Table S1: List of the reviewed publications about snowmelt-runoff or hydrological models, where a snow redistribution approach is applied. A1-4 refers to the approaches described in the review.

Snowmelt-runoff / hydrological models	Reference	year	Snow redistribution approach: Type A1	A2	A3	A4	Description	Hosted approach	Com-plexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km^2)	Modeling Period
SnowModel (MicoMet (meteorlogical forcing), EnBal (snow/ice melt), Snowpack (snow evolution) & SnowTran-3D(snow transport))[1]	Liston & Elder[1]	2006		■			A2: SnowTran-3D. In SnowPack, snow density changes with time in response to snow-T and weight of overlying snow is computed following Anderson[2] formulation. Snow density changes due to melting: the melted snow decreases snow depth and meltwater is redistributed through the snowpack until a maximum snow density is reached. any additional meltwater is assumed to reach the ground.	SnowTran 3D	phys.	1–200 m	10 min – 1d	-	-	-	-	-	-
	Bernhardt & Schulz[3]	2010		■	■		A2: SnowTran3D: MM5 wind simulations. A3: SnowSlide	SnowTran 3D, Snow-Slide	phys.	30 m	hr	-	Landsat ETM+	-	Watzmann massif, Berchtesgaden National Park, Bavaria, Germany	Massif east face (1800 m height)	2 winter: 2004/05 and 2005/06
	Gascoin et al.[4]	2013		■			A2: MM5 wind simulations.	SnowTran 3D	phys.	90 m	1hr	-	MODIS	+measurements	Pascua-Lama, high dry Andes, Chilean Atacama Region	1043	1 winter: May–Nov 2008
ALPINE3D (SNOW-PACK+SnowDrift + EnergyBalance+Runoff module)[5]	Lehning et al.[6]	2000		■			A2: Snow transport estimated solving diffusion equation with a simple finite element method.	SnowDrift	phys.			-	-	-	-	-	-
	Lehning et al.[5]	2006		■			A2: wind fields calculated comparing the commercial fluid dynamics package CFX against that of the meteorological model system. saltation processes from equilibrium saltation model. Unsteady advection-diffusion process solved with stremline upwind/Petrov-Galerkin technique, yielding a semi-discretization in space. Full discretization in time obtained by finite elements. Sublimation treated by a source-sink term.	SnowDrift	phys.	10 m	1 hr	-	AVHRR (1km)	-	Dischma valley catchment, Switzerland	43,3 km2 (max size ALPINE3D modeling ~100km2)	10 yr (1990–99)
	Mott et al.[7]	2008	■	■			Simulation of wind fields with a mesoscale atmospheric model	SnowDrift	phys.	10 m	1hr	-	-	Snow height monit.	Goldbergkees and Kleinfleisskees, Austrian Alps		2002–03
	Dadic et al.[8]	2010	■	■			A1: wind fields from the regional atmospheric model ARPS. A simple parameterization of preferential deposition derived from almost linear correlation between mean horizontal wind v and modelled snow depth for cases with low wind speed (no erosion). 14 typical wind field situations identified based on frequency distribution of wind direction and wind speed at station. A2: see Lehning et al.[5].	SnowDrift	phys.	10 m	1hr	-	LiDAR data (snow-depth)	-	Haut Glacier d'Arolla, Alps, Switzerland	13	Accum. season: 2006/07
	Mott et al.[9]; Zwaaftink et al.[10]	2010; 2013	■	■			Wind fields simulation with ARPS	SnowDrift	phys.	10 m	1hr	-	Terr. airborne laser scanning (snow depos. patterns)	-	Wannengrat, near Davos, Switzerland	2.4	Storm 2008/09 and 2009/10
	Bavay et al.[11]	2013	■	■			Wind fields: model forced with the data from 35 automatic weather stations.	SnowDrift	phys.		1hr	-	-	-	Canton Graubünden, Eastern Switzerland	7214	2021–50 and 2070–95

Snowmelt-runoff / hydrological models	Reference	year	Snow redistribution approach: Type A 1	A 2	A 3	A 4	Description	Hosted approach	Complexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
SES[12]	Schöber et al.[13]	2014	■		■		A1: curvature is used as a proxy for wind[14]. A3: Gravitational processes calculated as a function of slope under consideration of a minimum slope and a maximum slope angle threshold [15]	Farinotti et al.[14]; Blöschl[15]	phys.	50 m	1hr	-	Lidar	-	Tyrolean Alps (Austria)	167	short periods between 2002 and 2011
AMUNDSEN[16]	Strasser et al.[17]	2008		■	■		A2: Implementation of SnowTran-3D with modelled wind fields[18]. A3: Gravitation: MTD-Algortihm[19]	SnowTran-3D; MTD-Algorithm	phys.	10–50 m	1 hr	-	-	-	Berchtesgaden National Park (Germany)	210	Winter 2004/05
	Strasser[20]	2012		■	■		A2: Wind: use of sky view factor to determine if erosion (SVF=1) or deposition (SVF<1). Parameterization of the wind as main direction (in this case SW) to define which slopes are luv and lee. A3: Gravitation: inspired from MTD-Algortihm[19]. snowslide starts if slope > 35° and is deposited downhill on slope ≤ 35°.	SnowTran 3D; MTD-Algorithm	phys.	10–50 m	1 hr	-	TERRA ASTER	-	Blaueis Glacier, Watzmanngletscher, Eiskappelle, Schöllhorneis (Austria)		
	Helfricht[21]	2014			■		A3: spatial correction of snow depth with topographic openness.		phys.	10 m	1 hr	-	Lidar	-	Ötztal Alps (Austria)		2001–13
	Hanzer et al.[22]	2016			■		A3: Uses openness[21] and multilevel spatiotemporal validation as a systematic independent, complete, and redundant validation procedure: meteorology, snow measurements, SCA from remote sensing, runoff, glacier data.	Openness	phys.	50 m	1 hr	-	MODIS, LANDSAT, LiDar	-	Ötztal Alps (Austria)	558	17yr; 1997–06
Water balance Simulation Model (WaSiM[23]; WaSIM-ETH[24])	Warscher et al.[25]; WaSIM-Documentation[23]	2013; 2015		■	■		A2: Wind: Simple parametrization to capture all wind-driven snow processes[26]. A3: Topography analysis (modified algorithm by Corripio[27] and using sky view factor) is used to sheltered of exposed location. Gravitation: MTD-Algorithm (DEM 50m).	MTD-Algorithm; Sky view factor	phys.	51 m	2 hr	-	LANDSAT ETM imagery	-	Berchtesgaden National Park (Germany)	210	2009–10
RHESSys[28]	Hartman et al.[28]	1999			■		A3: Topographic similarity index (similar to wetness index[29]. Snow transport follows the flow paths of water. Modeled distributed wind speeds used in conjunction with daily wind measurements to estimate sublimation.	Snow-Model	phys.	HRU	1 d	-	photogramm. rectified aerial images	-	Loch Vale Basin, Rocky Mountain National Park (USA)	6.6	12yr; 1984–95
TOPKAPI-ETH[30,31]	Ragettli et al.[32]	2016			■		A3: Mass conservative algorithm based on slope dependent maximum snow holding depth		phys.	100 m	1 hr	-	-	-	Himalayan and Andes Mountains (Nepal and Chile)		2001–91
Utah Energy Balance (UEB[33])	Luce et al.[34]; Luce and Tarboton[35]	1999; 2004	■			■	A1: Snowfall inputs are adjusted by basin average drift factor[36]. A4: Subgrid variability using depletion curves representing the functional decrease of SCA fraction.		phys.	30 m & lumped (2 models)		-	-	-	Upper Sheep Creek, Idaho (USA)	0.25	1 yr 1993;
	Clark et al.[37]	2011	■			■	A1: Snowfall inputs are adjusted by basin average drift factor[36].A4: Subgrid variability of SWE with probability distribution[34]. 2-parameters probability distribution function: mean of the distribution equal to total snow accumulation and coefficient of variation is a model parameter that must be specified.		phys.	5–100 m + elevation bands		-	-	Snow cover measurement field campaign	Upper Jollie Catchment, Central Southern Alps (New Zealand)	30	1 day, 20 Sept. 2007

Snowmelt-runoff / hydrological models	Reference	year	Snow redistribution approach: Type A1	A2	A3	A4	Description	Hosted approach	Com-plexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
Glacier mass balance	Pellicciotti et al.[38]	2014					A1: scaling of solid precipitation with a linear relationship based on slope and curvature[40]; A3: Gravitation: MTD-Algorithm[19]	Huss et al.[40]; MTD-Algorithm	phys.		1 hr	-	-	-	Haut Glacier d'Arolla, Rhonegletscher and Gorner-gletscher (CH); Miage Glacier (IT)		2000–50
LARSIM[41]	LARSIM documentation[42]	2014					A3: SWE transported to the bottom of the valley depending on slope and SWE thresholds. 2 parameters		phys.	1 - 30 km	1 d	-	-	-	Tested in different basins	large scale modeling	-
COSERO[43]	Frey & Holzmann[44]	2015					A3: Vertically redistribution of precipitation through preferential deposition from the steepest slopes to the neighbor slopes. The amount of redistributed snow depends on slope, age (density), land cover. Only downward. A4: Subgrid variability: log-normal distribution of snow during accumulation into 5 classes within a grid cell;		B-T	1 km	1 d	-	MODIS	-	Ötztal Alps (Aus-tria)	511	2005–10
HBV[45,46]	HBV documen-tation[47]	2013					A1: Altitude gradient for precipitation; A4: lognormal distribution of snow and snow cover percentage.		B-T	km/HRU	1 d	-	-	-	not specifically for alpine basins	-	-
BOKU-HBV[48]	Frey and Holzmann[48]	2013					A3 & A4: same as COSERO		B-T	1 km	1 d	-	MODIS	-	Pinzgau, Austrian Alps		2005–10
HBV-light[49]	Griessinger et al.[50]	2016					A3: Snow redistribution was assessed with slope and aspect-dependent correction functions using high-resolution snow depth maps from airborne lidar data[51] at a subgrid of 25 m.		B-T	25 m		-	-	Lidar SC data & snow melt as model input	20 alpine basins (Switzerland)	-	15 yr
	Stahl et al.[52]	2016					A1: Precipitation corrected with discharge values and water balance. A3: Snow is transported from the top of the mountain (elevation above a certain threshold, different for each basin) to the elevation zones between the threshold line and the treeline (1900 m asl) and to the glacier area. The amount of snow redistributed to each part depends on area. Snow redistributed once a snow threshold is reached (500 mm SWE).		B-T	HRU	1 d	-	-	-	49 glacierized catchments of the river Rhine (Swit-zerland & Austria)	-	106 yr; 1901–2006
DDD[53]	Skaugen & Weltzien[54]	2016					A4: Spatial probability density function (PDF) of SWE modelled as a sum of correlated gamma-distributed variables. Changes in SCA derived from PDF and intensity of melting event.	SD_G	B-T	semi-distr.	1 d / 3 hr	-	-	-	71 catchments in Norway	-	2000–15
Precipitation Runoff Evaporation Hydrotope (PREVAH)[55]	koboltschnig et al[56].; Randin et al.[57]	2008; 2015					Internal snow storage reset at the beginning of the year to avoid snow towers. No snow redistribution routine		B-T	HRU	1 hr	SCA from satel-lites	SCA from satel-lites	-	Upper Salzach River (Austria); Austrian Alps	593; 180	1999-02; 1981–2100
	Jörg-Hess et al.[58]	2015					Assimilation of gridded SWE maps derived from daily snow measure-ments to replace the model SWE at initialization.		B-T	distr.		-	-	-	Rhine basin (Switzerland, Austria)		

Snowmelt-runoff / hydrological models	Reference	year	Snow redistribution approach Type A 1	A 2	A 3	A 4	Description	Hosted approach	Com-plexity	Resolution Space	Time	Remote Sensing used for Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
CEQUEAU[59]	Bergeron et al.[60]	2016				■	A4: SCA computed separately using depletion curve [61] following 3-parameter beta distribution.		B-T	distr.	1 d	MODIS /Terra SCA	-	-	Nechako catch-ment, British-Columbia (Cana-da)	14000	
Glacier Evolution Runoff Model (GERM)[40]	Huss et al.[39]; Farinotti et al.	2008; 2012			■		A3: implementation of Huss et al.[40]	Huss et al. [40]	B-T	distr.	1 d	-	-	-	Swiss glacerized catchments (Switzerland)	-	1962-06; 1900–2100
	Huss & Fischer	2016	■		■		A1: Wind: snow redistribution multiplier derived statistically from topography[14], A3: Gravitation: Accumulation reduced from 100 to 0% for slope from 40 to 60°	Farinotti et al.[14]	B-T	10 m	1d	-	-	-	Swiss Glaciers - Global study	116	1961–2060
Water Availability in Semi-Arid Environ-ments (WASA[62])	Duethmann et al.[63]	2015			■	■	A3: Snow in high elevations with no glacier is redistributed to next lower HRU if SWE> 3 m; A4: spatial variability within HRU using deple-tion curve[64]. Lognormal distribution of SWE is assumed.	Liston[64], 2004	B-T	HRU	1 d	-	-	-	Headwater catchment of the Aksu River (China)	18410	1957–2004
OEZ[65]	Kuhn[65]	2003	■				A1: A constant fraction of snowfall is transported from ice free areas to glacier areas by tuning a parameter through observation		B-T	100 m elevation intervals	1 month	-	-	-	Paznaun basin (Austria)		1961/62, 1991/92

Table S2: List of the reviewed publications about snow evolution models, where a snow redistribution approach is applied. A1-4 refers to the approaches described in the review.

Snow evolution models	Reference	year	Snow redistribution approach: Type A 1	A 2	A 3	A 4	Description	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
SNOWPACK[83]	Lehning et al.[6]	2000					A2: Atmospheric model analysis of high resolution wind field over topography (with ARPS); Novel formulation for wind transport in saltation and suspension that allows treating preferential deposition and redistribution.			-	-	-	Gaudergrat ridge, Switzerland	ridge	event
	Doorschot et al.[84]	2001					A2: measurements of wind speed and precipitation. Saltation (model based on microscale physical processes), suspension (1D diffusion equation) processes are explicitly modeled for a mountain ridge. Effect of speed-up of wind over ridges included by assuming an analytical wind profile with maximum wind v at a few meters above ridge. Advective effects: parameterization of the turbulent shear stress profile.		30 min/ 1hr	-	-	-	Gaudergrat ridge, Switzerland	ridge	4 drift events, 1997 and 1999
	Lehning et al.[85]	2002					A2: Wind and turbulence fields over complex topography simulated with mesoscale atmospheric model (ARPS) using non-hydrostatic compressible Navier-Stokes equations solved using finite element method. Suspension and preferential deposition modeled without distinction using wind fields. Saltation modeled separately.	25 m	event	-	-	-	Gaudergrat ridge, Switzerland	ridge	event, 1998/99
	Luetschg et al.[86]	2004					A1: Snowfall decreased by a factor of 0.5 to account for strong wind erosion[87]. A2: see Lehning et al. [85]. A4: avalanche release was included by reducing snow cover at upper location by fracture depth of 0.3 m and by increasing snow depth by 2 m at the slope base.	ridge	event	-	-	-	Flüela pass, Eastern Swiss Alps, Switzerland	0.1 km2 (ridge)	event; 2002/03
	Lehning et al.[88]	2008					A2: Complex wind fields from ARPS atmospheric model. Uses mean flow characteristics of the wind fields. Parameterization of turbulences in the drift model. Saltation model: see Doorshot & Lehning[89]. Suspension and preferential deposition: snow particles in the suspension layer stem from snowfall and saltation layer and the wind field is assumed to be stationary during the modelling time step.	25	hr	-	-	-	Gaudergrat ridge, Switzerland	ridge	120h snow storm Jan 1999
ISNOBAL [90]	Winstral et al.[26]	2002					A2: Terrain-based parameters to avoid complex modeling of wind fields. S_x: based on maximum upwind slopes relative to seasonally averaged winds to characterize the wind scalar at each pixel location. S_b: measured upwind breaks in slope from a given location. Drift delineator parameter calculated from S_x and S_b to delineate sites of intense redeposition on lee slopes.	10-30 m	1 hr	-	1 classified photograph of 22 May 1999	504 snow depth samples	Upper Green Lakes Valley, Colorado (USA)	2.25	Winter 1998/99
	Winstral & Marks[91]	2002					A2: Wind data parameterized[26]. A series of wind-factors images, focused on all possible wind directions at 5° increments, was established to conduct weighted interpolations of the hourly measured wind data. If a cell's exposure, relative to the recorded wind direction, was => than the exposure of the ridge meteorological site, then it would receive the wind speed as measured at the ridge site. Else it will receive a linearly interpolated value based on the degree of shelter provided by the upwind topography and standing vegetation.	10-30 m	1 hr	-	time series of aerial photographs	-	Reynolds Mountain East, Idaho (USA)	0.38	1986, 1987, and 1989
	Winstral et al.[92]	2013					A1-A2: The distribution algorithm uses topography, vegetation and wind data to adjust the precipitation data to simulate wind-affected accumulation. upwind slope to linearly interpolate wind-sheltered and wind-exposed snow observations to other location while upwind slope determine enhanced accumulation areas[26]	10-30 m	1 hr	-	Landsat	-	3 catchments: Reynolds Moutain East, Upper Sheep Creek, and Dobson Creek, Idaho (USA)	0,36; 0,26; 14	2004–08

Table S3: List of the reviewed publications about snow redistribution approaches described independently of a hydrological or snow evolution model. A1-4 refers to the approaches described in the review.

Independent snow redis-tribution approach	Reference	year	Snow redistribution approach: Type A 1	A 2	A 3	A 4	Description	Appl. to hydrol. model	Com-plexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km^2)	Modeling Period
PBSM[66,67]	Pomeroy et al.[66]	1993		■			2D snow blowing model. Salt: calculated as a function of atm. density, atm. friction velocity. Friction velocity depends on snow quality. Susp: calculated as the integral of the mass flux over flow depth. Starts at the top of salt.-layer. Surface erosion/deposition rates at distance x downwind of the leading edge of a fetch is established by the net mass of snow entering or leaving the volume in x and z direction. Surface erosion/deposition rate per unit area from volume mass balance.		phys.	100 m	1 hr	-	-	-	Canadian Prairies environment	several location: fetches up to 4000m	1970–76
	Essery et al.[67]	1999		■		■	A2: windflow over complex terrain modelled using linear model and Fourier transform of topography specified by a DEM; only valid for flow over low hills (slopes <1:4) and assumes neutral stratification. The transport rates by blowing snow are scaled approximately as the 4th power of wind v, with weak dependence on T through the threshold wind v at which blowing snow starts. This threshold is calculated using a quadratic function of T (derived from observations). A4: distribution classified by vegetation type and landform can be approximated by lognormal distributions.		phys.	80 m	1/2hr	-	-	-	Arctic Tundra	168	1996–97, 210 d
SnowTran-3D[68] v1.0	Liston & Sturm[68]	1998		■			A2: Includes topographic modification of wind speeds, snow-cover shear strength, wind-induced surface shear stress, saltation and suspension, as well as sublimation of blowing and drifting snow. Amount and patterns of the redistributed snow depend on the amount of falling snow. Saltation and turbulent suspension as well as sublima-tion are modelled. The snow-transport model is based on a mass-balance equation describing the temporal variation o snow depth at a point.		phys.	10–100 m		-	-	-	Arctic Alaska (USA)		4 y
	Greene et al.[69]	1999	■	■			A2: Wind distribution is modified to account for topography by multi-plying with an empirically based weighting factor calculated from topographic slope and curvature. A1: snow amount corrected with elevation using observation from another catchment.		phys.	30 m		-	-	-	Montgomery Pass, Norther Colorado Rocky Mountains (USA)	6	Winter 1997–98, 56 d
	Prasad et al.[70]	2001		■			A2: wind speed and direction measurement from one station used for entire area despite question of representativity.	UEB	phys.	30 m	hr	-	-	-	Upper Sheep Creek, Idaho, USA	0.25	3 days: Feb/Mar 1993
	Hiemstra et al.[71]	2002		■		■	In order to apply model to the study area, modifications were made regarding model resolution, snow holding capacity, and small grid redistribution parameterization that removed a fraction of snow from areas of high accumulation and re-deposited it in downwind grid cells (to eliminate the artefact that snow can accumulate on leeside becom-ing higher than the object itself - ~ snow towers).		phys.	5 m		-	-	-	Libby Flats, Medicine Bow Mountains, Wyoming, USA	6.25	Winter 1997/98
	Hiemstra et al.[72]	2006		■			Wind fields calculated with interpolation using wind speed and direc-tion observations in conjunction with empirical wind-topography relationships.		phys.	5 m		-	-	-	Libby Flats, Medicine Bow Mountains, Wyoming, USA	6.25	3 water years 1997–00

Independent snow redistribution approach	Reference	year	Snow redistribution approach: Type A1	A2	A3	A4	Description	Appl. to hydrol. model	Complexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
SnowTran-3D[68] v2.0	Liston et al.[73]	2007					(1) improved wind sub-model, (2) a 2-layer submodel describing the spatial and temporal evolution of friction velocity that must be exceeded to transport snow, (3) implementation of a 3D equilibrium drift profile submodel that forces SnowTran-3D to simulate snow-transport processes in variable topography ad different snow climates. A2: coupled to MicroMet (spatially meteorological model) to distribute data (P, T, wind v and direction, rel. humidity). Also coupled to Snow-Model for snow evolution.		phys.	1–100 m	1hr-1d	-	-	-	-	-	Individual storms to entire winter seasons
	Bernhardt et al.[74]	2009					A2: modified version of MM5 model simulation for wind fields (v and direction) with 200 m resolution. To avoid computational efforts, 220 wind fields were separately generated and archived prior inclusion in snow transport model. They represent the most frequent synoptic wind situation for snow transport at the test site. Model solves non-hydrostatic equations of the motion in a terrain-following sigma coordinate system.	Snow-Model	phys.	200 m	1 hr	-	-	-	Berchtesgaden National Park, Bavaria, Germany	210	Winter 2003/04
SYTRON3[75]	Durand et al.[75]	2005					A2: Representation of creep, saltation and diffusion thanks to increased number of vertical layers in the SCM.		phys.	45 m	1 hr	-	digital photographs and field observation	-	Col du Lac Blanc, French Alps, France	Mountain pass	5 snow drift events between Jan and Apr 2004
SnowSlide[3]	Bernhardt & Schulz[3]	2010					A3: Variation of MTD-Algorithm. Threshold parameter snow holding depth depending on land cover and slope angle or calculated over a regression function, exceeding snow redistributed to lower grids. Snow redistribution starts from the highest and ends at the lowest elevated grid element thus avoiding snow transport into already processed grid cells.	Snow-Model	phys.	30 m	1 hr	-	Landsat ETM+	-	Watzmann massif, Berchtesgaden National Park, Bavaria, Germany	Massif east face (1800 m height)	2 winter: 2004/05 and 2005/06
P1	Gauer[76]	2001					A2: complex 3D wind fields over high resolution grids. Numerical model that includes particle trajectory calculations in the saltation simulations, and a two-way coupling between the particles and airflow. Model flow simulation, saltation and suspension. Modelled snow drift around a single crest		phys.	ridge	event based	-	-	-	Gaudergrat ridge (Switzerland)		Several events during winter 1996/97
MTD-Algorithm[19]	Gruber[19]	2007					A3: Mass-conservative snow sliding with multiple flow direction to propagate the snow mass along predefined couloirs. Snow is deposited at decreasing slope angles. Snow is removed from steep area and deposited at the foot of the hill (valley). In each cell, the fraction of mass drained to a neighbor is a function of topography only and totals one over all neighboring cells in order to conserve mass. Deposition is limited by the local maximum deposition and determined by the available incoming mass that is the sum of the received inflows from the neighboring cells.	Used in many different studies. Main gravitational snow module	phys.	10, 25, 50 m (DEM)	-	-	-	-	Glacier Vadret in Misaun (Switzerland)	small area	6 snow slide events between 1997 and 1999
C1	Huss et al.[40]	2008					A3: For snowdrift and avalanches: simply scale of the solid precipitation using a linear relationship based on slope and curvature (derived from DEM). Accumulation linearly decreased from 100 to 0% between a slope angle of 40° to 60°. The curvature is evaluated for each grid cell within a range of 200m and solid precipitation is multiplied with a factor varying between 0.5 and 1.5 on curvature. Therefore a precipitation matrix is generated that describes the differential deposition of snow. For all precipitation data the same correction, do not depend on the amount of snow falling.	GERM	Conc.	1–2 km (P & T data), DEM 50 and 25 m		-	-	-	Grosser Aletschgletscher, Rhonegletscher, Griesgletscher, Silvrettagletscher (Switzerland)	glacier area up to 83 km2	142 y

Independent snow redistribution approach	Reference	year	Snow redistribution approach: Type A1	A2	A3	A4	Description	Appl. to hydrol. model	Complexity	Resolution: Space	Time	Remote Sensing used for: Cal.	Val.	Other	Study area	Size (km2)	Modeling Period
S1	Perona et al.[77]	2007				■	A4: stochastic poissonan growths and deterministic decay as simple model for the inter-annual dynamic of SWE storage and melting.		Stat.	-	-	-	-	-	Arosa station (Switzerland)	-	1 season
S2	Grünewald et al.[78]	2013				■	A4: Compared high resolution snow data and statistical methods for SWE variability estimation around the world and how they are linked to topography, vegetation.		Stat.	-	-	-	-	-	7 locations around the world	1,5 - 28	2002–09
S3	Farinotti et al.[14]	2010	■				A1: Snow multiplier is iteratively defined and correlated with local slope and curvature. Modeled and observed patterns from photographs are compared,		Stat.			-	-	Time-lapse photography	Dammagletscher (Swiss Alps)	9.1	1939–2007
S4	Grünewald et al.[79]	2010				■	A4: Terrestrial Laser Scanning to calculate spatial variability of ablation rates. Correlation of ablation rates with slope and wind speeds (ARPS)		Stat.	2.5 m		-	-	Terrestrial Laser Scanning	Albertibach (Switzerland)	1.3	winter season 2007/2008
S5	Jackson[36]	1994	■						Stat.			-	-	-			Winter 1985/86
	Tarboton et al.[80]	1995	■				A1: Predefined spatial precipitation matrix with location-dependent 'snow multiplier'		Stat.	30,48 m		-	-	-	Upper Sheep Creek, Idaho, USA	0.25	Winters 1985/86 &1992/93
S6	Blöschl[15]	1991		■			A2: Curvature is used as a proxy for the degree of wind exposure of a given grid cell.		Stat.			-	-	-	Sellrain region in Stubai Alps (Austria)		
SD_G	Skaugen & Randen[81]	2013				■	A4: Spatial probability density function (PDF) of SWE modelled as a sum of correlated gamma-distributed variables. Changes in SCA derived from PDF and intensity of melting event.		Stat.		1 d	-	-	-	Norefjell and Filefjell (Norway)		2002-2012
SG1	Kerr et al.[82]	2013				■	A5: Images from digital cameras used to describe the		Stat.	50 m		-	-	Digital cameras	Pinnacle Stream Catchment (New Zealand)	12.5	Oct – Feb 2008

1. Liston, G. E. & Elder, K. A Distributed Snow-Evolution Modeling System (SnowModel). *Am. Meteorol. Soc.* 1259–1276 (2006).
2. Anderson, E. A. A point energy and mass balance model of a snow cover. *NOAA Tech. Rep. NWS-19, 150 pp* (1976).
3. Bernhardt, M. & Schulz, K. SnowSlide: A simple routine for calculating gravitational snow transport. *Geophys. Res. Lett.* **37,** 1–6 (2010).
4. Gascoin, S., Lhermitte, S., Kinnard, C., Bortels, K. & Liston, G. E. Wind effects on snow cover in Pascua-Lama, Dry Andes of Chile. *Adv. Water Resour.* **55,** 25–39 (2013).
5. Lehning, M. *et al.* ALPINE3D : a detailed model of mountain surface processes and its application to snow hydrology. *Hydrol. Process.* **20,** 2111–2128 (2006).
6. Lehning, M., Doorschot, J. & Bartelt, P. A snowdrift index based on SNOWPACK model calculations. *Annals of Glaciology* **31,** 382–386 (2000).
7. Mott, R. *et al.* Simulation of seasonal snow-cover distribution for glacierized sites on Sonnblick, Austria, with the Alpine3D model. *Annals of Glaciology* **49,** 155–160 (2008).
8. Dadic, R., Mott, R., Lehning, M. & Burlando, P. Parameterization for wind-induced preferential deposition of snow. *Hydrol. Process.* **2006,** n/a-n/a (2010).
9. Mott, R., Schirmer, M., Bavay, M., Grünewald, T. & Lehning, M. Understanding snow-transport processes shaping the mountain snow-cover. *Cryosphere* **4,** 545–559 (2010).
10. Groot Zwaaftink, C. D., Mott, R. & Lehning, M. Seasonal simulation of drifting snow sublimation in Alpine terrain. *Water Resour. Res.* **49,** 1581–1590 (2013).
11. Bavay, M., Grünewald, T. & Lehning, M. Response of snow cover and runoff to climate change in high Alpine catchments of Eastern Switzerland. *Adv. Water Resour.* **55,** 4–16 (2013).
12. Asztalos, J., Kirnbauer, R., Escher-Vetter, H. & Braun, L. A distributed energy balance snow and glacier melt model as a component of a flood forecasting system for the Inn river. *Alpine/Snow/Workshop. Berchtesgaden Natl. Park Res. Rep. Nr. 53, Munich* 9–17 (2007).
13. Schöber, J. *et al.* Snow cover characteristics in a glacierized catchment in the Tyrolean Alps - Improved spatially distributed modelling by usage of Lidar data. *J. Hydrol.* (2014). doi:10.1016/j.jhydrol.2013.12.054
14. Farinotti, D., Magnusson, J., Huss, M. & Bauder, A. Snow accumulation distribution inferred from time-lapse photography and simple modelling. *Hydrol. Process.* **24,** 2087–2097 (2010).
15. Blöschl, G. The Influence of Uncertainty in Air Temperature and Albedo on Snowmelt. *Nord. Hydrol.* **22,** 95–108 (1991).
16. Strasser, U. *et al.* Spatial and temporal variability of meteorological variables at Haut Glacier d'Arolla (Switzerland) during the ablation season 2001: measurements and simulations. *J. Geophys. Res.* **109,** D03103 (2004).
17. Strasser, U., Bernhardt, M., Weber, M., Liston, G. E. & Mauser, W. Is snow sublimation important in the alpine water balance? *Cryosph.* **2,** 53–66 (2008).
18. Bernhardt, M. Using wind fielfs from a high-resolution atmospheric model for simulating snow dynamics in mountainous terrain. *Thesis* (2008). doi:10.1002/hyp
19. Gruber, S. A mass-conserving fast algorithm to parameterize gravitational transport and deposition using digital elevation models. *Water Resour. Res.* **43,** 1–8 (2007).
20. Strasser, U. & Warscher, M. *Das Gebirgsschneedeckenmodell AMUNDSEN und seine Anwendung - Kolloquium 11.07.2012, Freiburg*. (2012).
21. Helfricht, K. *Analysis of the spatial and temporal variation of seasonal snow accumulation in Alpine catchments using airborne laser scanning - basic research for the adaptation of spatially distributed hydrological models to moutain regions. Doctoral Thesis*. (2014).
22. Hanzer, F., Helfricht, K., Marke, T. & Strasser, U. Multi-level spatiotemporal validation of snow/ice mass balance and runoff modeling in glacierized catchments. *Cryosph.* **10,** 1859–1881 (2016).

23. Model Description - WaSiM (Water balance Simulation Model). *Tech. Report, Hydrol. Softw. Consult. J Schulla, Regensdorfstrasse 162, CH-8049 Zurich, Switzerland.* **last exten,** 318 (2015).

24. Schulla, J. & Jasper, K. Model Description WaSiM-ETH. *Tech. Rep.* 181pp (2007).

25. Warscher, M. *et al.* Performance of complex snow cover descriptions in a distributed hydrological model system: A case study for the high Alpine terrain of the Berchtesgaden Alps. *Water Resour. Res.* **49,** 2619–2637 (2013).

26. Winstral, A., Elder, K. & Davis, R. E. Spatial Snow Modeling of Wind-Redistributed Snow Using Terrain-Based Parameters. *J. Hydrometeorol.* **3,** 524–538 (2002).

27. Corripio, J. *et al.* Modelling and monitoring snow redistribution by wind. *Geophys. Res. Abstr. Abstr. EGS-AGU-EUG Jt. Assem. Nice, Fr. 06 - 11 April 2003* **5,** 8294 (2003).

28. Hartman, M. D. *et al.* Simulations of snow distribution and hydrology in a mountain basin. *Water Resour. Res.* **35,** 1587–1603 (1999).

29. Beven, K. J. & Kirkby, M. J. A physically based, variable contributing area model of basin hydrology. *Hydrol. Sci. Bull.* **24,** 43–69 (1979).

30. Finger, D., Pellicciotti, F., Konz, M., Rimkus, S. & Burlando, P. The value of glacier mass balance, satellite snow cover images, and hourly discharge for improving the performance of a physically based distributed hydrological model. *Water Resour. Res.* **47,** n/a-n/a (2011).

31. Ragettli, S. & Pellicciotti, F. Calibration of a physically based, spatially distributed hydrological model in a glacierized basin: On the use of knowledge from glaciometeorological processes to constrain model parameters. *Water Resour Res* **48,** (2012).

32. Ragettli, S., Immerzeel, W. W. & Pellicciotti, F. Contrasting climate change impact on the hydrology of the Andes and the Himalayas. *Nat. Clim. Chang.* **113,** under review (2016).

33. Tarboton, D. & Luce, C. Utah energy balance snow accumulation and melt model (UEB). *Comput. Model Tech. Descr. users Guid.* 1–64 (1996). at <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.73.6983&rep=rep1&type=pdf>

34. Luce, C. H., Tarboton, D. G. & Cooley, K. R. Sub-grid parameterization of snow distribution for an energy and mass balance snow cover model. *Energy* **1933,** 1921–1933 (1999).

35. Luce, C. H. & Tarboton, D. G. The application of depletion curves for parameterization of subgrid variability of snow. *Hydrol. Process.* **18,** 1409–1422 (2004).

36. Jackson. A Spatially Distributed Snowmelt-Driven Hydrologic Model applied to the Upper Sheep Creek Watershed. *PhD thesis. Dep. Civ. Environ. Eng. Utah State Univ. Logan, Utah, USA.* (1994).

37. Clark, M. P. *et al.* Representing spatial variability of snow water equivalent in hydrologic and land-surface models: A review. *Water Resour. Res.* **47,** (2011).

38. Pellicciotti, F., Carenzo, M., Bordoy, R. & Stoffel, M. Changes in glaciers in the Swiss Alps and impact on basin hydrology: current state of the art and future research. *Sci. Total Environ.* **493,** 1152–70 (2014).

39. Huss, M., Farinotti, D., Bauder, A. & Funk, M. Modelling runoff from highly glacierized alpine drainage basins in a changing climate. *Hydrol. Process.* **22,** 3888–3902 (2008).

40. Huss, M., Bauder, A., Funk, M. & Hock, R. Determination of the seasonal mass balance of four Alpine glaciers since 1865. *J. Geophys. Res.* **113,** F01015 (2008).

41. Bremicker, M. Das Wasserhaushaltsmodell LARSIM - Modellgrundlagen und Anwendungsbeispiele. *Freiburg. Schriften zur Hydrol.* 119 (2000). at <http://www.hydrology.uni-freiburg.de/publika/band11.html>

42. LARSIM-Entwicklergemeinschaft - Hochwasserzentralen LUBW, BLfU, LUWG, H. Das Wasserhaushaltsmodell LARSIM - Modellgrundlagen und Anwendungsbeispiele (Entwurf). (2014).

43. Nachtnebel, H. P., Baumung, S. & Lettl, W. Abflussprognose- modell für das Einzugsgebiet der Enns und Steyer. *Inst. Water Manag. Hydrol. Hydraul. Eng. Uni- versity Nat. Resour. Life Sci. Vienna* (1993).

44. Frey, S. & Holzmann, H. A conceptual, distributed snow redistribution model. *Hydrol. Earth Syst. Sci.* **12,** 609–637 (2015).

45. Bergström, S. *Development and application of a conceptual runoff model for Scandinavian catchments*. (1976).

46. Lindström, G., Johansson, B., Persson, M., Gardelin, M. & Bergström, S. Development and test of the distributed HBV-96 hydrological model. *J. Hydrol.* **201,** 272–288 (1997).

47. Administration, N. W. R. and E. ‘ Nordic ’ HBV model. *Model Doc.* (2013).

48. Frey, S. & Holzmann, H. Dealing with snow accumulation in high mountains A simple conceptual snow drift model. in *EGU* (2013).

49. Seibert, J. & Vis, M. J. P. Teaching hydrological modeling with a user-friendly catchment-runoff-model software package. *Hydrol. Earth Syst. Sci.* **16,** 3315–3325 (2012).

50. Griessinger, N., Seibert, J., Magnusson, J. & Jonas, T. Assessing the benefit of snow data assimilation for runoff modeling in Alpine catchments. 3895–3905 (2016). doi:10.5194/hess-20-3895-2016

51. Grünewald, T. & Lehning, M. Are flat-field snow depth measurements representative? A comparison of selected index sites with areal snow depth measurements at the small catchment scale. *Hydrol. Process.* **29,** 1717–1728 (2015).

52. Stahl, K. *et al.* Abflussanteile aus Schnee- und Gletscherschmelze im Rhein und seinen Zuflüssen vor dem Hintergrund des Klimawandels. *Abschlussbericht an die Int. Kommission für die Hydrol. des Rheingebietes - Enderfassung 08/2016. Bericht CHR 00-2016. www.chr-khr.org/en/publications* (2016).

53. Skaugen, T. & Onof, C. A rainfall-runoff model parameterized from GIS and runoff data. *Hydrol. Process.* **28,** 4529–4542 (2014).

54. Skaugen, T. & Weltzien, I. H. A model for the spatial distribution of snow water equivalent parameterized from the spatial variability of precipitation. *Cryosph.* **10,** 1947–1963 (2016).

55. Viviroli, D., Zappa, M., Gurtz, J. & Weingartner, R. An introduction to the hydrological modelling system PREVAH and its pre- and post-processing-tools. *Environ. Model. Softw.* **24,** 1209–1222 (2009).

56. Koboltschnig, G. R., Schöner, W., Zappa, M., Kroisleitner, C. & Holzmann, H. Runoff modelling of the glacierized Alpine Upper Salzach basin (Austria): multi-criteria result validation. *Hydrol. Process.* **22,** 3950–3964 (2008).

57. Randin, C. F., Dedieu, J. P., Zappa, M., Long, L. & Dullinger, S. Validation of and comparison between a semidistributed rainfall-runoff hydrological model (PREVAH) and a spatially distributed snow-evolution model (SnowModel) for snow cover prediction in mountain ecosystems. *Ecohydrology* **8,** 1181–1193 (2015).

58. Jörg-Hess, S., Griessinger, N. & Zappa, M. Probabilistic Forecasts of Snow Water Equivalent and Runoff in Mountainous Areas. *J. Hydrometeorol.* **16,** 2169–2186 (2015).

59. Charbonneau, R., Fortin, J.-P. & Morin, G. The CEQUEAU Model: Description and Examples of its use in Problems Related to Water Resource Management / Le modèle CEQUEAU: description et exemples d’utilisation dans le cadre de problèmes reliés à l’aménagement 10. *Hydrol. Sci. Bull.* **22,** 193–202 (1977).

60. Bergeron, J. M., Trudel, M. & Leconte, R. Combined assimilation of streamflow and snow water equivalent for mid-term ensemble streamflow forecasts in snow-dominated regions. *Hydrol. Earth Syst. Sci.* **20,** 4375–4389 (2016).

61. Anderson, E. A. National Weather Service River Forecast System – Snow Accumulation and Ablation Model, National Oceanographic and Atmospheric Administration (NOAA) Department of Commerce, Silver Spring,MD. *Tech. Mem., NWS-HYDRO-17, U.S., Natl. Weather Serv. Silver Spring* 217pp (1973).

62. Güntner, A. & Bronstert, A. Representation of landscape variability and lateral redistribution processes for large-scale hydrological modelling in semi-arid areas. *J. Hydrol.* **297,** 136–161 (2004).

63. Duethmann, D. *et al.* Attribution of streamflow trends in snow and glacier melt-dominated catchments of the Tarim River, Central Asia. *Water Resour. Res.* **51,** 4727–4750 (2015).

64. Liston, G. E. Representing subgrid snow cover heterogeneities in regional and global models. *J. Clim.* **17,** 1381–1397 (2004).

65. Kuhn, M. Redistribution of snow and glacier mass balance from a hydrometeorological model. *J. Hydrol.* **282,** 95–103 (2003).

66. Pomeroy, J. W., Gray, D. M. & Landine, P. G. The Prairie Blowing Snow Model : characteristics, validation, operation. *J. Glaciol.* **144,** 165–192 (1993).

67. Essery, R., Li, L. & Pomeroy, J. A distributed model of blowing snow over complex terrain. *Hydrol. Process.* **13,** 2423–2438 (1999).

68. Liston, G. E. & Sturm, M. A snow-transport model for complex terrain. *Journal of Glaciology* **44,** 498–516 (1998).

69. Greene, E. M., Liston, G. E. & Pielke, R. A. Simulation of above treeline snowdrift formation using a numerical snow-transport model. *Cold Reg. Sci. Technol.* **30,** 135–144 (1999).

70. Prasad, R., Tarboton, D. G., Liston, G. E., Luce, C. H. & Seyfried, M. S. Testing a blowing snow model against distributed snow measurements at Upper Sheep Creek, Idaho, United States of America. *Water Resour. Res.* **37,** 1341–1356 (2001).

71. Hiemstra, C. A., Liston, G. E. & Reiners, W. A. Snow redistribution by wind and interaction with vegetation at upper treeline in the Medicine Bow Mountains, Wyoming, USA. *Arctic, Antarct. Alp. Res.* **34,** 262–273 (2002).

72. Hiemstra, C. a., Liston, G. E. & Reiners, W. a. Observing, modelling, and validating snow redistribution by wind in a Wyoming upper treeline landscape. *Ecol. Modell.* **197,** 35–51 (2006).

73. Liston, G. E. *et al.* Simulating complex snow distributions in windy environments using SnowTran-3D. *J. Glaciol.* **53,** 241–256 (2007).

74. Bernhardt, M., Liston, G. E., Strasser, U. & Mauser, W. Using wind fields from a high-resolution atmospheric model for simulating snow dynamics in mountainous terrain. *Hydrol. Process.* **23,** 1064–1075 (2009).

75. Durand, Y., Guyomarc'h, G., Mérindol, L. & Corripio, J. G. Improvement of a numerical snow drift model and field validation. *Cold Reg. Sci. Technol.* **43,** 93–103 (2005).

76. Gauer, P. Numerical modeling of blowing and drifting snow in Alpine terrain. *J. Glaciol.* **47,** 97–110 (2001).

77. Perona, P., Porporato, a. & Ridolfi, L. A stochastic process for the interannual snow storage and melting dynamics. *J. Geophys. Res. Atmos.* **112,** 1–10 (2007).

78. Grünewald, T. *et al.* Statistical modelling of the snow depth distribution in open alpine terrain. *Hydrol. Earth Syst. Sci.* **17,** 3005–3021 (2013).

79. Grünewald, T., Schirmer, M., Mott, R. & Lehning, M. Spatial and temporal variability of snow depth and ablation rates in a small mountain catchment. *Cryosph.* **4,** 215–225 (2010).

80. Tarboton, D. G., Chowdhury, T. G. & Jackson, T. H. A spatially distributed energy balance snowmelt model. **1994,** 141–155 (1995).

81. Skaugen, T. & Randen, F. Modeling the spatial distribution of snow water equivalent, taking into account changes in snow-covered area. *Ann. Glaciol.* **54,** 305–313 (2013).

82. Kerr, T., Clark, M., Hendrikx, J. & Anderson, B. Snow distribution in a steep mid-latitude alpine catchment. *Adv. Water Resour.* **55,** 17–24 (2013).

83. Lehning, M. *et al.* SNOWPACK model calculations for avalanche warning based upon a new network of weather and snow stations. *Cold Reg. Sci. Technol.* **30,** 145–157 (1999).

84. Doorschot, J., Radershall, N. & Lehning, M. Measurements and one-dimensional model calculations of snow transport over a mountain ridge. *Ann. Glaciol.* **32,** 153–158 (2001).

85. Lehning, M., Doorschot, J., Fierz, C. & Raderschall, N. Wind Transported Snow A 3D MODEL FOR SNOW DRIFT AND SNOW COVER DEVELOPMENT IN STEEP ALPINE TERRAIN Michael Lehning*, Judith Doorschot, Charles Fierz and Norbert Raderschall VVSL, Swiss Federal Institute for Snow and Avalanche Research, SLF. *Stevens, J.R., ed. Proceedings, Int. Snow Sci. Work. 29 Sept. - 4 Oct. 2002, Penticton, Br. Columbia. Victoria, BC, Minist. Transp.* 579–589 (2002).

86. Luetschg, M., Stoeckli, V., Lehning, M., Haeberli, W. & Ammann, W. Temperatures in two boreholes at Flüela Pass, eastern Swiss Alps: The effect of snow redistribution on permafrost distribution patterns in high mountain areas. *Permafr. Periglac. Process.* **15,** 283–297 (2004).

87. Gauer, P. Blowing and drifting snow in alpine terrain: A physically based numerical model and related field measurements. *Ph.D. Diss.* 125 (1999). doi:10.3929/ethz-a-002047499

88. Lehning, M., Löwe, H., Ryser, M. & Raderschall, N. Inhomogeneous precipitation distribution and snow transport in steep terrain. *Water Resour. Res.* **44,** n/a-n/a (2008).

89. Doorschot, J. J. J. & Lehning, M. Equilibrium saltation: Mass fluxes, aerodynamic entrainment, and dependence on grain properties. *Boundary-Layer Meteorol.* **104,** 111–130 (2002).

90. Marks, D., Domingo, J., Susong, D., Link, T. & Garen, D. A spatially distributed energy balance snowmelt model for application in mountain basins. *Hydrol. Process.* **13,** 1935–1959 (1999).

91. Winstral, A. & Marks, D. Simulating wind fields and snow redistribution using terrain-based parameters to model snow accumulation and melt over a semi-arid mountain catchment. *Hydrol. Process.* **16,** 3585–3603 (2002).

92. Winstral, A., Marks, D. & Gurney, R. Simulating wind-affected snow accumulations at catchment to basin scales. *Adv. Water Resour.* **55,** 64–79 (2013).