Sensitivity of snow models to the accuracy of the meteorological forcing in mountain environment:

the NextSNOW experiment

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Introduction

Mountain snow cover is an essential component of the climate

→ high albedo, cooling effect

→ "water reservoir"

Information on snow depth variability:

→ surface stations, accurate but sparse

→ gridded datasets, continuous but coarse

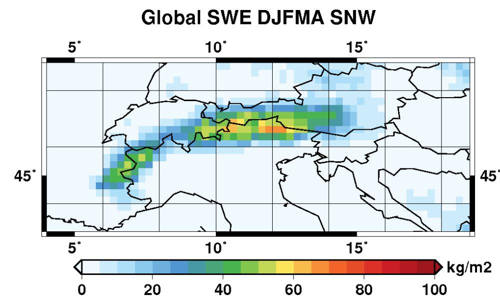
In a recent paper [1] we compared the major gridded datasets of *snow water equivalent in the Alps,* in terms of climatology and annual cycle

→ Large spread among datasets

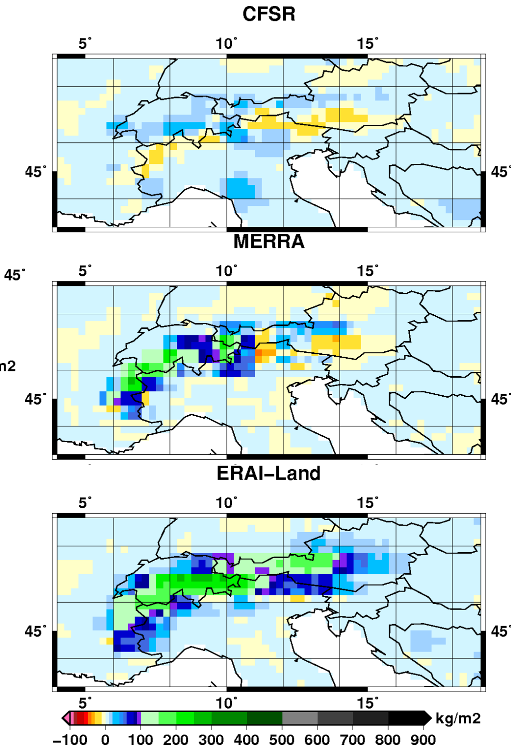
→ Large uncertainties in SNW

Need for accurate, high-resolution SNW estimates at mountain range scale, for sustainable water management, as well as for climate change assessment and climate model evaluation

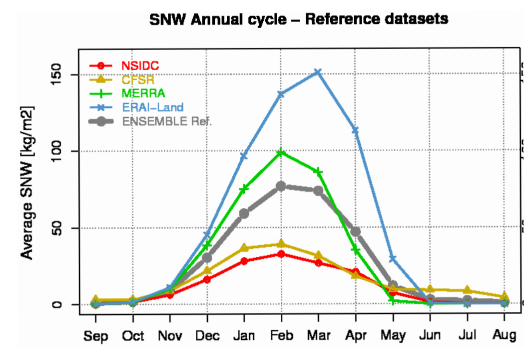
1980-2005
Snow water equiv.
climatology
from satellite



Difference
Reanalysis - Satellite



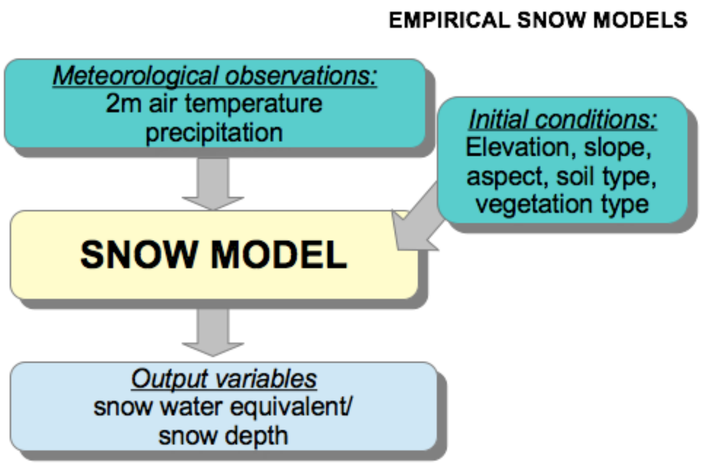
1980-2005
snow annual cycle

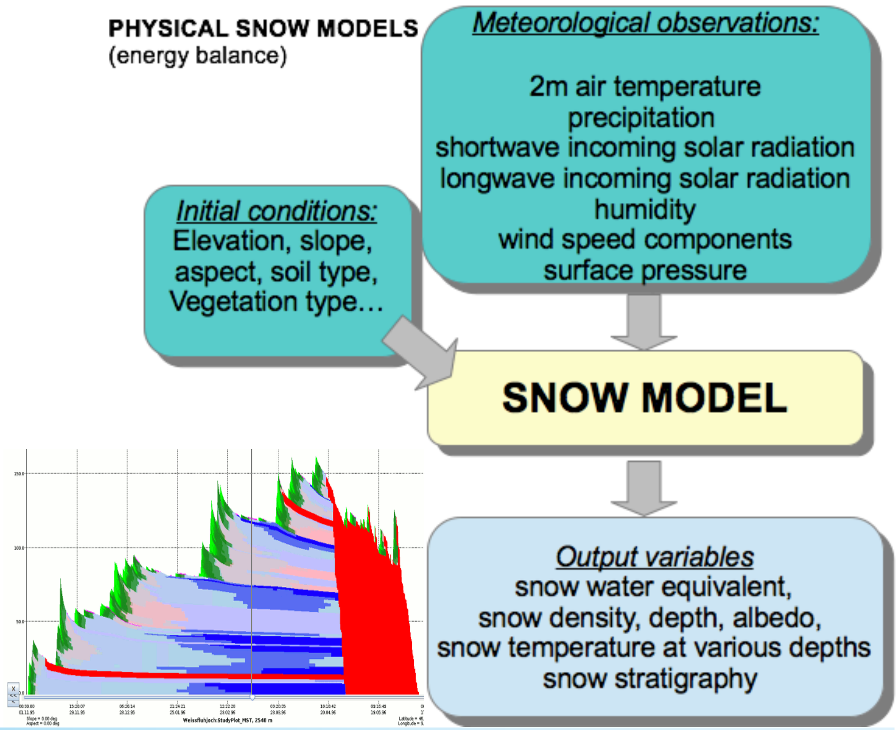


[1] Terzago, S. et al., : Snow water equivalent in the Alps as seen by gridded data sets, CMIP5 and CORDEX climate models, The Cryosphere, 2017.

Introduction

- In order to estimate snow depth, a possible approach is to run land-surface models forced by available gridded meteorological data
- A variety of snow models, with different degrees of complexity





Introduction

- In order to estimate snow depth, a possible approach is to run land-surface models forced by available gridded meteorological data
- A variety of snow models is available, with different degrees of complexity

- Complex orography → meteorological variables used to drive snow models characterized by high spatial variability, errors reflected in the snow output

- **Q1**: What is the impact of the ***degree of complexity*** of the snow model on snow depth simulations?
- **Q2**: What is the impact of ***the accuracy of the meteorological forcing*** on the snow simulations?

The NextSnow experiment

	Snow Model	Number of snow layers	The model in a nutshell	Reference
Sophisticated snow model	SNOWPACK	Multi-layer	Mass and energy exchange between snow, atmosphere and soil. Snowpack microstructure, the internal phase changes and water transport in snow.	Bartelt and Lehning (2002)
Intermediate complexity	GeoTOP	Multi-layer	Heat transfer from atmosphere to soil through the snowpack, snow accumulation, densification (destructive metamorphism and overburden), water percolation	Endrizzi et al., 2014
	UTOPIA	Single layer	Thermal and hydrological balances. It can simulate snow water equivalent, snow water content, snow density, snow depth, snow cover and snow temperature	Cassardo et al., 2015
	SMASH	Multi-layer	Energy- and mass-balance snow model Pysically-based evolution of snow density, albedo Provides SWE, snow density, snow depth and temperature of each layer.	Piazzi et al., 2018
Simple	S3M	Single-layer	Single-layer energy balance snow model designed for hydrological purposes. It combines several sources of information to provide the best estimation of snowpack state.	Boni et al., 2010

The test site: Torgnon station

Experimental measurement site of Torgnon, 2160 m a.s.l.

Period 2012-2017

Meteorological observations:

2m air temperature
precipitation
shortwave incoming solar radiation
longwave incoming solar radiation
humidity
wind speed components
surface pressure

SNOW MODEL

Initial conditions:
Elevation a.s.l., slope,
Aspect, Soil type,
Vegetation type,
Soil humidity,...

Output variables
Many surface/near-surface variables,
among others:
snow water equivalent
snow density,
snow depth

Validation data:
snow water equivalent
snow density,
snow depth, albedo,
Snow temperature, Soil temperature,….

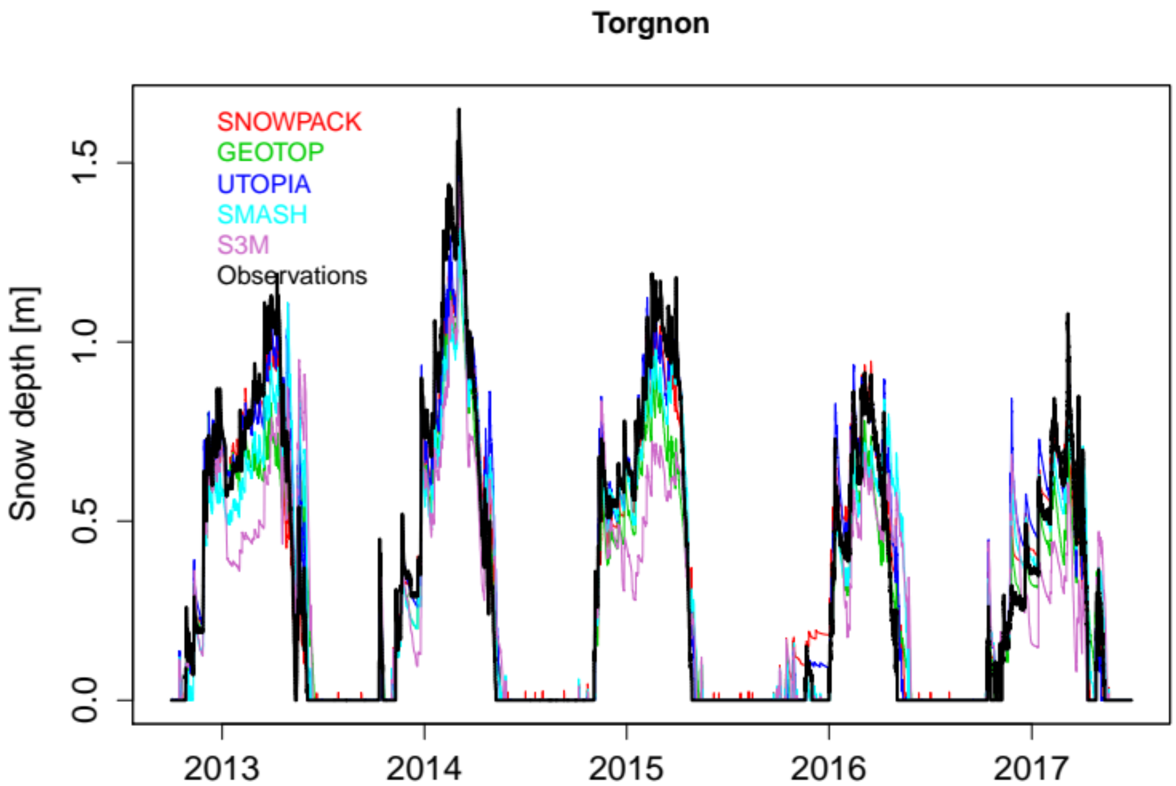
The set of experiments

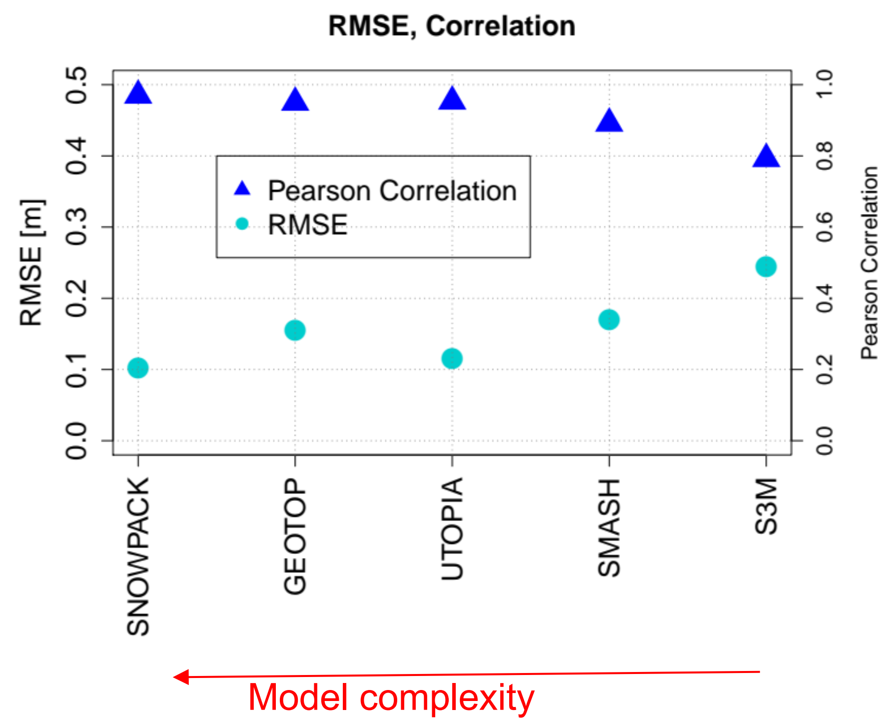
	Exp	Forcing	Time res.
CONTROL	1	Torgnon station data	30'
Shortwave In. Radiation	2	Station data, SWIN, LWIN in case of snowfall are derived from ERA-Interim	30'
	3	Torgnon station data except for SWIN, Clearsky parameterization	30'
Temporal Resolution	4	Torgnon station data	3h
	5	Torgnon station data	6h
	6	Torgnon station data	12h
Spatial Resolution/ Accuracy	7	Interpolation of nearest-stations (MeteoIO)	1h
	8	GLDAS	3h
	9	ERA5	1h
	10	ERA-Interim	3h
Bias adjustment	11	ERA-Interim_corrected_quota	3h
	12	ERA-Interim_corrected_bias	3h

- Default models configurations → no tuning on the Torgnon dataset
- Same parameterization for rain/snowfall separation (except for GeoTOP)

Impact of the snow model complexity

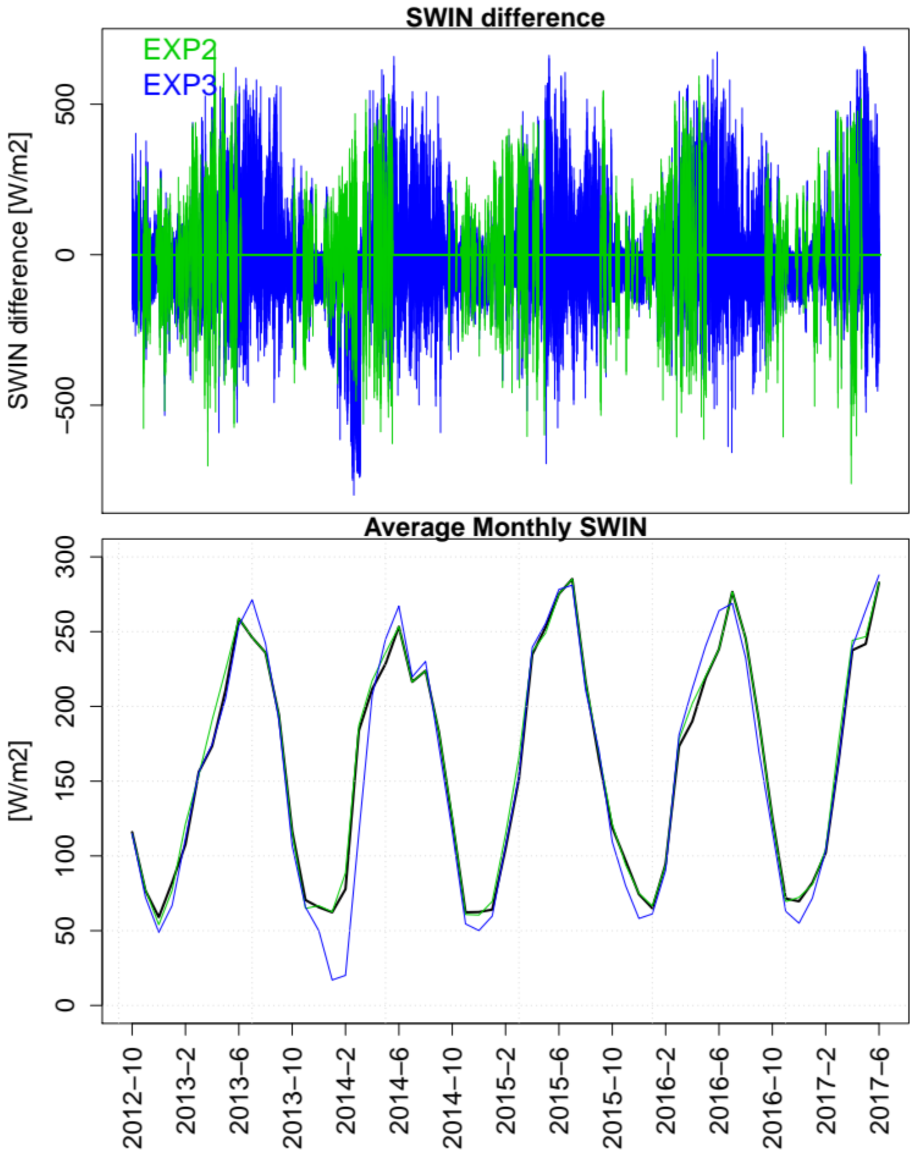
EXP1: → 5 different snow models, driven by accurate station measurements





- The lowest RMSE are obtained with SNOWPACK and UTOPIA

Sensitivity to incoming SW radiation



- EXP2 : Snowfall → SWIN ERAI
- EXP3: External param. for SWIN

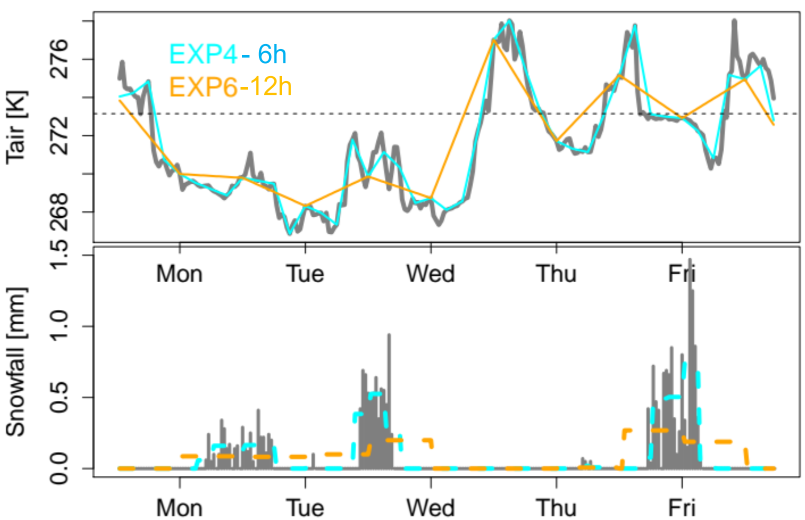
	RMSE [m]				
	Snow-pack	**Geotop**	**Utopia**	**Smash**	**S3M**
CTL	0.10	0.15	0.12	0.17	0.24
EXP2	0.12	0.15	0.13	0.17	0.24
EXP3	0.11	0.15	0.13	0.17	0.24

Sensitivity to the temporal resolution of the forcing

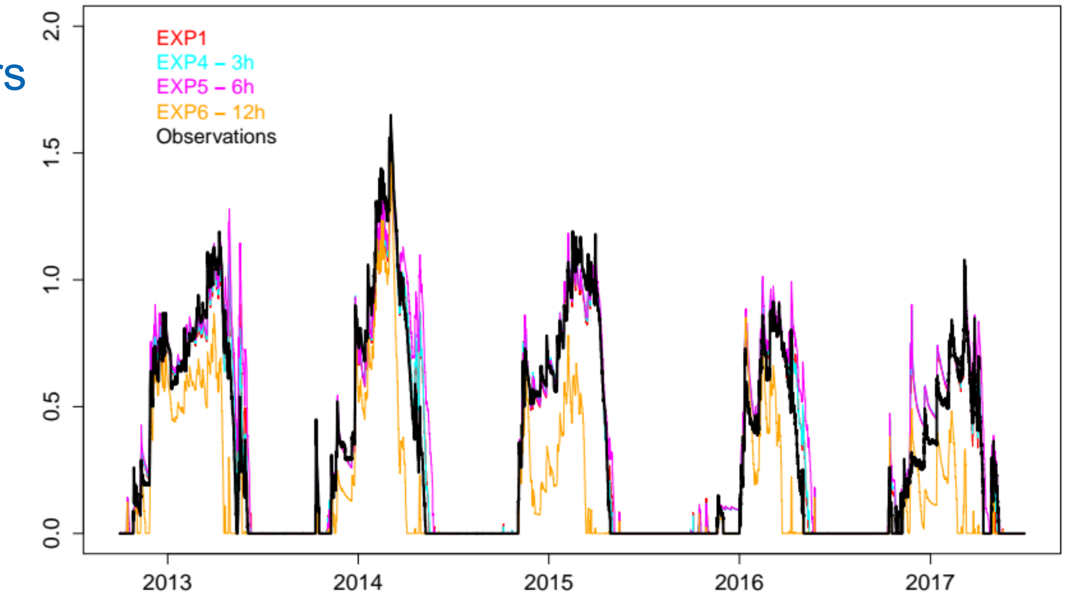
EXP4, EXP5, EXP6

→ Torgnon data aggregated at 3h, 6h, 12 hours

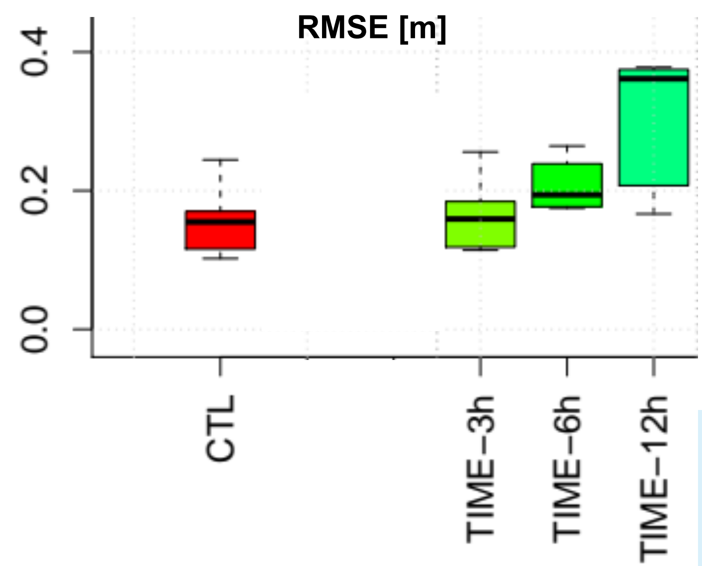
INPUT



OUTPUT – SNOW DEPTH FROM UTOPIA



ALL 5 MODELS



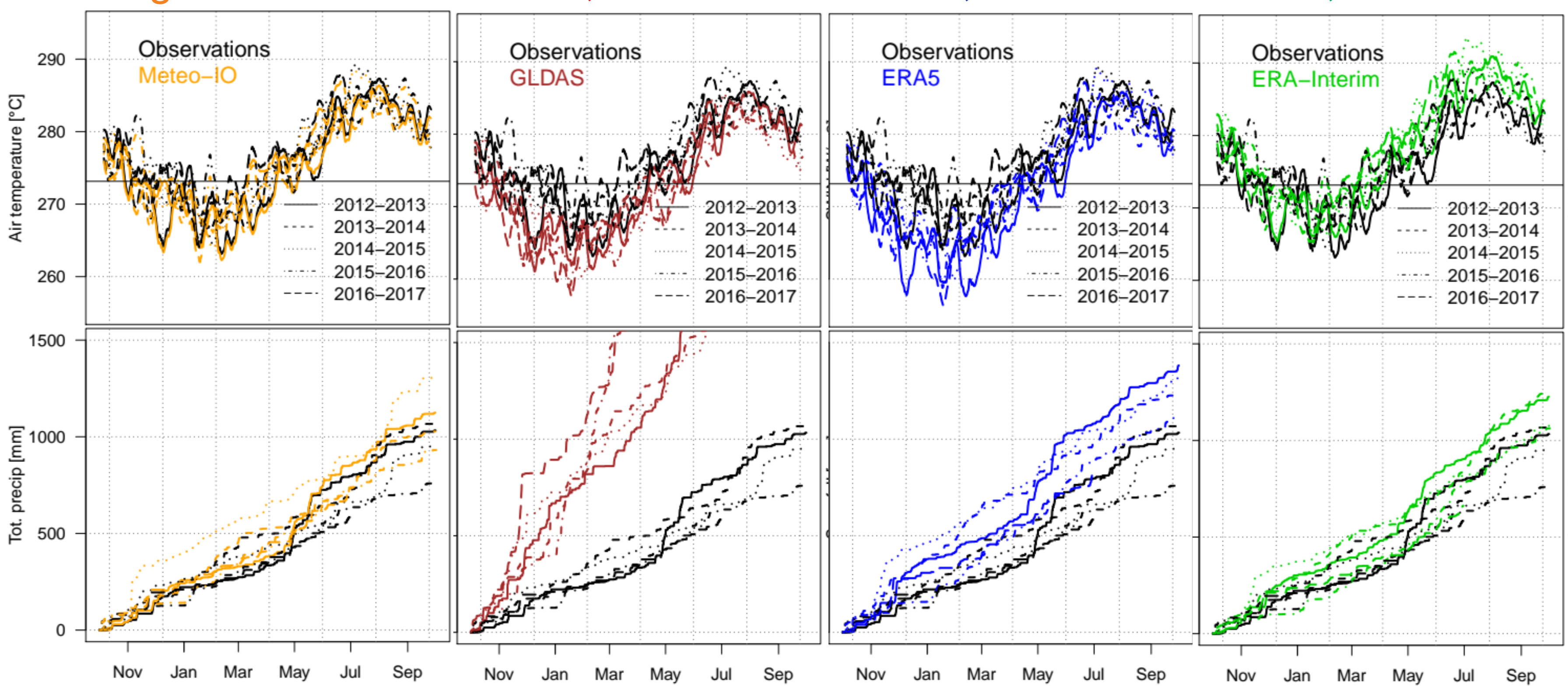
Sensitivity to the accuracy of the meteo input
The gridded datasets at Torgnon

METEO-IO
Interpolation
neighbor stations

GLDAS
Reanalysis,
25 km, 3 h resol.

ERA5
Reanalysis,
31 km, 1 h resol.

ERA-Interim
Reanalysis,
80 km, 3 h resol.



Cold bias +
Strong wet bias

Cold bias +
Wet bias

Spring: Warm bias
Slight wet bias

The gridded datasets at Torgnon

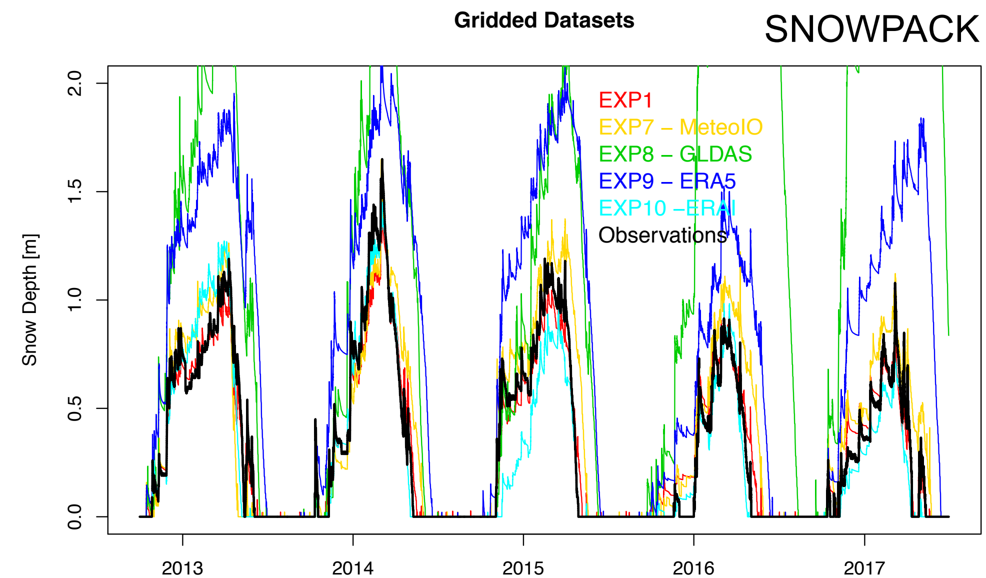
Biases in the meteorological forcing are reflected in the snow simulations

- All models show large overestimation errors when forced with GLDAS and ERA5 data

Simulations driven by Meteo-IO and ERA-Interim show relatively good agreement with observations for all the models

SNOWPACK and UTOPIA provide good results when forced by ERA-Interim:

-> Is it possible to reduce the RMSE of lower complexity models by correcting biases in the meteorological forcings?



> rmse

	SNOWPACK	GEOTOP	UTOPIA	SMASH	S3M
CTL	0.10	0.15	0.12	0.17	0.24
SWIN-ERAI	0.12	0.15	0.13	0.17	0.24
SWIN-CLS	0.11	0.15	0.13	0.17	0.24
TIME-3h	0.12	0.18	0.11	0.16	0.26
TIME-6h	0.17	0.24	0.18	0.19	0.26
TIME-12h	0.21	0.36	0.37	0.17	0.38
MeteoIO	0.23	0.15	0.40	0.19	0.31
GLDAS	1.99	2.74	3.45	1.88	3.54
ERA5	0.74	0.47	0.80	0.71	0.85
ERA-Int	$\boxed{0.18}$	0.38	$\boxed{0.20}$	0.27	0.32

Bias correction of ERA-Interim

ERA-Interim temperature is adjusted:

- EXP11
  Taking into account the difference in elevation between ERAI-Interim gridpoint at Torgnon and the elevation of the station:

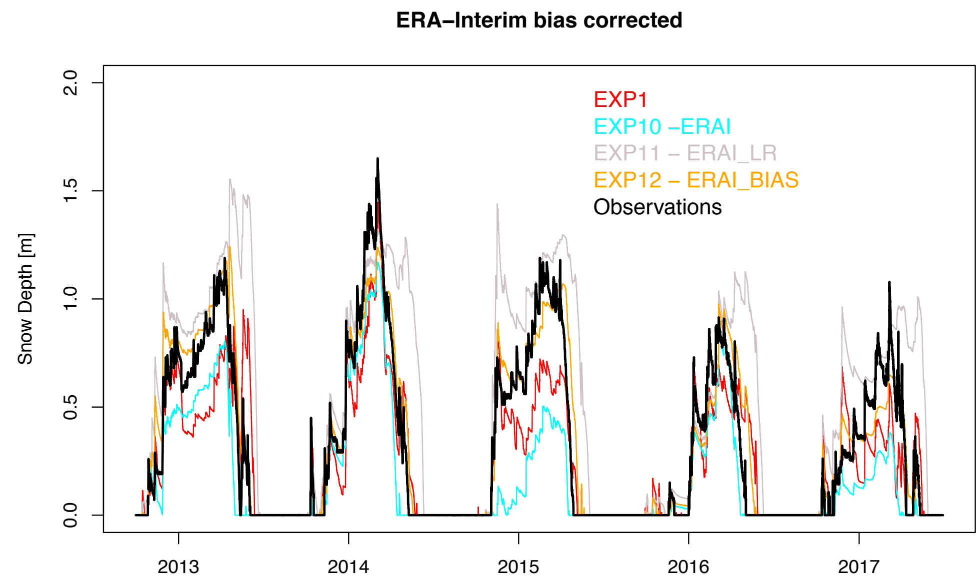
  $$T_{LR} = T + \gamma \cdot \Delta z, \qquad \gamma = -6.5°/\text{km};\ \Delta z = 680\text{m}$$
  $$\gamma \cdot \Delta z = -4.4°\text{C}$$

- EXP12
  Taking into account the average bias of ERA-Interim with respect to the station measurements:

  $$T_{\text{bias-adjusted}} = T + \Delta T \qquad \Delta T = -2.6°\text{C}$$

While the lapse rate correction “cools too much” the original ERA-Interim temperature, the adjustment of the mean bias seems the most appropriate

BIAS adjustment allows to reduce the RMSE for the intermediate (GEOTOP, SMASH) and low complexity snow models (S3M).



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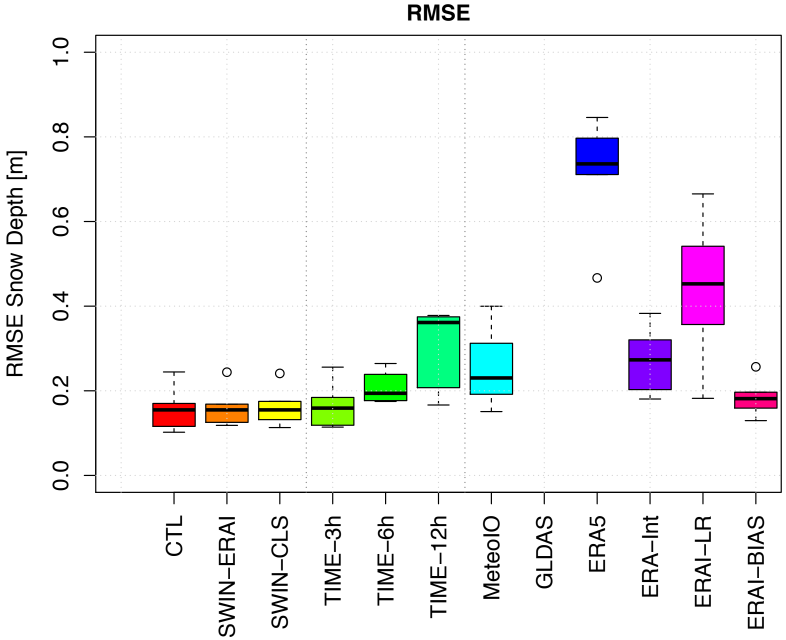
ERA5	0.74	0.47	0.80	0.71	0.85
ERA-Int	0.18	0.38	0.20	0.27	0.32
ERAI-LR	0.54	0.18	0.67	0.36	0.45
ERAI-BIAS	0.18	0.20	0.26	0.13	0.16

Summary and Conclusions



1. All the 5 snow models reproduce with good accuracy the snowpack evolution when they are forced by the high-resolution station data.

   The most detailed snow model (SNOWPACK) provides the lowest error, however similar performances can be obtained with intermediate complexity models (i.e. UTOPIA)

2. The models give similar performances when they are forced with 30 min or 3-hourly data, so 3-hourly forcing can be used without loosing accuracy.

3. When the models are forced with coarse-grid data their reliability decreases. SNOWPACK and UTOPIA performed better when forced by ERA-Interim, but this is not the case for GEOTOP, SMASH and S3M

4. However, **simple bias-adjustment techniques applied to ERA-Interim data allowed to improve the performances of the less sophisticated snow models**

Thank you for your attention