Efficiency of Snowmelt Modeling Approaches in Watershed Models

Anand Verdhen, RS and Bhagu R. Chahar, Assoc. Prof.

Dept. of Civil Engg., IIT Delhi, India

Contact mail: averdhen4@gmail.com

International Conference on SWAT-2012 (18-20 July, 2012) at Delhi, India

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Objective:: *to verify the performance regarding the point melt computation on TI, EB or mixed approaches adopted in HEC-HMC, SSARR, UBC, NWSRFS, PRMS, SHE, SWAT, SRM and TANK like popular models.*

Importance:: *is to identify easily measurable and reliable indicators in modeling snow/ice melt and climate change.*

Approach:: *Average point melt water equivalent (w. e./day) simulation (on 2008 data) and validation (on 2003 and 1983 data) using TI (except PRMS) and EB (except TANK) algorithm of above 9 models and observed snowpack ablation at Solang.*

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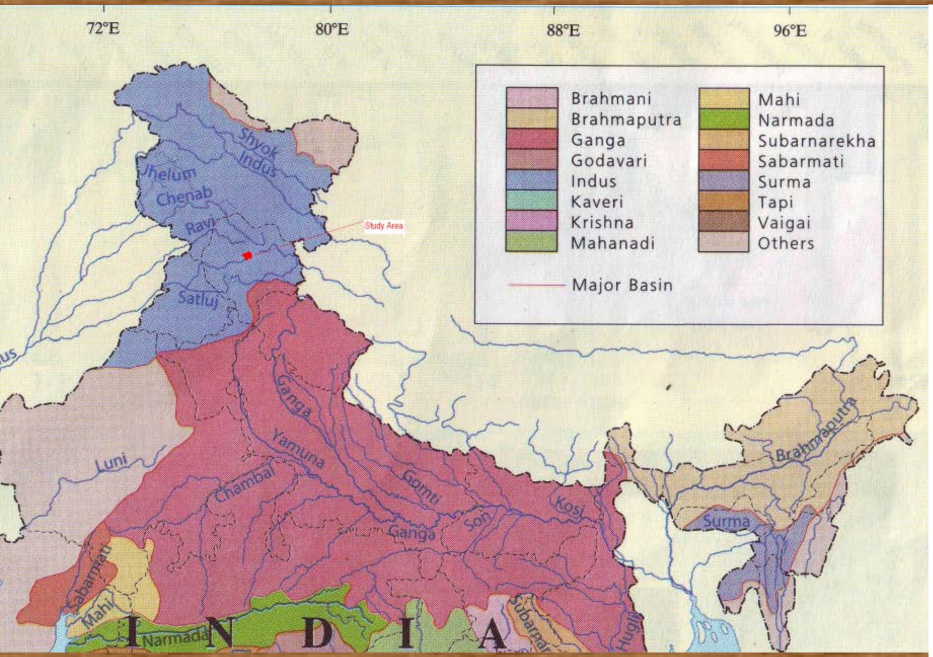
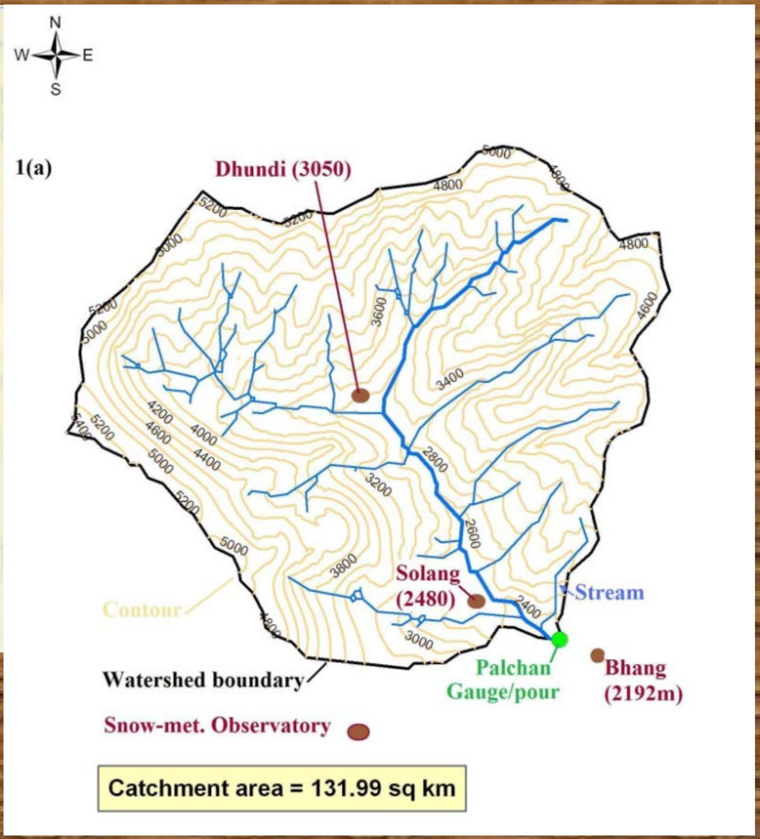




:: Weekly Tmax, Tmin, Precipitation,
idity, Snow depth, Snow temperature, Wind of
2003 and 2008 Spring period (15 Feb to 5th
data of SASE at Solang station (2480 m)

Fig.1. Himalayan River Beas Watershed Observation at Solang.

Snowmelt Model Structure

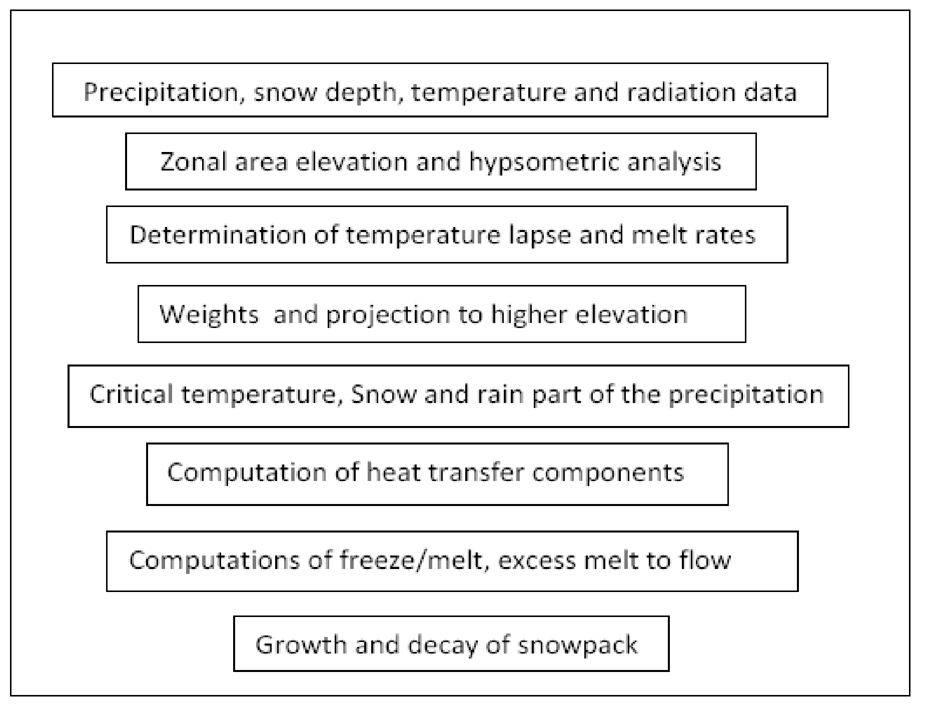


Figure 1a. Generic snowmelt model structure

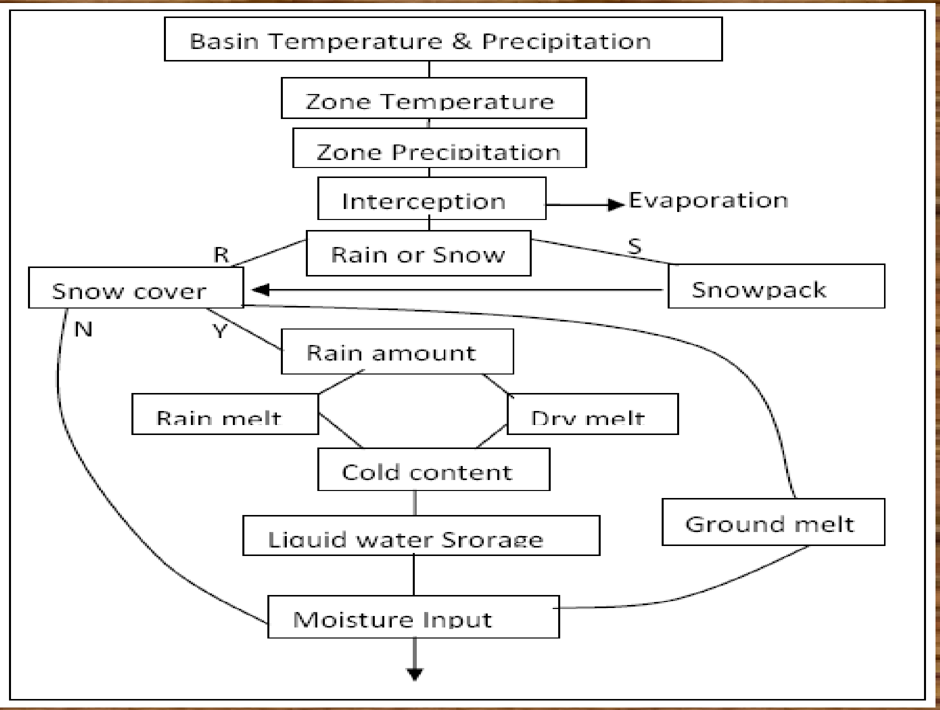


Figure 2b. SARR integrated snowmelt   routine

Temperature Index for Snowmelt in Watershed Models

$Mt = (Mf + (0.0126P))Ta$ (Moore and Owens, 1984)

Degree-day melt [mm/day] :: $Mt = Mf * (Ta - Tb)$ (HEC)

Rain and cloudy condition

$Mt = 25C_1(0.09 + (0.029 + 0.00504\, v*5/8 + 0.007\, RAIN/25)\,(Ta - Tf)*9/5)$ (HEC)

$Mt = Mf'(Ta - Tb)$ (SSARR, UBC, NWSRFS)

$Mf' = Mf + \{Mf*(0.5*\sin(6.283*(JD+90)/365))\}$ (NWSRFS)

$Mt = Mf'*((Tsp + Tmax)/2 - Tsb)$ (SWAT)

$Mrate = Mf' = ((M_{max}+M_{min})/2) + \sin((j-81)/58.09)(M_{max}-M_{min})/2$ (SWAT)

Daily snowpack temp: $Tsp(dn) = Tsp\,(dn-1)\,(1-\lambda sno) + Tav\,\lambda sno$ (SWAT)

$Mt = Mf*(Ta-Tb)*p$; also $Mt = K*(Ta-Tb)*p*L_f*pw$ (SHE)

$Mt = Mf_* Ta$ (SRM)

$Mt = U(i, k) = Mf*T(i) + 1/80\, P(i, m, k)\, T(i)$ (TANK)

where *Ta = mean temperature* [°C]; Mf = melt factor [mm/°C/day]; *P* = precipitation [mm/day

Snowmelt Computation on Temperature Index

Table 1. Weekly day averaged snowmelt using TI of models.

TI/EB efficiency criteria is based upon nos. of correct estimation out of total 21 weeks for each model (weight of logical index;
Y = ok, H = high, L = low)

Week	Ta (°C)	ΔWDs (mm)	MooreEq.(1)	HEC	SSARR/UBC/NWSRFS	SWAT	SHE	SRM	TANK	R
	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
1	**3.9**	***Yr 2008***	**13.52**	**11.4**	**11.27**	**14.86**	**11.5**	**13.50**	**13.52**	
2	**4.0**	**11.99**	**14.17**	**11.9**	**12.06**	**13.33**	**12.1**	**14.00**	**14.17**	**Y**
3	**7.3**	**27.35**	**25.50**	**23.4**	**24.20**	**21.35**	**23.7**	**25.50**	**25.50**	**Y**
4	**8.6**	**27.81**	**30.08**	**27.9**	**29.29**	**25.09**	**28.3**	**30.00**	**30.08**	**Y**
5	**8.5**	**21.38**	**29.95**	**27.8**	**29.46**	**24.55**	**28.1**	**29.88**	**29.95**	**H**
6	**9.5**	**8.47**	**33.25**	**31.2**	**33.21**	**28.55**	**31.5**	**33.25**	**33.25**	**H**
7	**8.9**	**0.00**	**0.00**	**0.0**	**0.00**	**0.00**	**0.0**	**0.00**	**0.00**	
1	2.1	*Yr 2003*	8.18	5.4	5.34	7.63	5.5	7.50	8.18	
2	3.4	11.73	12.06	9.9	10.04	10.42	10.0	12.00	12.06	Y
3	1.5	-4.59	5.33	3.2	3.26	3.77	3.2	5.25	5.33	H
4	3.0	22.96	10.64	8.5	8.95	7.51	8.6	10.63	10.64	L
5	4.6	18.62	16.25	13.9	14.74	12.29	14.1	16.00	16.25	L
6	7.3	16.62	25.58	23.4	24.95	18.37	23.7	25.50	25.58	H
7	6.0	4.76	21.80	19.0	20.29	16.69	19.3	21.13	21.80	H
8	11.2	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	
1	0.5	*Yr 1983*	1.69	0.0	0.00	4.41	0.0	1.63	1.69	
2	0.1	-6.89	0.40	0.0	0.00	4.14	0.0	0.37	0.40	Y
3	0.9	-8.16	3.13	0.9	0.93	7.52	0.9	3.00	3.13	Y
4	3.4	24.18	12.56	10.0	10.44	8.74	10.1	12.05	12.56	L
5	3.2	6.38	11.63	9.0	9.54	8.88	9.1	11.10	11.63	H
6	1.8	-8.88	6.71	4.4	4.64	6.64	4.4	6.45	6.71	H
7	5.6	15.71	19.97	17.6	18.75	17.15	17.8	19.68	19.97	Y
8	6.6	32.91	23.74	20.9	22.17	16.99	21.1	22.98	23.74	L
9	4.0	9.34	14.29	11.5	12.05	9.68	11.6	13.55	14.29	Y
10	9.0	13.21	31.33	29.2	30.33	24.67	29.6	31.33	31.33	H
11	10.0	21.84	34.83	32.7	33.33	25.31	33.1	34.83	34.83	H
Tb		°C	NA	0.6	0.6	0.6	0.6	NA	NA	
Mf (mm°C^{-1} day^{-1}		Mf^{v}(2.5-3.7)	3.5	3.5	Mf^{v}	Mf^{v}	7	3.5	3.5	

Energy Balance Approach for Snowmelt in Watershed Models

Rain-free partly (50%) forested areas ::

$Mt = 25C_2(0.002Ir(1-\alpha)+(0.0011v5/8+0.0145)(Ta\text{-}Tf)9/5+0.0039v(DEWPT\text{-}Tf)45/40)$ (HEC/

$Mt = 25C_2\{k'(1\text{-}F)(0.004Ir)(1-\alpha)+k(0.008v)[(0.22Ta')+(0.78Td')]9/8+F(0.029Ta')9/5\}$ SSARR)

$Mt = m*(0.5*(Tmax+Tmin)+\beta*(((Tmax-Tmin)/\o)+Tmin))$ (UBC)

$Mt=3.67(10\text{^}\text{-}9)((Ta+273)\text{^}4)-20.4+0.0125PTa+8.5f(u_a)\{(0.9e_{sat}-6.11)+0.00057PaTa\}$ (NWSRFS)

$Mt = 0.0029875*(Qn + Qh + Qe + Qm + Qg - \Delta Qi)$

$Mt = Rs*\{\tau c(1-fs) + fs\}*(1\text{-}alb) + Rl$ (SWAT)

$alb = 0.43\{1+exp(- Ke * t)\}$ (varying albedo with day, t=0 on fresh snowfall)

Qh = {(Ca/rhe+Eho)(Ta-Ts)} is replaced by { *pa**Cp*(Ta-Ts)*0.8*ur} modified (for SWAT)

$Mt= r*Td+Mq*R$ (SRM)

$Mt = K (Ta-Tb) + (1- \alpha)*Isr/L_f$ (PRMS)

$Mt = R_s*(1-\alpha)*V_t +(1-V_{den})*\sigma(E_m*Tc^4-Ts^4)+ V_{den}*\sigma(Tv^4-Ts^4) +C_m Ta$ (PRMS)

where *P* = precipitation [mm/day] where Ca=1.29 [KJ m^{-3} $^oC^{-1}$]; Eho= energy for no wind [172.8 KJ m^{-2}]; *pa* = air density [1.29 Kg m^{-3}]; Cp =[KJ Kg^{-1} $^oC^{-1}$]; ur = coefficient [43.4 Km h^{-1} day]

Snowmelt Computation on Energy Balance Approach

Table 2. Weekly day averaged snowmelt using energy budget algorithm of models

Weight of logical index:

Y = 1, N = 0.2, L = -0.5, H = 0.5

Week	Rain (m)	ΔWDs mm/d	HECT,R-F/SSARR		UBC	NWSRFS	SWAT	SHE	SRM	PRMS		Inference
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
3F08	**0.0**		**11.2**	**11.6**	**9.6**	**11.74**	**9.01**	**5.9**	**11.5**	**9.7**	**11.2**	
4F08	**0.0**	**11.99**	**11.6**	**15.8**	**10.0**	**12.65**	**11.41**	**8.7**	**12.0**	**10.6**	**11.9**	**Y**
1M08	**0.0**	**27.35**	**22.0**	**21.3**	**19.8**	**27.44**	**21.83**	**22.8**	**18.2**	**20.9**	**22.3**	**L,Y7,9,12**
2M08	**5.0**	**27.81**	**26.3**	**25.2**	**27.9**	**31.80**	**24.28**	**32.4**	**20.8**	**25.1**	**24.3**	**Y, N7,9**
3M08	**5.0**	**21.38**	**26.6**	**28.0**	**29.3**	**37.17**	**28.28**	**36.5**	**21.0**	**25.3**	**27.4**	**H,Y10**
4M08	**0.0**	**8.47**	**29.2**	**31.1**	**34.2**	**42.09**	**28.44**	**45.6**	**23.1**	**28.5**	**29.9**	**H**
1A08	**10.0**	**0.00**	**0.0**	**0.0**	**0.0**	**0.00**	**0.00**	**0.0**	**0.0**	**0.0**	**0.0**	**OK**
3F03			6.0	6.6	5.4	8.08	6.19	1.3	8.4	4.1	4.6	**NA**
4F03		11.73	10.1	15.7	8.6	13.94	13.41	7.0	11.0	8.9	10.7	**~Y**
1M03		-4.59	4.0	7.1	3.8	5.54	8.43	0.6	7.8	2.2	4.7	**Y, 9,11**
2M03		22.96	9.1	22.4	7.6	16.03	18.56	8.7	10.9	8.5	12.9	**L, Y5**
3M03		18.62	15.3	26.1	11.4	26.34	25.04	17.3	13.9	13.4	16.2	**H/L, Y4,9,12**
4M03		16.62	25.1	30.8	18.2	63.04	30.25	33.7	19.1	21.8	22.1	**H,Y6,10**
1A03		4.76	24.0	32.2	20.5	49.42	26.00	29.3	17.1	18.3	16.7	**H**
2A03		0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.0	**OK**
3F83			0.0	5.6	1.2	-1.08	1.81	0.0	5.4	0.0	1.5	**NA**
4F83		-6.89	0.0	5.6	0.3	-2.48	2.49	0.0	5.0	0.0	1.4	**Y, N5,10**
1M83	8.2	-8.16	0.0	6.7	2.1	0.89	4.81	0.0	6.6	0.0	3.3	**H, N5,10**
2M83	72.9	24.18	13.3	23.0	8.6	26.38	11.55	10.4	11.6	9.7	10.3	**L,~Y5,7**
3M83	12.3	6.38	10.2	8.9	7.9	21.26	6.29	3.1	11.4	7.3	6.8	**Y,H4,7,10**
4M83	43.0	-8.88	5.7	8.4	4.6	9.88	6.15	1.3	9.3	3.4	5.2	**H, Y6,9**
1A83	29.3	15.71	20.7	31.9	14.1	50.12	28.90	26.9	16.4	17.1	21.7	**H,Y6,10,11**
2A83	54.8	32.91	26.0	34.6	20.6	58.16	34.89	34.8	18.4	20.2	22.9	**H/L,Y5,8,9**
3A83	45.8	9.34	14.0	10.0	9.7	27.08	5.53	4.9	13.8	9.6	7.3	**Y, H7**
4A83		13.21	31.3	39.0	30.6	91.24	38.65	55.9	23.2	27.8	33.9	**H**
1M83		21.84	36.6	41.6	41.3	125.48	41.30	66.2	25.3	31.0	36.8	**H,~Y5,10**
Tb	**°C**		**1**	**1**	**2.5,4**	**1**	**NA**	**1**		**1**		
Mf/Mf'/k			**1.8**	**C2=0.65**	**m, ø**	**Mf',b=0.8**	**NA**	**1.8**	**1.8**	**k = 3**	**k = 1.8**	

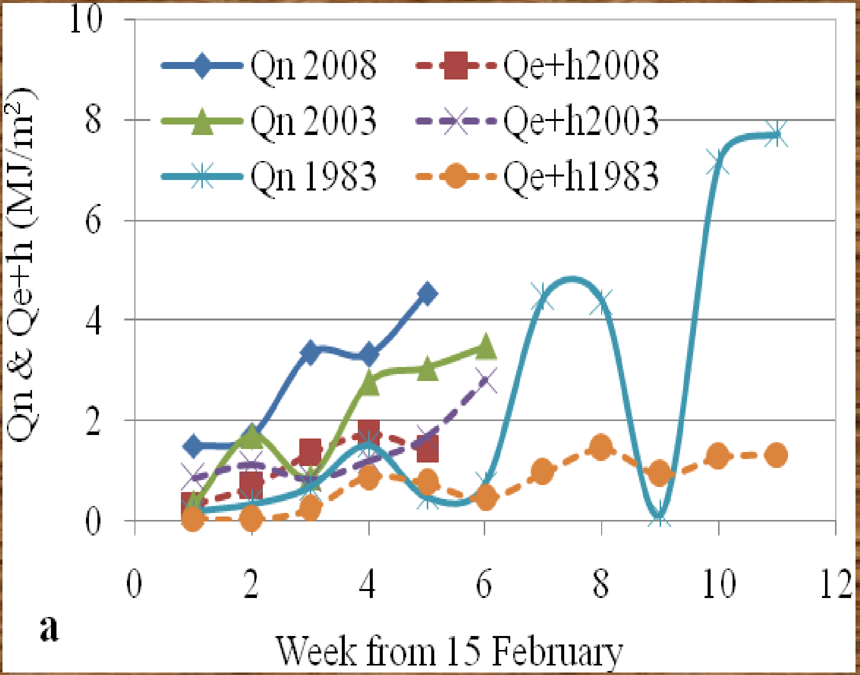
Overall, probability of accuracy:
Simulation using TI/EB of all the models are 0.75 (yr 2008) and
Computation using TI/EB for and are 0.43/0.47 (yr 2003) and 0.62/0.46 (1983) r
On average simple degree-day/TI is not bad than EB

SWE accounting for the computation result on SWAT

Radiation fluxes contribute 86% and turbulent fluxes by 14% (Wills et al., 2002)

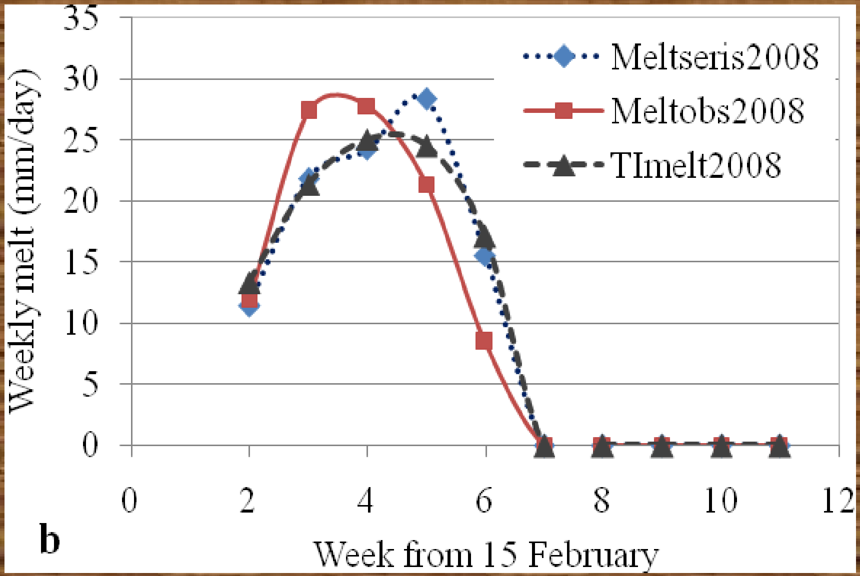
Ratio of radiant to combined radiant and turbulent fluxes are 0.73 (2008), 0.55 (2003) and 0.68 (1983) in the study area.

The net radiation (Qrn) and turbulent (Qe+Qh) heat flux (Figure 3a) show early high value over the Year; indicating warming trend in the Pirpanjal range of the western Himalayas.



SWAT based EB components [MJ/m^2]

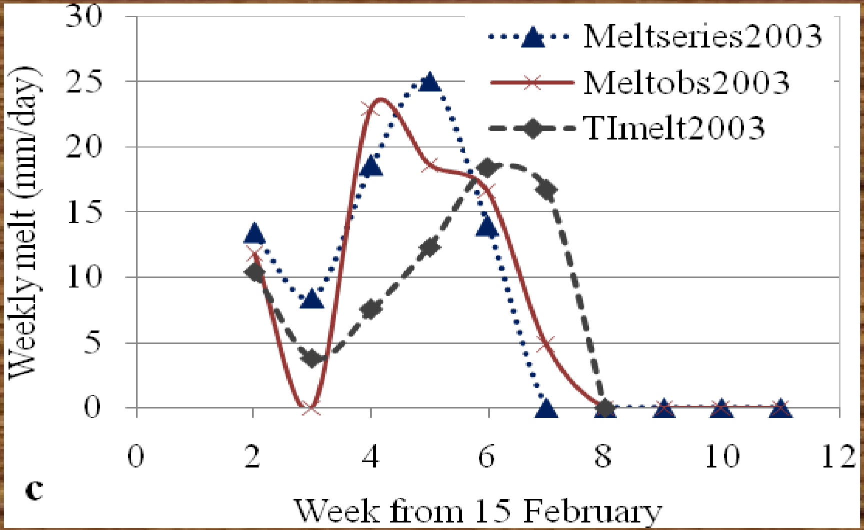
Simulation and Computation on TI and EB with Observed SWE

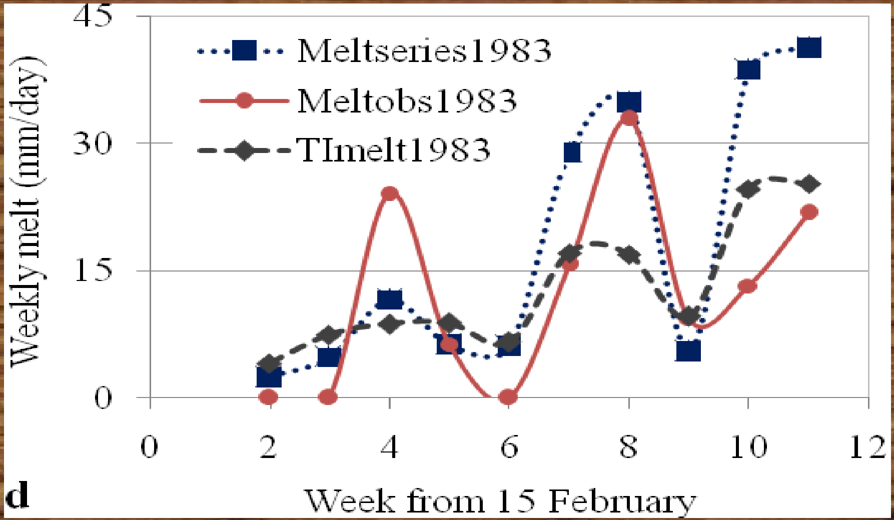


SWAT Simulated (2008) efficiency = 0.89/0.9

- Simulation effect of EB is better than TI
- EB under estimation in 1983 may be due to cold content, wind and stability factor
- Estimation Efficiency (TI/ EB) = 0.2/0.8 (2003) and 0.4/0.5 (1983).
- Melting peak time advanced over years

SWAT Computed (2003 and 1983)





Observed vs Computed SWE

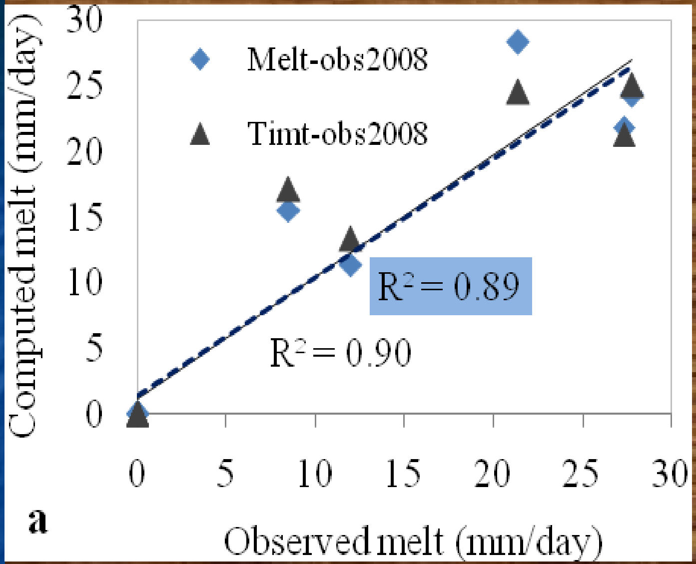
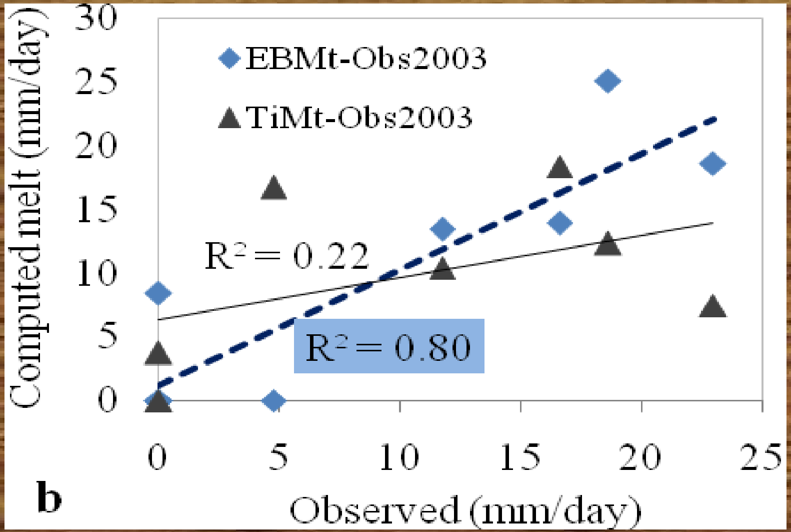


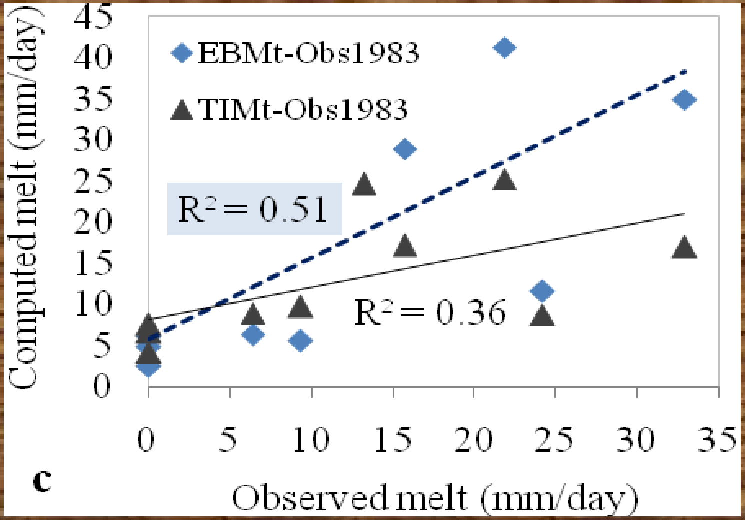
Fig.7. Regression of observed vs computed (day averaged) point melt water equivalent for TI and EB approaches (SWAT).

Pradhanang et al. (2011) have reported correlation coefficients of 0.35 to 0.85 for melt using SWAT.

Debele et al. (2009) presented SWAT snowmelt computation efficiency from 0.33 to 0.59 on EB and 0.49 to 0.73 on TI.

Computation data years (b) 2003 and (c) 1983.





Snowmelt Modelling Efficiency

Conclusion

TI Calibrated T_b = 0.6 ºC, melt factor (M_f) = 3.5 mm/degree-day, but Mf = 7 (SHE) and varying Mf' = 2.5 to 3.7 (for NWSRFS, SWAT and UBC).
EB calibrated (non-rain) T_b = 1ºC and M_f =1.8 mm/degree-day.
Calibrated coefficients (for UBC model) m = 2.5 and ø = 4.

♂ *(HEC, SSARR, UBC, PRMS and SRM) a little better than (SWAT, SHE and NWSRFS), as the more variables and wind function fluctuate the result widely.* , The probability of success in simulation using TI/EB of all the models together is 0.75 and in computation = 0.43/0.47 (data year 2003) and is 0.62/0.46 (data year 1983). Estimate gets improved up to 0.6 on averaging TI and EB estimates.

Climate Change: Analysis shows the change in trend and pattern over years. During 21 weeks of analysis, 2003 and 2008 has only 6 and 5 days of melting period. *SWAT based weekly peak snowmelt is 30 mm/day in March 2nd week of 2008, while it happen so (25mm) in March 3rd week and (32mm) in April 2nd week of 2003 and 1983, respectively which may be due to anthropological and climate changes or warming to advance the peak snowmelt by 1.6 weeks per decade. Consequently, snowpack accounting is important under changing climatic conditions.*.

Acknowledgements

Authors acknowledge Prof. Om P. Sharma, Centre for Atmospheric Sciences, IIT Delhi for the guidance. Authors acknowledge Mr. A. Ganju, Director, Mr. Snehmani and Mr. N. K. Thakur of SASE for their support data. Authors acknowledge the organizing committee of this International Conference 2012on SWAT for the time and opportunity.

THANKS