Using MODIS imagery to validate the spatial representation of snow cover extent obtained from SWAT in a data-scarce Chilean Andean watershed

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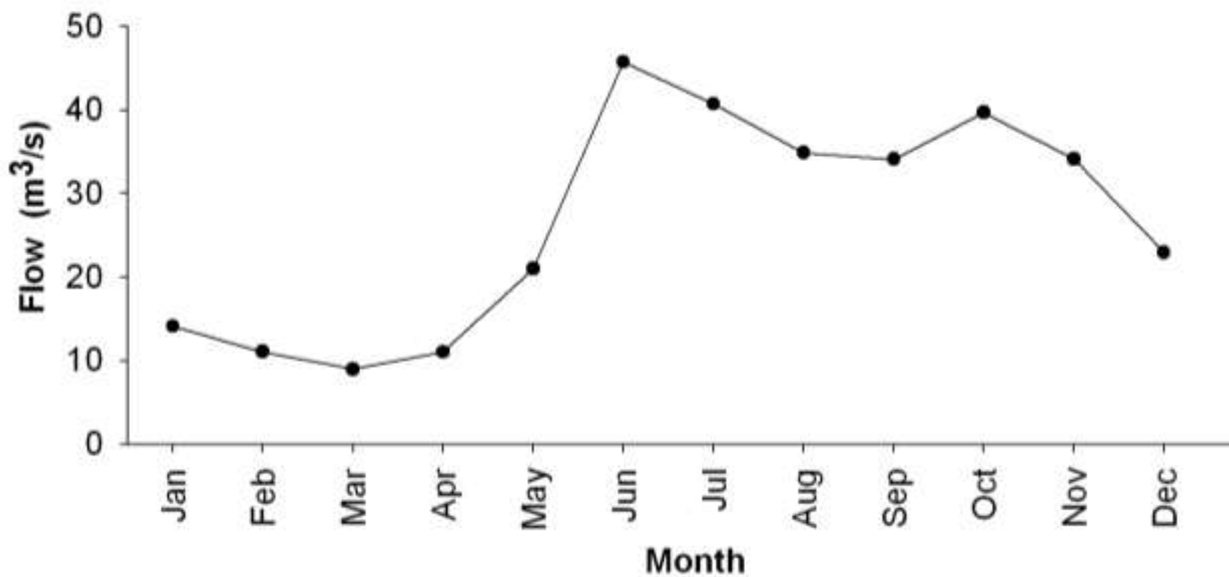
Outline

- Background and objectives
- Study area
- Methodology
- Results
- Conclusions

Background and objectives

- Depending on the relative altitude and ambient temperature, Andean watersheds present important snow coverage during the winter season.
- Snowpack stores significant amount of precipitation water.
- Released to surface runoff and groundwater when solar radiation increases.



Background and objectives

- 25% of the south central Chilean surface is contained in areas where snow precipitation takes place during a normal winter.

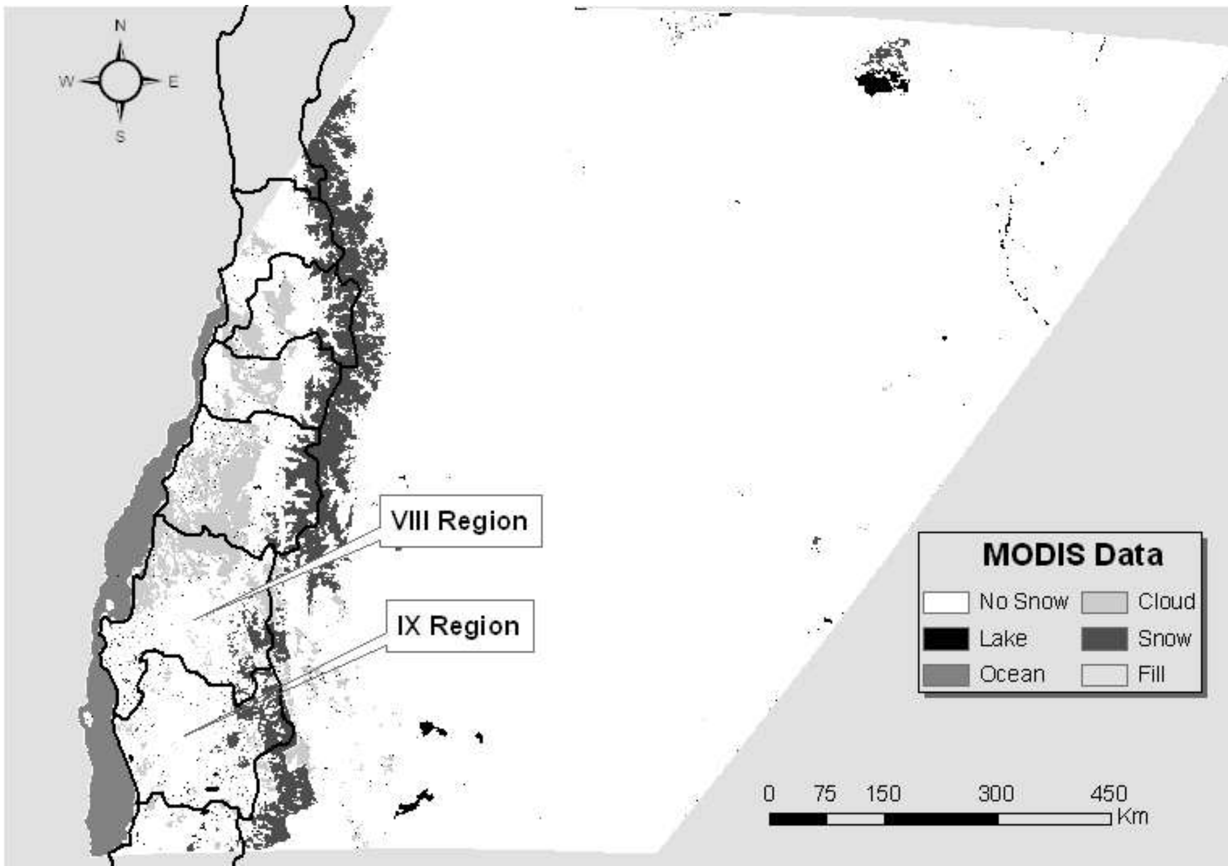
Chilean Andes of lack

- meteorological input
- hydrological validation data

Complicates the analysis of those hydrological processes that take place in this important part of many of the country's river basins.

Background and objectives

- Remote sensing provide a promising opportunity to enhance the assessment and monitoring of the spatial and temporal variability of the different variables involve in the precipitation runoff process in areas where data availability for hydrological modelling is scarce.



Background and objectives

- The objective of this study is to use remotely-sensed snow cover information obtained from MODIS imagery in order to validate the spatial snow cover extent and the thus the representation of stream hydrology calculated with SWAT.

Remote sensing techniques

- In data-scarse regions such as the Himalayan or Andean mountains, satellite derived (NOAA-AVHRR, MODIS, etc.) SCA information provides a promising opportunity to enhance the assessment and monitoring of the spatial and temporal variability of snow characteristics.

- The spatial distribution and temporal variability characterization of snow distribution can be improved combining satellite snow cover products with field data and snowpack models.

- In MODIS, classification of SCA is done based on the Normalized Difference Snow Index (NDSI)

$$NDSI = (Band\ 4 - Band\ 6)/(Band\ 4 + Band\ 6)$$

Visible infrared

Shortwave infrared

Remote sensing techniques

For a first approximation, MODIS MOD10A2 product were validated for the year 2010 at one observation point in a Chilean Andean watershed; using measured snow depth data obtained from a Sonic Ranging Sensor (SR50A/AT).

Hydrological modelling with snowmelt

Effect of spatial heterogeneity on the surface runoff and groundwater flow → Physically-based distributed or semi-distributed models

- Semi-distributed hydrological models divide the watershed in subbasins and each subbasisn is again divided in hydrological response units (HRU) that are homogeneous in their hydrological characteristics (soil type, land use and slope).
- In this work the semi-distributed approach of surface runoff which is included in the SWAT model with emphasis on their snowmelt contribution was use.

Hydrological modelling with snowmelt

Snow accumulation and snowmelt are modelled using a temperature-index snowmelt relationship:

$$SM = b_{mlt} * sno_{cov}\left[(T_{snowpack} + T_{mx})/2 - TMLT\right]$$

SM: snowmelt (mm H_2O)

B_{mlt}: melt factor for that day (mm H2O day-1- °C)

$T_{snowpack}$: snow pack temperature(ºC)

T_{mx}: maximum air temperature on a given day (ºC)

TMLT: threshold temperature to occur snowmelt (ºC)

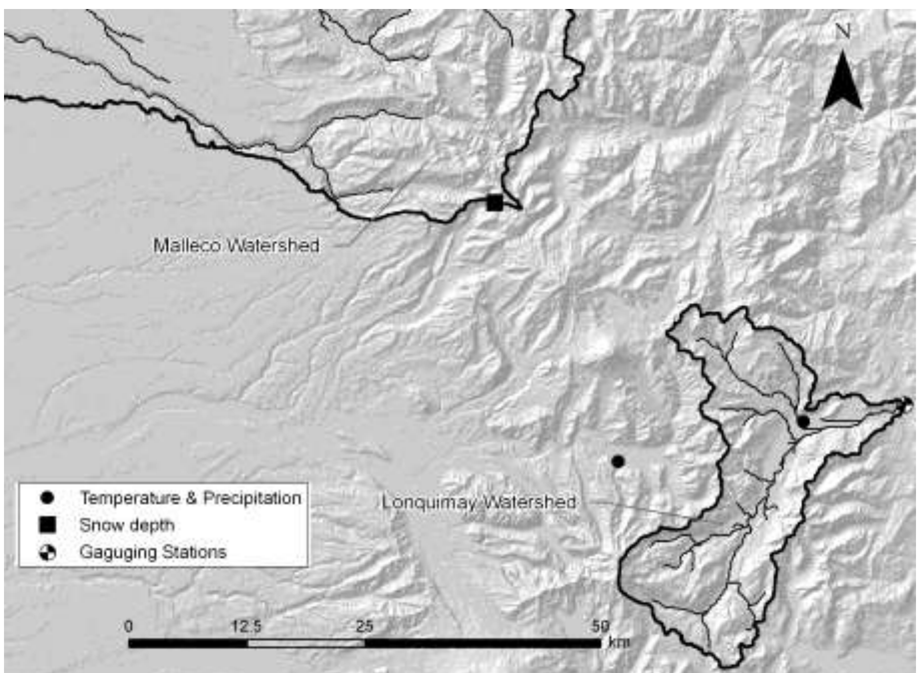
sno_{cov}: fraction of area covered by snow

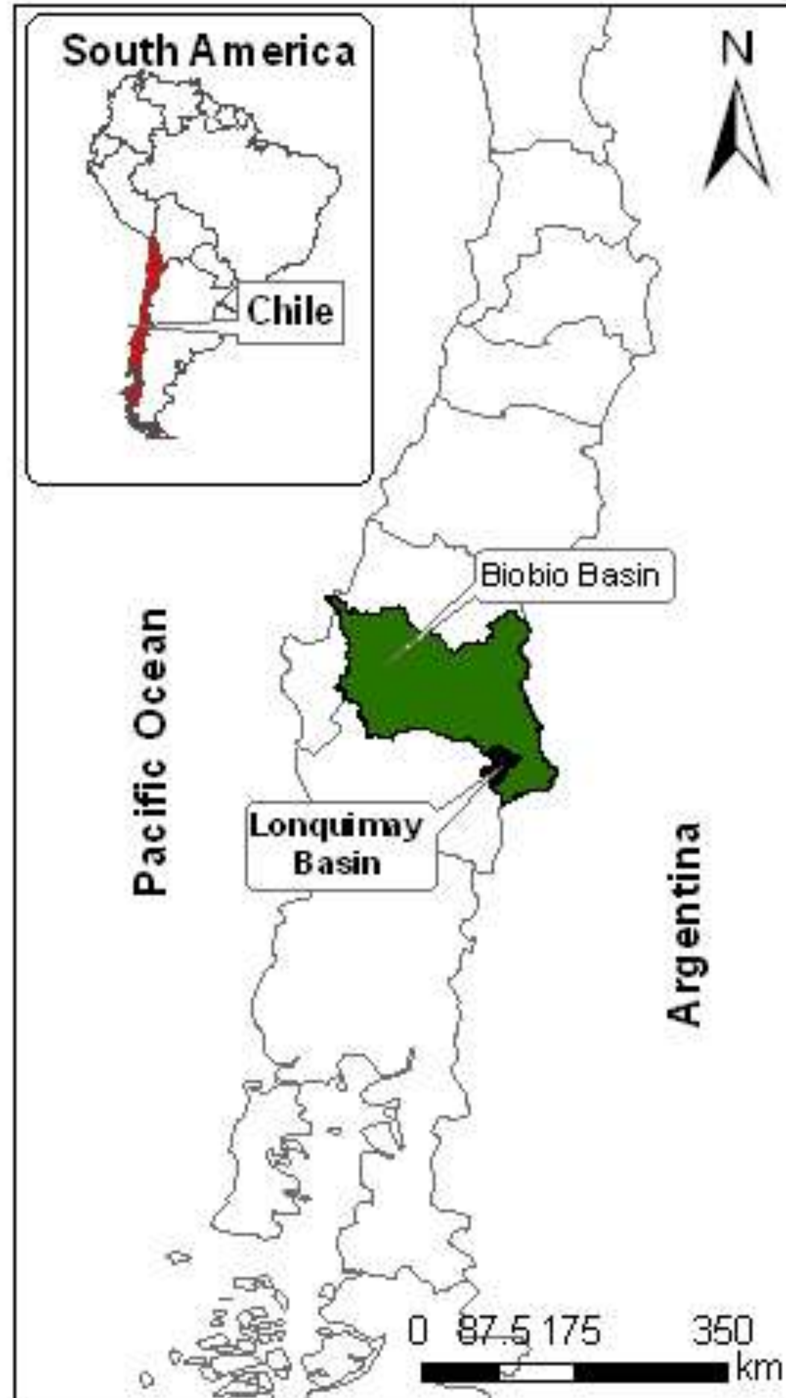
$$SWE_{day} = SWE_{(day-1)} + SF - SM - E_S$$

SWE: snowpack water equivalent (mm H_2O day^{-1})
SM: snow melt (mm H_2O day^{-1})
SF: snow fall (mm H_2O day^{-1})
E_s: sublimation (mm H_2O day^{-1})

Study area

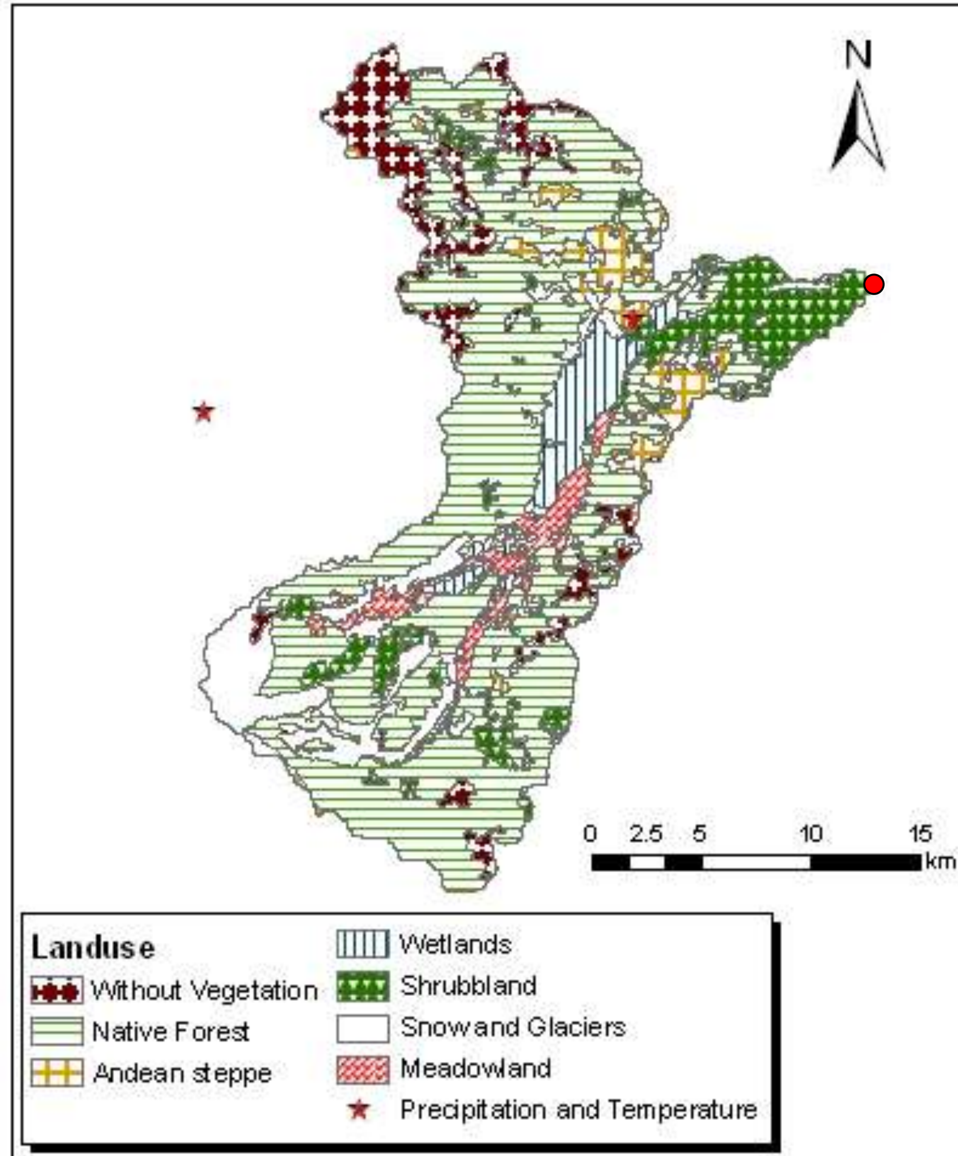
- Area of 455 km^2
- Elevation values from 880 to 2533 m a.m.s.l.
- Flow regime is pluvio-nival, mean monthly discharges:
  Maximum → 45.75 m^3/s June
  Minimum → 8.96 m^3/s March





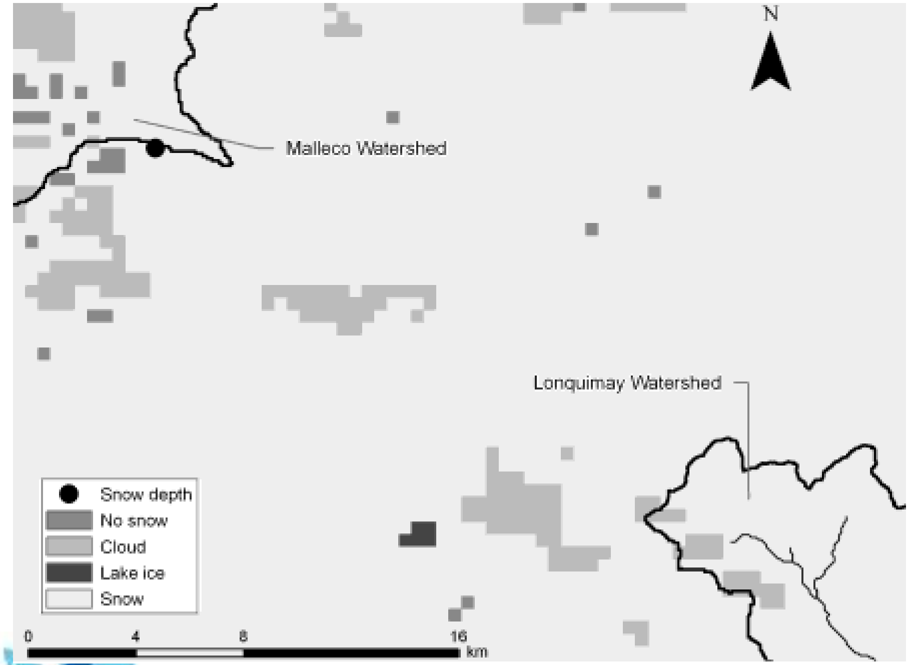
Model Setup

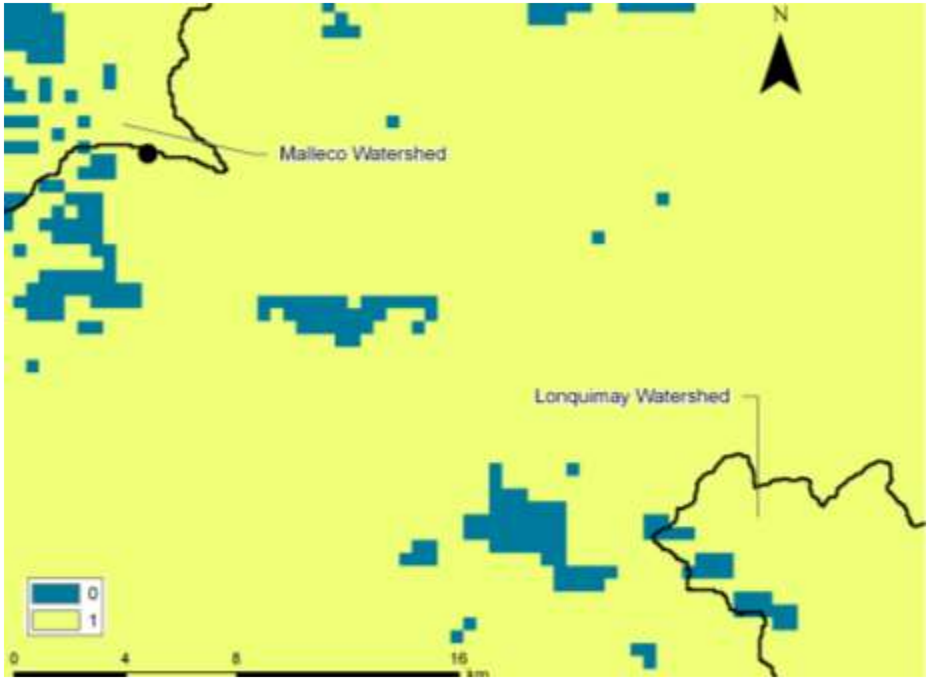
- ✓ 90 x 90 m Digital Elevation Model (DEM) (based on the final SRTM data sets)
- ✓ Meteorological and fluviometric input data were obtained from the National Chilean Water Data Bank
- ✓ The model was run for the period **2001 – 2004** for calibration and **2005 - 2007** for validation.



MODIS

- MOD10A2 snow product was used.
- MOD10A2 pixels were reclassified as snow (1) were MODIS indicated the presence of snow and no snow (0) in other cases.
- MOD10A2 product was validated for April to September of 2010 at one observation point (1190 m.a.s.l.).





Results - MODIS validation

- Results obtained comparing observed snow depths with MOD10A2 snow cover data for April to September 2010.
- 23 MOD10A2 imagines available for April to September 2010.
- For this period snow depth data from the station located at the Malleco watershed are available.

Date	"1" if Snow depth > 0	"1" if Modis pixel value = snow	Match up
4/07/2010	0	0	Match
4/15/2010	0	0	Match
4/23/2010	0	0	Match
5/01/2010	0	0	Match
5/09/2010	1	0	No Match
5/17/2010	1	1	Match
5/25/2010	1	1	Match
6/02/2010	1	1	Match

Results - MODIS validation

- The snow depth sensor indicated presence of snow during 83% of the time, while MODIS10A2 during 87%.
- In the specific case of the day 8/21/2010 the imagine is classified as cloud at the observation point, but the surrounding area is classified as snow, thus it is assumed that the presence of snow at the observation point matches up to 91% .
- Results in agreement with previous studies.

Modelling Results

- For calibration and validation two temporal scales were used, namely 8 days and 1 month.
- Subsequently, sub-basins were classified as 0 or 1. A value of 0 was assigned only if snowfall, snowmelt, sublimation and snowpack were all zero.
- After reclassification values obtained from the modeling process were subtracted from the MODIS results with:
  - ✓ 0 values indicating agreement between the imagery and model results
  - ✓ a value of -1 indicates that model results reveal presence of snow where the MODIS imagery does not. (over-estimation)
  - ✓ a value of 1 indicates that the model does not represent the presence of snow in areas where the MODIS imagery does. (sub-estimation)

Modelling Results

Calibration

- Calibration was done using measured flows and MOD10A2 data.
- First a sensitivity analysis was done, results for both time scales (8 days and 1 month) indicate that the four most sensitive parameters are snowfall temperature, snowmelt base temperature and maximum melt factor for snow.

Snow cover area calibration results 2001-2004

Time scale	Sub-estimation (%)	Over-estimation (%)	Total error (%)
8 days	15.5	5.7	21.2
1 month	8.0	5.7	13.7

Modelling Results

Calibration

Monthly snow cover area results for calibration period 2001-2004

	Sub-estimation (%)	Over-estimation (%)	Total error (%)
April	17.2	4.4	21.7
May	17.8	0.6	18.3
June	12.2	0.6	12.8
July	6.7	0.0	6.7
August	6.1	0.0	6.1
September	3.9	2.8	6.7
October	6.1	12.2	18.3
November	12.2	11.1	23.3
December	8.3	10.6	18.9
January	0.6	9.4	10.0
February	5.0	4.4	9.4
March	0.6	12.2	12.8

Modelling Results

Validation

Snow cover area validation results 2005-2007

Time scale	Sub-estimation (%)	Over-estimation (%)	Total error (%)
8 days	12.6	8.4	21.0
Monthly	7.5	9.8	17.2

Modelling Results

Validation

Monthly snow cover area results for validation period 2005-2007

	Sub-estimation (%)	Over-estimation (%)	Total error (%)
April	28.1	4.4	32.6
May	19.3	0.0	19.3
June	15.6	1.5	17.0
July	0.0	2.2	2.2
August	0.0	5.2	5.2
September	2.2	5.9	8.1
October	3.7	6.7	10.4
November	13.3	13.3	26.7
December	1.5	16.3	17.8
January	0.0	20.7	20.7
February	3.7	15.6	19.3
March	2.2	25.2	27.4

Modelling Results

Efficiency and determination coefficient calculated for the calibration (2001–2004) and validation (2005 -2007) period

	Calibration	**Validation**
RRMSE	0.64	0.64
ABSERR	12.59	12.64
EF	0.61	0.35
R^2	0.68	0.80

Conclusions

- ✓ When comparing MOD10A2 data with ground snow observations at one location, good results are obtained which can indicate that this product is suitable to use for calibration and validation of snow cover area. Comparison at more measuring points is needed.

- ✓ Results obtained from the presented SWAT model application for the Lonquimay sub-basin, located in the Central-Chilean Andes, shows a good performance when comparing snow cover area obtained from MOD10A2 with snow cover area obtained from the simulations done with SWAT.

Conclusions

- ✓ The model shows a satisfactory general model performance in term of representation of monthly mean discharge at the basin outlet.
- ✓ Improvements can be done in the future including more parameters into the calibration process.
- ✓ Although a reasonably good description of snow cover extent could be obtained under most circumstances, the present case study shows the limitations inherent to the low density of stations providing meteorological input data in the case of basins featuring high altitudinal gradients.

Acknowledgments

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