HGS-PDAF v1.0 (I)

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Introduction to a real-time DA framework for an integrated hydrological model: HGS-PDAF

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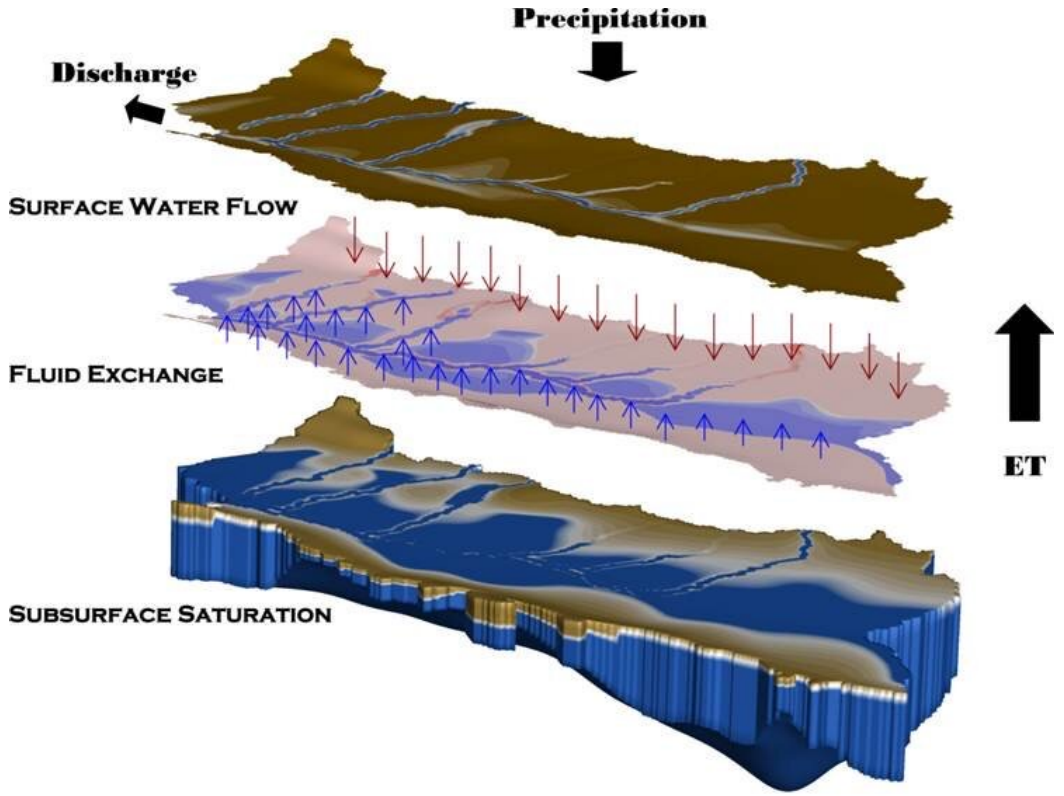
Integrated hydrological model: HydroGeoSphere



From Aquanty Inc., https://www.aquanty.com/

- Unstructured finite-element grids
- Surface domain: 2-D overland flow, *diffusion-wave approximation*
- Subsurface domain: 3-D variably saturated flow, *Richards' equation*
- Flow coupling between surface and subsurface: common node approach/ dual node approach
- Two-way coupling
- Simulation of heat and solute transport

Hydrological model and data assimilation software

HGS

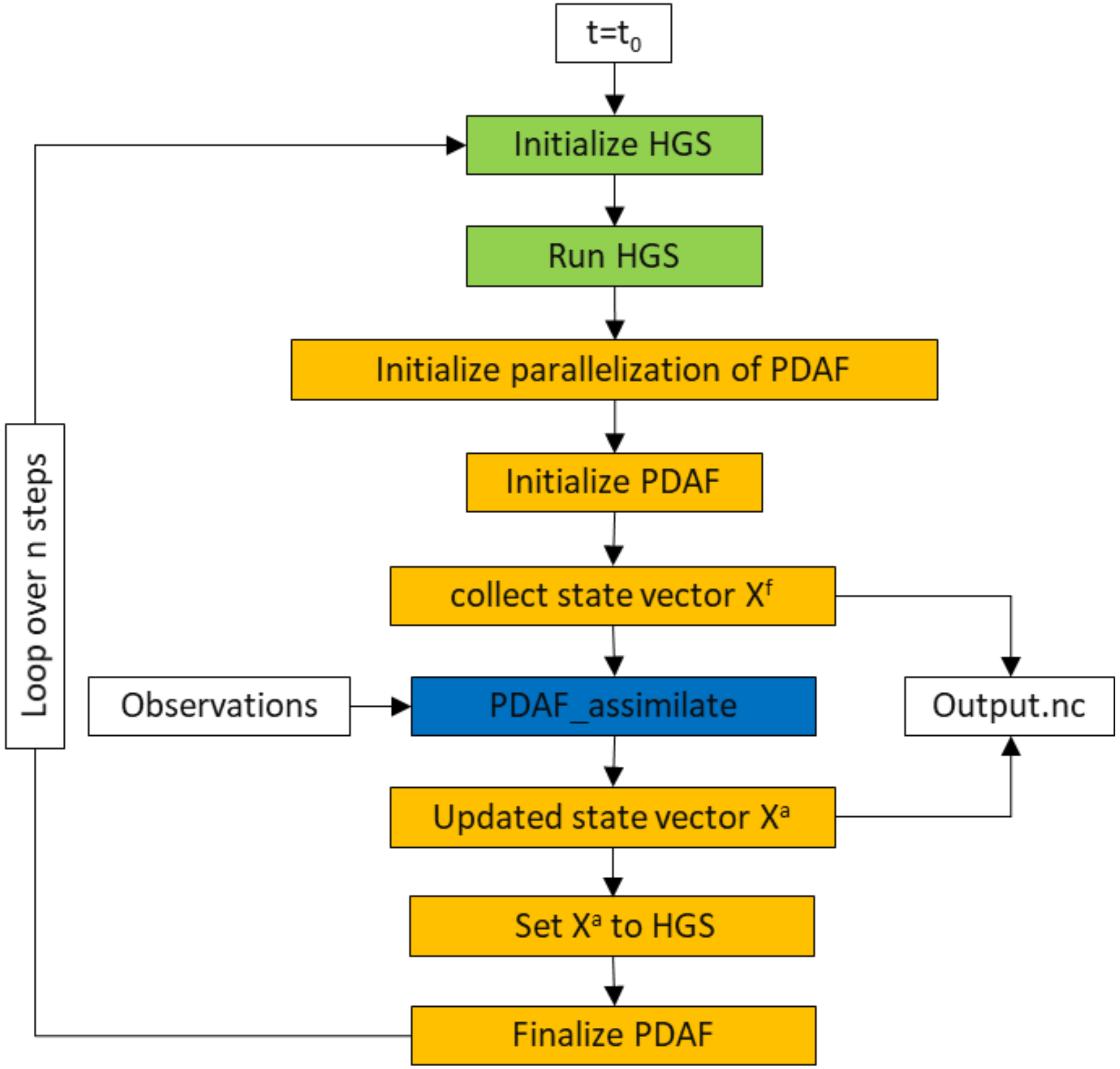
- Physically based fully integrated hydrological model
- Agricultural infrastructures can be explicitly simulated
- Different soil and crop types are considered

PDAF Parallel Data Assimilation Framework

- Ensemble and variational assimilation algorithms
- fully-implemented & parallelize
- Open source and model independent

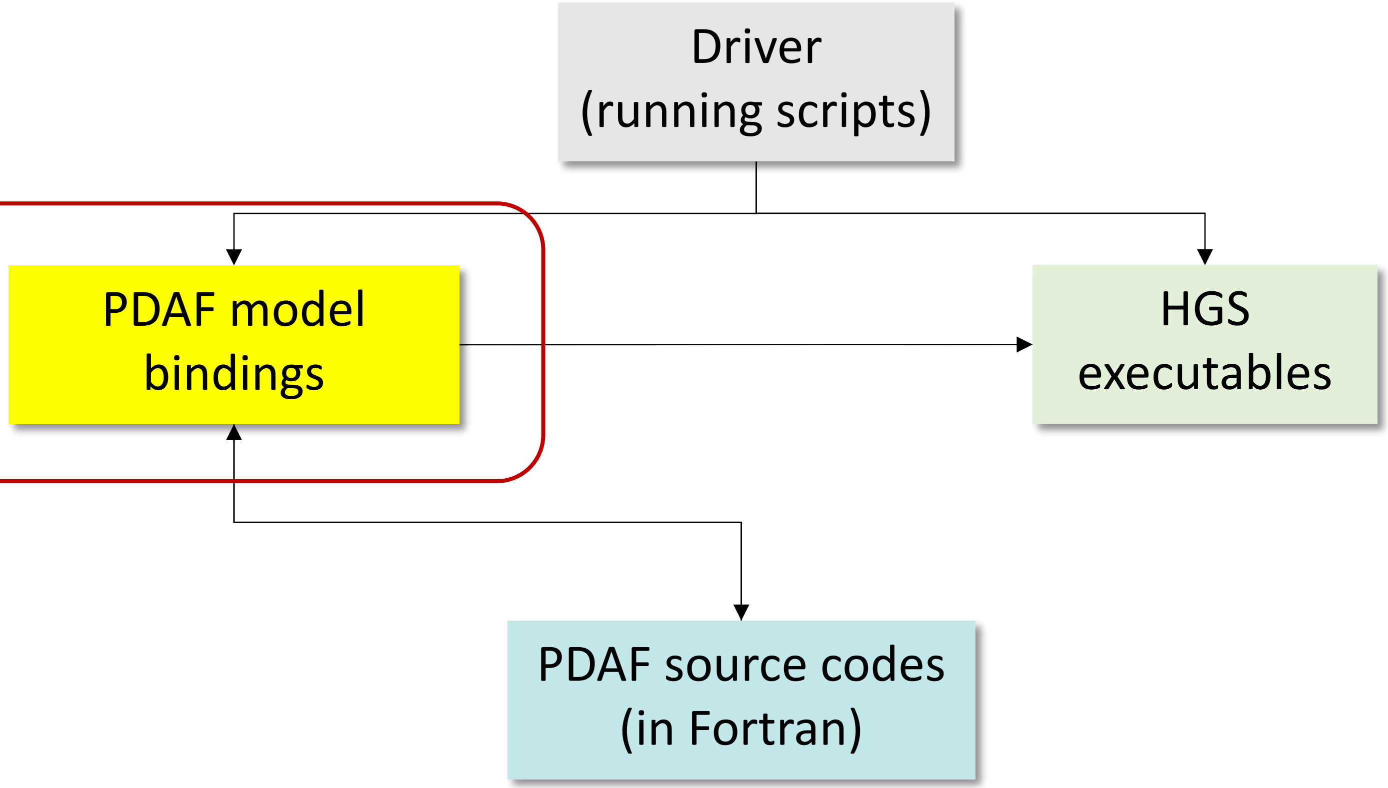
WATERAGRI

HGS-PDAF - Flowchart



HGS-PDAF

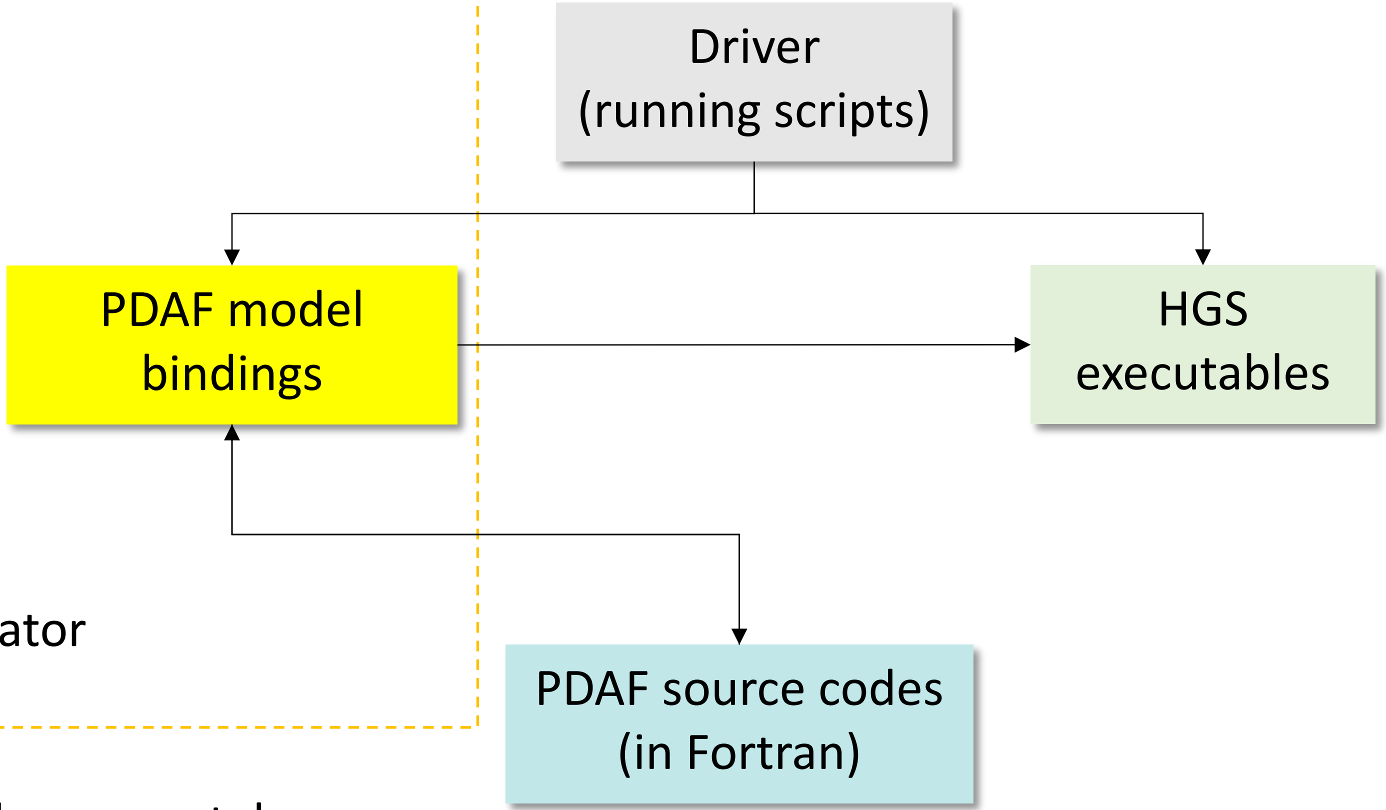
- Four components:
  - HGS executables
  - PDAF source code
  - Model bindings: a set of user-specified subroutines acting as an interface to the PDAF source code
  - Driver: run scripts to manage the data assimilation simulation runs, written in bash and python



- HGS and model bindings are called by the Driver
- PDAF library is complied independently
- PDAF is called within modeling bindings

HGS-PDAF

- For each ensemble state
  - Initialize from restart files
  - Integrate
  - Write restart files
  - Read restart files (ensemble)
  - Compute analysis step
  - Write new restart files
- For each observation type
  - Independent observation operator module



- DA results are stored in netCDF files separately
- Pre-/Post- processing tools for dealing with raw observation data and results analysis are also included in the package

HGS-PDAF

- State vector: updated directly through DA
  - Hydraulic head
  - Hydraulic conductivity (K)
  - Water saturation
  - Noble gas concentration (^{222}Rn, ^{37}Ar, and ^{4}He)
- Observations: used to assimilate
  - Piezometric heads
  - Water saturation
  - Noble gas concentration (^{222}Rn, ^{37}Ar, and ^{4}He)

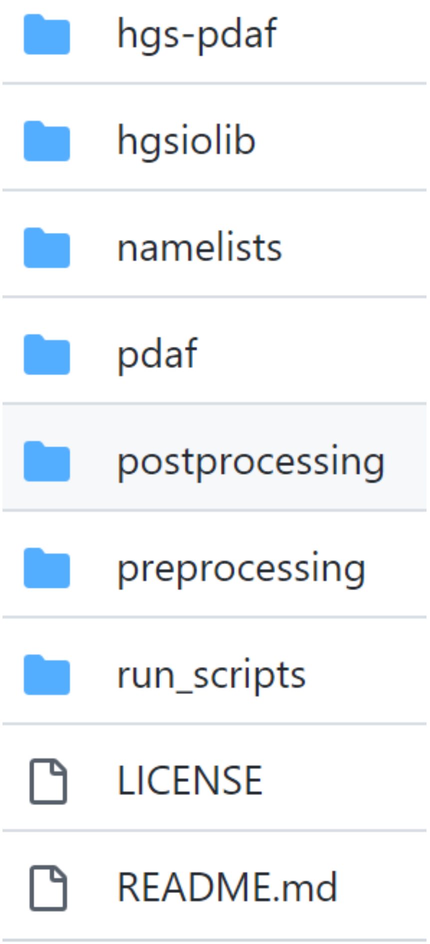
Done, tested

Done, testing

- Multiple types of observations can be assimilated separately or jointly
- The combination of variables in the state vector can be flexible

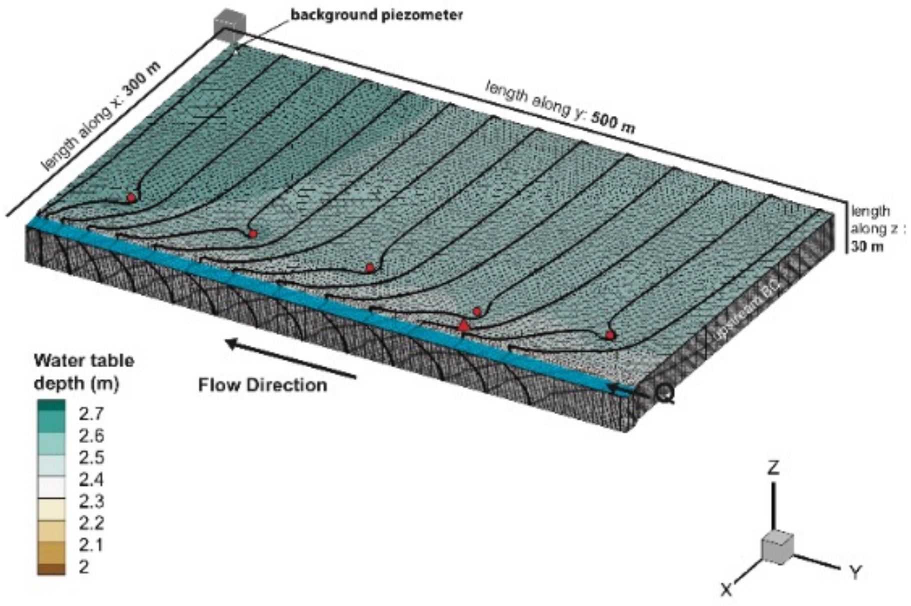
HGS-PDAF

Github repository https://github.com/qiqi1023t/HGS-PDAF_v1.0_GMD



- hgs-pdaf: model bindings, under development
- hgsiolib: routines to read and write HGS original output written in Fortran
- namelists file: namelist files where parameters used by PDAF & HGS are defined
- pdaf: PDAF source code
- Postprocessing: Python script to visualize DA output
- Preprocessing: routines to prepare the observation written in Fortran
- Run_scripts: bash script to manage the data assimilation simulation runs
- LICENSE
- README.md

Example: simplified conceptual model

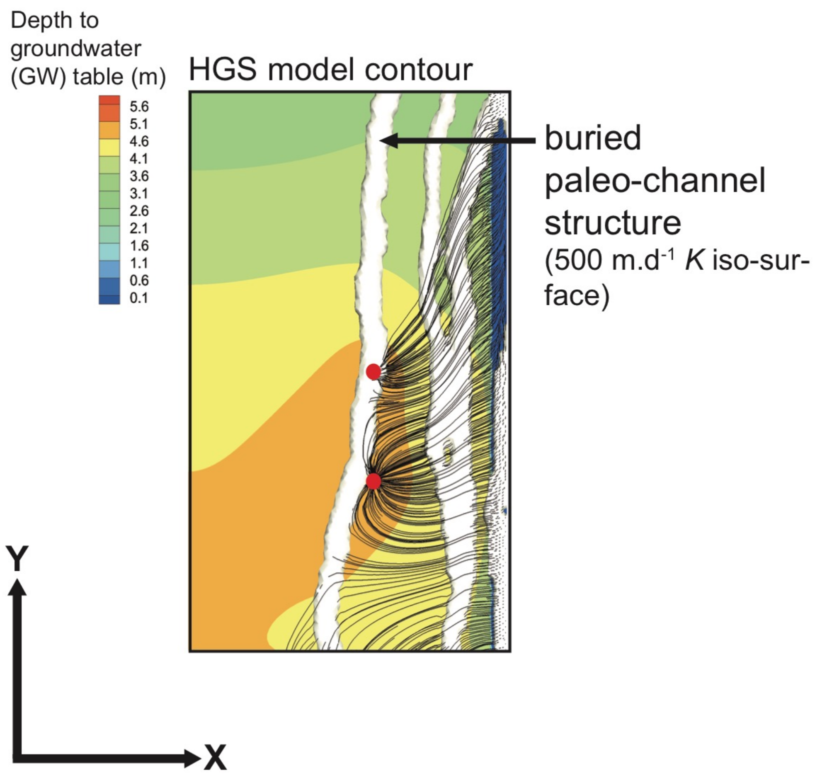


Delottier et al., 2022

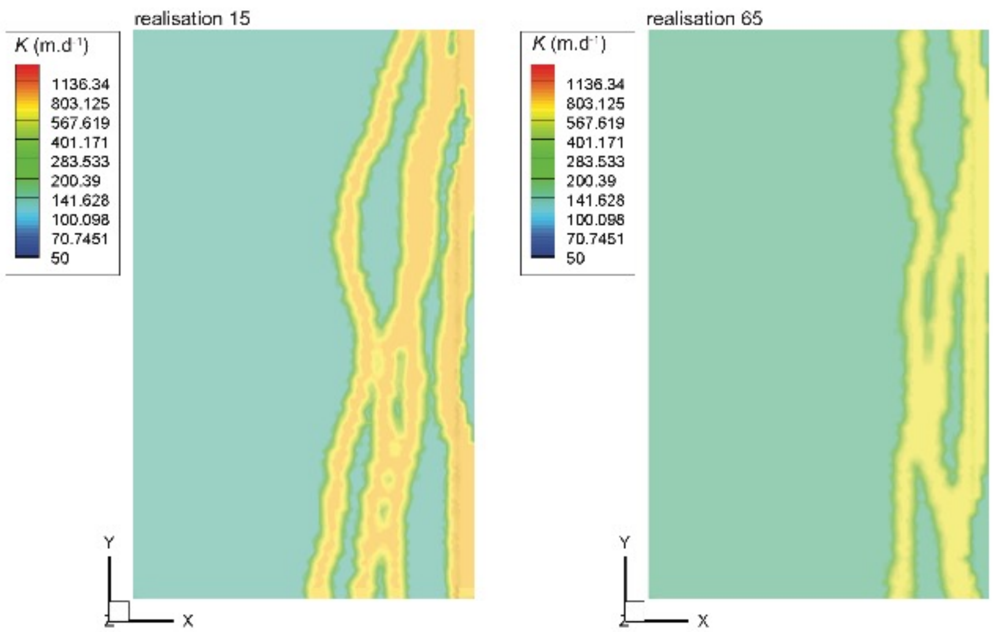
- 3-D rectangular synthetic alluvial plain model
- Ideally suited to develop and test the integration of DA to HGS.
- 500 m length, 300 m width and 30m depth alluvial plain, discretized into 544,000 model elements in total.
- 20 m wide and 2 m deep stream
- A river is placed on top of the model layer

Example: simplified conceptual model

- Heterogeneity of such systems in reality is characterized by continuous categorical structures
- parameter fields like the hydraulic conductivity (K) has been parameterized following these categorical features

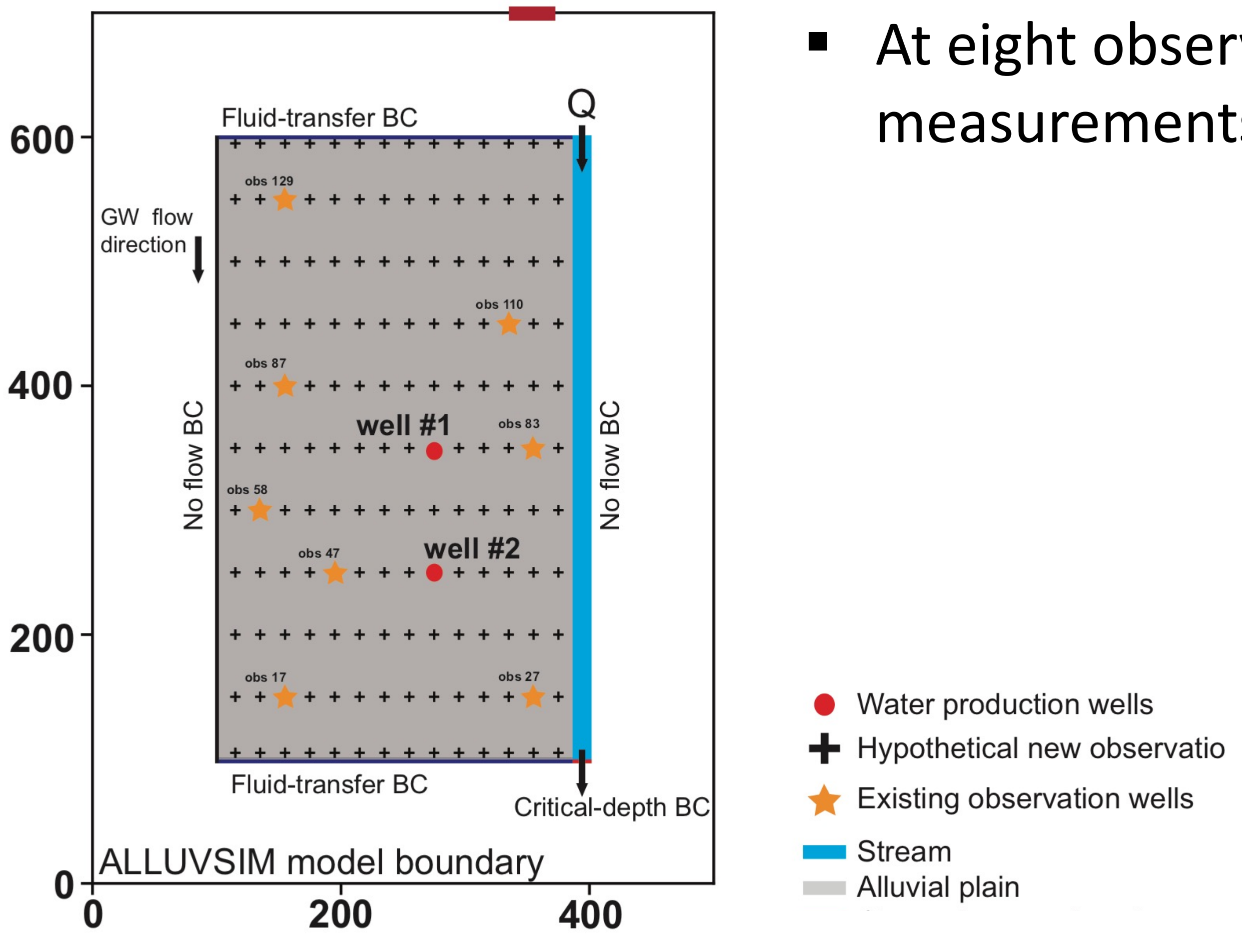


Two examples of the heterogeneous K fields used in the model

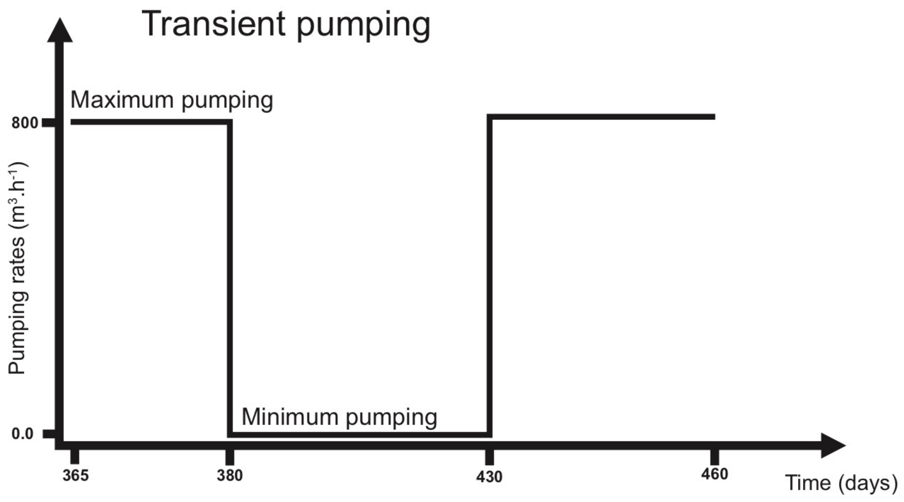


Example: simplified conceptual model

Model boundary conditions



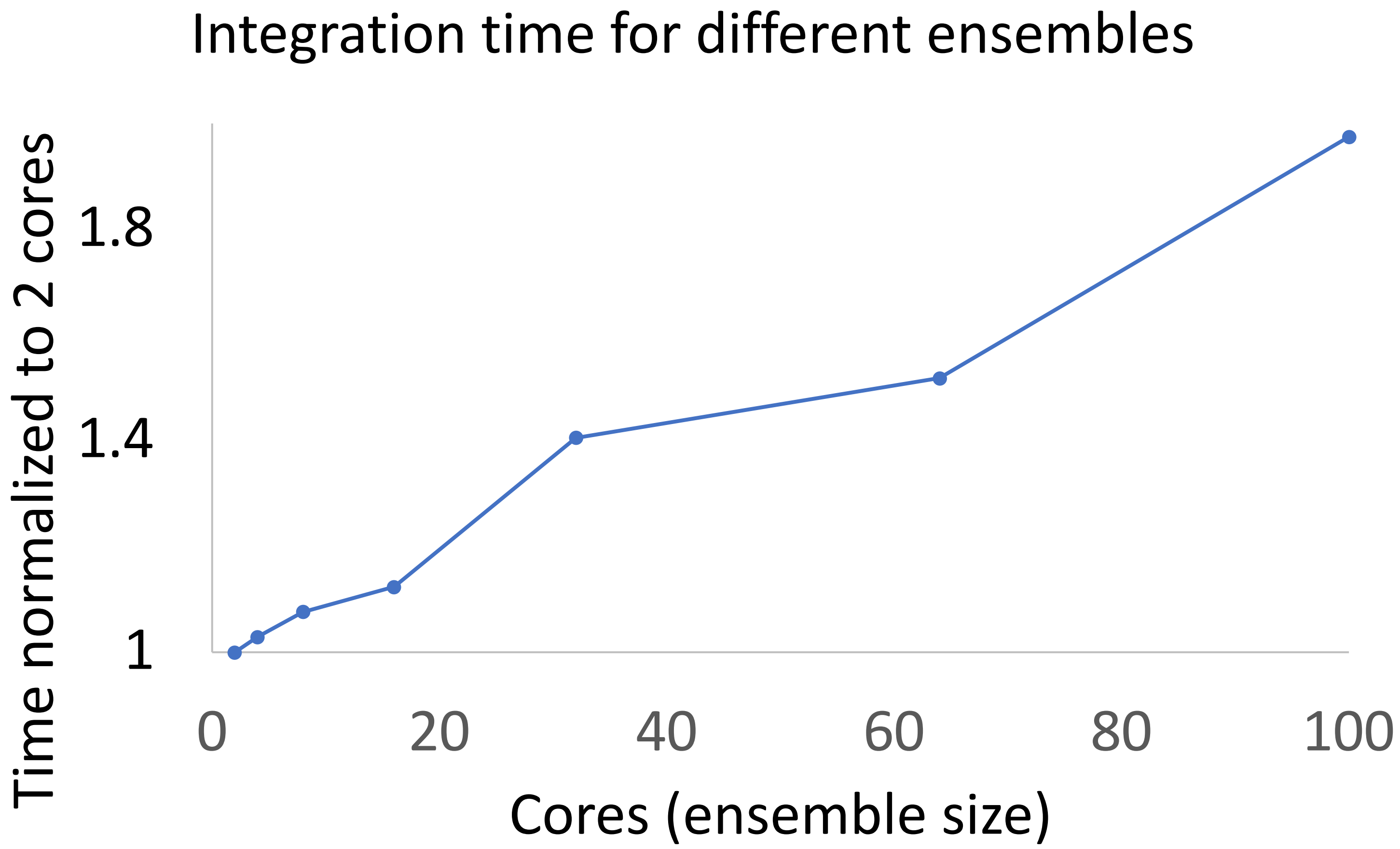
- At eight observation points synthetic hydraulic head measurements have been generated and assimilated



Example: data assimilation experiments

- Observation:
  - Heads
  - groundwater saturation
- Observation error
  - 5cm for heads
  - 1% for saturation
- Ensemble size: 100
- Assimilation method: EnKF, no localisation
- Simulation/Assimilation period: 96 days
- Assimilation frequency: 1 day
- Inflation: for parameter udpate

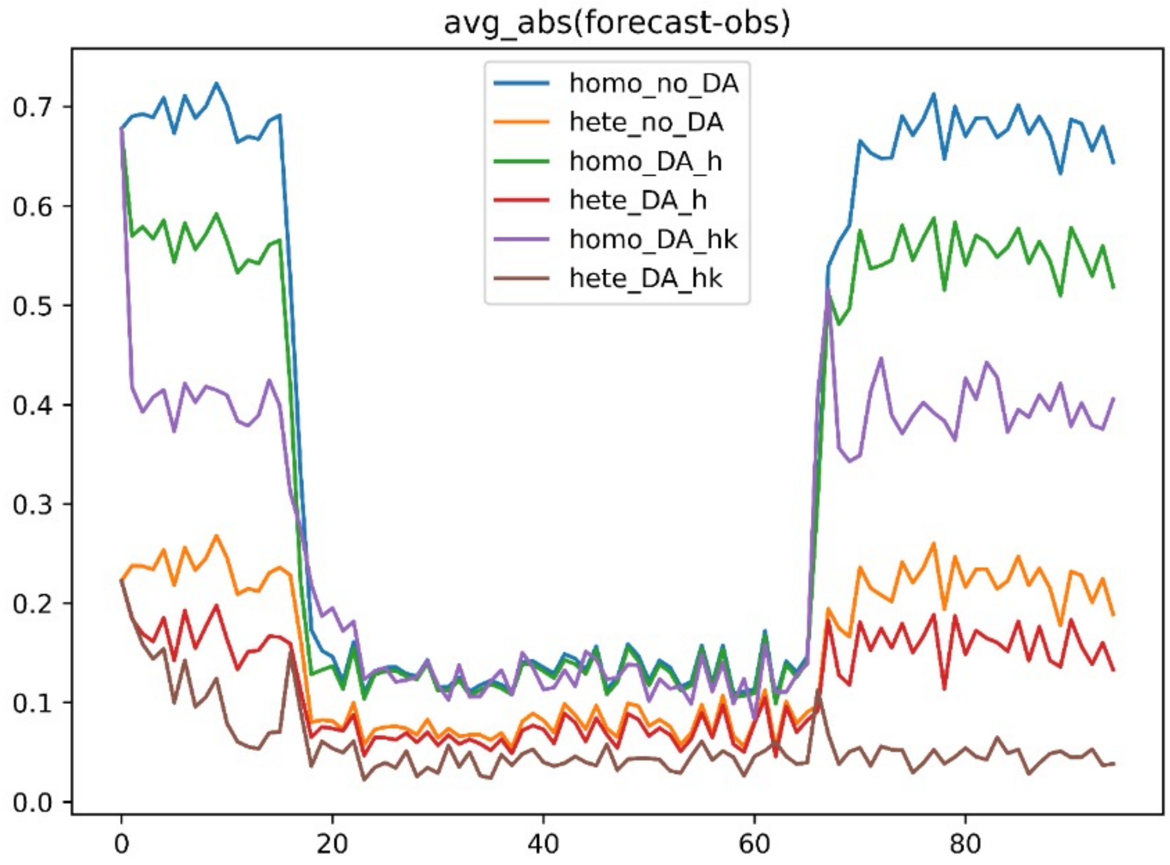
Scalability of HGS-PDAF



The execution time increases by about *50%*

Data assimilation experiments: results

average absolute difference between the simulated and observed heads (calculated over 8 observation points)



- Errors are higher for all simulation runs in the pumping period (first 15 days) than in the no-pumping period (after 15 days), especially for the free run with homogeneous parameter fields
- With DA, the errors are reduced by 40% for the homogeneous case in the pumping period
- The improvement is even larger for the heterogeneous case with a reduction of up to 90%
- In the non-pumping period, no improvement is observed for the homogeneous case while for the heterogeneous case the improvement is 60%.

Summary

- A coupled DA framework has been developed and tested for the ISSHM HGS which allows:
  - Assimilation of multiple type of observations
  - Joint state-parameter estimate
  - For both the flow and solution transport simulation
- The performance of HGS-PDAF has been tested with a synthetic alluvial plain model. The states of the model are reasonably well constrained by data assimilation, in particular during the pumping period.

Enjoy it!

Feel free to contact us if you need any help:

Email: qi.tang@unine.ch

Or write directly on GitHub!