Parallelizing SWAT Calibration in Windows using SUFI2 Program,

Lessons learned from Black Sea Catchment study

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Introduction to the Black sea project

BSC SWAT model
  - model set up
  - complication regarding river flows

Calibration
  - Calibration Set up
  - Iteration 1 (rough decisions)
  - Iteration 2
    a) parallelization
    b) parameterization
I. Black Sea Catchment
The project aims at building:

- A high resolution calibrated water quantity and water quality model for the entire region accounting for agricultural activities and point source pollutions using SWAT.
- **Major challenges in calibration process**
  - Lack of sufficient data
  - Large scale application
  - Calibration run time
  - Water managements in the basin
  - Inaccurate data (gauge locations)
  - Flow directions
  - Glacier and snow parameters
II. SWAT model of the Black Sea basin
• Arc SWAT 2009.93.7 was used to parametrize the whole area

• 2 Mkm² drainage area

• 12982 subbasins

• 89202 Hrus

• About 600,000 SWAT input files

• CRU data sets were used as weather data

• Agricultural management for three major crops: wheat, Maize and Barely.

• ET Calculation based on Hargreaves Method

• Daily step SWAT run

• 36 yrs of simulation, 3 yrs warm up period (1970-2006)
Basin, Subbasin, Hrus
Complication in flow directions
Imprisice Basin mask or wrong rivers!
III. Calibration Of the hydrologic model of the Black sea basin
- SWAT Cup, SUFI2
SUFI-2 algorithm

- Uncertainty
  - Attributed to parameters
  - Obtained by calibrating a set of parameter ranges against observed data (priors → posteriors)
  - Characterised by 95% prediction uncertainty (95PPU)

- Dual aim:
  - Maxmise P-factor
  - Minimise R-factor

- Process for each calibration iteration
  - Latin hypercube sampling of parameter space, model simulations, objective function evaluation and parameter updating
Observation stations
First run

- 1970- 2006, 3 years warm up period (34 years)
- Discharge (monthly, 125 stations)
- Default parameter
- 1 run- 37 hours
Observation station check_deleted

Calibration_First Run

![Graph and map image]

*Graph and map details for analysis.*
Observation station check_deleted
Observation station check_deleted

![Graph](image)
Observation station check_ kept to apply Elev band
Observation station check_deleted
Observation station check_dislocation

Calibration_First Run

q_10565

q_10524

q_10524

q_10524
A few good stations

q_7477

q_7635

q_9393
A few good satations

q_9687

q_11021
Iteration 1

- Calibration and evaluation
  - 1970-2006, 3 years warm up period,
  - 34 years calibration
  - Discharge (monthly, 87)

- Parameter selected based on sensitivity analysis
  → 23 parameters sensitive to flow, global parameters, not parameterized yet

- Initial parameter ranges from physically meaningful limits

- New ranges based on parameterization with highest objective function

200 runs (Estimated run time in a single machine → 350 days!!)

Parameter selected based on sensitivity analysis

23 : Number of Parameters
200 : number of simulations

```
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<thead>
<tr>
<th>Parameter</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
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<tbody>
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<td>r_CN2.mgt</td>
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<td>0.4</td>
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<tr>
<td>r_SOL_AWC(1).sol</td>
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<td>0.2</td>
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<tr>
<td>v_ESCO.hru</td>
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<td>0.8</td>
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<tr>
<td>v_GWQMN.gw</td>
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<td>1000</td>
</tr>
<tr>
<td>v_GW_REVAP.gw</td>
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<td>0.1</td>
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<tr>
<td>v_REVAPMN.gw</td>
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<td>500</td>
</tr>
<tr>
<td>v_EPCO.hru</td>
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<td>0.5</td>
</tr>
<tr>
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<td>1.0</td>
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<tr>
<td>v_GW_DELAY.gw</td>
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<td>160.0</td>
</tr>
<tr>
<td>v_CH_N2.rte</td>
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<td>0.3</td>
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<tr>
<td>v_CH_K2.rte</td>
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<td>130.0</td>
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<tr>
<td>v_ALPHA_BNK.rte</td>
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<td>1.0</td>
</tr>
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<td>0.8</td>
</tr>
<tr>
<td>r_SOL_BD(1).sol</td>
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<td>0.6</td>
</tr>
<tr>
<td>v_SFTMP.bsn</td>
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<td>5.0</td>
</tr>
<tr>
<td>v_SMTMP.bsn</td>
<td>-5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>v_SMFMX.bsn</td>
<td>0.0</td>
<td>10.0</td>
</tr>
<tr>
<td>v_SMFMN.bsn</td>
<td>0.0</td>
<td>10.0</td>
</tr>
<tr>
<td>v_PLAPS.sub</td>
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<td>10</td>
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<tr>
<td>v_TLAPS.sub</td>
<td>-10</td>
<td>-6</td>
</tr>
<tr>
<td>r_OV_N.hru</td>
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<td>0.3</td>
</tr>
<tr>
<td>r_HRU_SLP.hru</td>
<td>-0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>r_SLSUBBSN.hru</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>
```
Running time issue

Copy all files in TxtInOut to BACKUP directory

SUFI2_LH_sample.exe
par_val.txt

par_inf.txt
SUFI2_new_pars.exe

no. of parallel processes

SUFI2_extract_*.def

Modified SWAT inputs

SWAT_Edit.exe

swat2009.exe

SWAT outputs

SUFI2_extract_*.exe

*.out

observed.txt

*.out

SUFI2_goal_fn.exe
goal.txt

SUFI2_95ppu.exe
95ppu.txt

Is calibration criteria satisfied?

yes

stop

no
o parallel Sufi2 Speed up tested in Different projects

More details:
o parallel Sufi2 Efficiency tested in Different projects

More details:
parallel Sufi2 Efficiency tested in Different projects

More details:
CERN super computer center
Gridification on CERN Grids
Gridification scheme

200 runs using the parallel processing and Grid infrastructure → 8 days!!

(4 blocks of 50 worker node)
Snow melt, glaciers, elevation band
Model consistently over predicts the flow

- High Surface flow

- Solutions
  - Curve number for different land uses- decrease (CN in *.mgt)
  - Soil available water- increase (SOL_AWC in *.sol)
  - Soil evaporation compensation factor- increase up to 1.0 (ESCO in *.sub)
Model consistently over predicts the flow

- High base flow
- Too little evapotranspiration

- **Solutions**
  - Increase deep percolation loss (adjust threshold depth of water in shallow aquifer required for the base flow to occur) (max 100 mm, GWQMN in *.gw)
  - Increase groundwater revap coefficient (max of 0.4, GW_Revap in *in.gw)
  - Decrease threshold depth of water in shallow aquifer for revap tp occur (min of 0.0, REVAPMN in.gw)
Simulated flow follows the observed pattern but lags the actual flow consistently

- Time of concentration is too long
- Less than actual slope for overland flow
- Over estimated surface roughness
- Snow melt parameters
- Flood routing coefficients

Solutions:

- Increase slope (up to 20%) for overland flow (SLOPE)
- Lower Manning`s roughness coefficient (OV_N)
- Lower the value of overland flow length to 4-10 m, if necessary (SLSUBBSN)
New parameter set

440...... Number of Parameters
500...... number of simulations

- r_CN2.mgt 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- r_SOL_AWC(1).sol 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_ESCO.hru 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_GWQMN.gw 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_GW_REVAP.gw 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_REVAPFMN.gw 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_EPCO.hru 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_ALPHA_BF.gw 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_GW_DELAY.gw 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- r_SOL_K(1).sol 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- r_SOL_BD(1).sol 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_SUB_SFTMP().sno 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_SUB_SMTMP().sno 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_SUB_SMEMX().sno 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- v_SUB_SMFMN().sno 1580,16,24,31,33,35,51,53,54,55,63,64,81,102,104,107,113,142,143,159,162,166,171,172,1
- r_CN2.mgt 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_GWQMN.gw 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_GW_REVAP.gw 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_REVAPFMN.gw 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_ESCO.hru 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_ALPHA_BF.gw 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_GW_DELAY.gw 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- r_SOL_K(1).sol 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- r_SOL_BD(1).sol 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_SUB_SFTMP().sno 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_SUB_SMTMP().sno 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_SUB_SMEMX().sno 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- v_SUB_SMFMN().sno 5013,1,2,3,4,5,10,11,14,17,18,22,23,25,27,28,36,39,40,45,47,58,59,60,68,73,74,75,76,77
- r_CN2.mgt 6174,6069,6073,6075,6076,6081,6091,6094,6101,6102,6104,6105,6115,6149,6158,6159,6168,6
Once the model is calibrated, the impact of climate change and land use change on water resources will be evaluated.
Acknowledgments
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