



Assimilating surface moisture satellite images into a coupled and spatialized water quality model: strategies and challenges

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Assimilating surface moisture satellite images into a coupled and spatialized water quality model: strategies and challenges

Emilie Rouzies (INRAE, France)

PhD supervised by Arthur Vidard (LJK/Inria, France) and Claire Lauvernet (Inrae, France)



Introduction

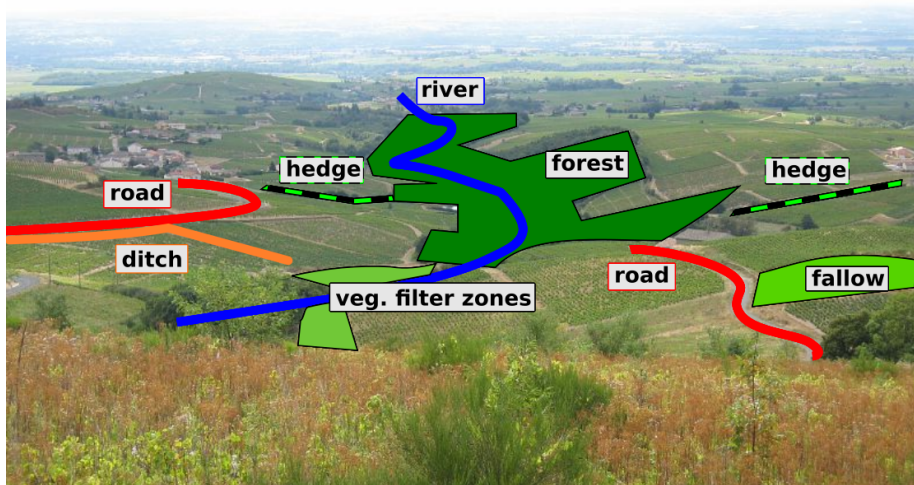
Context



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Introduction

Context

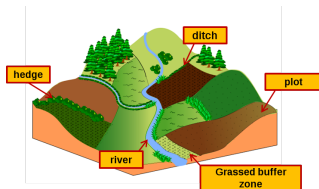


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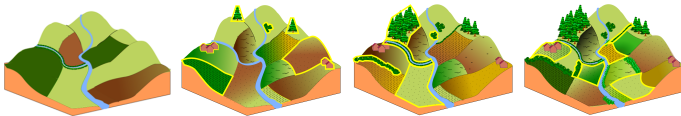
The PESHMELBA model

Development of the **PESHMELBA** model (Rouzies et al. 2019) to simulate pesticide transfers and fate on small agricultural catchments

- ✓ Simulations of heterogeneous landscapes composed of plots, vegetative filter zones, hedges, ditches and rivers



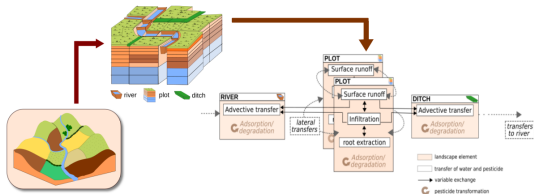
- ✓ Modular structure to explore landscape management scenarios



Introduction

The PESHMELBA model

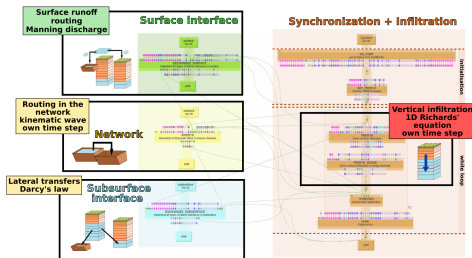
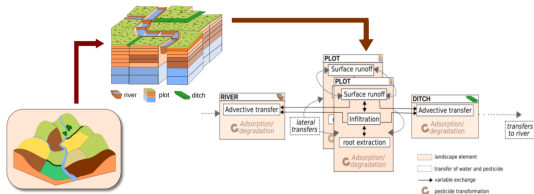
- ✓ Process-oriented, fully spatialized model
- ✓ Water transfers on surface and subsurface + pesticide advection, adsorption and degradation



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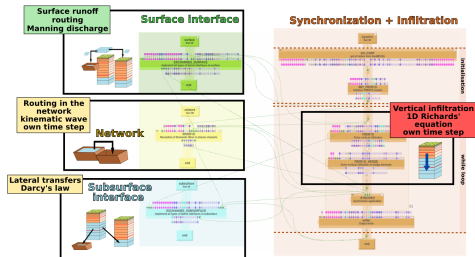
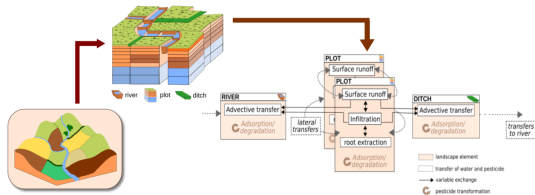
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- ✓ Water transfers on surface and subsurface + pesticide advection, adsorption and degradation
- ✓ One module $\equiv$ one process or ensemble of processes on a landscape element
- ✓ Coupling of modules within the OpenPALM coupler (Buis, Piacentini, and Déclat 2006) turning the structure flexible



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⇒ **Complex structure may lead to additional difficulties to diagnose model behavior!**

Introduction

PhD Objectives



We have a dream that one day PESHMELBA will be used as a decision-making tool to set up management scenarios and to identify an optimal landscape configuration for pesticide transfer mitigation.

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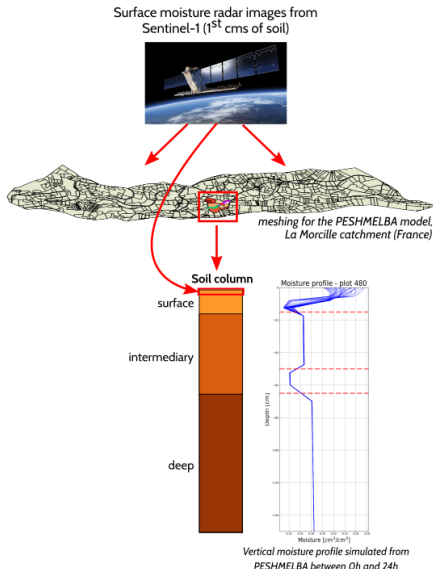
PhD objectives

1. **Quantify**: performing an uncertainty analysis and a sensitivity analysis of the model
2. **Reduce**: performing data assimilation to integrate different sources of data: soil moisture images, ERT measurements and in-situ data of pesticide concentration

Introduction

PhD Objectives - Part2 : reducing the uncertainty

1. Assimilate surface moisture images to improve moisture dynamics modelling **both in surface and subsurface**
2. Estimate input parameters that would be set for the landscape management scenarios exploration

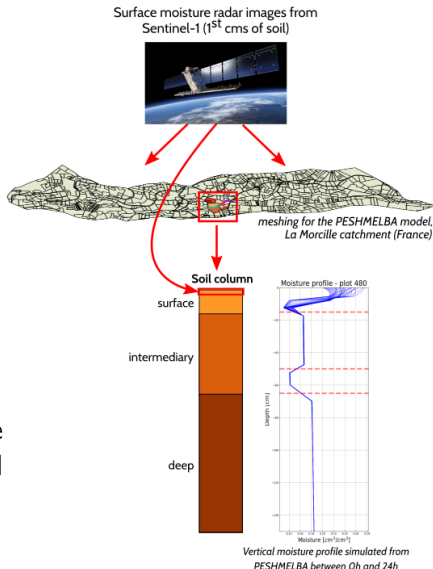


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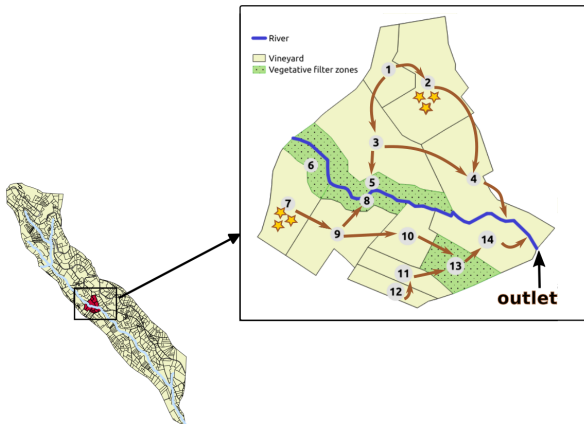
⇒ Joint-estimation abilities are investigated



Material and method

Study case

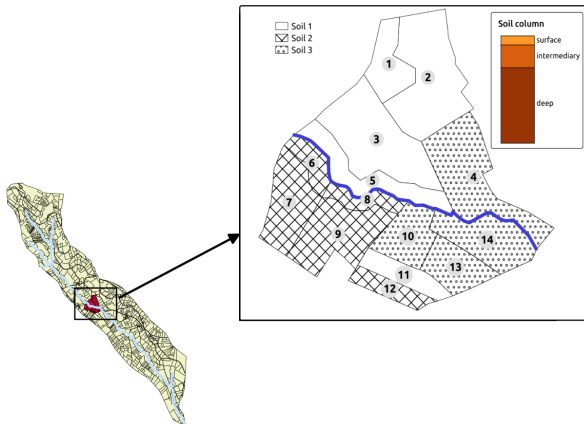
First attempt of GSA and DA in the PESHMELBA model: let's keep it simple...but realistic! (types of landscape elements, number of parameters, climate conditions...)



Material and method

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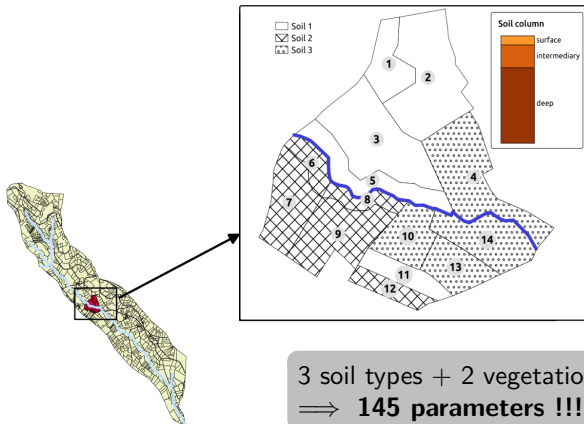
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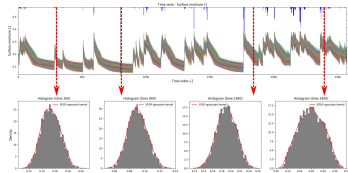
3 soil types + 2 vegetation types + ...
⇒ **145 parameters !!!**

Material and method

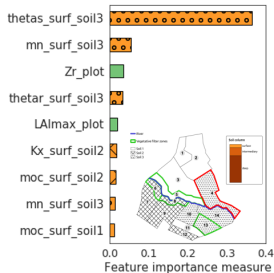
Uncertainty and sensitivity analysis

Main findings from UA/GSA on moisture temporal series:

✓ Surface moisture is mostly gaussian.



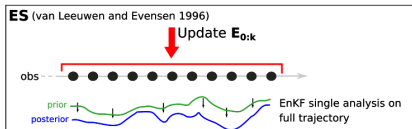
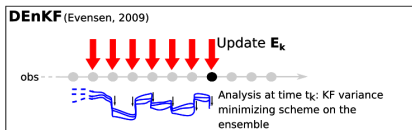
✓ High dependency on surface water content at saturation θ_{sat} .
⇒ Joint-estimation will focus on estimating such parameters



Material and method

DA method

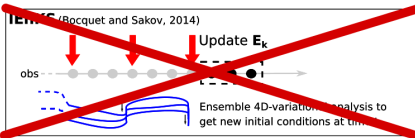
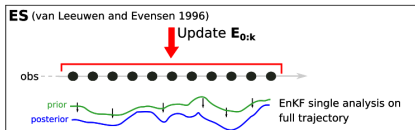
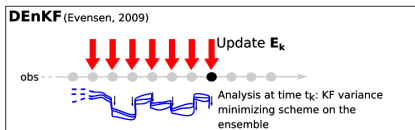
Chosen method should be suited to heterogeneous structure of the model, highly nonlinear processes and landscape discontinuities **but** also suited to PESHMELBA high computational cost.



Material and method

DA method

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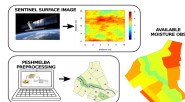
**Computational cost
for iterative method
cannot be
afforded ...**

Material and method

Ingredients

Observation

- ✓ Twin experiments
- ✓ Freq. of observation: 24h (⚠ overestimated)
- ✓ Obs. error : $\sim 5\%$ of observed surface moisture
- ✓ Assumption: one surface moisture observation per landscape element



Ensemble

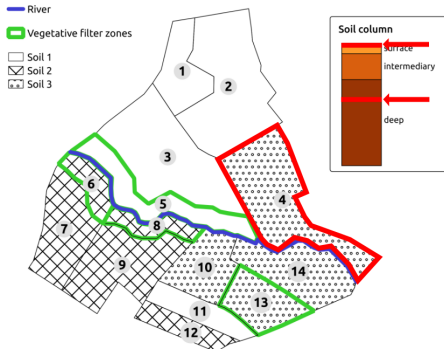
- ✓ 50 members
- ✓ Ensemble spread by perturbing the 145 input parameters

DEnKF set-up

- ✓ State vector dimension : 316 (will increase ++ for real case application)
- ✓ No inflation

Results

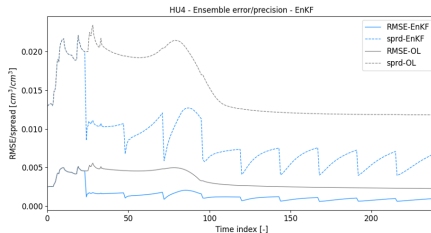
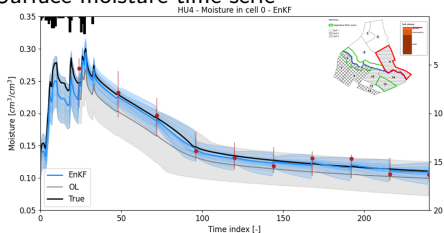
EnKF vs ES



Results

EnKF vs ES

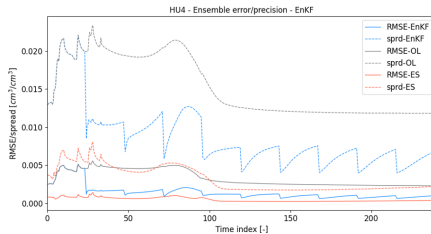
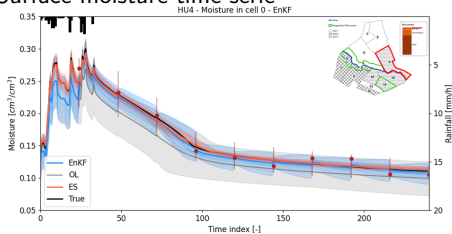
Surface moisture time serie



Results

EnKF vs ES

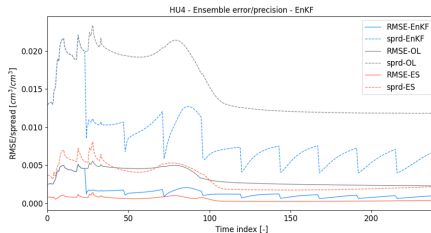
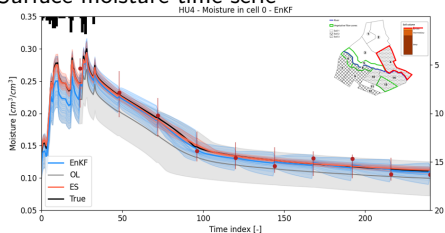
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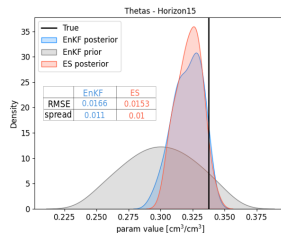
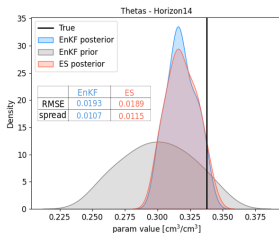
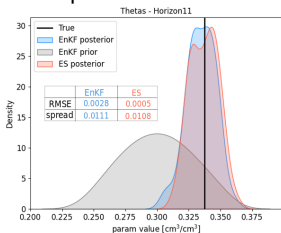
Results

EnKF vs ES

Surface moisture time serie



Surface parameters

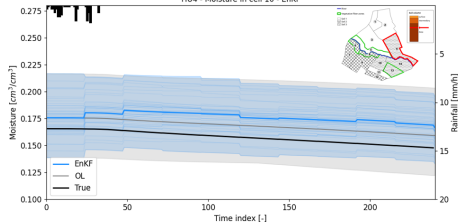


Results

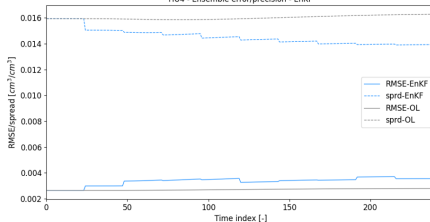
EnKF-subsurface

Subsurface moisture time serie

HU4 - Moisture in cell 10 - EnKF



HU4 - Ensemble error/precision - EnKF

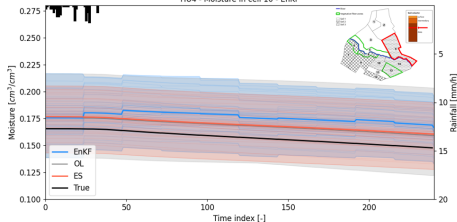


Results

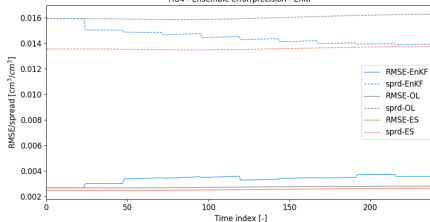
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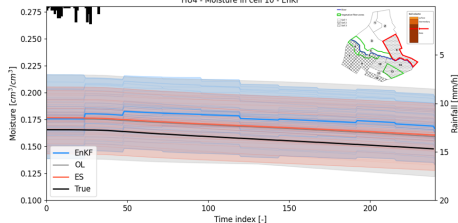


Results

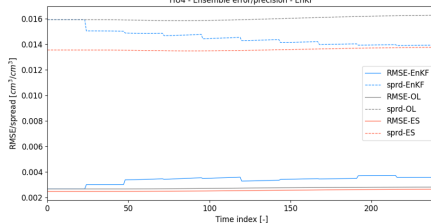
EnKF-subsurface

Subsurface moisture time series

HU4 - Moisture in cell 10 - EnKF



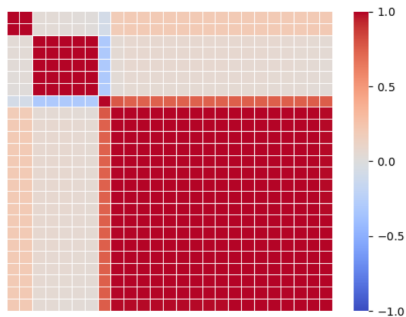
HU4 - Ensemble error/precision - EnKF



⇒ No strong effect of DA to correct moisture in subsurface compartment

Results

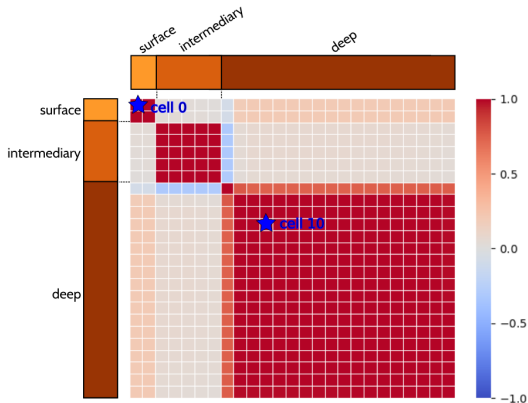
Correlation matrix - extract



*Extract of the ensemble correlation matrix for
numerical cells from plot 14 at time 24h*

Results

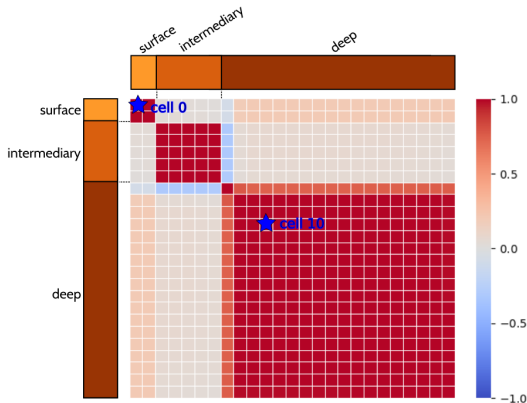
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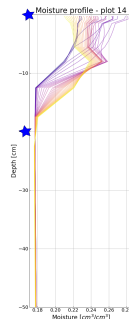
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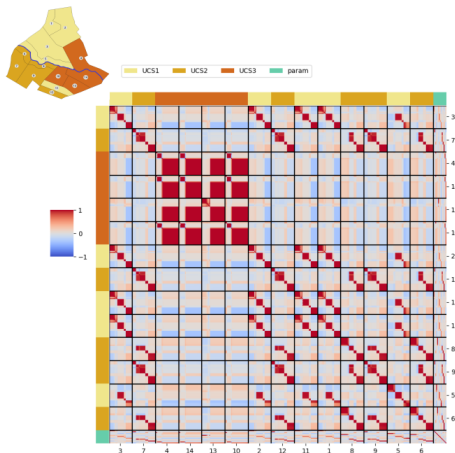
Extract of the ensemble correlation matrix for numerical cells from plot 14 at time 24h

No correlation can be established between surface and subsurface. Dynamics strongly differs between the model compartments.



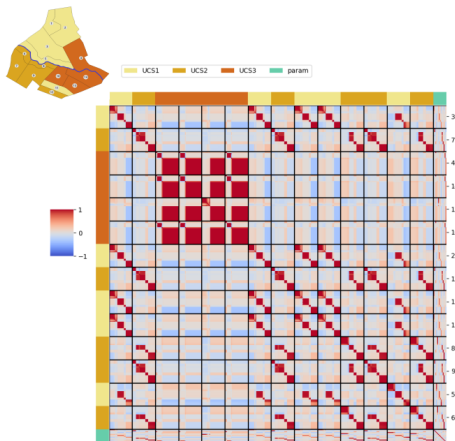
Results

Full correlation matrix



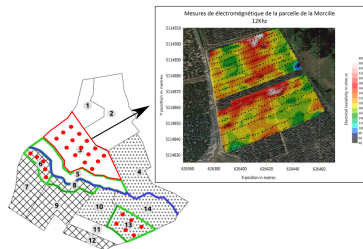
Results

Full correlation matrix



Ponctual moisture observations in subsurface may improve DA performances.

Next step: try and integrate field measurements from Electrical Resistivity Tomography (ERT)



Accounting for observation error correlation

Strategy

Available data sources: satellite surface moisture images + ponctual ERT measurements: both affected by spatial correlations of error

⚠ Spatial correlations are often ignored ($\mathbf{R}$ treated as diagonal matrix): may lead to unsatisfactory DA performances (Stewart, Dance, and Nichols 2013; Chabot et al. 2015)

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⇒ Chabot et al. 2015; Chabot, Nodet, and Vidard 2020: use of **multiscale transformations** (Fourier, wavelet,...)

Accounting for observation error correlation

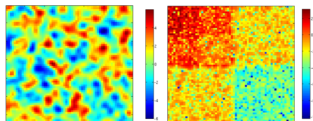
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⇒ Chabot et al. 2015; Chabot, Nodet, and Vidard 2020: use of **multiscale transformations** (Fourier, wavelet,...)

Allows for parcimonious representation of the signal + description of noise influence on structures instead of pixels



Left: correlated white noise. Right: decomposition of the noise in a wavelet space with three scales. From Chabot et al. (2020)

Accounting for observation error correlations

Technical implementation

- ✓ Obs is described by its coefficients in the wavelet basis by wavelet operator $\mathbf{W}$: $\mathbf{y}_w = \mathbf{W}\mathbf{y}$
- ✓ Error covariance matrix can be approximated by a diagonal matrix $\mathbf{D}_w$ in this new basis. A change of variable is performed :

$$\mathbf{D}_w = \mathbf{W}^T \mathbf{R} \mathbf{W}$$

where $\mathbf{W}$ gathers the wavelet coefficients.

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DEnKF Analysis scheme is re-written:

$$\mathbf{x}^a = \bar{\mathbf{x}}^f + \mathbf{X}^f \mathbf{w}^a$$

$$\begin{aligned} \text{with } \mathbf{w}^a &= (\mathbf{I}_m + \mathbf{Y}_f^T \mathbf{R}^{-1} \mathbf{Y}_f)^{-1} \mathbf{Y}_f^T \mathbf{R}^{-1} \delta \\ &= (\mathbf{I}_m + (\mathbf{W} \mathbf{Y}_f)^T \mathbf{D}_w^{-1} (\mathbf{W} \mathbf{Y}_f))^{-1} (\mathbf{W} \mathbf{Y}_f)^T \mathbf{D}_w^{-1} (\mathbf{W} \delta) \end{aligned}$$

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⇒ Should lead to affordable additional computational cost (Chabot, Nodet, and Vidard 2020)

Conclusion

- ✓ On-going development of a DA framework based on ensemble methods in the PESHMELBA coupled model.
- ✓ Assimilating surface moisture images allows for satisfying correction of surface moisture variable and surface parameters estimation
- ✓ Correction does not propagate towards subsurface component
- ✓ **Next step (1):** integration of ERT measurements may improve DA performances for the subsurface
- ✓ **Next step (2):** wavelet transformation to account for observation error spatial correlations (satellite images and ERT measurement)