Runoff simulation in a glacier dominated watershed using semi distributed hydrological model

Kazi Rahman
University of Geneva, Switzerland
kazi.rahman@unige.ch

International SWAT conference, June 2011 Toledo Spain

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RESEARCH BACKGROUND

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40 % of stream runoff is coming from snow and glacier melt in the Rhone valley
[Huss el al. 2009]

In Switzerland, 84 out of 85 glaciers under observation became shorter
[WGMS, 2008]

55 % of Swiss energy from Hydropower.
[Schleiss et al. 2007]

Alarming negative mass balance trend observed in the Rhone Glacier
[Funk et al 2008]

Assessing climate change impact on quantity and quality of water [**www.acqwa.ch**]

RESEARCH QUESTIONS

How well hydrological models (SWAT-RS 3.0) are capable simulating runoff in Upper Rhone River

Taking into account

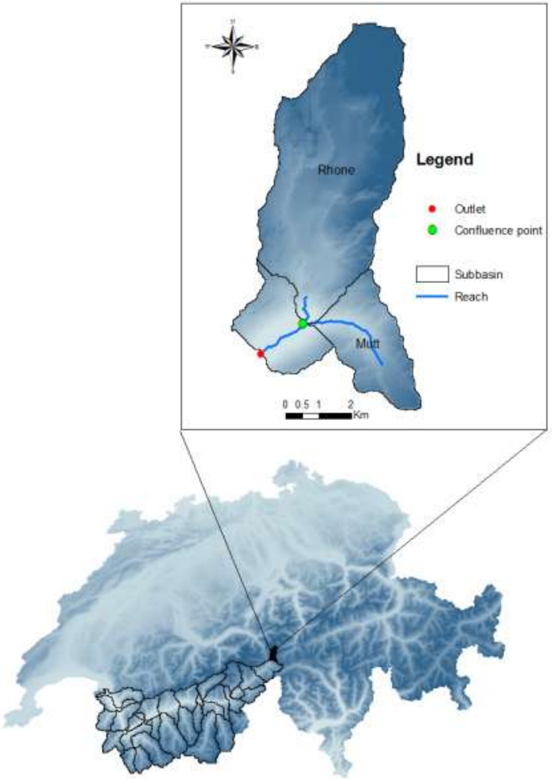
- Glacier
- Orographic Precipitation
- Snow melt

Long term forecast for water status for glacier dominated Upper Rhone watershed

Taking into account

- Climate change scenarios(IPCC, Ensemble/Prudance)
- Energy driven scenarios
- Land use scenarios (EnviroGRID)

STUDY AREA HIGHLIGHTS



Watershed area: 39.60 km^2

Elevation:
min 1758 m
max 3617 m

Land use :
Glacier (48%)
Solid rocks (14%)

STUDY AREA HIGHLIGHTS

DATA USED AND SOURCES

Data type	Data Source
Digital Elevation Model (DEM)	Swiss-topo (grid cell: 25 m · 25 m) www.swisstopo.ch
Land use	FOEN (grid cell: 100 m · 100 m) http://www.bfs.admin.ch
Soil type	FOEN (grid cell: 100 m · 100 m) http://www.bfs.admin.ch
River & channel network	FOEN (grid cell: 100 m · 100 m) http://www.bfs.admin.ch
Hydrometeorlogic data	MeteoSwiss http://www.meteosuisse.admin.ch
River flows	FOEN, Switzerland http://www.hydrodaten.admin.ch

3 Sub basin 25 HRU

YEAR OF STUDY

- Model Interface: ArcSWAT 2009
- Total year of study: 1997-2009
- Warm up Period: 1997-2000
- Calibration Period: 2001-2006
- Validation Period: 2007-2009
- Time step: Monthly Average
  Daily Average
- Model evaluation: Visually (graph fitting)
  Statistically

FIRST SIMULATION

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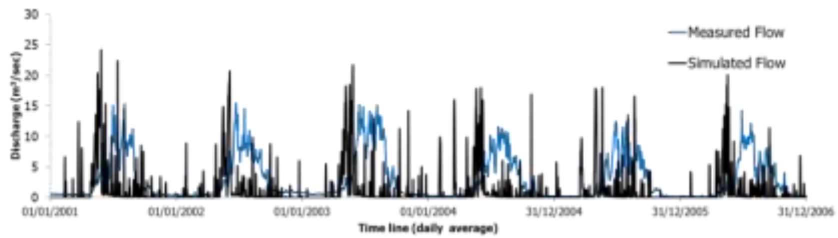
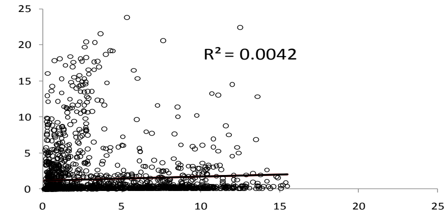
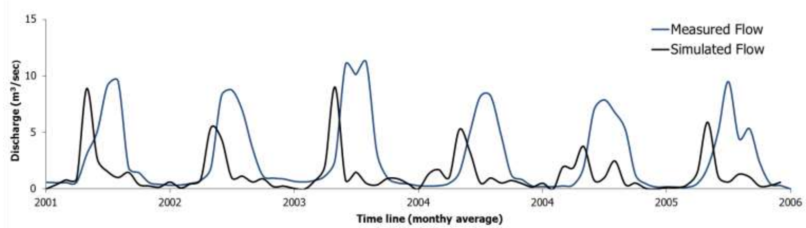
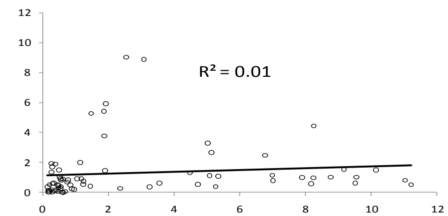








Time lag of rising limb

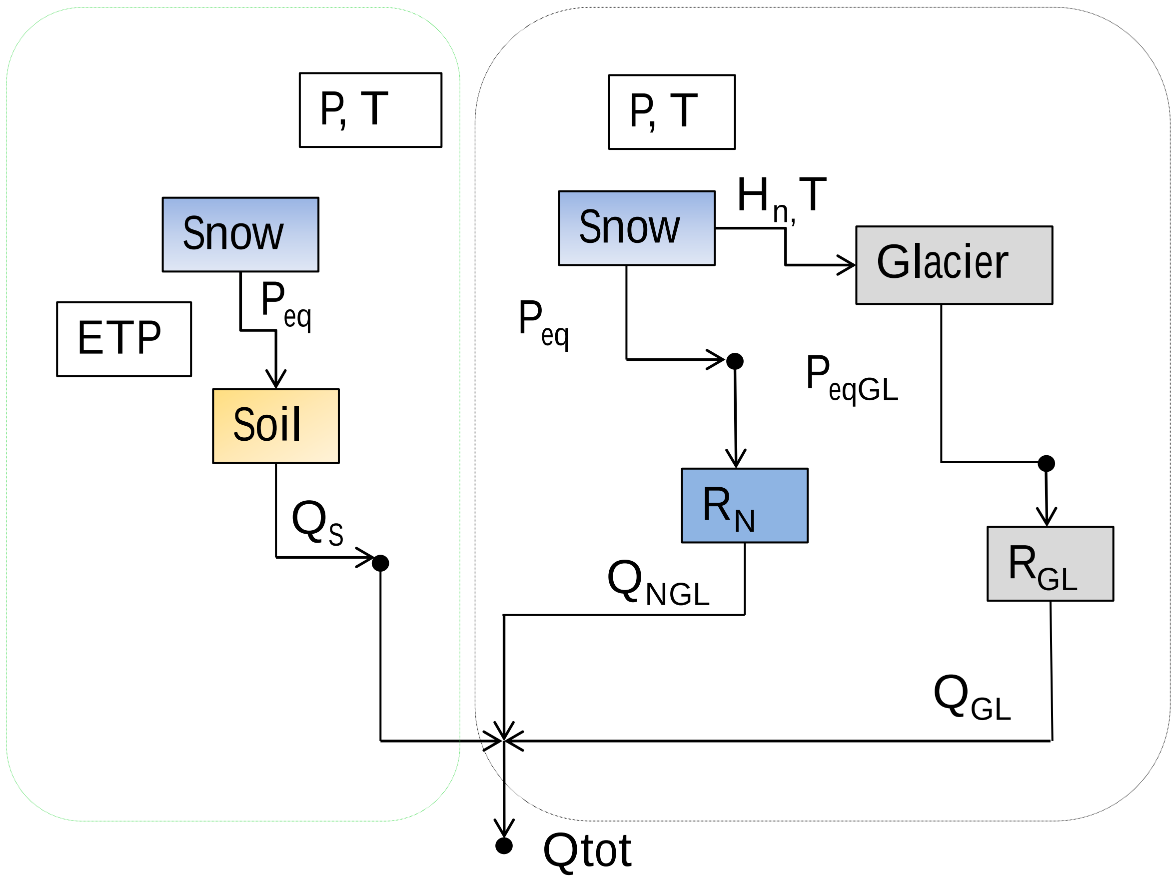
Systematic underestimation

Sharp dropdown of recession limb

Secondary peaks

MODELING CONCEPT..RS 3.0

[Jordan et al, 2007]



HYDROLOGICAL PROCESS…

Process	SWAT	RS 3.0
Surface runoff	(i) **Curve Number** (CN) (ii) Green and Ampt approach	Kinemtic wave over a inclined plan (SWMM)
Evapotranspiration	(i) Priestley-Taylor (ii) **Penman-Monteith** (iii) Hargreaves	Turc method
Flow routing	(i) Variable storage coefficient (ii) Muskingum approach	Kinematic wave St-Venant dynamic wave
Snow melt	Temperature Index **Temperature Index with Elevation** Energy budget based SNOW 17	Enhanced Temperature Index with 2 reservoirs
Glacier Melt	?	Enhanced Temperature Index

FIRST IMPROVEMENT

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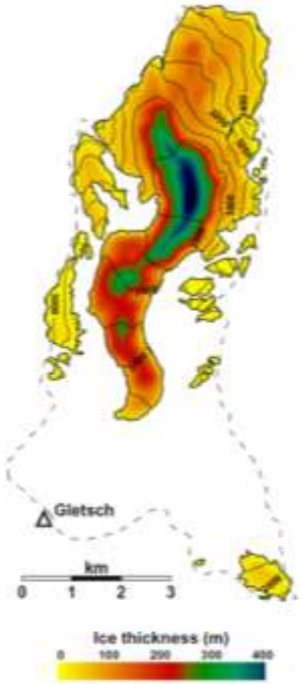
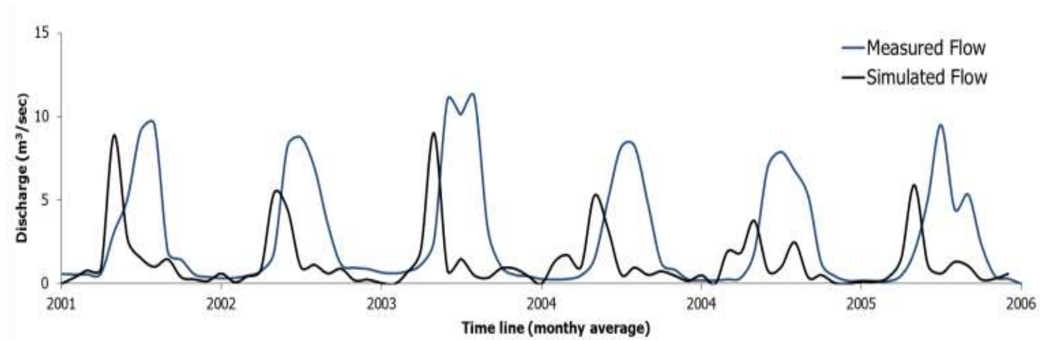
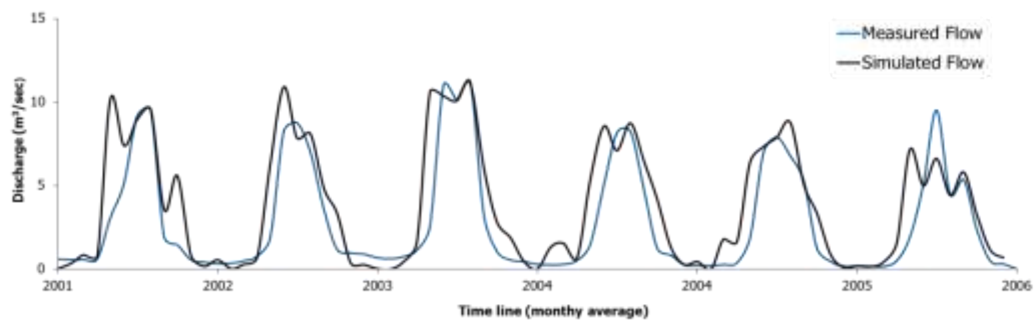


(Huss, et al., 2009)

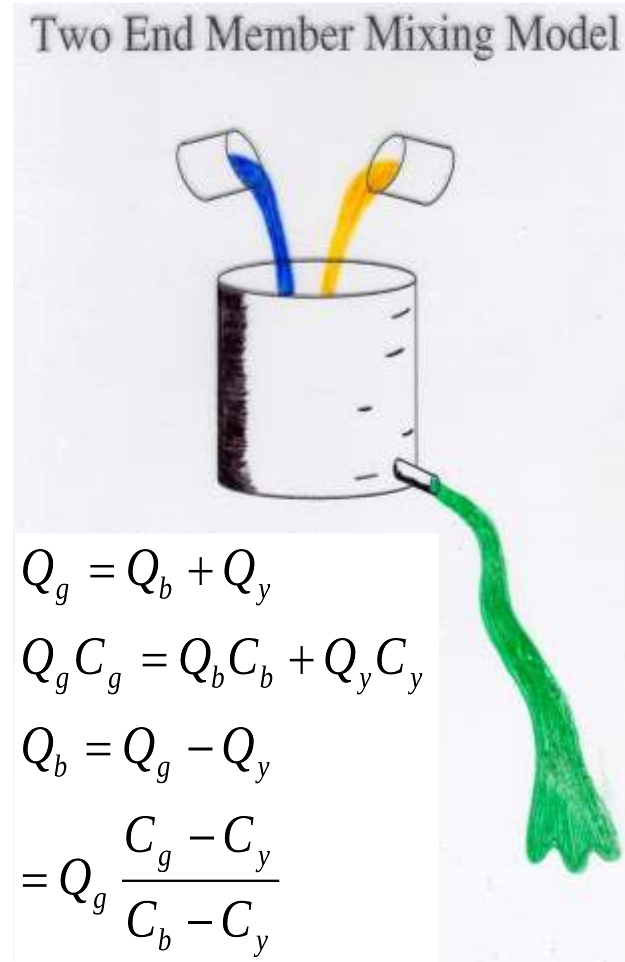




Time lag of rising limb no longer exists
Summer overestimation, Winter underestimation
Secondary peaks

HYDROGRAPH SEPARATION

- Tracers are conservative (no chemical reactions);
- All components have significantly different concentrations for at least one tracer;
- Tracer concentrations in all components are temporally constant or their variations are known;
- Tracer concentrations in all components are spatially constant or treated as different components;



$$Q_g = Q_b + Q_y$$

$$Q_g C_g = Q_b C_b + Q_y C_y$$

$$Q_b = Q_g - Q_y$$

$$= Q_g \frac{C_g - C_y}{C_b - C_y}$$

Liu et al. (2008)

HYDROGRAPH SEPARATION

3 component mixing model

- Two Conservative Tracers

Simultaneous Equations

$$f_1 + f_2 + f_3 = 1$$

$$C_1^1 f_1 + C_2^1 f_2 + C_3^1 f_3 = C_t^1$$

$$C_1^2 f_1 + C_2^2 f_2 + C_3^2 f_3 = C_t^2$$

Solutions

$$f_1 = \frac{(C_t^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_t^2 - C_3^2)}{(C_1^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_1^2 - C_3^2)}$$

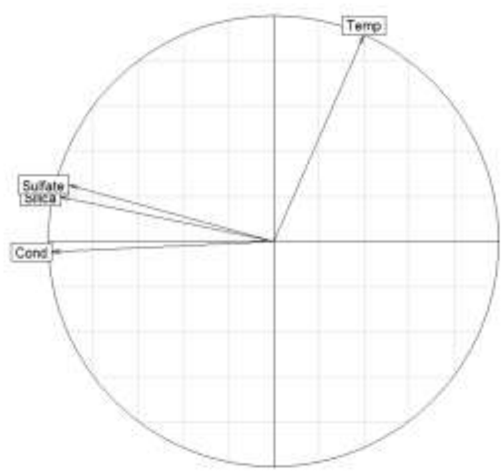
$$f_2 = \frac{C_t^1 - C_3^1}{C_2^1 - C_3^1} - \frac{C_1^1 - C_3^1}{C_2^1 - C_3^1} f_1$$

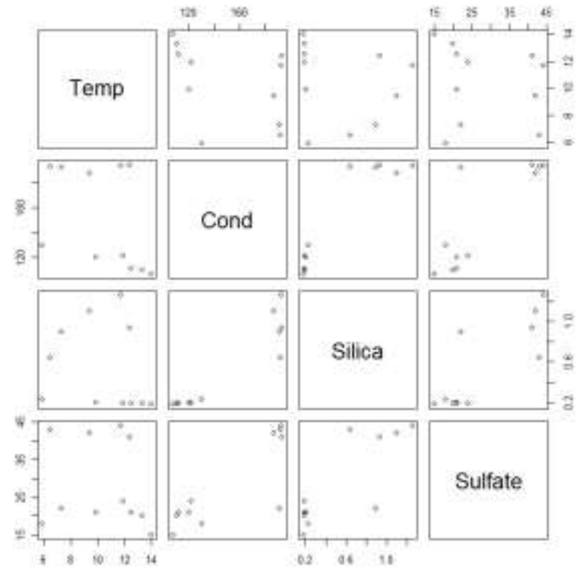
$$f_3 = 1 - f_1 - f_2$$

f - Discharge Fraction
C - Tracer Concentration
Subscripts - # Components
Superscripts - # Tracers

HYDROGRAPH SEPARATION

Co-relation matrix formation

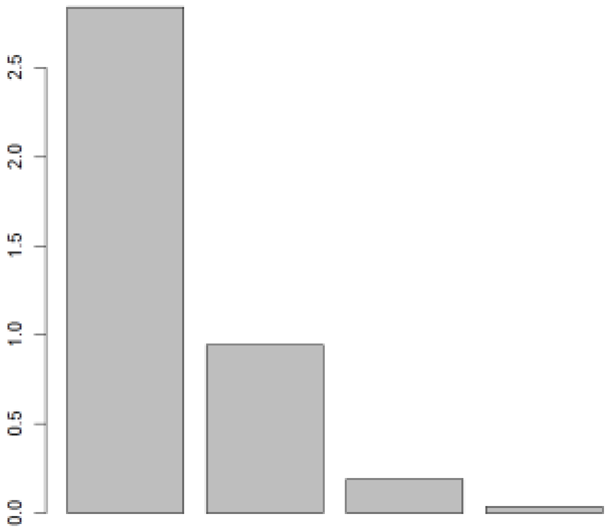




HYDROGRAPH SEPARATION

Principal component analysis

Proportion of Variance
PC 1= 0.7095
PC 2= 0.2347
PC 3= 0.04696
PC 4= 0.00879



94 percent variability can be explained though first 2 axis

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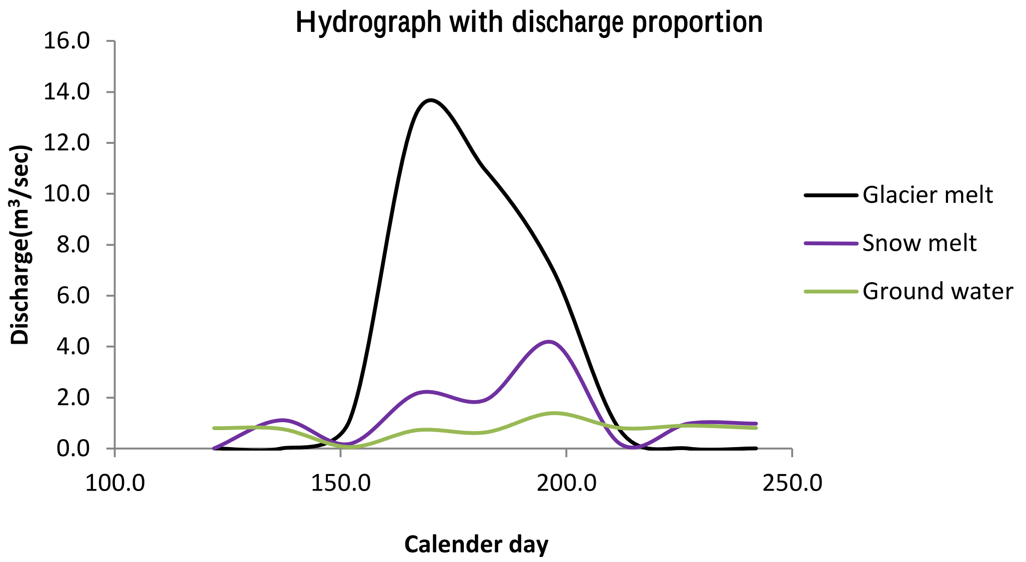
PCA Matlab	PCA R (ade4)	PCA R (prcomp)
[COEFF,SCORE] = princomp(X) [COEFF,SCORE,latent] = princomp(X) [COEFF,SCORE,latent,tsquare] = princomp(X) [...] = princomp(X,'econ')	data2<-read.table("data2.txt",header=T) attach(data2) names(data2) pca_data2<-dudi.pca(data2,scannf=T) pca_data2 pca_data2$li pca_data2$co s.corcircle(pca_data2$co) par(mfrow=c(2,2)) s.corcircle(pca_data2$co) pca_data2$eig	data2<-read.table("data2.txt",header=T) attach(data2) names(data2) prcomp(data2) summary(prcomp(data2, scale = TRUE))

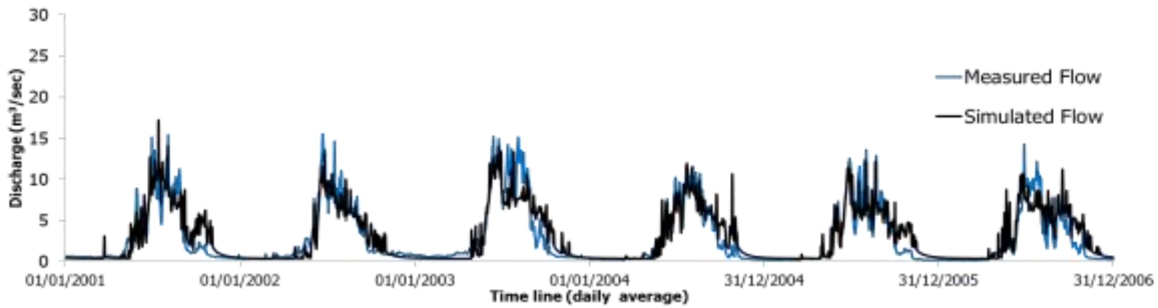
HYDROGRAPH SEPARATION



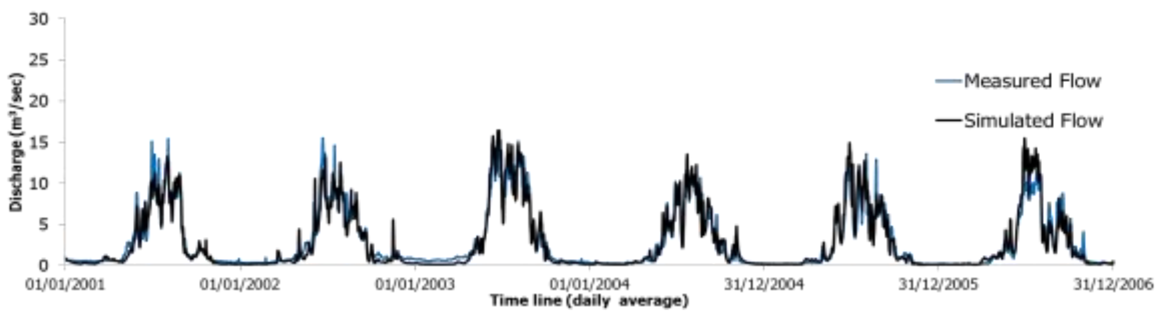
OPTIMIZED PARAMATERS.

Parameter	Description	Range	Optimized value
SFTMP	Snowfall temperature [°C]	−5,+5	1.221
SNOEB	Initial snow water content [mm]	0, 300	150
SMTMP	Snow melt base temperature [°C]	−5,+5	2.823
TIMP	Snow pack temperature lag factor [–]	0, 1	0.032
SMFMN	Melt factor for snow on December 21st [mm H_2O/°C day]	0, 10	4.825
SMFMX	Melt factor for snow on June 21st [mm H_2O/°C day]	0, 10	3.319
SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover [mm]	0, 500	300

FINAL CALIBRATION

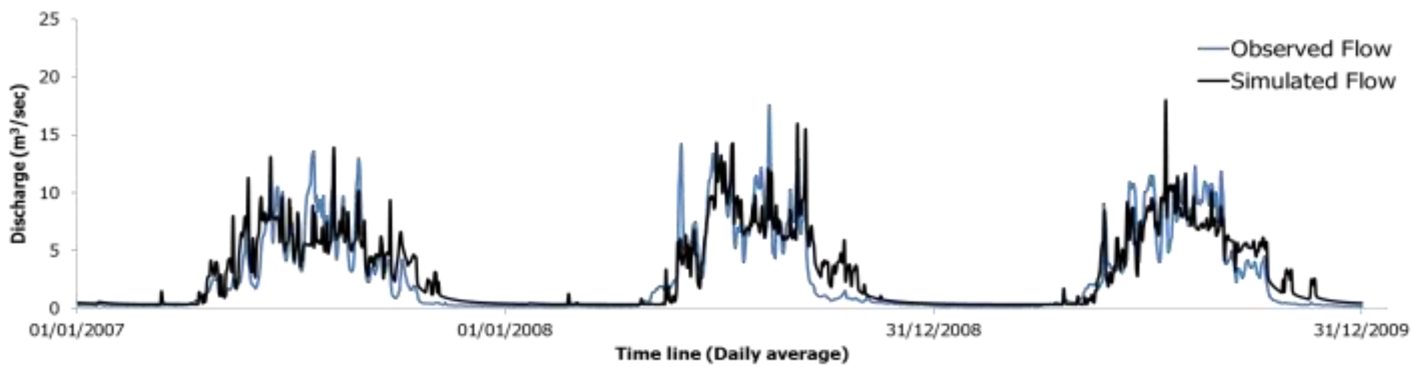


SWAT Output
NS 77

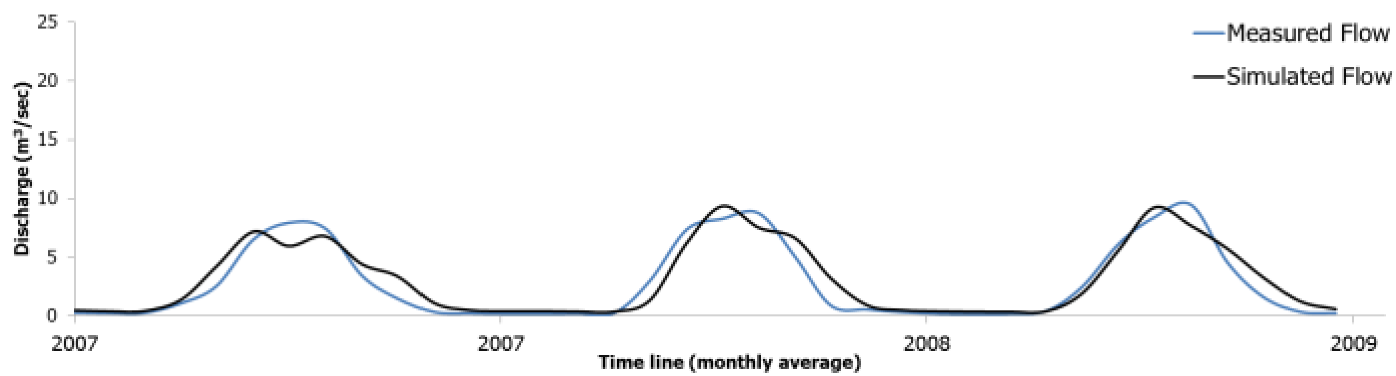


RS 3.0
NS 93

VALIDATION



Observed Flow
Simulated Flow
Discharge (m³/sec)
0
5
10
15
20
25
01/01/2007
01/01/2008
31/12/2008
31/12/2009
Time line (Daily average)



Measured Flow
Simulated Flow
Discharge (m³/sec)
0
5
10
15
20
25
2007
2007
2008
2009
Time line (monthly average)

PERFORMANCE EVALUATION

Moriasi, D.N. et al., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the Asabe, 50(3): 885-900.

[NSE > 0.5, RSR $\leq$ 0.70, PBIAS = ± 25%]

Criteria	Equation	SWAT	RS 3.0
NSE	$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{mean}\right)^2}\right]$	77	93
PBIAS	$\mathrm{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right) \times 100}{\sum_{i=0}^{n}\left(X_i^{obs}\right)}\right]$	5.43	5.26
RSR	$\mathrm{SR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \left[\frac{\sqrt{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(X_i^{obs} - X_i^{mean}\right)^2}}\right]$	0.46	0.41

Where X_i^{obs} = observed variable (flow in $m^3 s^{-1}$)
X_i^{sim} is the simulated variable (flow in $m^3 s^{-1}$)
X_i^{mean} is the mean of n values and n is the number of observations

RESEARCH FINDINGS

Key Findings..

- Model generated runoff has close match with measured runoff
  [NSE varies between 77 (daily) to 84 (monthly)]
- Glacier can be treated as reservoir and the outflow can be routed through reservoir
- Application of Elevation band has significant impact on snow/glacier melt process
  [Efficiency varies based on number of elevation band selection]
- Sensitive parameters are mostly related to snow/glacier melt process
  [SMTMP, SMFMN SMFMX..]

NEXT STEPS…

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Extend the calibration for entire Rhone
Link with species community
Sub daily calibration (Hydropower optimization)
Climate change scenario implementation(Prudence)
Land use change scenario implementation(enviroGRIDS)

QUENSTIONS
& ANSWERS..

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1. was there any point source? if so what were they? how did you get the point source data? was it daily or monthly?
2. what were the final calibration parameter? I see the sensitivity list?
3. was it using auto calibration? if so what are the uncertainty?
4. how does rock parameters help in final calibration..
5. how was the glacier area was estimated?
6. did you implement elevation bands? also permanent snow depths?

hope some of these questions help to make your presentation better.

LIMITATIONS

1. Availability of spatial extents and thickness
2. Hydrograph separation for one melt season
3. Expensive equipment's

Acknowledgements...

Institute for Environmental Sciences
University of Geneva

Main promoter
Dr. Anthony Lehmann
University of Geneva

Co promoters
Dr. Emmanuel Castella
University of Geneva
Dr. Karim Abbaspour
EAWAG, Switzerland

Resource persons
Dr. Fred Jordan
Edric. Switzerland
Dr. Stéphane Goyette
University of Geneva
Dr. Chetan Maringanti
University of Geneva

Overall Support
Prof. Martin Beniston
Director, ISE. UNIGE

Merci beaucoup

kazi.rahman@unige.ch

QUENSTIONS & ANSWERS..

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