Incorporation of Tritium Transport Processes into Atmosphere-soil-vegetation Model: SOLVEG

~HTO transport from atmosphere to bare soil~

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Outline of Study

Objectives

- Development of sophisticated land surface model including radionuclide (Tritium) transport processes
- Understand and predict behavior of radionuclide at land-surface by numerical experiment

Model development

- Step 1: Heat and water exchange processes
- Step 2: Canopy radiation and stomatal resistance → SOLVEG
- Step 3: CO_2 exchange processes → SOLVEG2

- EMRAS-II: Radionuclide transport processes (THO)

Description of model

Overview

Structure	One-dimensional multi-layer sub-models for atmosphere, soil, and vegetation. Scheme for radiation transmission in the canopy and CO_2 exchange processes.
Function	Simulation of water, heat, and CO_2 exchanges in the atmosphere-soil-vegetation system.
Objectives	Diurnal variation and seasonal change. Atmospheric surface layer, root zone soil, and vegetation canopy.

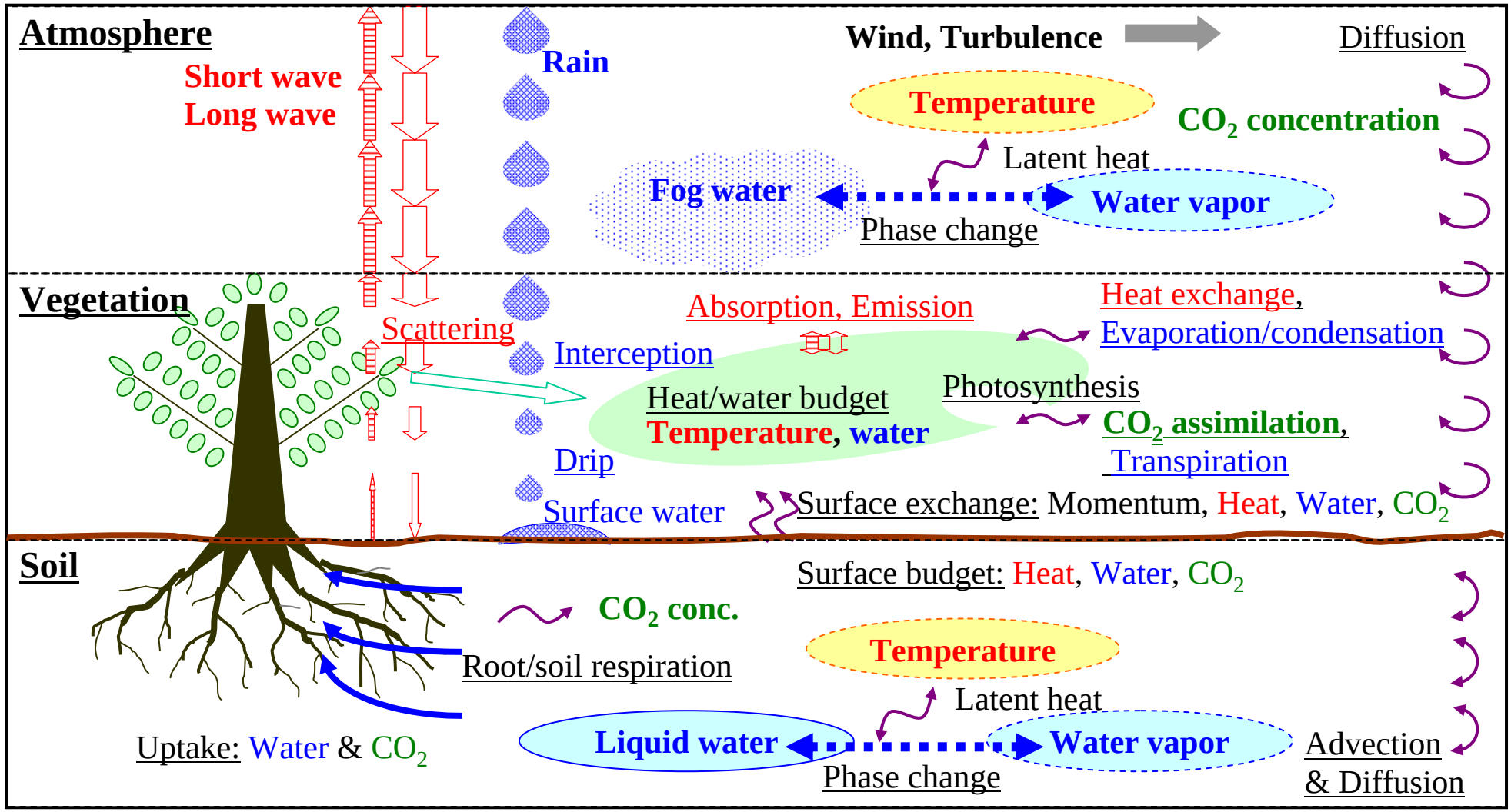
Variables

Atmosphere	Horizontal wind components (u, v) Specific humidity CO_2 concentration	Potential temperature Fog water Turbulence kinetic energy, length scale
Soil	Temperature Specific humidity of soil air	Volumetric water content CO_2 concentration
Vegetation	Leaf surface temperature Vertical liquid water flux in canopy	Leaf surface liquid water Leaf CO_2 concentration
Radiation	Down/upward solar radiation (direct and diffuse, visible and near-infrared) Down/upward long-wave radiation	

Physical processes

Physical processes are calculated at each layer of vertical multi-layer model

Bold: main var., Underlined: processes, Red: heat/rad., Blue: water, Green: CO_2



Basic equations (1): heat, water, momentum

Atmosphere Diffusion:

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial z} K_z \frac{\partial \phi}{\partial z} + F_\phi \qquad \phi = u, v, \theta, q_a, e, e\lambda, w_f$$

Source term

Boundary condition

Soil

Heat:

$$\frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z} K_T \frac{\partial T_s}{\partial z} + \frac{H_b}{C_s \rho_s} - \frac{C_w E_w}{C_s \rho_s} \frac{\partial T_s}{\partial z}$$

Evaporation/ condensation

Liquid water:

$$\frac{\partial \eta_w}{\partial t} = -\frac{1}{\rho_w}\left(\frac{\partial E_w}{\partial z} + E_t + E_b \right)$$

$$H_b = -lE_b$$

Water vapor:

$$\frac{\partial [(\eta_{ws} - \eta_w) q_s]}{\partial t} = \frac{\partial}{\partial z} D_w f_a(\eta_w) \frac{\partial q_s}{\partial z} + \frac{E_b}{\rho}$$

Transpiration

Vegetation

Heat budget:

$$R_c = H_c + lE_c + H_p \qquad E_c = E_d + E_s$$

Leaf water:

$$\frac{dw_d}{dt} = E_{\text{int}} - E_d + E_{cap} - P_d$$

Water flux:

$$\frac{dP_r}{dz} = a(E_{\text{int}} - P_d) + E_{pr} - E_{col}$$

Net radiation

Radiation

(Next slide)

Short wave: Downward and upward transfer

Direct (visible + near-infrared) + Diffuse (visible + near-infrared)

Long wave: Downward and upward transfer

Basic equations (2): radiation

Radiation scheme (coefficients based on Verstraete 1987, 1988)

Short: (direct)

⇩ (diffuse)

(visible)

(near-IR)

$$\frac{dS_d^{\downarrow}}{dz} = -(aF_{rd} + a'_w + A'_w)S_d^{\downarrow},$$

$$\frac{dS_s^{\downarrow}}{dz} = -[aF_{rs}(1-f_{sf}) + a'_w + A'_w]S_s^{\downarrow} + (aF_{rs}f_{sb} + A'_w)S_s^{\uparrow} + aF_{rd}f_{df}S_d^{\downarrow},$$

$$\frac{dS_s^{\uparrow}}{dz} = -[aF_{rs}(1-f_{sf}) + a'_w + A'_w]S_s^{\uparrow} + (aF_{rs}f_{sb} + A'_w)S_s^{\downarrow} + aF_{rd}f_{db}S_d^{\downarrow}.$$

Scattering

Leaf projection cf.: F_{rd}

Scattering cf.: f_{df} (forward), f_{db} (backward)

Depend on solar angle and leaf surface angle

Long wave:

$$\frac{dL^{\downarrow}}{dz} = -aF_{rs}[(1-f_{sf})L^{\downarrow} - f_{sb}L^{\uparrow} - \varepsilon_c\sigma T_c^4] + k_l w_l(L^{\downarrow} - \sigma T_a^4),$$

$$\frac{dL^{\uparrow}}{dz} = -aF_{rs}[(1-f_{sf})L^{\uparrow} - f_{sb}L^{\downarrow} - \varepsilon_c\sigma T_c^4] - k_l w_l(L^{\uparrow} - \sigma T_a^4).$$

Leaf projection cf.: F_{rs} Depend on leaf area density

Forward scattering cf.: f_{sf} Back scattering cf.: f_{sb}

└Depend on leaf surface angle┘

Basic equations (3): CO_2, stomata resistance

CO_2 assimilation (A_n): Farquhar et al. (1980)

$$A_n = \min(w_c, w_e, w_s) - R_d$$

w_c, w_e, w_s, R_d : Depend on PAR, leaf CO_2 conc., temperature

Stomatal resistance (r_s): Collatz et al. (1991, 1992)

$$\frac{1}{r_s} = g_s = m \frac{A_n}{c_s} \frac{e_s}{e_{sat}(T_v)} p_a + b$$

CO_2

***m* (constant), *b* (minimum conductance)** ⇒ measured parameter

c_s	CO_2 partial pressure at leaf surface
$e_s/e_{sat}(T_v)$	Relative humidity at leaf surface
p_a	Atmospheric pressure

2 options

Stomatal resistance (Jarvis scheme): BATS (Dickinson et al. 1993)

$$r_s = r_{s,\min} f_r f_s^{-1} f_m^{-1} f_t^{-1}$$

$r_{s,min}$ ⇒ measured parameter

No CO_2

f_r, f_s, f_m, f_t : Functions of PAR, soil water, humidity, temperature

Basic equations (4): soil CO_2

Soil CO_2 conservation: Simunek and Suarez (1993)

$$\frac{\partial}{\partial t} V_E c_a = \frac{\partial}{\partial z} D_E \frac{\partial c_a}{\partial z} - \frac{\partial}{\partial z} E_E^* c_a - E_t^* K_H RT c_a + S$$

Volume: $V_E = (\eta_{ws} - \eta_w) + K_H RT \eta_w$,

Diffusion: $D_E = (\eta_{ws} - \eta_w) D_a + K_H RT \eta_w D_w$,

Advection: $E_E^* = E_a^* + K_H RT E_w^*$,

⇒ Treatment of CO_2 in gas and aqueous phase together by Henry's Law: $c_w = K_H RT c_a$

c_a CO_2 conc. in soil air

η_w Volumetric water content

E_t^* Root uptake (transpiration)

S CO_2 source term (= soil: S_s + root: S_r)

$$S_s = S_{s0} f_s(z) f_s(\eta_w) f_s(T) f_s(c_a) f_s(t)$$

$$S_r = S_{r0} f_r(z) f_r(\eta_w) f_r(T) f_r(c_a) f_r(t)$$

Land surface model SOLVEG2

Water and CO_2 fluxes at grassland

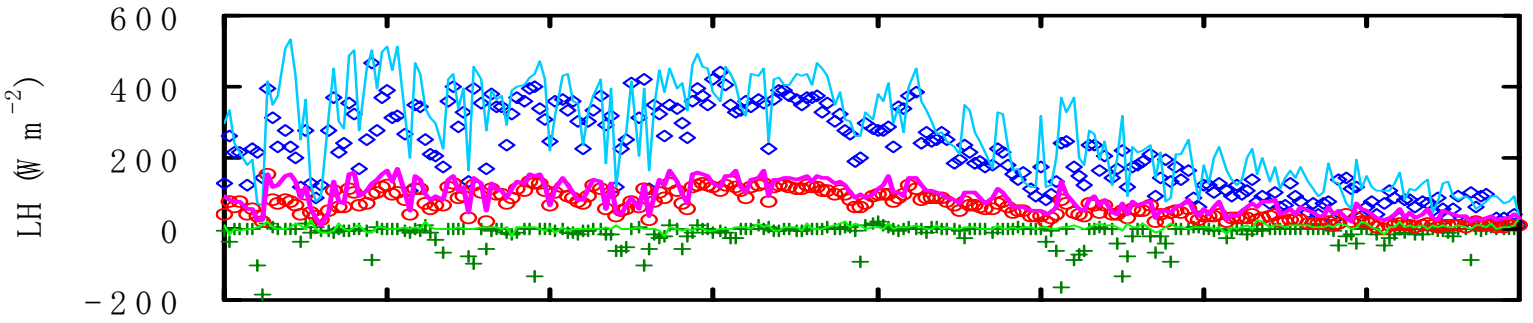
- **Good performance for water and CO_2 exchanges at grassland (AmeriFlux data)**
  Diurnal variation and seasonal change are well reproduced.
  → It can be applied for detailed simulation of ^{3}H and ^{14}C transport.

Observation
○: daily mean
◇: daily max
+: daily min

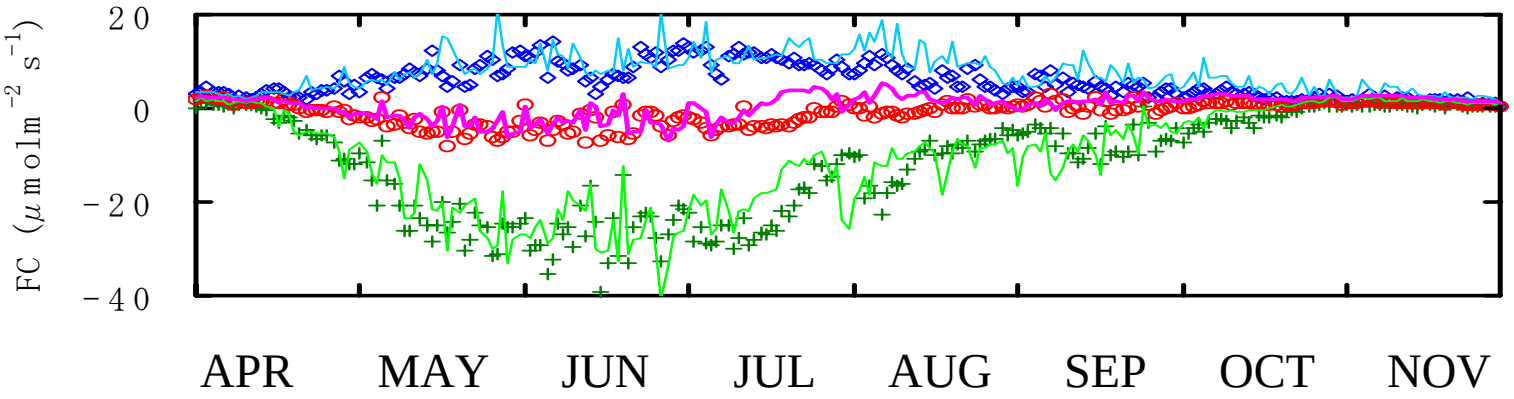
Calculation
—: daily mean
—: daily max
—: daily min

Upward positive

Latent heat (water vapor) flux



CO_2 flux



Incorporation of HTO transport processes

Concept

- Process based HTO transport model to simulate dynamic behavior of HTO in air-soil-plant system
- Explicit calculation of HTO transport in a similar way as water and vapor transport

Model development

- Step 1: transport in the atmosphere and bare soil (no decay)
  - In-soil transport by Yamazawa (2001) applied for BIOMASS Theme 3-F (rise of HTO from contaminated groundwater)
  - Atmospheric transport for HTO vapor (1-D diffusion eq.)
  - Test calculation using met. data of AmeriFlux (previous slide)
- Step 2: inclusion of plant uptake processes
- Step 3: OBT production and translocation

Land surface model SOLVEG2

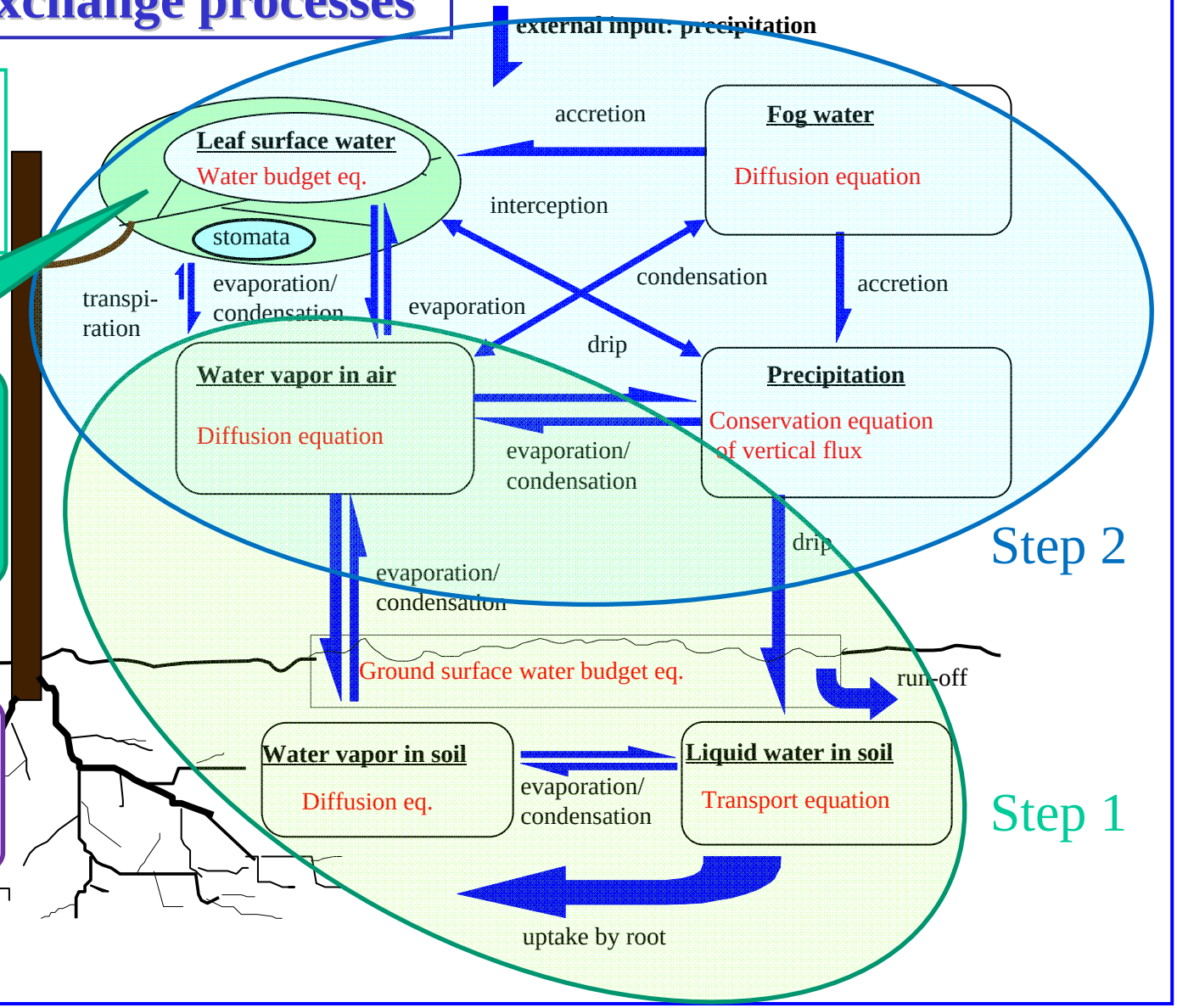
Incorporation of HTO transport processes

Water and vapor exchange processes

HTO transport process
Calculate HTO conc. for each variable of water

New variable:
Plant water
Water budget eq.
(root uptake - transpiration)

Step 3
OBT formation and translocation



Land surface model SOLVEG2

In-soil HTO transport processes

Soil HTO transport: Yamazawa (2001) applied for BIOMASS theme 3

Liquid phase:
$$\frac{\partial}{\partial t}\eta_w \chi_w = -\frac{1}{\rho_w}\frac{\partial}{\partial z}E_w \chi_w + \frac{\partial}{\partial z}\left(D_{Tw}\frac{\partial \chi_w}{\partial z}\right) - e_b$$

Gas phase:
$$\frac{\partial}{\partial t}\left[(\eta_{ws} - \eta_w)\chi_{sa}\right] = \frac{\partial}{\partial z}\left[D_{Ta} f_{sa}(\eta_w)\frac{\partial \chi_{sa}}{\partial z}\right] + e_b$$

+: evaporation
-: Condensation

Surface B.C.:
$$-D_{Ta} f_{sa}(\eta_{w0})\left.\frac{\partial \chi_{sa}}{\partial z}\right|_{z=0} + e_{b0} = c_{E0}|\mathbf{u}_r|(\chi_{sa0} - \chi_r)$$

Atmosphere-land exchange

χ_w, χ_{sa}, χ_r HTO conc. in soil water (Bq/m^3-water), soil air and air (Bq/m^3-air)

η_w, η_{sw} Volumetric soil water content and saturated value (m^3/m^3)

ρ_w Density of soil water (kg/m^3)

E_w Vertical liquid water flux (kg/m^2/s)

D_{Tw}, D_{ta} Effective diffusivities of HTO in water and HTO vapor in air (m^2/s)

$f_{sa}(\eta_w)$ Tortuosity for diffusion in soil air

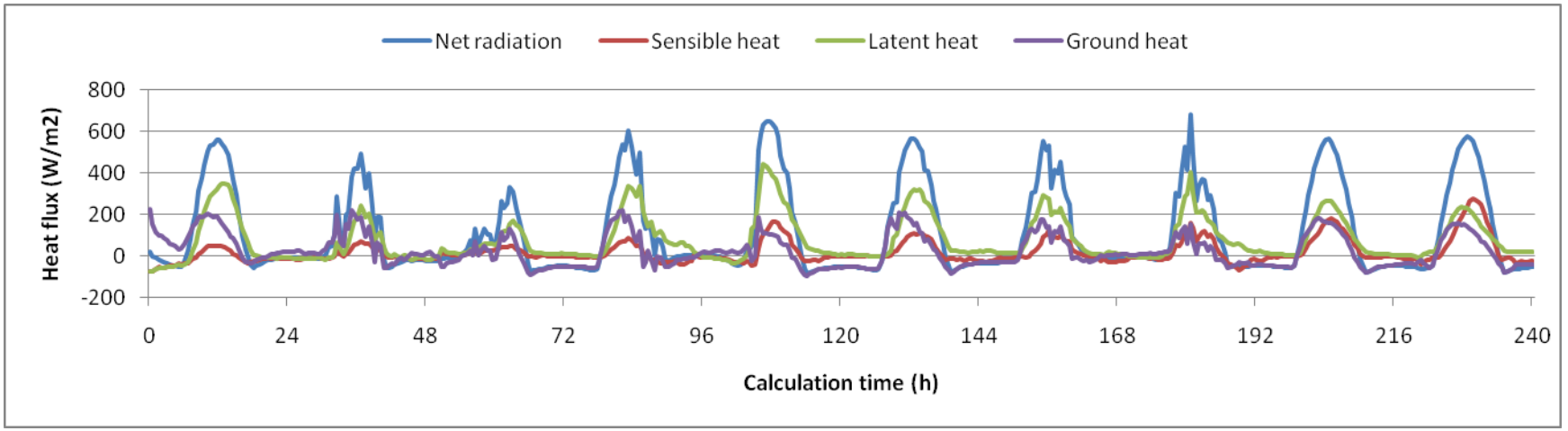
e_b HTO conc. in soil air (Bq/m^3-air)

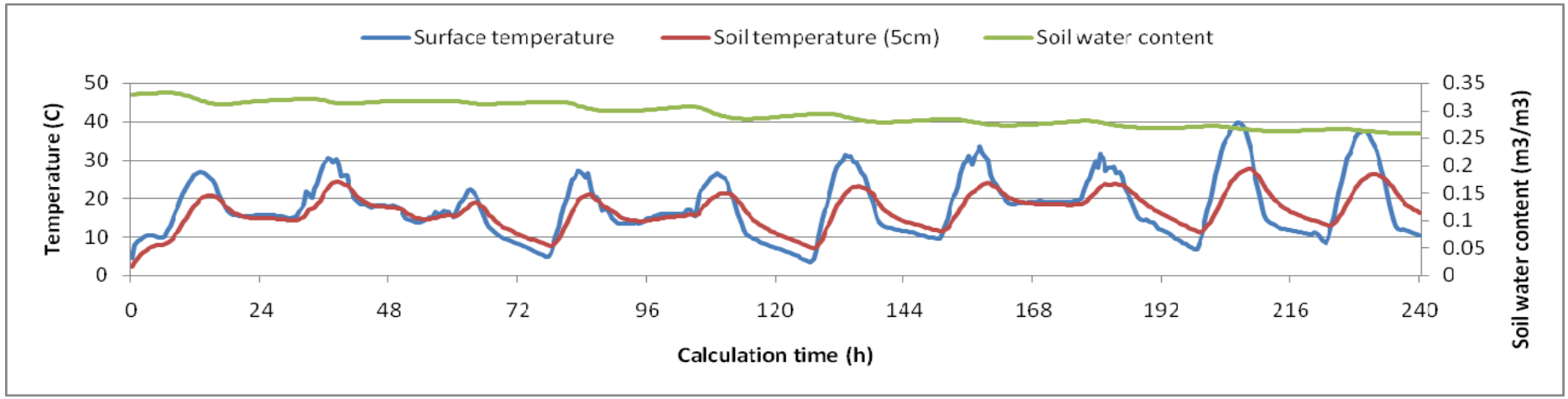
c_{E0}, $|\mathbf{u}_r|$ Bulk transfer coefficient for evaporation, wind speed (m/s)

Test calculation

[Calculation condition]

- **Bare soil (7 layers: boundary depth = 0.02, 0.05, 0.1, 0.2, 0.5, 1.0, 2.0 m)**
- **First 10 days of AmeriFlux data with hypothetical no rain condition**

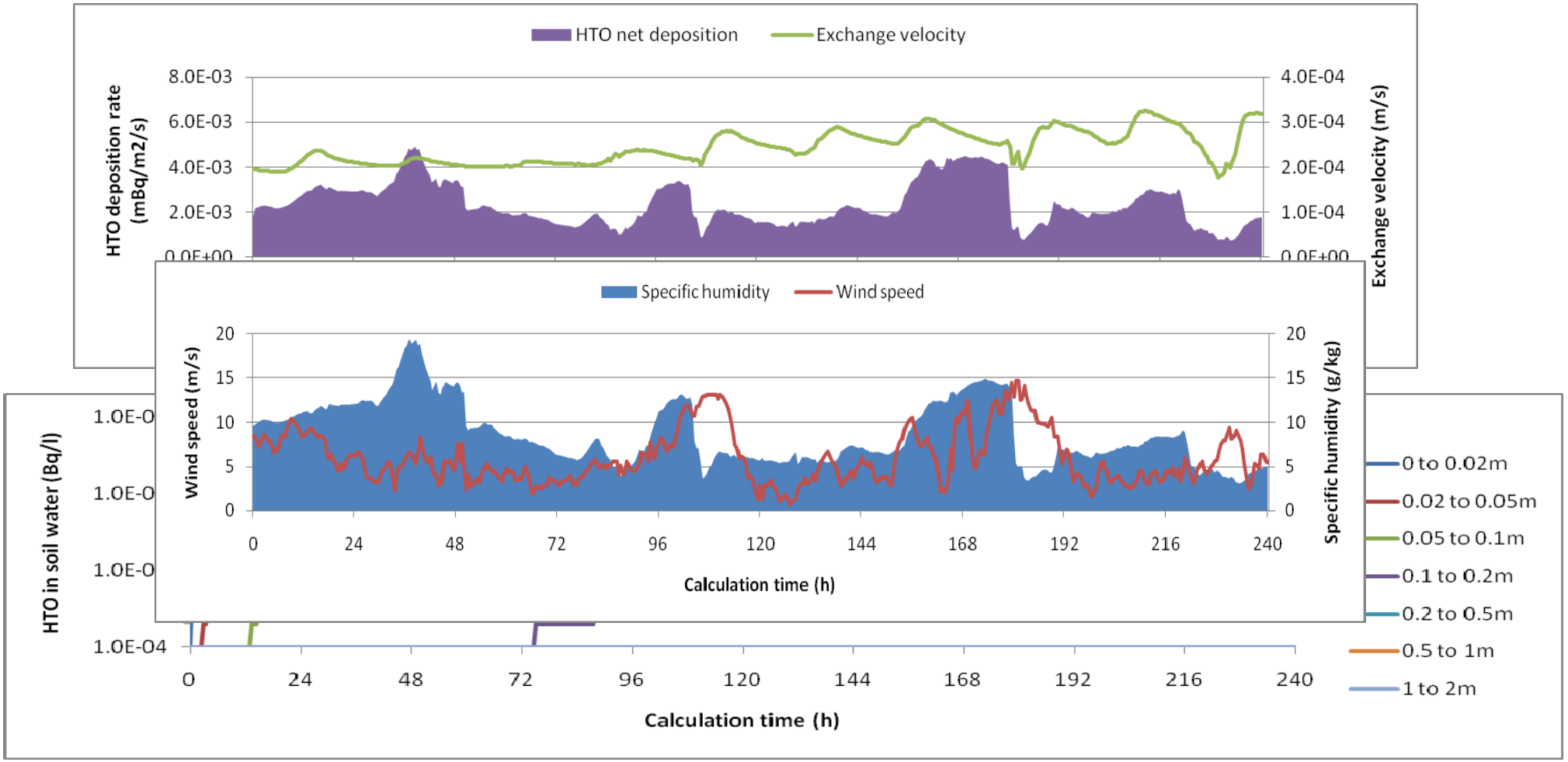




Test calculation

[Case 1]

- **Constant HTO concentration in air humidity (1Bq/l)**
- **No HTO in soil at the calculation start time**

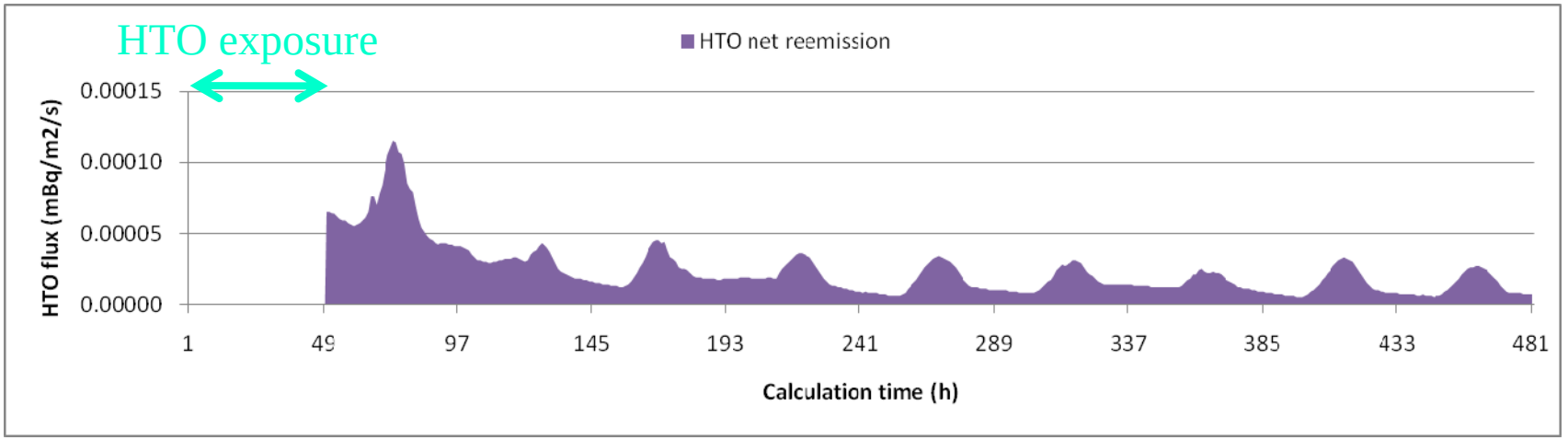


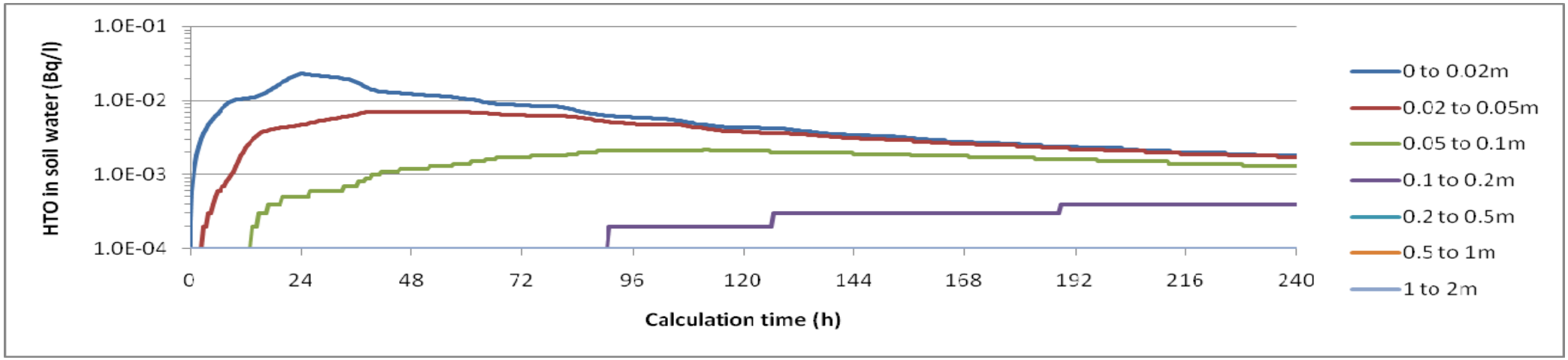
Land surface model SOLVEG2

Test calculation

[Case 2]

- **Constant HTO concentration in air humidity (1Bq/l) during the first 24 hour**
- **No HTO in soil at the calculation start time**





Summary

Incorporation of HTO transport into SOLVEG

- Process based HTO transport model to simulate dynamic behavior of HTO in air-soil-plant system
- Explicit calculation of HTO transport in a similar way as water and vapor transport
- Coding for transport in the atmosphere and bare soil (no decay)
- Test calculation using met. data of AmeriFlux

➔ Calculated results seem to be reasonable.

Farther tests using experimental data (EMRAS or BIOMASS) are necessary.

Next step

- Step 2: inclusion of plant uptake processes (under construction)
- Step 3: OBT production and translocation (need suggestions)