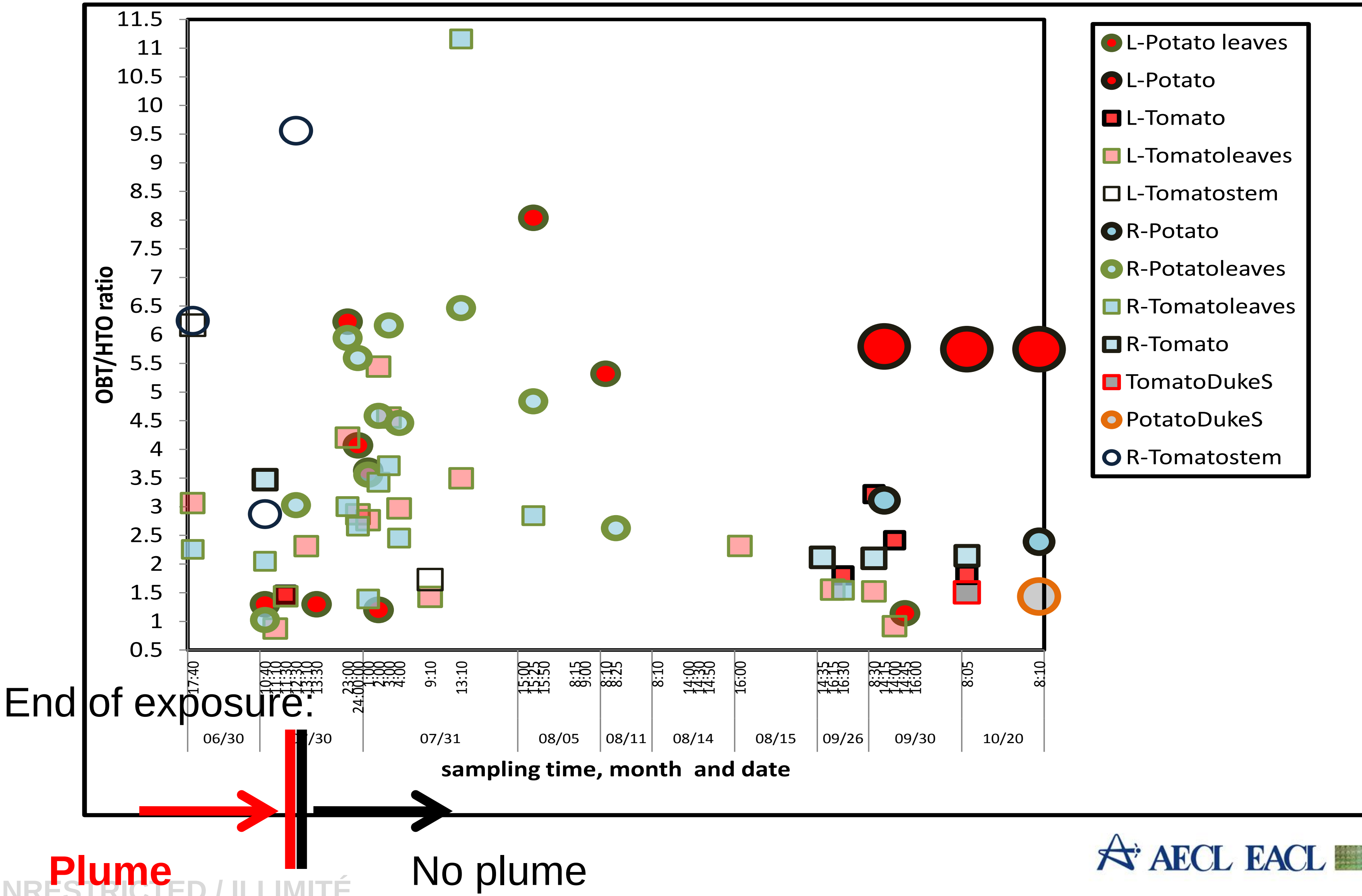
Available rates of HTO and OBT depuration





Vex for Simple Model has been has been measured using in-house observations of HTO and OBT dynamics.

High OBT/HTO ratio measured in parts of tomato and potato plants

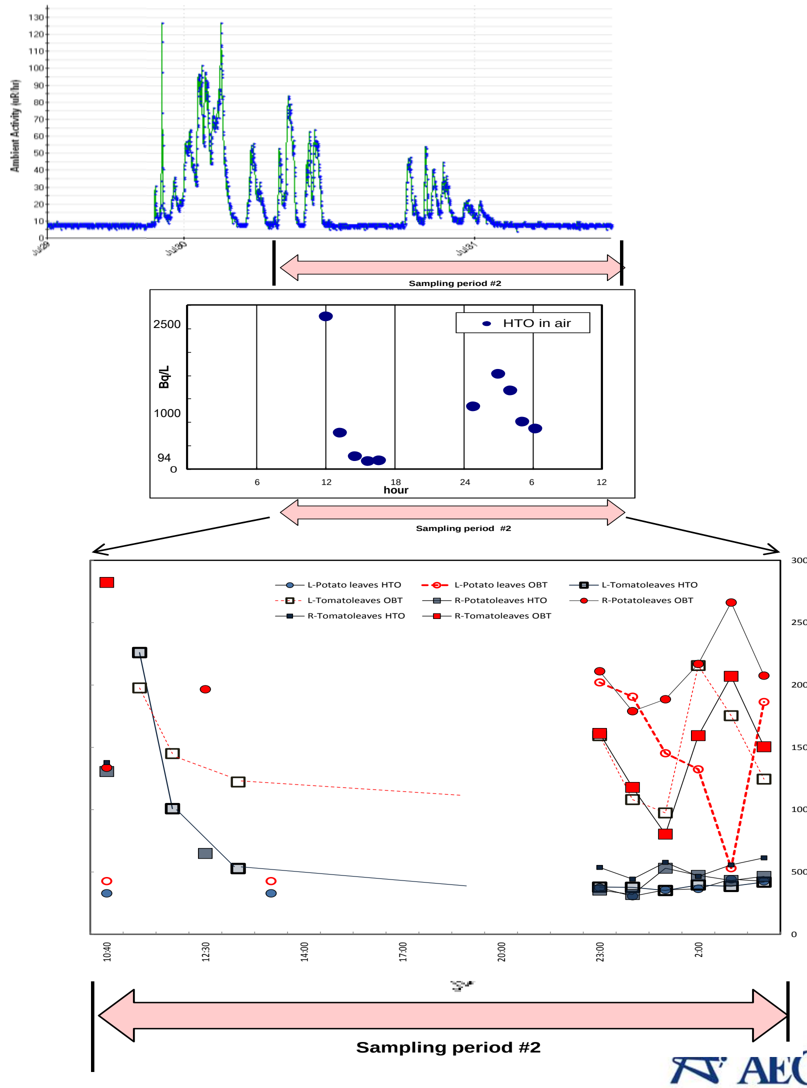


Sampling approach: Drivers synchronization

Gamma monitoring:

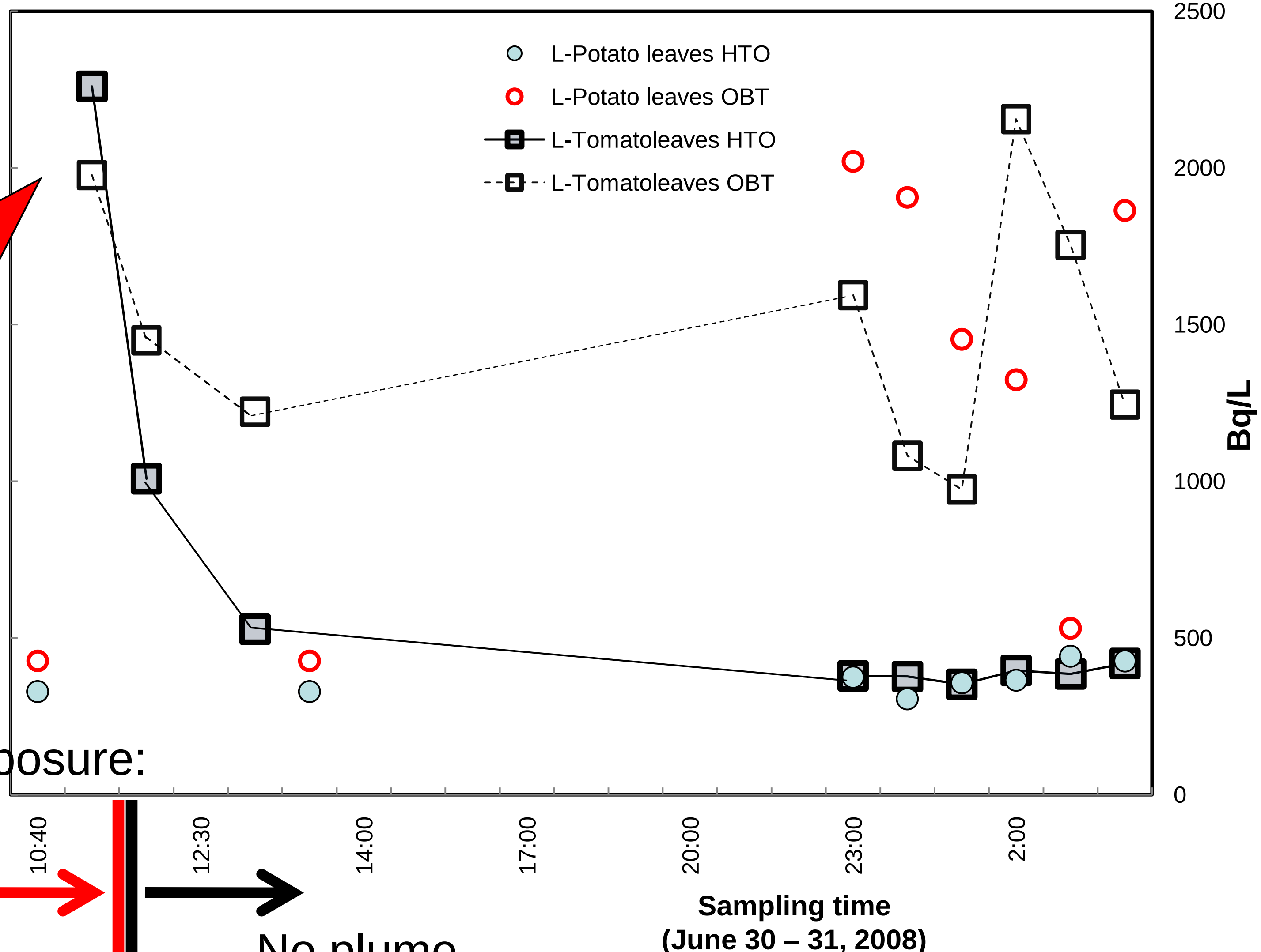
Air HTO active sampling (bubbler):

Collection and measuring HTO and OBT in plant tissues:



Is there a rapid OBT formation?

Could be an indication of rapid OBT formation

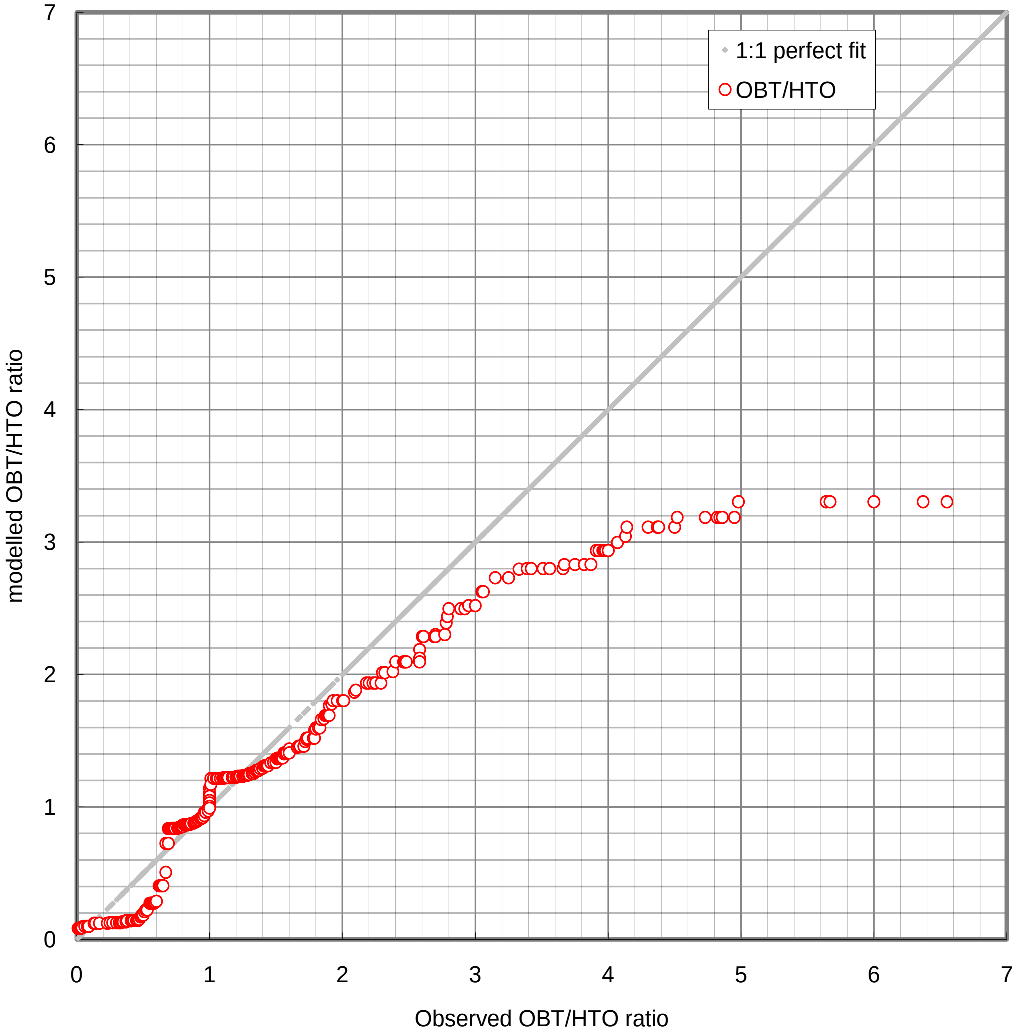


End of exposure:

Plume

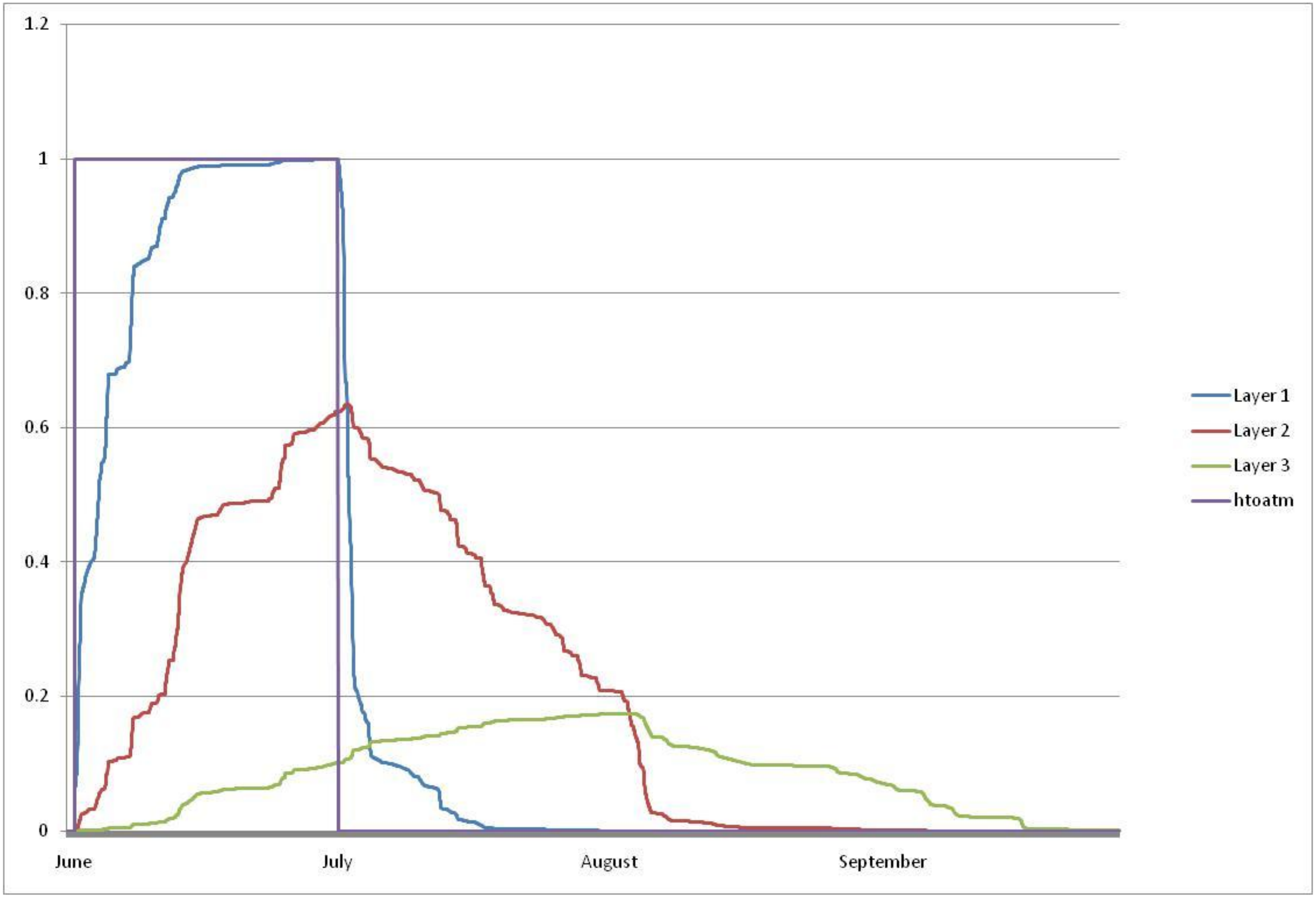
No plume

Validation of Simple Model using OBT/HTO ratios collected worldwide



model vs. ensemble of 1976-2005 field and laboratory measurements: QQ plot of ranked statistics

Approach to on-going verification of tritium translocation in CTEM+CLASS



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SUMMARY

• Model update by inclusion of ambient drivers into the Simple Plant Tritium Model (through E) works reasonably well – explains most of the range of observed OBT/HTO ratios.

•OBT is probably formed much more rapidly (~minutes) in plant, than it has been suggested before. Investigation of this possibility and general quantification of maintenance sugars with their decomposition in “dark” reactions require targeted experiments.

•Elaborate process-based models are sensitive to tritium parameterization – accuracy in parameters definition is required.

Future prospects

•Implement seasonal (dynamical) adjustments in the CSA N288.1-08 tritium procedures

•Complete simple OBT formation model

•Assess the role of Soil compartment

THANK YOU

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