

Modulation of gas fluxes at the soil-atmosphere interface due to coupled physical, chemical and biological effects

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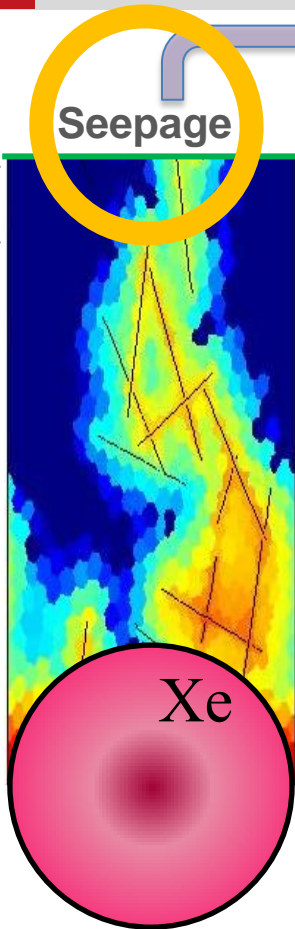
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Rationale for seepage studies

Gas migration

Underground nuclear explosion

Mourzenko et al. (2014)



Atmosphere

Geosphere

Detection



- Radioactive decay
- Dilution & Modulation of gas flux
- Fractionation (elements & isotopes)

$(^{135}\text{Xe}, ^{133\text{m}}\text{Xe}, ^{133}\text{Xe}, ^{131\text{m}}\text{Xe})$ in atmosphere

Total activity and isotope ratios

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$(^{135}\text{Xe}, ^{133\text{m}}\text{Xe}, ^{133}\text{Xe}, ^{131\text{m}}\text{Xe})$ in cavity at t_0

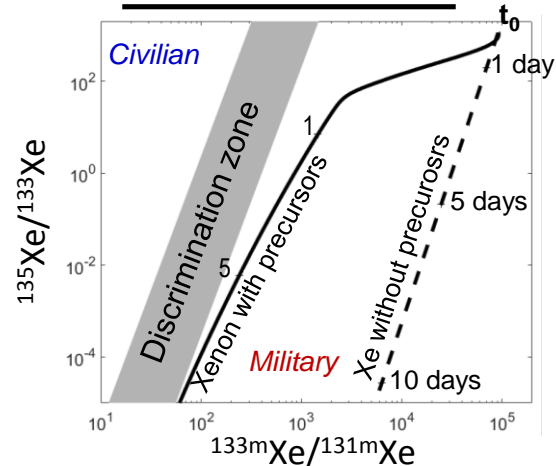
Far field:

- ✓ Advection-diffusion in unsaturated fractured porous media under pressure & temperature gradients

Near field:

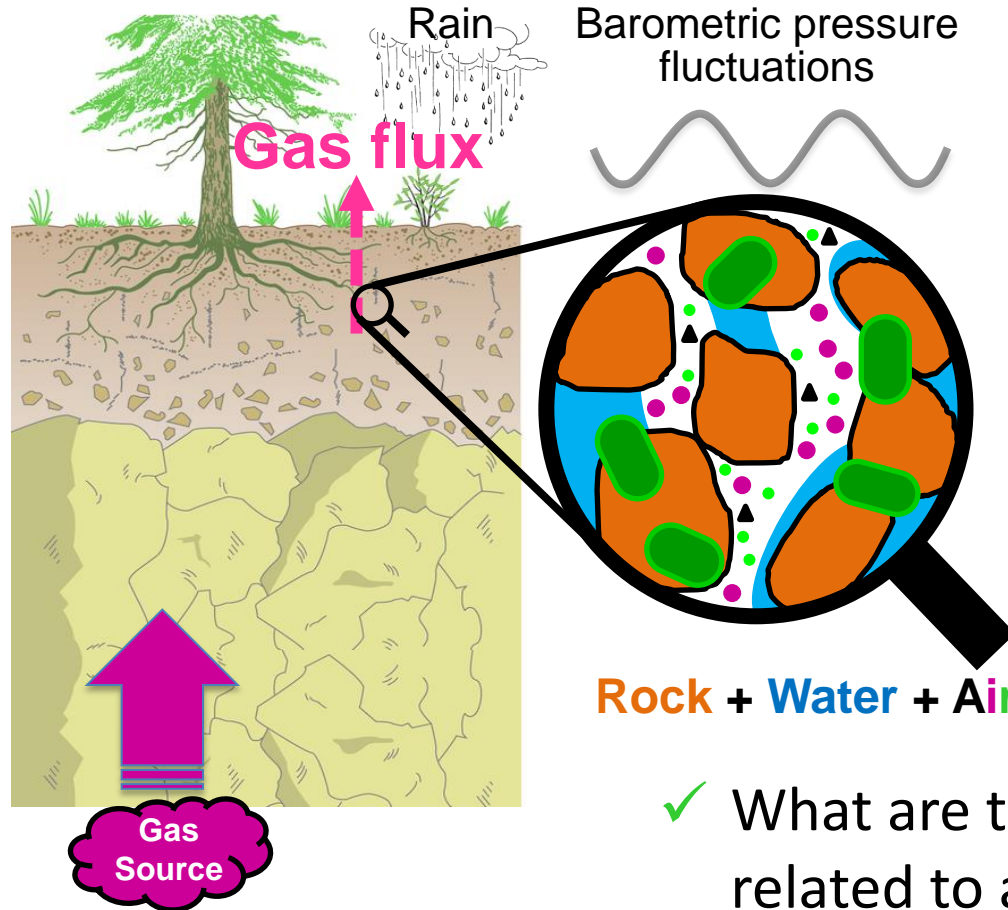
- ✓ Making of radionuclide source term
See also poster T2.4-P39

Discrimination



Multi-Isotope Ratio Chart modified from (Kalinovski et al., 2010)

The Soil-Atmosphere Interface



- ✓ Highly dynamical and heterogeneous system with variations in space & time:
 - *Water content,*
 - *Pressure & Temperature,*
 - *Gas permeability & porosity,*
 - *Biological activity.*

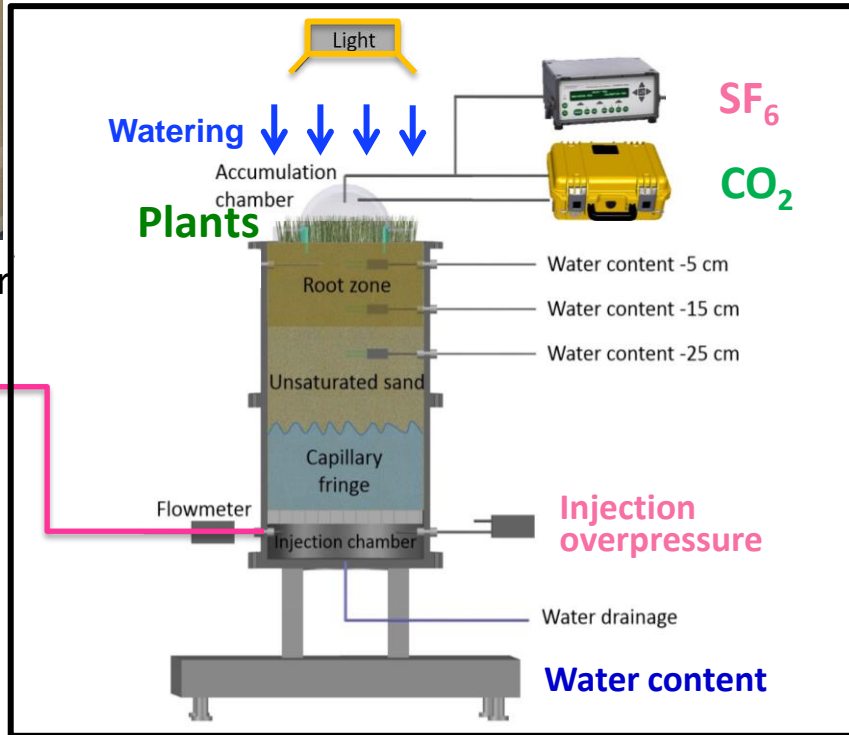
Rock + Water + Air + Microorganisms & Plants

- ✓ What are these effects on surface gas fluxes related to a deep gas source?

Controlled tracer gas injections in soil columns

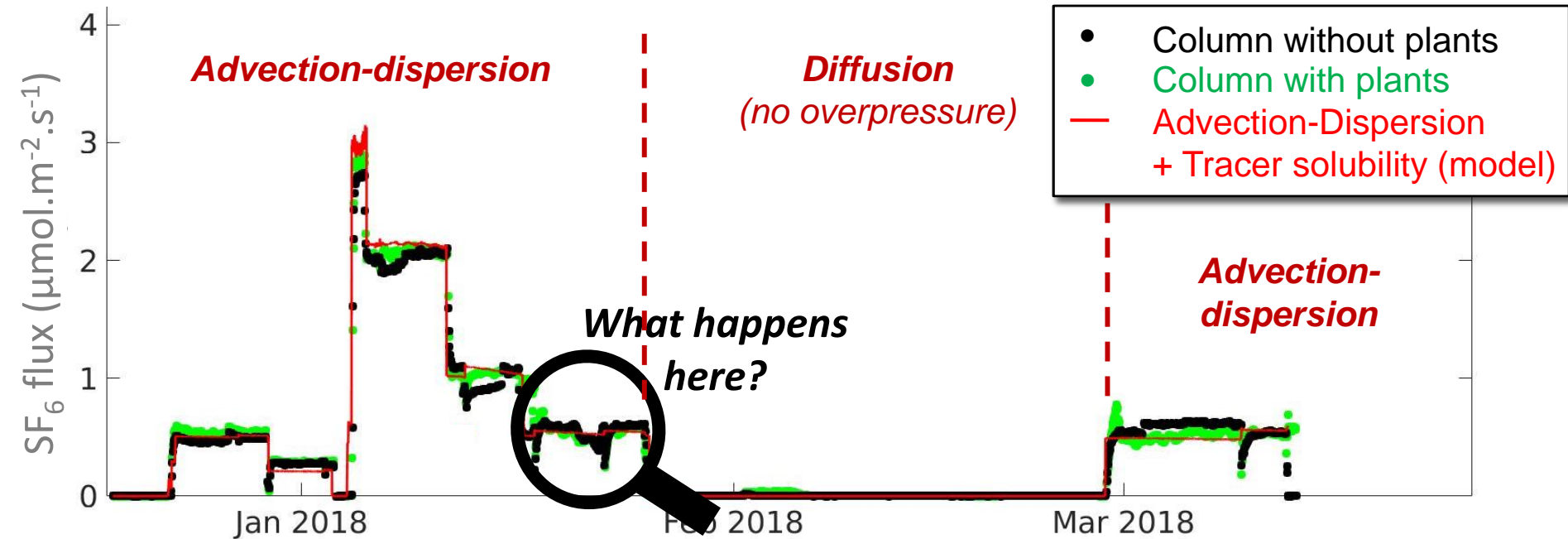


Climatic chamber



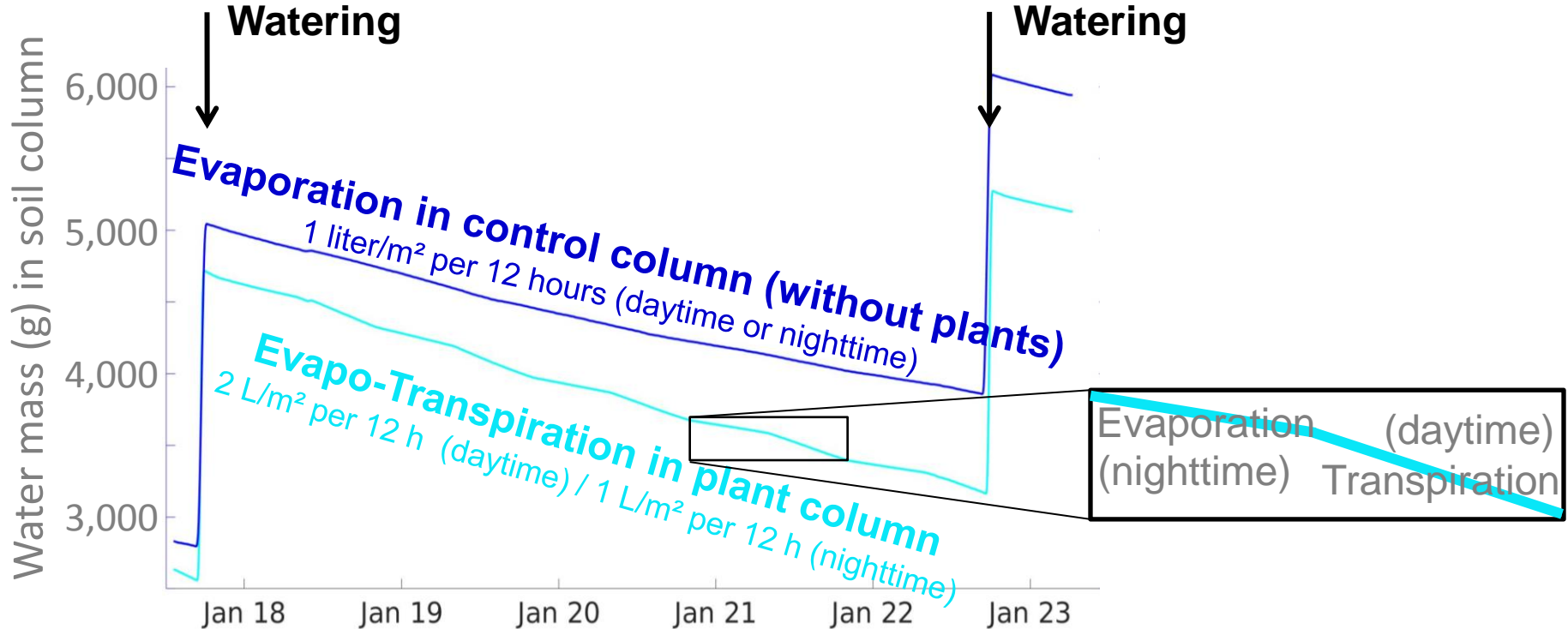
- ✓ Controlled conditions:
 - Constant Temp. & humidity,
 - **Watering**,
 - **Diurnal light cycles** (12 hours daytime / 12 hours nighttime).
- ✓ Natural barometric pressure fluctuations;
- ✓ SF_6 injected at the base of column (constant flow rate);
- ✓ **One column with plants**, another column without plant;
- ✓ Long-term & high-resolution monitoring:
 - **Injection overpressure**,
 - SF_6 & CO_2 surface fluxes,
 - Changes in **water content**.

Observed SF₆ fluxes following injection in soil columns



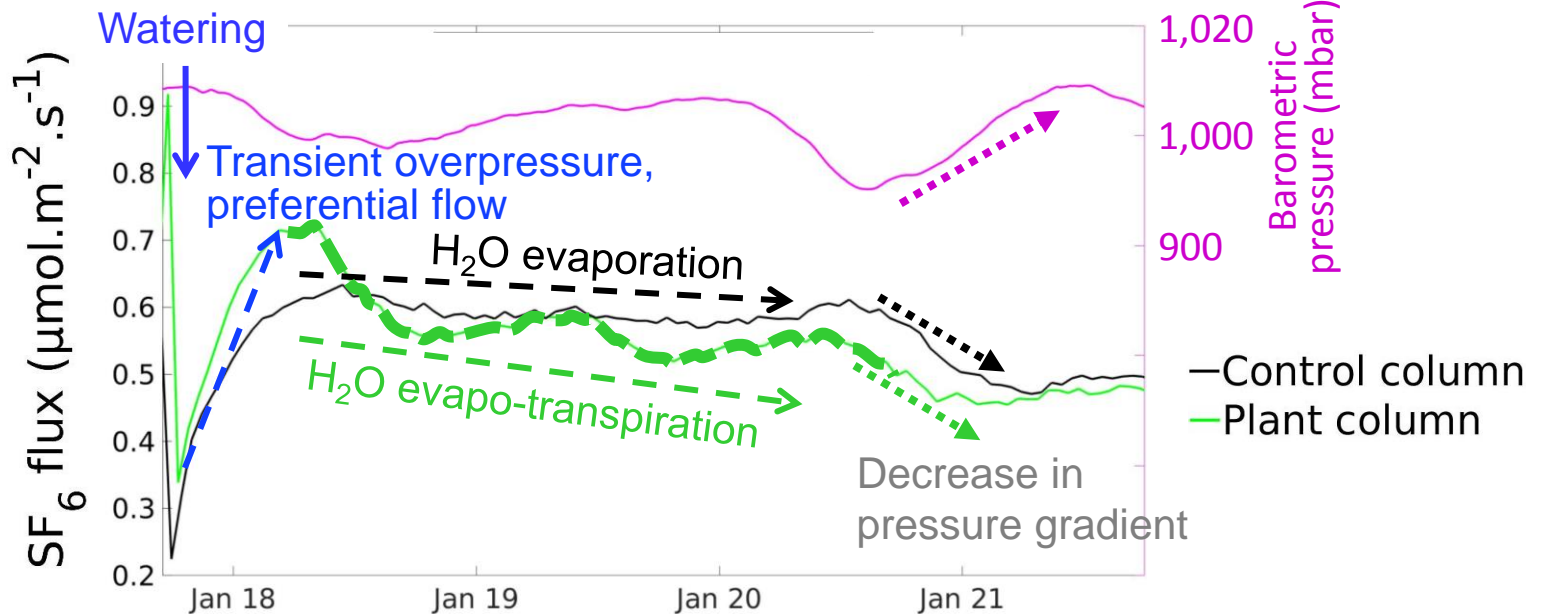
- ✓ SF₆ injected at various concentrations and flowrates,
- ✓ Transport by Advection-Dispersion in response to the injection overpressure,
- ✓ **Tracer solubility in water** must be taken into account.

Soil Water Budget Controlled by Biologically-driven Evaporation



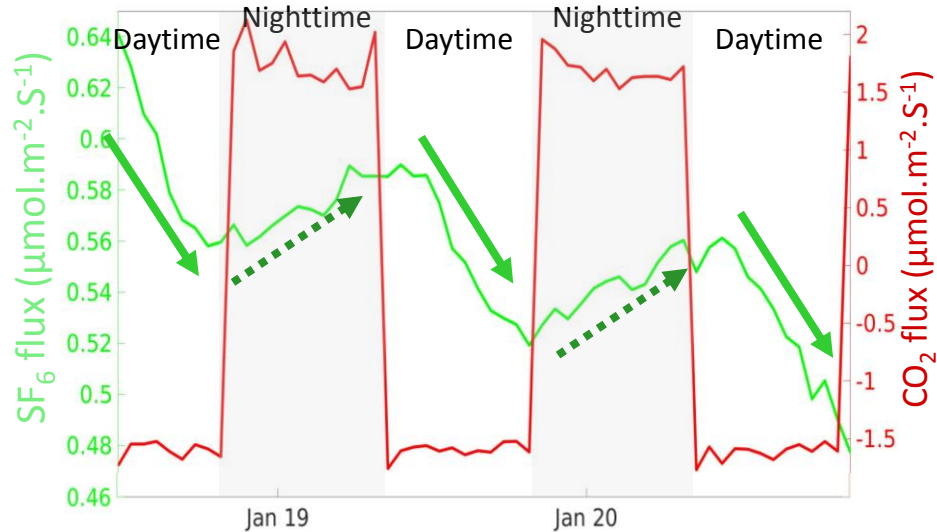
- Biologically-driven water evaporation: ✓ Rate twice as efficient as evaporation alone, (aka transpiration)
- ✓ Fluctuations controlled by daytime lighting.

Controls on Gas Fluxes by Soil Water Content and Pressure

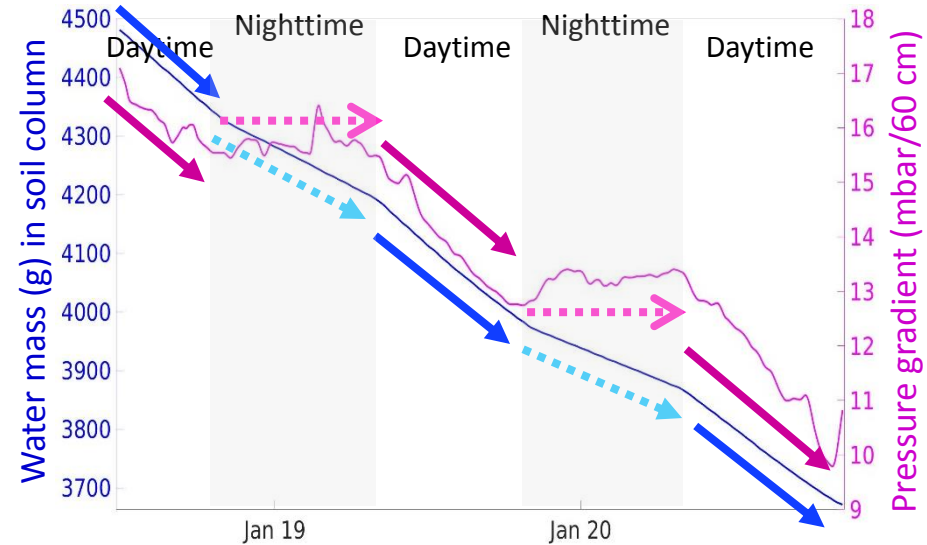


- ✓ Gas fluxes are controlled by pressure gradient & gas porosity, in turn controlled by:
 - ✓ water content (infiltration, evapo-transpiration)
 - ✓ barometric pressure fluctuations.
- ✓ **What controls the second-order variations seen only in the plant column?**

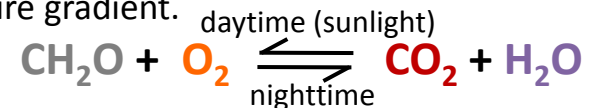
Diurnal effect of plant metabolism on gas fluxes



- ✓ During Daytime:
 - Decrease in SF₆ flux,
 - Negative CO₂ flux (photosynthesis),
 - High water loss by evapotranspiration,
 - Decrease in pressure gradient.
- ✓ During Nighttime:
 - Increase in SF₆ flux,
 - Positive CO₂ flux (plant respiration),
 - Moderate water loss by evaporation,
 - Constant pressure gradient.



- Increase in gas porosity, transient gas storage.
- CO₂ produced by respiration has higher solubility in pore water than O₂, which decreases local pressure and increases pressure gradient.



- ✓ Gas fluxes at the soil-atmosphere interface show a large dynamical response controlled by 1) barometric pressure, 2) water content and 3) plant metabolism.
- ✓ Biologically-driven controls on gas fluxes ($\geq 10\%$ effect, higher for larger biome):
 - Evapo-transpiration (plants) controls water budget, hence gas porosity & pressure;
 - Respiration (plants & microorganisms): O_2 consumption / CO_2 production drive important pressure changes due to contrasted solubility in water.
- ✓ Important consequences regarding detection of underground nuclear explosions:
 - **On-Site Inspection:** caution on high space & time variability for one-time gas collection
 - **International Monitoring System:** modulations of radionuclides released to the atmosphere must be taken into account by Atmospheric Transport Modeling.
- ✓ On-going modeling effort will provide further quantification and prediction.