Grid simplification to accelerate calibration of integrated catchment models: Accuracy vs. efficiency

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Integrated Catchment Model

Description

PDE-based models, which couple surface flow and variably-saturated subsurface flow

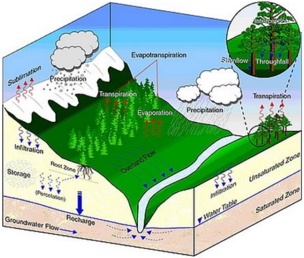


Figure: IRTG,2014

Pro and Con

- simulate spatially distributed, coupled surface-subsurface interactions
- can model changes in environmental conditions (Perez,2011)

But

- Long simulation times
- Results in a long and tedious calibration process

Problem and Proposed Solution

Fact: The grid resolution largely determines the length of the simulation (Vazquez,2002).

Problem: Model calibration of integrated catchment models is very slow (Li, 2008).

Proposed calibration method: Using grids of lower spatial resolution during model calibration.

Challenge: Discretization errors of the coarser grids.

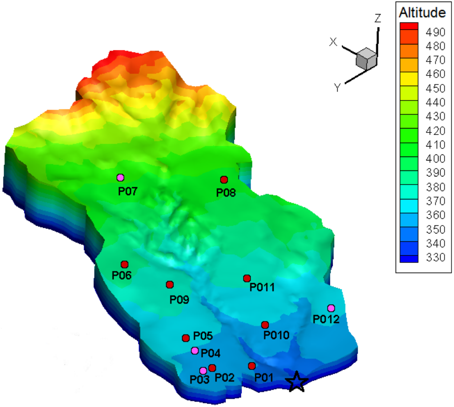
Proposed calibration method

- Set up and comparison of three computational grids:
  - a fine grid used in the final model,
  - an intermediate grid
  - a coarse grid
- Constraining the feasible parameter space using the coarse grid
- Calibration of model parameters on the intermediate grid
- Transfer of the model parameters to the fine grid
- Model validation and evaluation

Case study: Lerma's basin

Country: Spain

Area: 7.5 km^2
Altitude: 330-490m a.s.l.
Land-use: Agriculture
Irrigation: Increase (from 0 $\frac{m^3}{year}$ in 2005 to $1.8 \cdot 10^6$ $\frac{m^3}{year}$ in 2008)



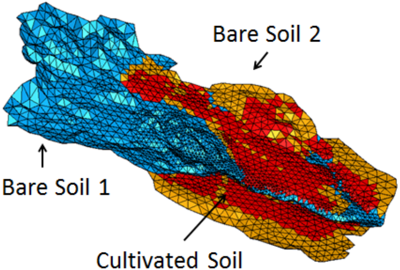
Black star: Position of the catchment outlet
Red or magenta circles: Position of the wells
Vertical exaggeration: 5x

HydroGeoSphere

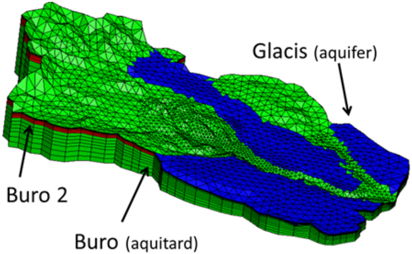
- 3-dimensional, fully coupled hydrological model
- Surface flow: 2D diffusive wave approximation of the Saint Venant equations
- Variably saturated subsurface flow: Richards equation
- Developed at the university of Waterloo, Canada and by aquanty.

Model Design

Soil zones

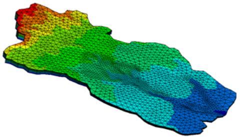


Porous media

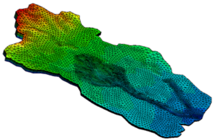


Computational Grids

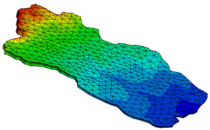
Fine reference grid



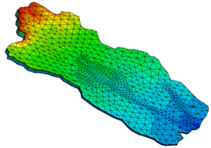
Very fine grid for verification



Coarse grid for pre-calibration

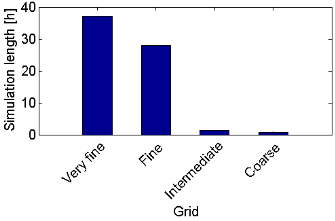


Intermediate grid for calibration



Grid	Elements	Layers
Coarse	10448	14
Interm.	16200	14
Fine	79332	22
Very fine	217872	24

Simulation time:



Hydrogeological units are identical for all grids

For one year on one core with a desktop computer Intel Core i7-2600 CPU @ 3.40Ghz

Grid Comparison

Method:

- Use of 4 parameter sets and 2 artificial initial conditions.
- Comparison of flow hydrograph, hydraulic heads and soil saturation
- Meteorological input from 2009

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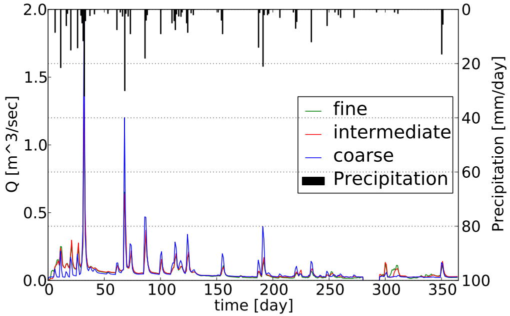
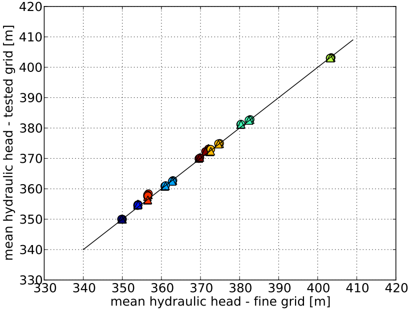
Hydrograph Comparison:

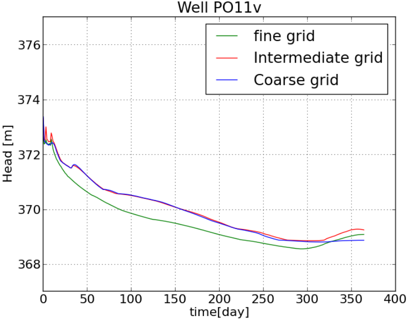


Param. set	1	2	3	4
Nash eff.	0.98	0.93	0.96	0.98
RMSE [%]	1.4	2.6	1.9	1.5

between the fine and intermediate grid

Hydraulic Heads Comparison

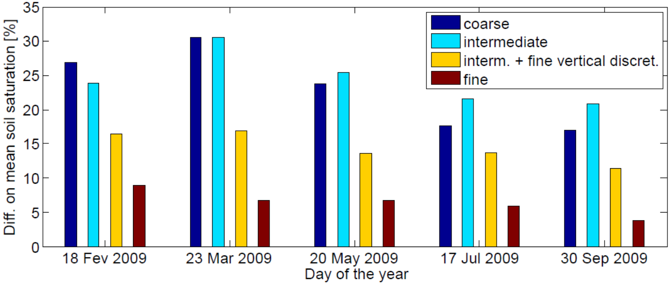




Parameter set 1

Water Saturation

Comparison of mean water saturation of top soil (depth: 0-40cm) between the very fine grid and the other grids:



Water saturation is significantly higher in the coarse and intermediate grid than in the very fine grid.
Due to non-linearities in the modeling of transpiration.

Calibration and Validation Data

Calibration:

- Daily flow at the catchment outlet (2006-2009)
- Monthly hydraulic head at 8 observation wells (2008-2009)

Validation:

- Daily flow at the catchment outlet (2010-2011)
- Monthly hydraulic head at 14 observation wells (2010-2011)

Sensitivity Analysis

Among the 42 parameters tested, the most sensitive parameters were:

Most sensitive parameters

• Saturated hydraulic conductivity K	for all zones	(6)
• Pore-size factor n (Van Genuchten)	for the soil zones	(3)
• Porosity	in the glacis or aquifer	(1)

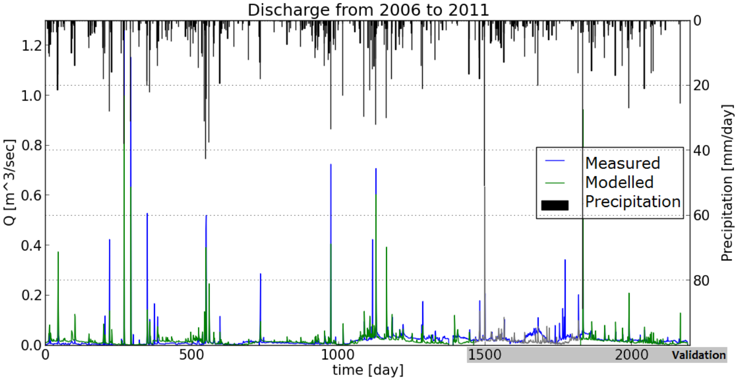
As a result: 10 parameters will be calibrated

tested for the meteorological input of 2008 on the intermediate grid with the initial conditions of the calibrated model.

Calibration Procedure

1. Test 200 parameter sets on the coarse grid with an initially saturated domain.
2. Update the initial conditions, using the best performing parameter set and the intermediate grid.
3. Manually calibrate the model on the intermediate grid.
4. Update the initial conditions on the intermediate grid. Transfer them to the fine grid.
5. Finish the manual calibration on the fine grid.

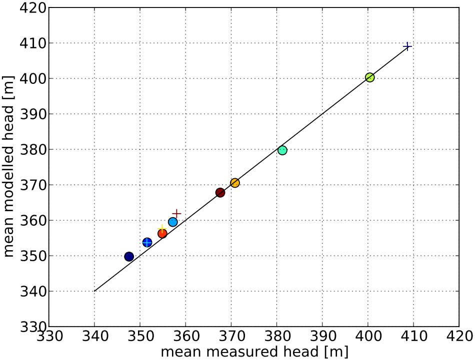
Hydrograph: Calibration and Validation



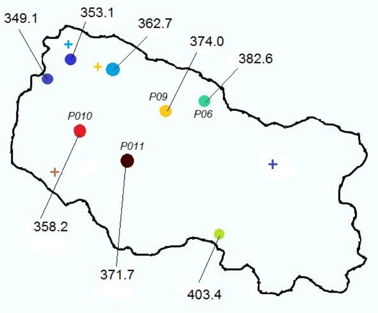
Calibration NSE: 0.74 RMSE: 3.16 %

Validation NSE: 0.92 RMSE: 1.36 %

Calibrated Hydraulic Head - Mean

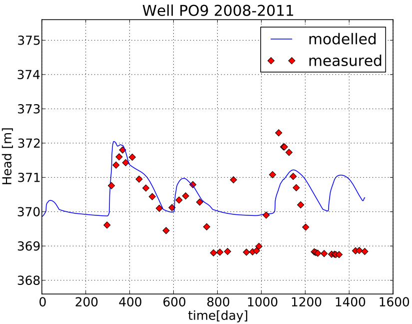


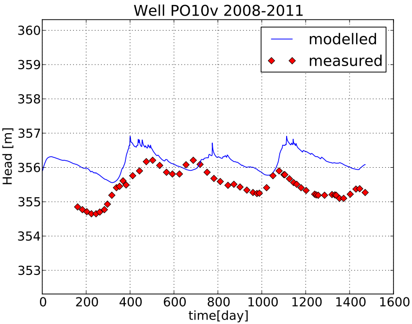
Position of the wells



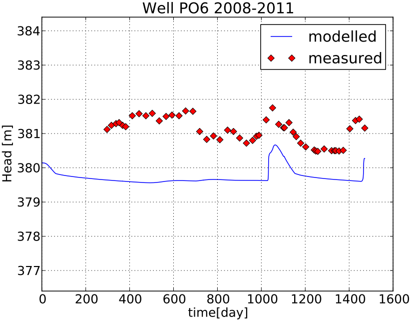
Position and surface elevation of the wells [meter].
Mean: 2008-2011 (circle) or 2010-2011 (cross)

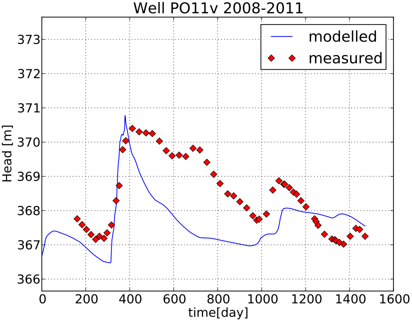
Calibrated Head - Variability I





Calibrated Head - Variability II





Approximate duration of the calibration

Conventionally:

- Initial conditions: 100 years of simulation = 28'000h
- Manual Calibration: 70 sets · 6 years =11'300h

Using the fine grid

TOTAL: 39'000h or **1625 days**

Proposed Approach:

- Initial calibration on the coarse grid: 200·6years =800h
- Initial conditions on the intermediate grid: 100years = 150h
- Manual calibration on the intermediate grid: 70·6 years =630h
- Update of the initial conditions: 70years = 105h
- Final calibration on the fine grid: 6 years · 3 = 480h

TOTAL: 2165h or **90 days**

Conclusion

- Using grids of various size is a practical solution to accelerate model calibration in integrated models.
- It also simplifies the obtention of the initial conditions.
- This approach was successfully tested in our catchment-scale case study.
- It might be easily adapted for reactive transport problems or for automatic calibration.

Reference

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3. Vazquez,2002: Vazquez, R. F., Feyen, L., Feyen, J., Refsgaard, J. C, *Effect of grid size on effective parameters and model performance of the MIKE -SHE code. Hydrological Processes*, 16:355-372, 2002
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Thank you for your attention

Any question?

Additional Slide

Parameter Set		Param. 1	Param. 2	Param. 3	Param. 4
Bare Soil 1	K	$1.5 * 10^{-5}$	$5 * 10^{-5}$	$1.5 * 10^{-5}$	$1.5 * 10^{-5}$
	α	3	5	3	3
	β	2.25	2	1.5	2.25
Bare Soil 2	K	10^{-5}	10^{-4}	$1.5 * 10^{-5}$	10^{-5}
	α	2	5	3	2
	β	1.35	2	1.5	1.35
Cultivated Soil	K	$2 * 10^{-5}$	$4 * 10^{-5}$	$1.5 * 10^{-5}$	$2 * 10^{-5}$
	α	2	5	3	2
	β	1.25	2	1.5	1.25
Glacis	K	0.0002	$2 * 10^{-6}$	$1.5 * 10^{-5}$	0.0002
	α	2	5	3	2
	β	1.5	2	1.5	1.5
Buro 2	K	10^{-6}	10^{-5}	10^{-5}	10^{-6}
	α	5	5	3	5
	β	1.4	2	1.5	1.4
Buro	K	$5 * 10^{-7}$	10^{-7}	10^{-7}	10^{-7}
	α	3	5	3	3
	β	1.8	2	1.5	1.8
Initial head		Surface	Surface	West: 380m East: Surface	West: 380m East: Surface

Additional Slide

Parameter Set 3: