Estimating SWE from snow depth data: comparison of different approaches

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Davos Atmosphere and Cryosphere Assembly DACA-13
Davos, 10-07-2013

Background and objectives

- Snow Water Equivalent (SWE) has a fundamental role in mountain hydrology
- Many recent papers focused on estimating SWE from snow depth (HS) modelling snow density (ρ_s) using historical datasets or field campaigns (e.g. Jonas *et al.* 2009, Sturm *et al.* 2010, Bormann *et al.* 2013, Lopez-Moreno *et al.* 2013, Sexstone *et al.* 2013, ...)
- Monthly or biweekly modelling of SWE spatial distribution at regional scale (Aosta Valley-NW Italian Alps, 3000 Km^2). End users: water management authorities and hydropower companies
- Objectives: (*i*) test few approaches to estimate SWE at a given point and (*ii*) understand the impact of these approaches on SWE estimation at regional scale

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1. Estimating single point SWE

2. Current vs. past data

3. SWE at regional scae

Estimating single point SWE

How can we estimate SWE at a given point using snow depth?

SWE-HS-ρ_s dataset

- manual measurements in snow pits from **2005** to **2012**
- data elevation range: [880-3900 m asl]
- total number of SWE-HS-ρ_s data: 4154

HS [cm]	ρ_s $[kg \cdot m^{-3}]$	SWE [mm]
Min. : 7.0	Min. : 71	Min. : 9.9
Median : 92.0	Median :280	Median : 245.3
Mean :104.8	Mean :287	Mean : 311.0
Max. :530.0	Max. :583	Max. :2798.0

Approaches

- Test recently published methods to model snow density (ρ_s) from snow depth (HS) data on Aosta Valley dataset (2005-2012)

  1. Jonas *et al.* 2009: $\rho_{smod_i} = aHS_{obs_i} + b + offset_{reg}$
  2. Sturm *et al.* 2010: $\rho_{smod_i} = (\rho_{max} - \rho_0)[1 - e^{(-k1HS_{obs_i}) - k2DOY)}] + \rho_0$

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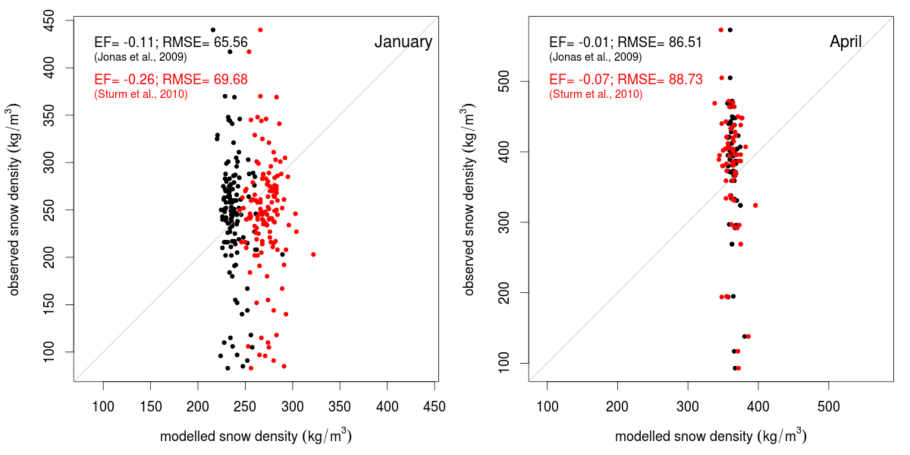
ρ_s modelling



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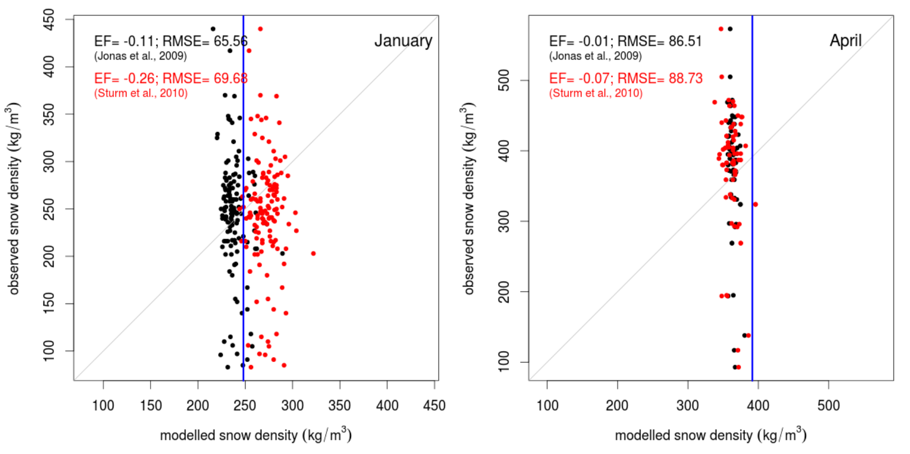

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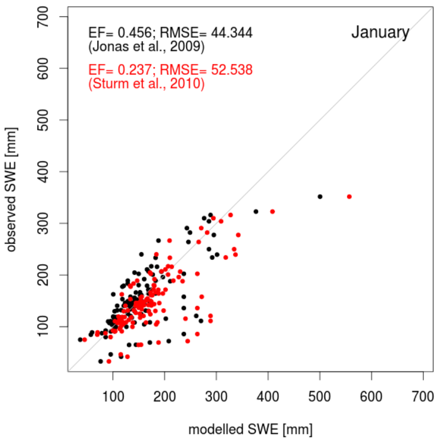
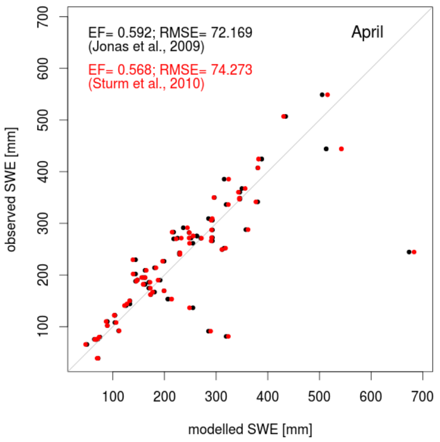
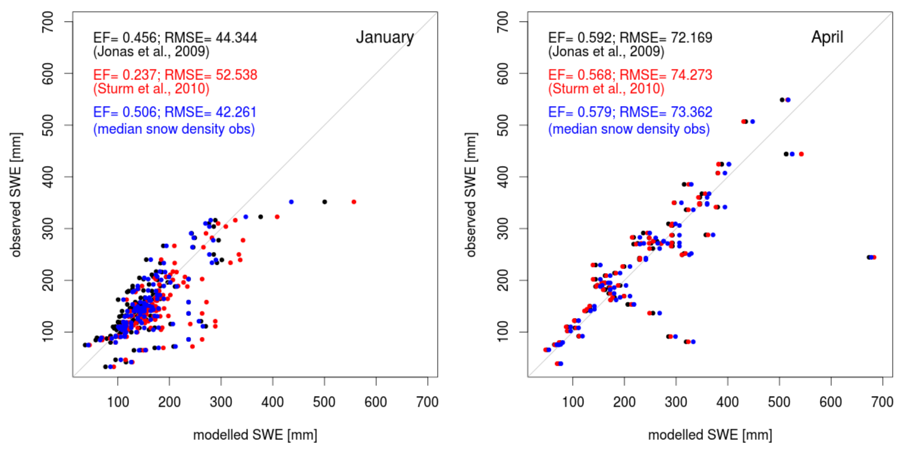
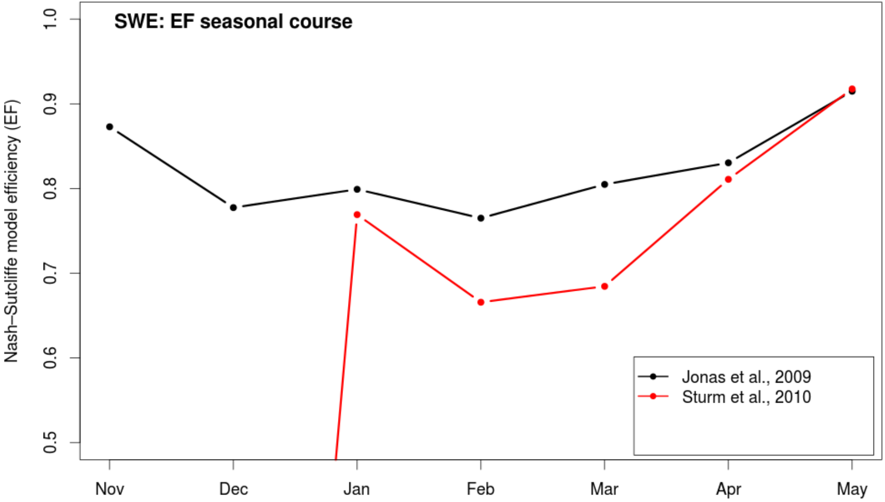




SWE modelling: $SWE_{mod_i} = HS_{obs_i}\rho_{smod_i}$ or $SWE_{mod_i} = HS_{obs_i}\overline{\rho_{sobs}}$



SWE modelling: Nash-Sutcliffe model efficiency (EF) seasonal course



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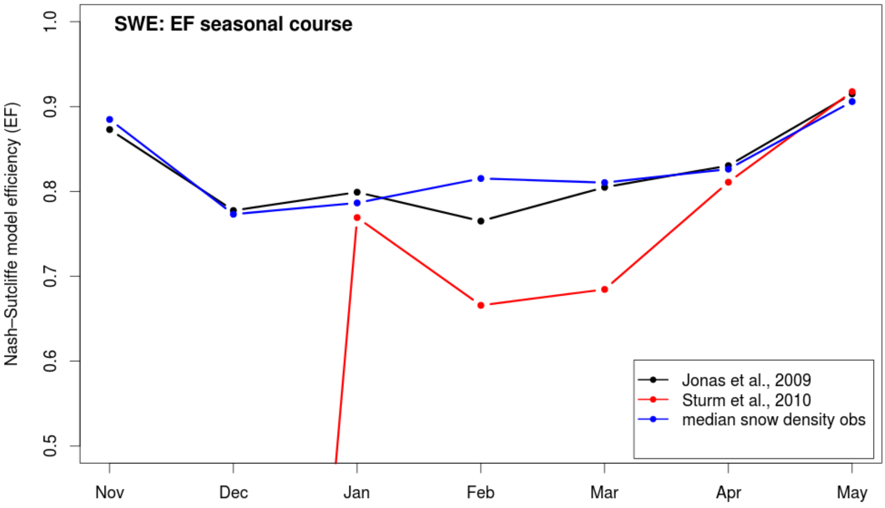

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- SWE variabilty is mainly explained by HS → fitting of mixed model: $SWE_{mod_i} = HS_{obs_i} + elev_i + east_i + north_i + 1|climatic_i$
  - based on restricted maximum likelyhood → more robust against heteroscedasticity
  - random effect (climatic) to account for spatial or temporal autocorrelation

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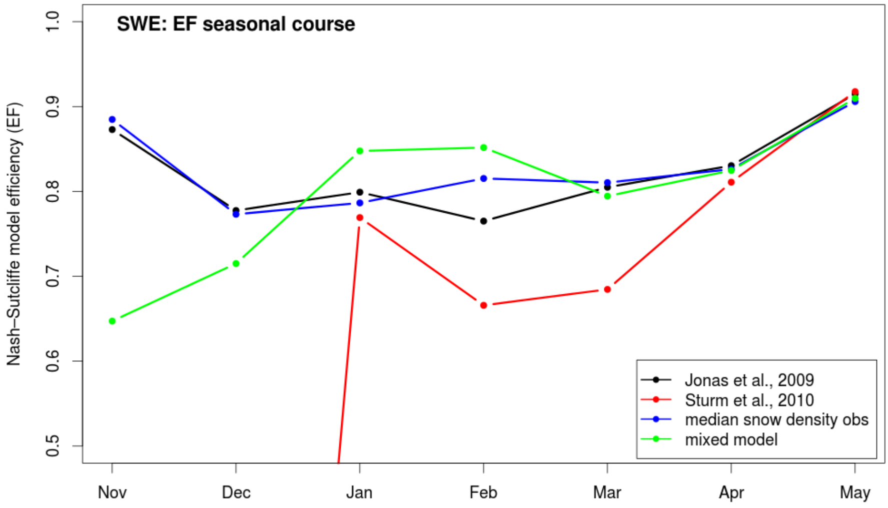

Current vs. past data

Do real time snow density data provide better SWE estimates than past years data?

Current vs. past data

- Do we get an improvement in point level SWE modelling using real time snow density data (i.e. snow density data of the current year)?
- $EF_{[current]}/EF_{[past]}$
  - $EF_{[current]}$: e.g. Jan 2013 SWE modelled using snow density data collected during Jan 2013
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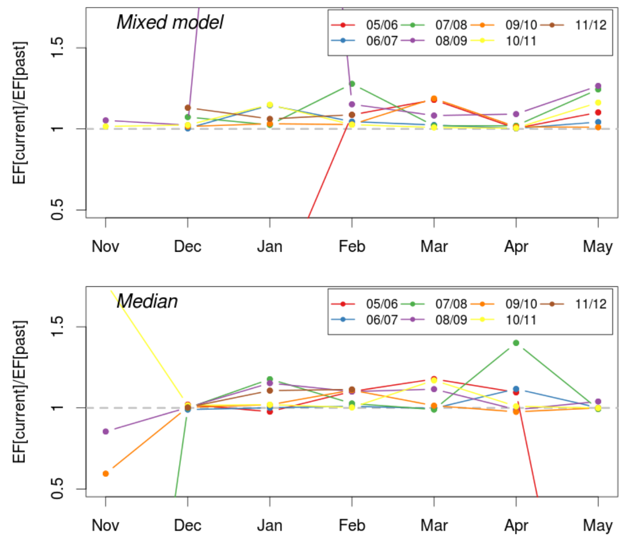
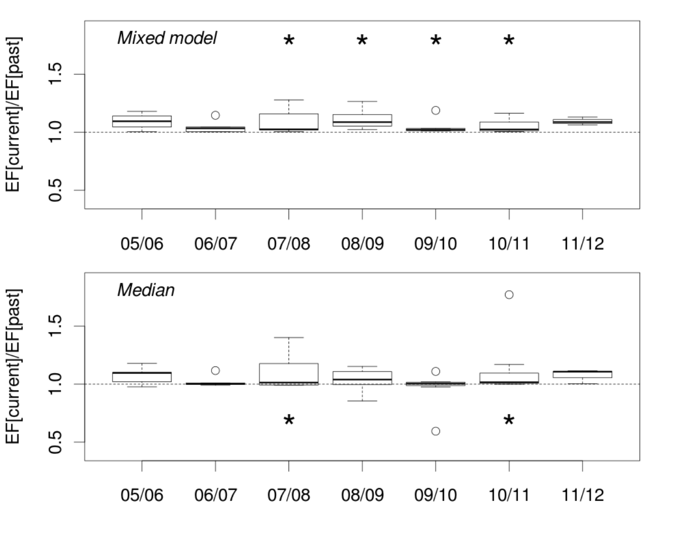
EF ratio: seasonal course



EF ratio: interannual variability



SWE at regional scale (3000 km^2)

What's the impact on total SWE at regional scale?

Impact on SWE at regional scale (3000 km^2)

- SWE at regional scale (Aosta Valley) is modelled, from Nov to May with monthly or biweekly frequency, using *MODIS Maximum Snow Cover Extent* data (MOD10A2 Product–v005) and *SWE regression kriging*
- To roughly evaluate the impact of the different approaches (*median vs. mixed models*) and datasets (*real time vs. past years data*) we compared the seasonal course of the total modelled SWE values

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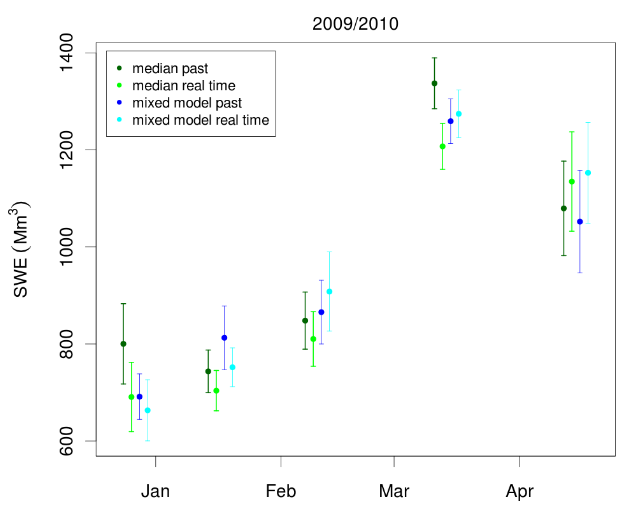
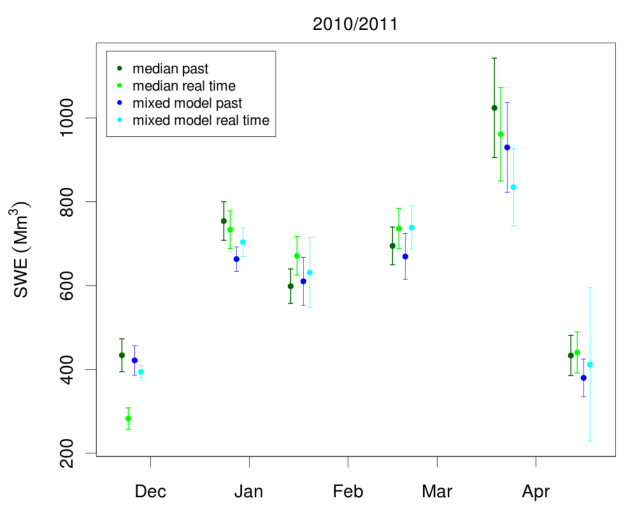
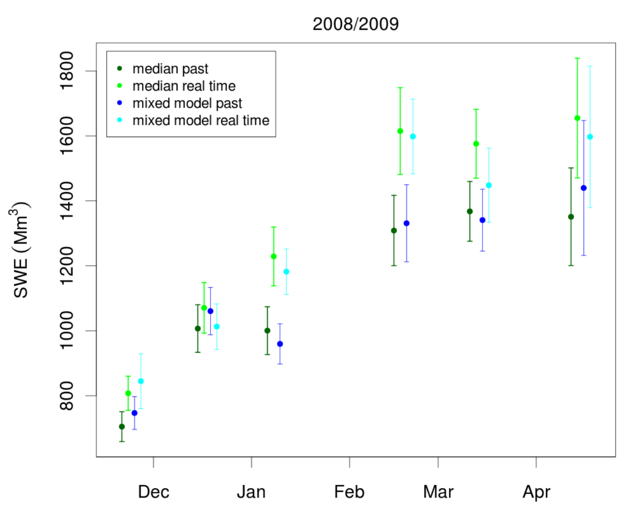
e.g. hydrological year 2009-2010 'normal' year



e.g. hydrological year 2010-2011 early snowmelt



e.g. hydrological year 2008-2009 anomalous snowy winter



Conclusions

take home messages (1/2): point modelling SWE

- using the median of observations ($\overline{\rho_{s_{obs}}}$) is not worse than the other tested methods
- mixed models ($SWE_{mod} \sim HS_{obs}$) are, in most cases, at least as good as $\overline{\rho_{s_{obs}}}$ or the other tested methods
- real time ρ_s data are usually better, but not always (e.g. edges of the season, periods with few data, ...)

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- given (*i*) our end users (hydropower companies and water management authorities) and (*ii*) the increase of extreme events frequency, keeping the four approaches could be a way to encompass model uncertainty

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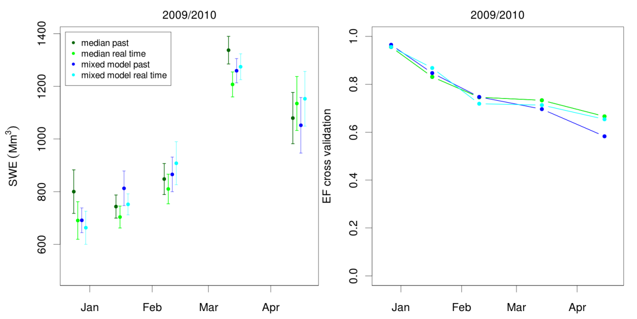
2009/2010: SWE and EFcv



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