Review of soil-plant tritium transfer

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AECL EACL

Summary of past tritium experiments

1. Tritium (HTO) moves with water and follows water cycle in soil-plant-atmosphere system.
2. HTO diffuses on its own according to the concentration gradient.
3. By BOTH of this pathways HTO gets into vegetation (leaves) and is bound into OBT by photosynthesis.

MODELS

1. GAZAXI

2. ETMOD

3. UFOTRI

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11. SOLVEG-II

Issue

Variability makes model validation limited and universal applicability of existing models appears only at a cost of high uncertainties

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Variability pertaining to soil-plant interaction comprises of:

- Spatial (soils, land use, etc.)
- Temporal (meteo-forcings)
- Inter-species/cultivar

Objective

Provide the overview of capabilities of existing models of tritium transfer in soil-plant system and outline the approach to spatial variability.

Processes in soil-plant system

1. Water Infiltration (HTO advection):
   - Storm (e.g. Green-Ampt, numerical Richards)
   - Free (Darcian flow)
2. Root uptake via plant transpiration
3. Diffusion of HTO

Processes in soil-plant system

1. Water Infiltration (HTO advection):
   - Storm (e.g. Green-Ampt piston, numerical Richards)
   - Free (Darcy flow)
2. Root uptake via plant transpiration
3. Diffusion of HTO (2 phase)
4. Soil Thermodynamics

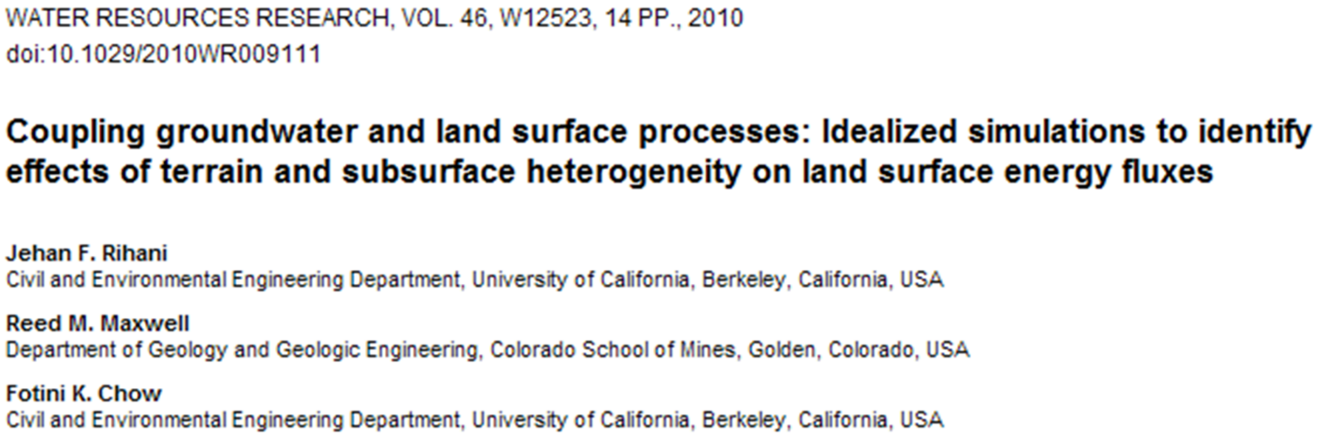
Boundary conditions for HTO

1. Independent surface gaseous deposition
2. Rainfall and dew-fall (assisted transport to soil)
3. Re-emission (independent loss to atmosphere according to gradient of concentration)
4. Evaporation-assisted transport to atmosphere
5. Drainage to aquifer (recharge/discharge)

Model Capabilities

- GAZAXI: B.cond.: wet (Chamberlain), dry - gradient exchange by Vex~LAI;
  Processes: root uptake via ET=const
- ETMOD: B.cond.: only dry dep. (Vex. by resistance approach);
  Processes: root uptake via ET (resistance approach),
  Diffusion and infiltration – semi-analytical (bottom - no flow),
- UFOTRI: B.cond.: wet (scavenging coeff), dry (Vex. by resistance approach),
  re-emission ~ ET (Monteith);
  Processes: root uptake via ET (Monteith),
  infiltration – matrix force (suction tension, h. conductivity,
  bottom - no flow);
- SOLVEG-II: B.cond.: wet (scavenging coeff),
  mixed b.c. (Vex., carbon-modelled stom. resistance),
  re-emission independently via Vex and carbon-based ET;
  Processes: Soil thermodynamics, CO2 diffusion,
  2-phase HTO diffusion and advection (1-phase Richards for water)

Soil-atmosphere coupling and sfc. fluxes spatial variability



WATER RESOURCES RESEARCH, VOL. 46, W12523, 14 PP., 2010
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Coupling groundwater and land surface processes: Idealized simulations to identify effects of terrain and subsurface heterogeneity on land surface energy fluxes

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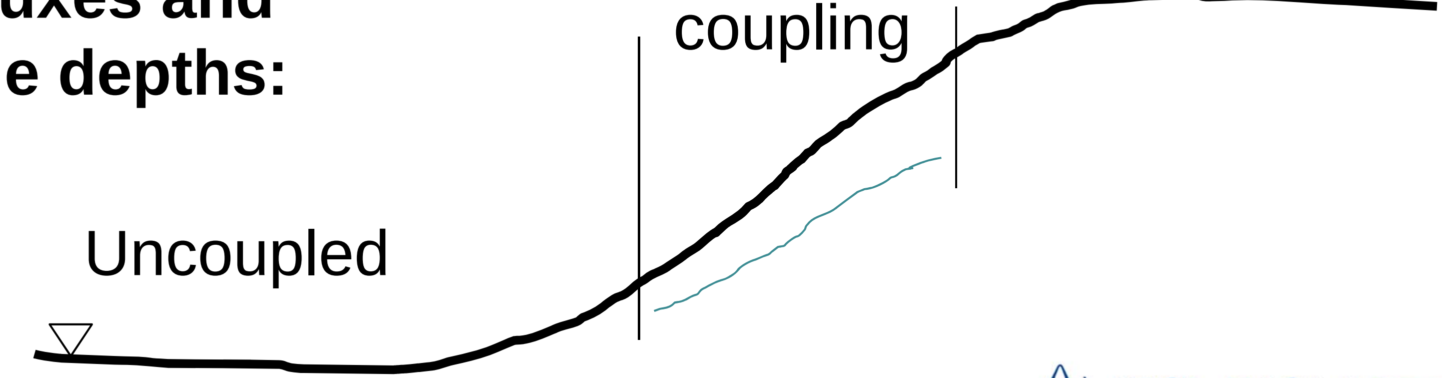
Example based on topography. Soil texture can have the same effect and

either multiply or cancel this out

Surface fluxes and water table depths:

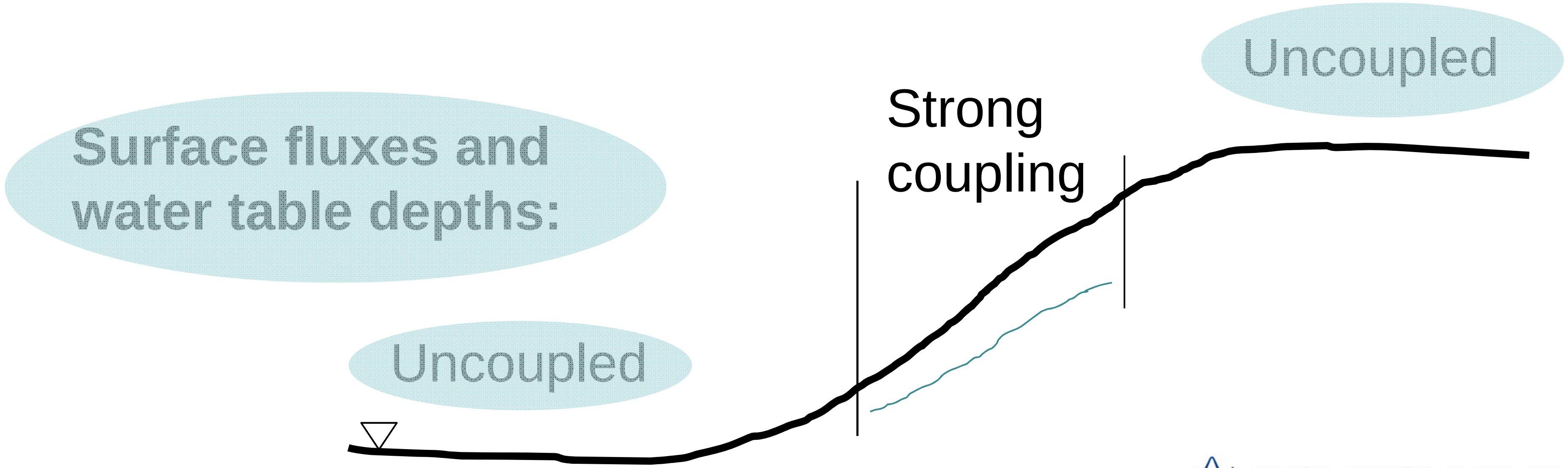


Uncoupled

Strong coupling

Uncoupled

HTO re-emission:
The need for sensitivity tests



Surface fluxes and water table depths:

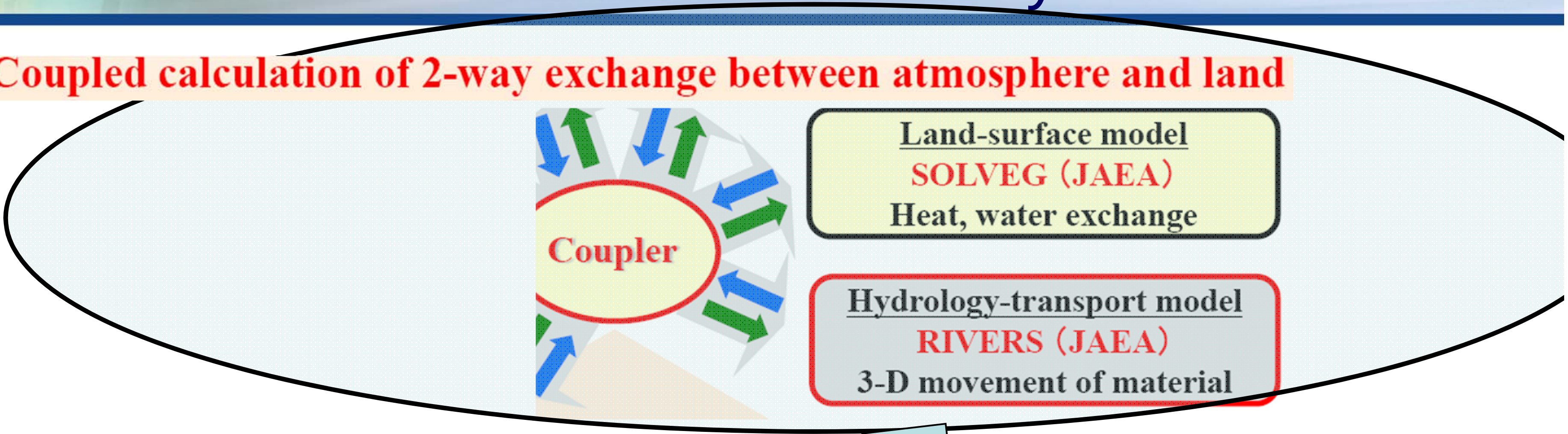
Uncoupled

Strong coupling

Uncoupled

HTO re-emission:
The need for sensitivity tests

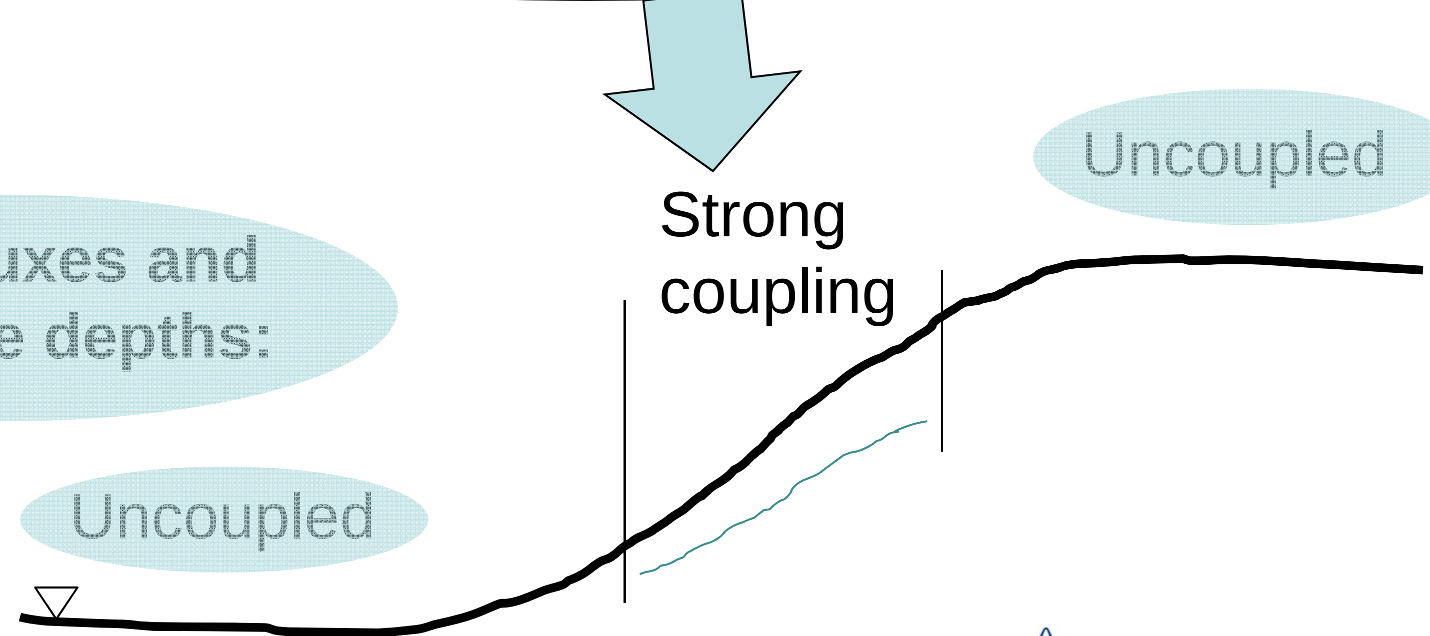
Coupled calculation of 2-way exchange between atmosphere and land



Land-surface model
SOLVEG (JAEA)
Heat, water exchange

Hydrology-transport model
RIVERS (JAEA)
3-D movement of material

Surface fluxes and water table depths:

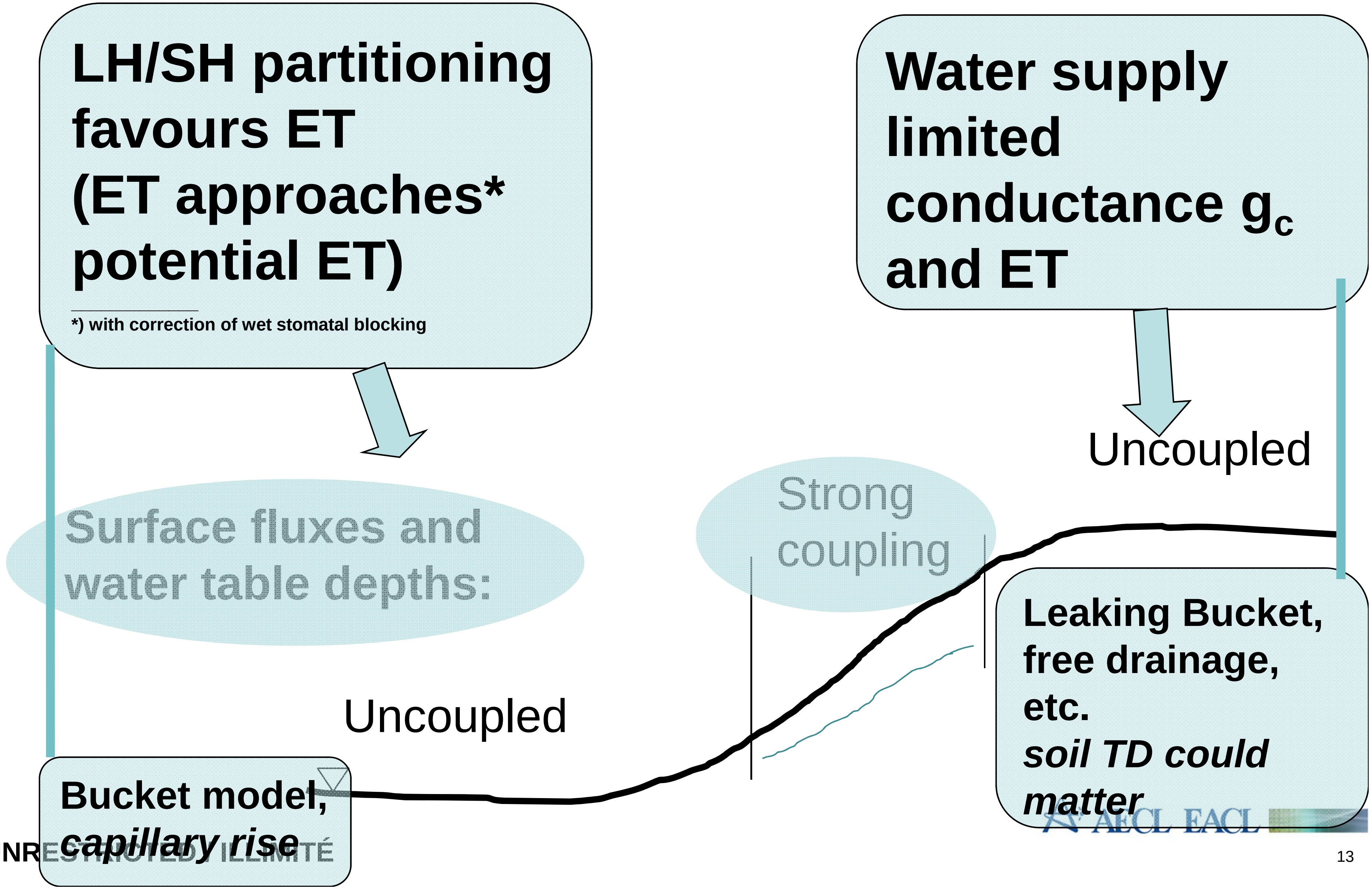


Strong coupling

Uncoupled

Uncoupled

Adjustment of existing models



LH/SH partitioning favours ET (ET approaches* potential ET)

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*) with correction of wet stomatal blocking

Water supply limited conductance g_c and ET

Uncoupled

Surface fluxes and water table depths:

Strong coupling

Uncoupled

Leaking Bucket, free drainage, etc.
soil TD could matter

Bucket model, *capillary rise*

Addressing spatial variability

- Sensitivity analysis of HTO re-emission
- Mapping DEM to soil texture
- GIS-based parameterization of HTO re-emission in each grid-cell using a combination of water-limited and water-unlimited HTO re-emission

Example 1:
wet conditions

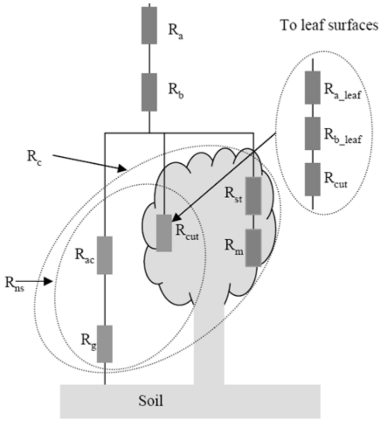
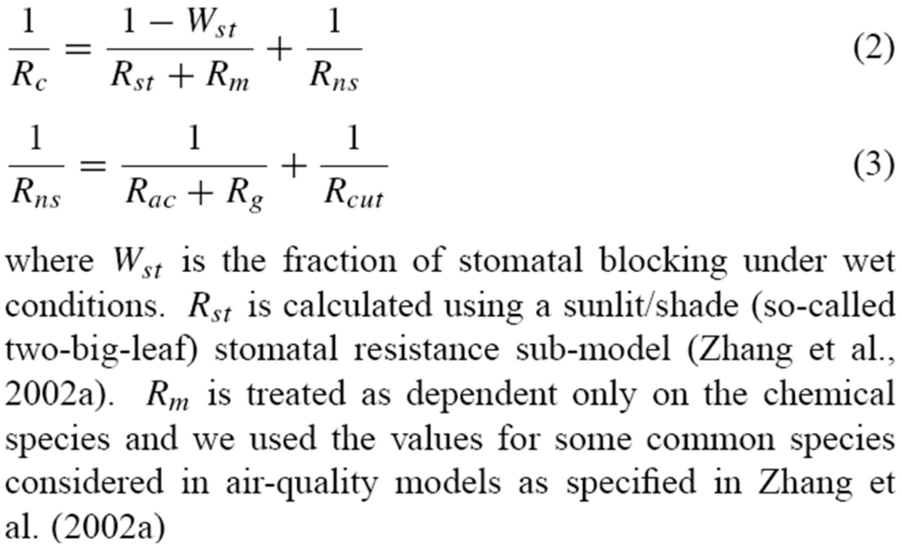


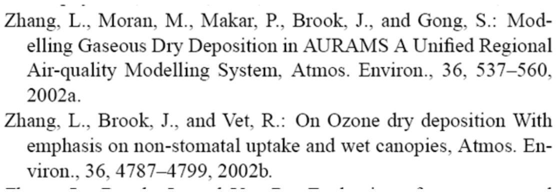
Fig. 1. Scheme of resistance analogy.



$$\frac{1}{R_c} = \frac{1 - W_{st}}{R_{st} + R_m} + \frac{1}{R_{ns}} \tag{2}$$

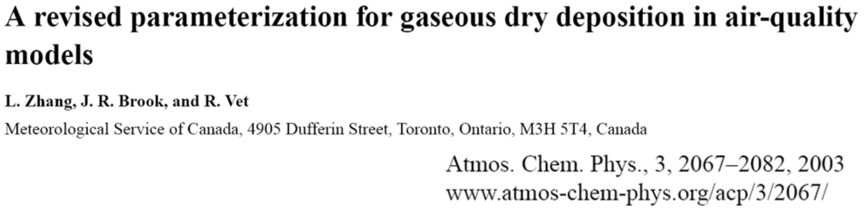
$$\frac{1}{R_{ns}} = \frac{1}{R_{ac} + R_g} + \frac{1}{R_{cut}} \tag{3}$$

where W_{st} is the fraction of stomatal blocking under wet conditions. R_{st} is calculated using a sunlit/shade (so-called two-big-leaf) stomatal resistance sub-model (Zhang et al., 2002a). R_m is treated as dependent only on the chemical species and we used the values for some common species considered in air-quality models as specified in Zhang et al. (2002a)



Zhang, L., Moran, M., Makar, P., Brook, J., and Gong, S.: Modelling Gaseous Dry Deposition in AURAMS A Unified Regional Air-quality Modelling System, Atmos. Environ., 36, 537–560, 2002a.

Zhang, L., Brook, J., and Vet, R.: On Ozone dry deposition With emphasis on non-stomatal uptake and wet canopies, Atmos. Environ., 36, 4787–4799, 2002b.



A revised parameterization for gaseous dry deposition in air-quality models

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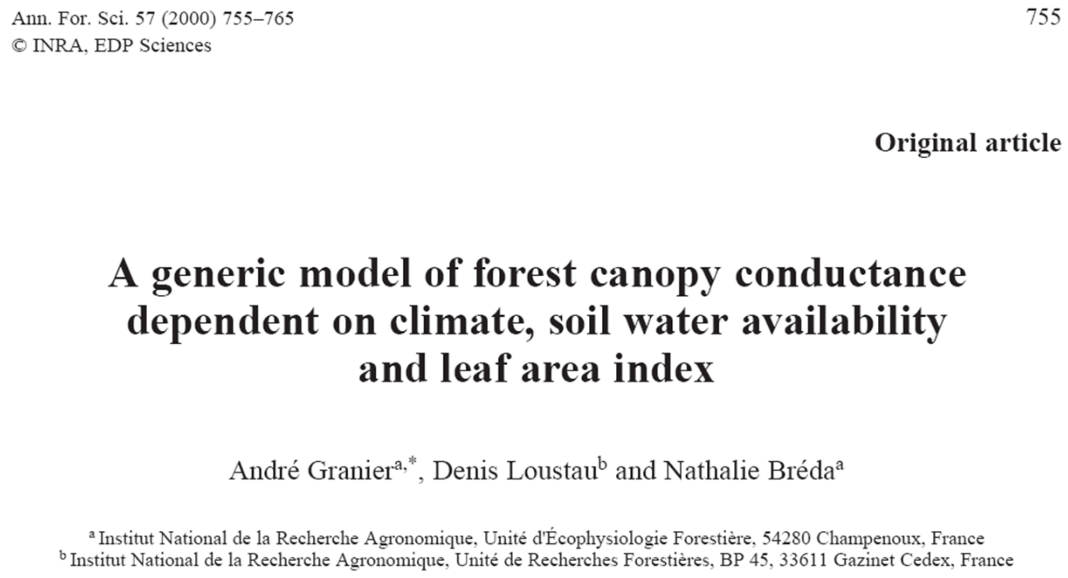
Atmos. Chem. Phys., 3, 2067–2082, 2003
www.atmos-chem-phys.org/acp/3/2067/

Example 2:
transient conditions, experiment



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Original article

A generic model of forest canopy conductance dependent on climate, soil water availability and leaf area index

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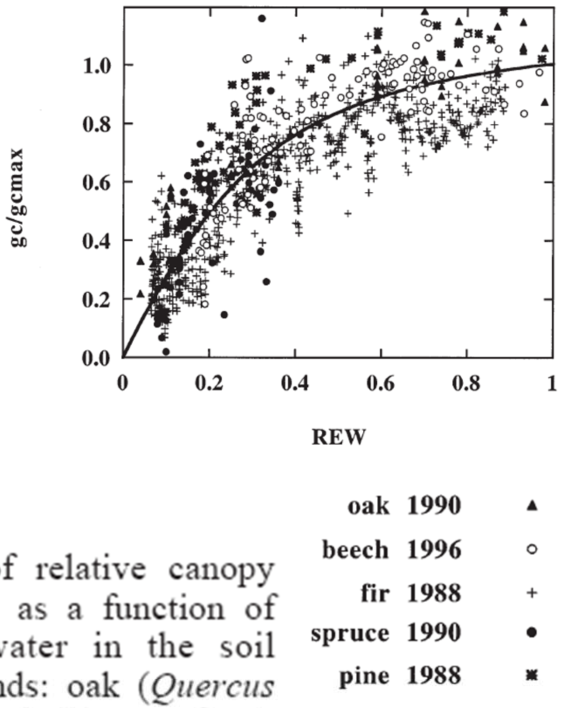
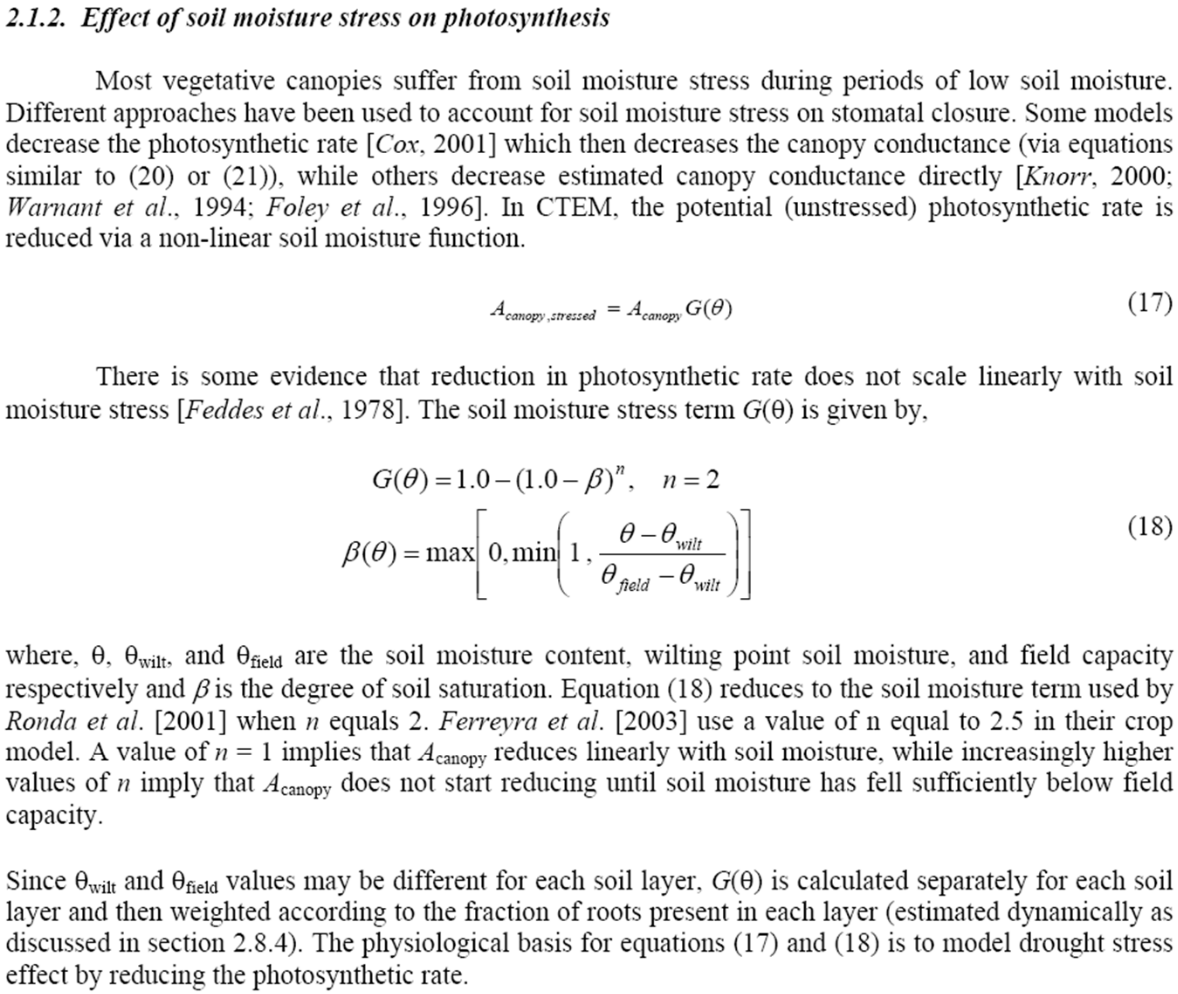


Figure 5. Variation of relative canopy conductance (g_c/g_{cmax}), as a function of relative extractable water in the soil (*REW*) in 5 forest stands: oak (*Quercus petraea*, *LAI* = 6.0), beech (*Fagus sylvatica*, *LAI* = 5.8), fir (*Abies bornmulleriana*, *LAI* = 8.9), spruce (*Picea abies*, *LAI* = 6.1) and pine (*Pinus pinaster*, *LAI* = 2.7). In oak, beech, spruce and pine, g_c is related to modelled g_{cmax}. In fir, g_c is related to g_{cmax} measured in a well-watered plot. A unique relationship was drawn.

Example 3: transient conditions, model



2.1.2. *Effect of soil moisture stress on photosynthesis*

Most vegetative canopies suffer from soil moisture stress during periods of low soil moisture. Different approaches have been used to account for soil moisture stress on stomatal closure. Some models decrease the photosynthetic rate [*Cox*, 2001] which then decreases the canopy conductance (via equations similar to (20) or (21)), while others decrease estimated canopy conductance directly [*Knorr*, 2000; *Warnant et al*., 1994; *Foley et al*., 1996]. In CTEM, the potential (unstressed) photosynthetic rate is reduced via a non-linear soil moisture function.

$$A_{canopy,stressed} = A_{canopy} G(\theta) \tag{17}$$

There is some evidence that reduction in photosynthetic rate does not scale linearly with soil moisture stress [*Feddes et al*., 1978]. The soil moisture stress term $G(\theta)$ is given by,

$$\begin{gathered} G(\theta) = 1.0 - (1.0 - \beta)^n, \quad n = 2 \\ \beta(\theta) = \max\left[0, \min\left(1, \frac{\theta - \theta_{wilt}}{\theta_{field} - \theta_{wilt}}\right)\right] \end{gathered} \tag{18}$$

where, θ, θ_{wilt}, and θ_{field} are the soil moisture content, wilting point soil moisture, and field capacity respectively and β is the degree of soil saturation. Equation (18) reduces to the soil moisture term used by *Ronda et al*. [2001] when n equals 2. *Ferreyra et al*. [2003] use a value of n equal to 2.5 in their crop model. A value of $n = 1$ implies that A_{canopy} reduces linearly with soil moisture, while increasingly higher values of n imply that A_{canopy} does not start reducing until soil moisture has fell sufficiently below field capacity.

Since θ_{wilt} and θ_{field} values may be different for each soil layer, $G(\theta)$ is calculated separately for each soil layer and then weighted according to the fraction of roots present in each layer (estimated dynamically as discussed in section 2.8.4). The physiological basis for equations (17) and (18) is to model drought stress effect by reducing the photosynthetic rate.

Arora, V.K. (2003) Simulating energy and carbon fluxes over winter wheat using coupled land surface and terrestrial ecosystem models, Agricultural and Forest Meteorology, 118(1-2), 21-47.

Conclusions

- Existing models are adequate but not universally applicable (if we are after narrow uncertainties)
- Spatial variability of HTO re-emission could be addressed by combination of models in wet and dry conditions
- Sensitivity study is required for critical zone of strong atmosphere-soil coupling
- Sensitivity to spatial variability should be compared to cultivar variability

THANK YOU