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Assimilation of image data into a spatialized water and pesticide flux model

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Abstract: Physically-based models represent detailed surface/subsurface transfer, but the required spatial information does not allow their operational use. To fill this gap, we propose a methodology that exploits surface images, in situ data and modeling components, to improve pesticide fluxes simulation and estimates of hydrological parameters. This paper discusses the proposed methodology as well as the available study site data and modeling components.

The Morcille study site (Beaujolais)

- small watershed (8.8 km²)
- 70% of vineyard
- high risk of pesticide contamination
- steep slopes > 25%
- permeable sandy soils
- continental climate with Mediterranean influence
- Research on pesticides since 1985
- River quality and flow monitored between 2006 and 2011.

Assimilation of images

- Usually, remote sensing data and sequences are under-used, though their content in information is very high (shapes evolution, correlations, ...)
- HR Images would also help to identify the landscape elements (grass strips, hedges, ...)
- In classical approaches : uncorrelated noise, diagonal error covariance matrices
- How to provide observation error covariance matrices adapted to spatially correlated errors? [2]
- Focusing on the observations operator description, and distances definition in the DA scheme


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CATHY-Pesticide Hydrological model

Coupled surface/subsurface flow and transport [1-7]

- Richards eq. for variably saturated porous media:

  \[
  S_m \frac{\partial \psi}{\partial t} + \frac{\partial S_w}{\partial t} = \nabla [K_c (\nabla \psi + n)] + q_w
  \]

- 1D diffusive wave equation at surface:

  \[
  \frac{\partial Q}{\partial t} + c_q \frac{\partial Q}{\partial x} = D_q \frac{\partial^2 Q}{\partial x^2} + q_s(x, t)
  \]

- Advection – dispersion equation

  \[
  \frac{\partial C}{\partial t} = \nabla (D C) - \nabla (\nabla c) + R
  \]

- Linear adsorption and first order decay

  \[
  K_d = \frac{c_T}{\omega} = -\lambda C
  \]

DA for pesticide transfer modeling

Modeling pesticide transfer in a watershed is particularly complex:

- very high heterogeneity of the system
- many processes in interaction
- few information on physico-chemical interactions of molecules
- lack of data deep in the soil

- research focuses on development of modeling in function of chosen processes to describe
- DA would improve input parameters characterization and pesticide transfer understanding.

Hypothese:

Assimilating hydrological variables will improve the pesticide fluxes simulations and the input parameters estimates.

⇒ Coupled Data Assimilation

Model setup on a simplified hillslope

<table>
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<th>Parameter</th>
<th>Unit</th>
<th>Zone 1</th>
<th>Zone 2</th>
</tr>
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<td>0.04 m/s</td>
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<tr>
<td>(v)</td>
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<td>(n)</td>
<td>cm</td>
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<td>(K_{sat})</td>
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</tr>
<tr>
<td>(K_{tor})</td>
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<tr>
<td>(K_{peak})</td>
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<tr>
<td>(t_{peak})</td>
<td>s</td>
<td>30.1</td>
<td>30.1</td>
</tr>
</tbody>
</table>

Twin experiments

Simulation of virtual temporal series of surface water images with CATHY

Deterministic Ensemble Kalman filter

\[
\begin{align*}
\hat{x}_k &= M(x_{k-1}, v_k, f, \lambda) \\
\hat{y}_k &= H(x_k, v_k) \\
\text{obs} ... x_{k-1} &\rightarrow x_k & \rightarrow x_{k+1} & \rightarrow \text{obs} ... \\
&\quad \rightarrow y_k \rightarrow y_{k+1} \\
\end{align*}
\]

⇒ Monte Carlo-based approximation of the Kalman filter for the forecast step \((\hat{x}_k^{M})\) and the analysis step \((\hat{x}_k^{A})\)

⇒ State augmentation to update the model parameters

⇒ applicable to non-linear large-scale problems

⇒ successfully tested in Cathy : Camporese et al. 2009 \(⇒\) assimilation of pressure head and streamflow improves surface and subsurface responses

⇒ assimilation of water content improved the parameter estimation of spatialized \(K_s\)

⇒ perturbation of observations ? Ens.TKF

4DVar

\[
J(x) = \frac{1}{2} [x - \alpha(x)]^T [H(M_{s+1}(x)) - y^{obs}]^T \omega^{-1} [H(M_{s+1}(x)) - y^{obs}] + \frac{1}{2} [\nabla J(x)]^T A [\nabla J(x)]
\]

⇒ with B and R background and observation error covariance matrices

⇒ would allow testing more situations to help estimate the input parameters for the hydrological part of CATHY

⇒ would reduce uncertainty for the pesticides transfer part

⇒ no need for expensive MC estimation, as long as the adjoint model coded.

Which DA method?