Numerical simulations of snow on ski slopes using SURFEX/ISBA-Crocus-RESORT

P. Spandre[1,2], S. Morin[1], <u>D. Verfaillie[1]</u>, H. François[2], M. Lafaysse[1], E. George-Marcelpoil[2]

[1]Météo-France – CNRS, CNRM UMR 3589, CEN, Grenoble, France
[2]Irstea Grenoble, France
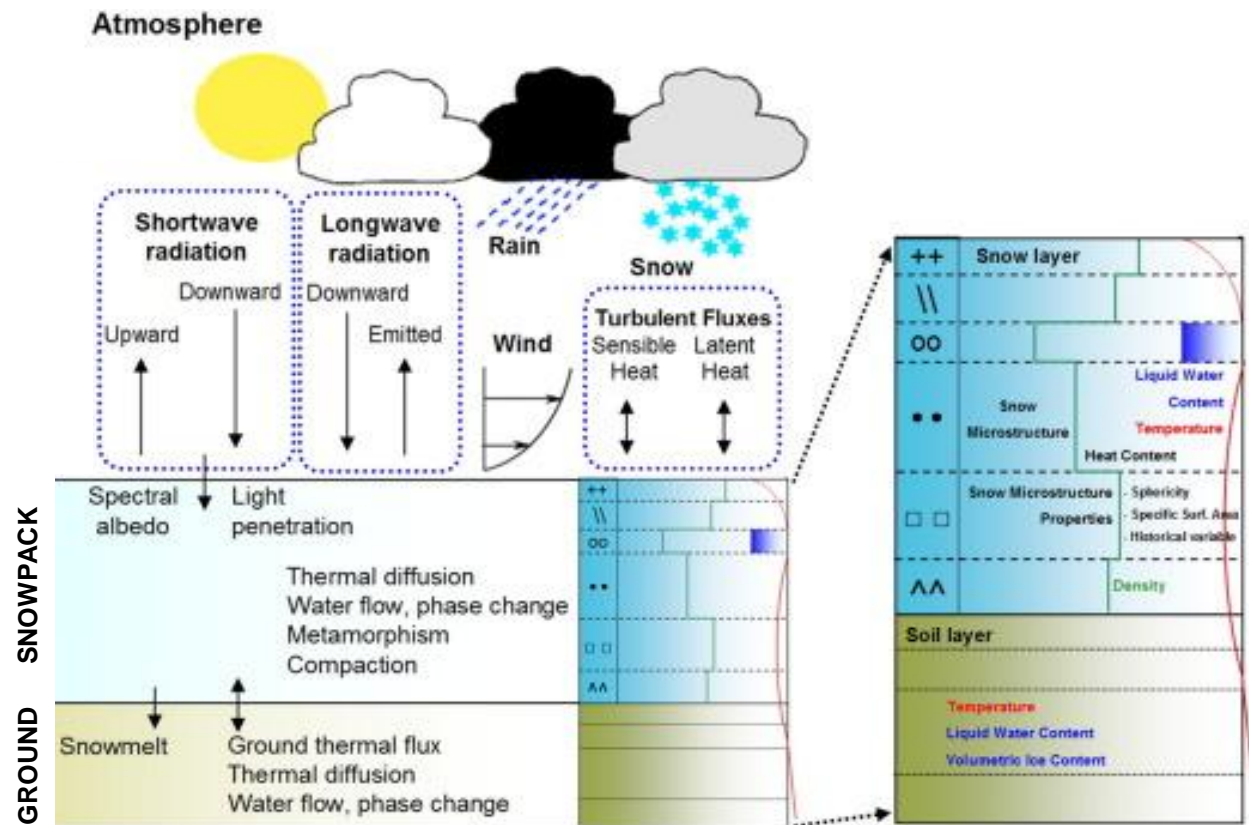
SURFEX Workshop, 2017, Toulouse

Context

- Snow conditions on ski slopes differ markedly from natural snow conditions because of **grooming** and **snowmaking**
- Critical socio-economic issues related to the **sustainability of winter tourism** in the context of climate variability and long term change
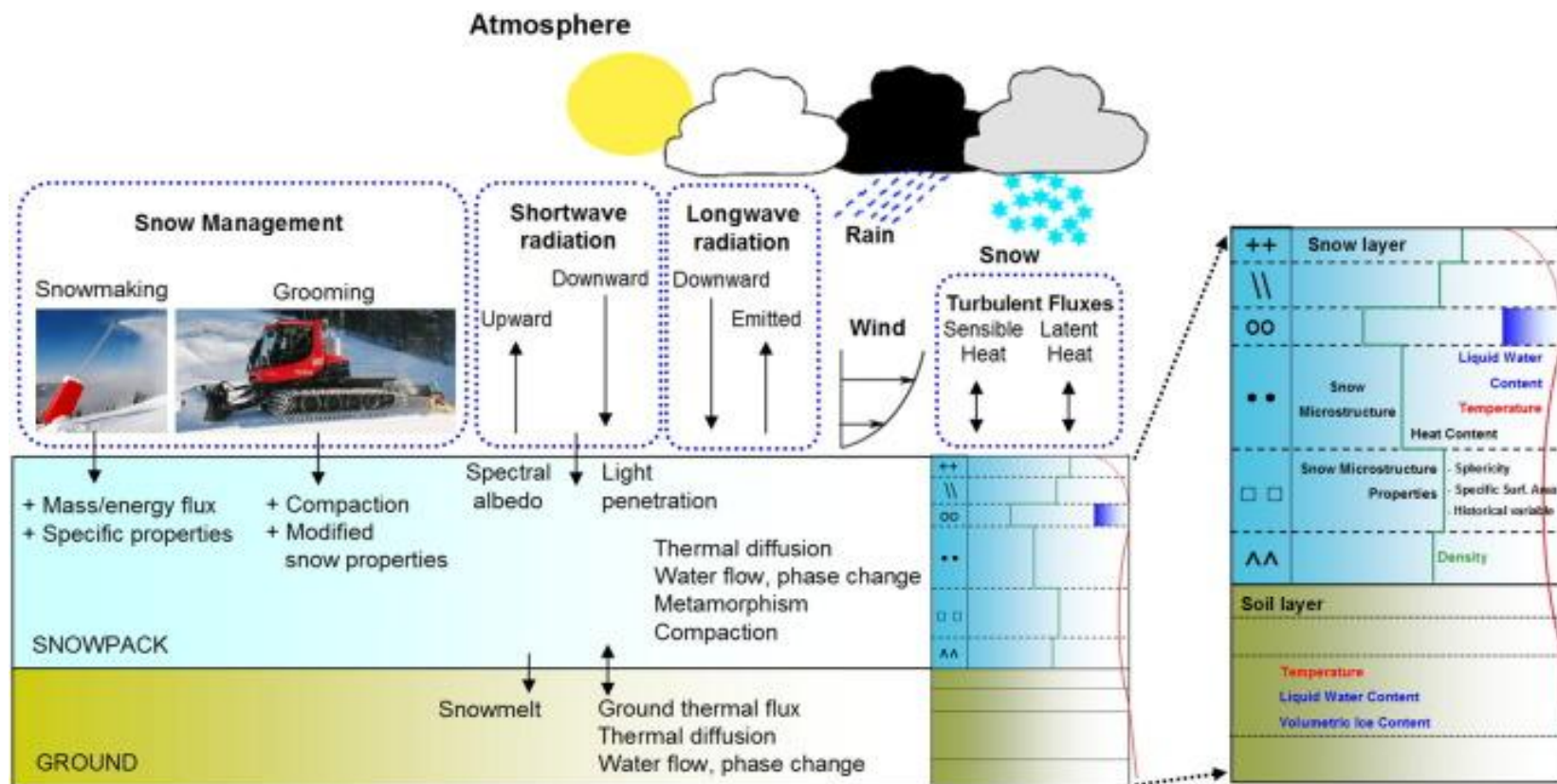
Crocus-RESORT

- Developed in SURFEX within **Crocus** (one of the snowpack schemes of ISBA), on the basis of official V8 release. Not yet implemented in official version.
- Full description and evaluation : Spandre, P., S. Morin, M. Lafaysse, Y. Lejeune, H. François and E. George-Marcelpoil, Integration of snow management processes into a detailed snowpack model, *Cold Reg. Sci. Technol.*, 125, 48-64,doi :10.1016/j.coldregions.2016.01.002, 2016.

Spandre et al., 2016

3

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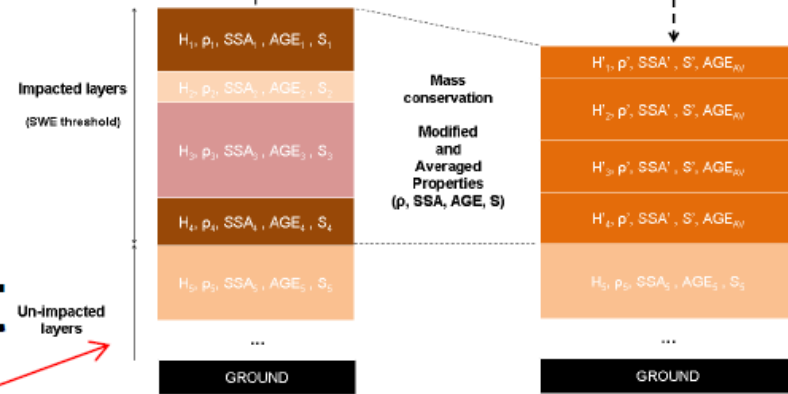

Spandre et al., 2016

4

Grooming

TILLING EFFECT

1/ Average properties over all impacted layers → 2/ Evolution of average properties → 3/ Set all layers to modified properties
(ρ, SSA, AGE, S)

Impacted layers
(SWE threshold)

H_1, ρ_1, SSA$_1$, AGE$_1$, S$_1$

H_2, ρ_2, SSA$_2$, AGE$_2$, S$_2$

H_3, ρ_3, SSA$_3$, AGE$_3$, S$_3$

H_4, ρ_4, SSA$_4$, AGE$_4$, S$_4$

Mass conservation

Modified and Averaged Properties
(ρ, SSA, AGE, S)

H'_1, ρ', SSA', S', AGE$_{AV}$

H'_2, ρ', SSA', S', AGE$_{AV}$

H'_3, ρ', SSA', S', AGE$_{AV}$

H'_4, ρ', SSA', S', AGE$_{AV}$

Un-impacted layers

H_5, ρ_5, SSA$_5$, AGE$_5$, S$_5$

H_5, ρ_5, SSA$_5$, AGE$_5$, S$_5$

...

GROUND

...

GROUND

Tiller effect

$\Rightarrow$ **Mixing effect**
$\Rightarrow$ **Densification**
$\Rightarrow$ **Modification of snow microstructure**

Static weight

=> Densification

Spandre et al., 2016
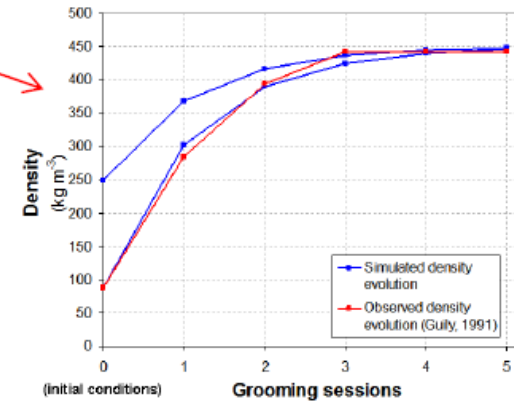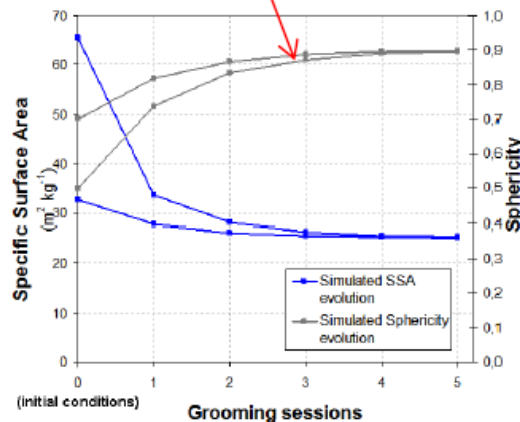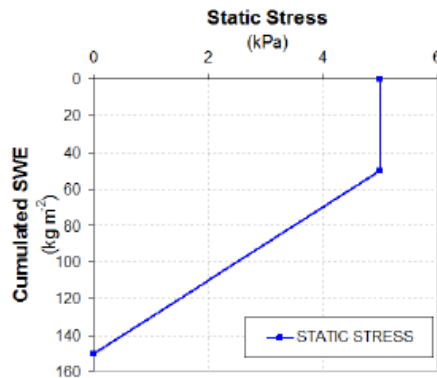
Grooming

- **Operational rules** and parameters based on literature and panel assessment involving **ski resort managers**

6
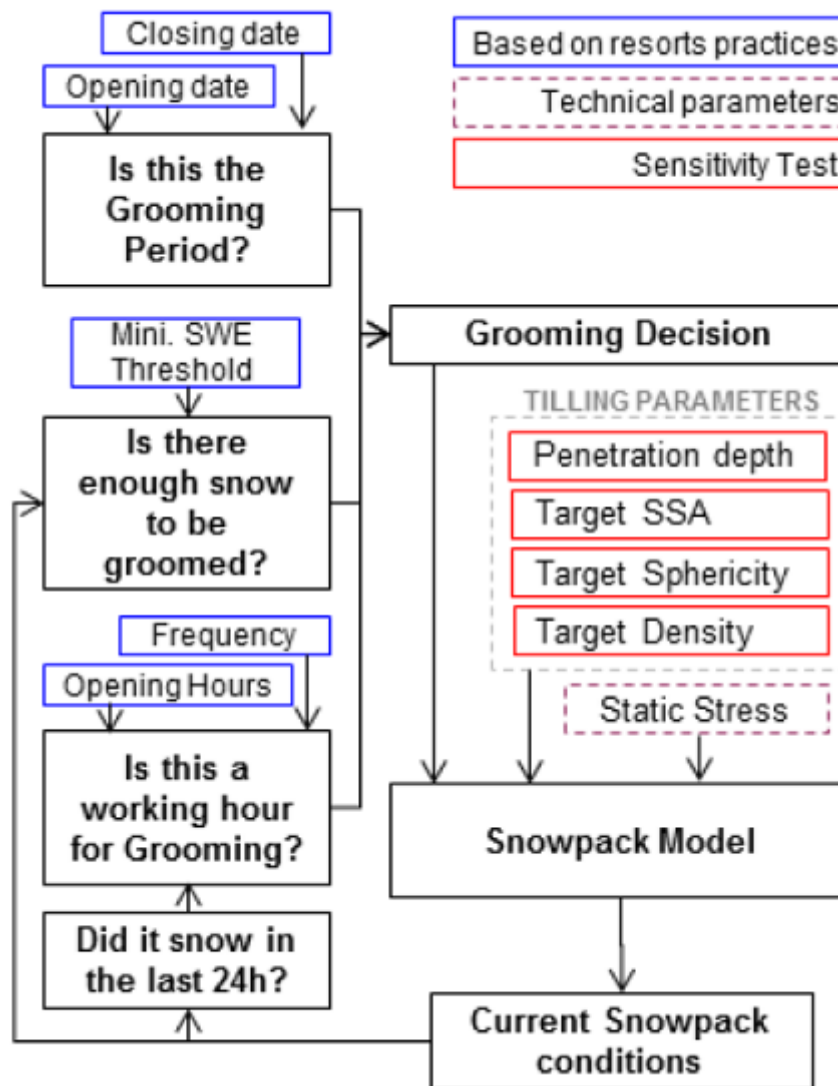
Grooming

- Impact and evaluation based on observations in 4 ski resorts near Grenoble during one full season, comparing natural snow and **groomed snow** in terms of depth, density, SWE and vertical profiles (not shown)

Spandre et al., 2016
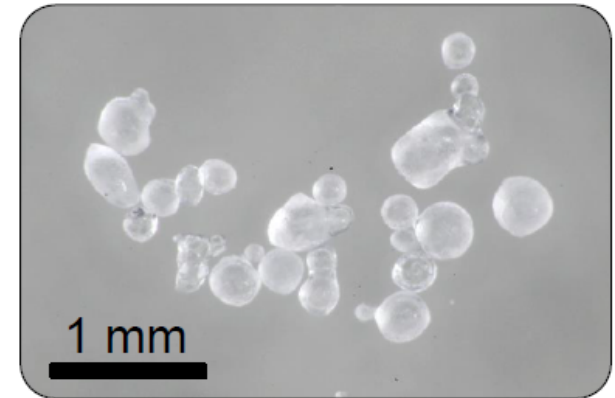

Seasonal evolution
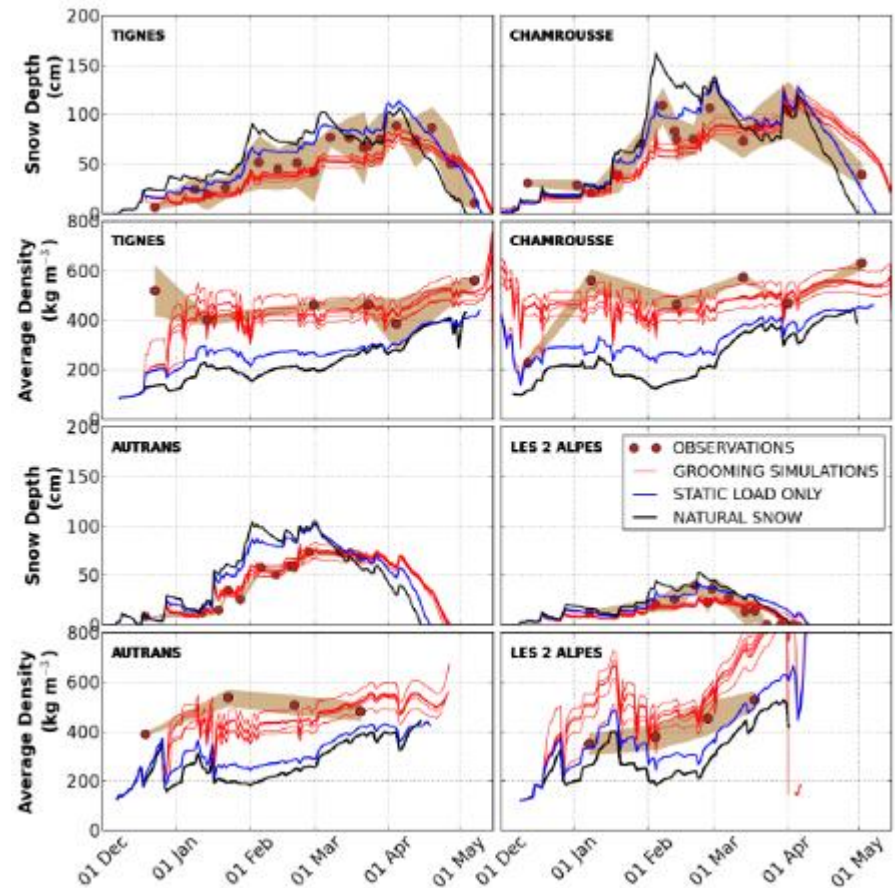
Snowmaking

- ## Initial properties specified
  - $\Rightarrow$ Density (600 kg/m^3)
  - $\Rightarrow$ Specific Surface Area (25 m^2 kg^{-1})
  - $\Rightarrow$ Sphericity (90%)

1 mm

- ## Production flow rate specified

- ## Wet-bulb temperature threshold specified

- ## Maximum wind speed (4.2 m s^{-1})

Spandre et al., 2016

Snowmaking

- Operational rules and parameters based on panel assessment involving ski resort managers

- Production can be driven by production targets, or related to snow depth/SWE thresholds at various times of the season

- Typically:
  - Early season production « as much as possible » before opening of resorts, typically December 15.
  - Wintertime production to sustain sufficient snow conditions if possible
 - Stop of production around March 1st.

Spandre et al., 2016
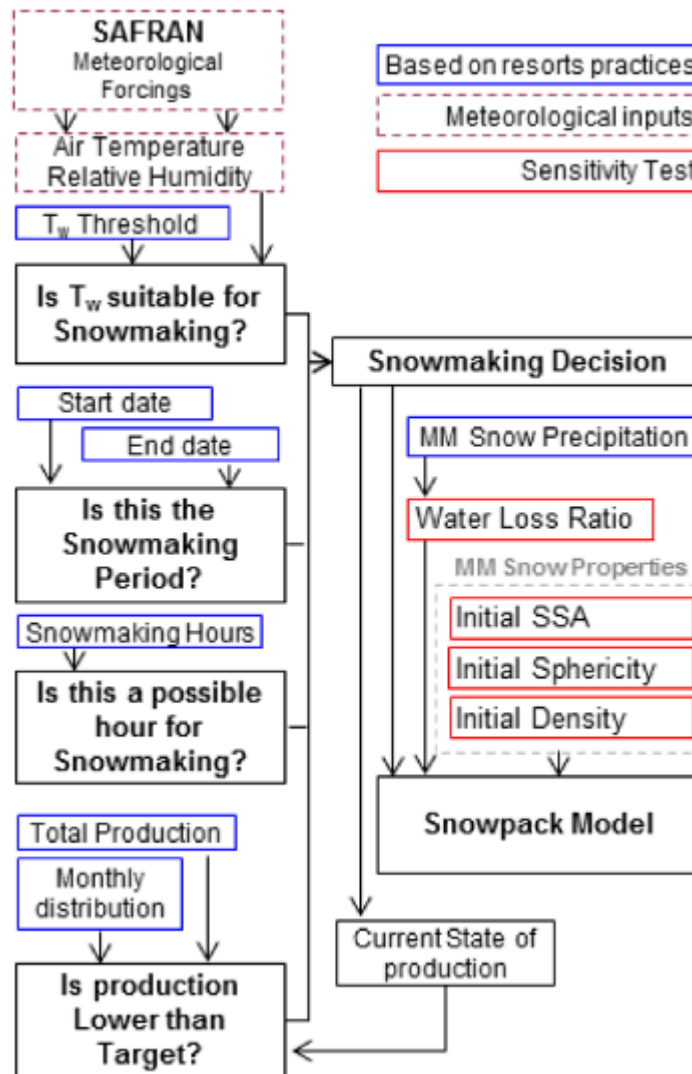
Snowmaking

Seasonal evolution

- Impact and evaluation based on observations in 4 ski resorts near Grenoble during one full season, comparing natural snow, groomed snow and groomed machine made snow in terms of depth, density, SWE and vertical profiles (not shown)

- Identification of significant losses of water used for snowmaking, up to 50%.

- Water losses issues refined in a follow-up publication. Still the highest uncertainty factor.
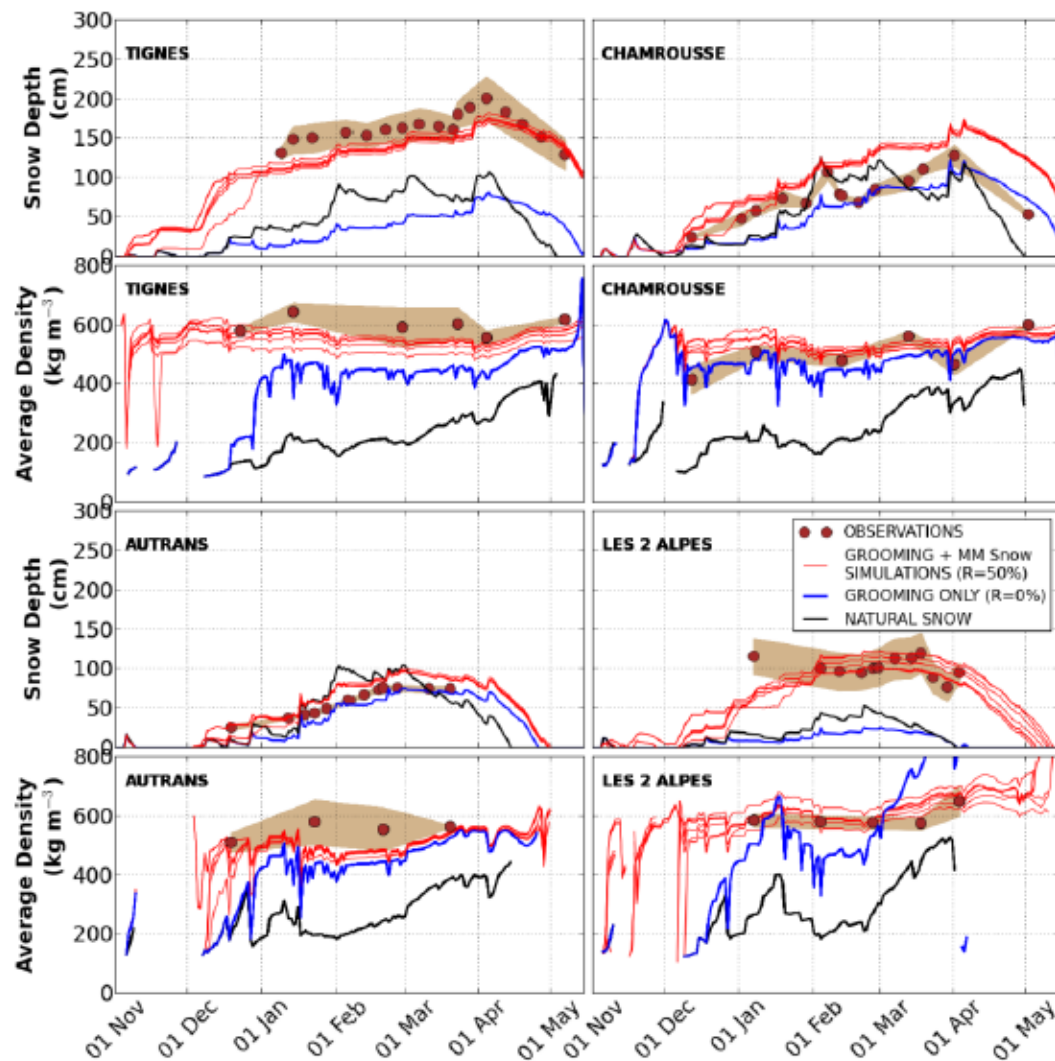
Spandre, P., François, H., Thibert, E., Morin, S., and George-Marcelpoil, E. : Seasonal evolution of a ski slope under natural and artificial snow : detailed observations and modelling, *The Cryosphere Discuss.*, doi :10.5194/tc-2016-194, in review, 2016.

Spandre et al., 2016

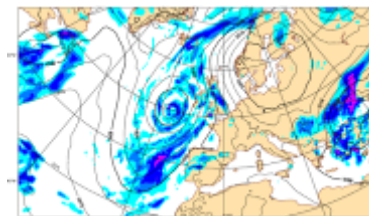# Applications driven by SAFRAN
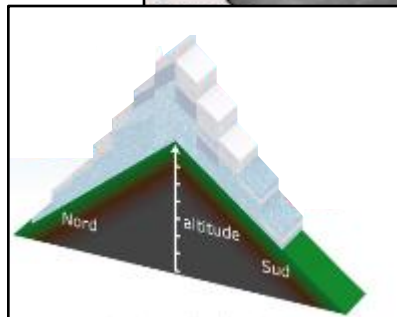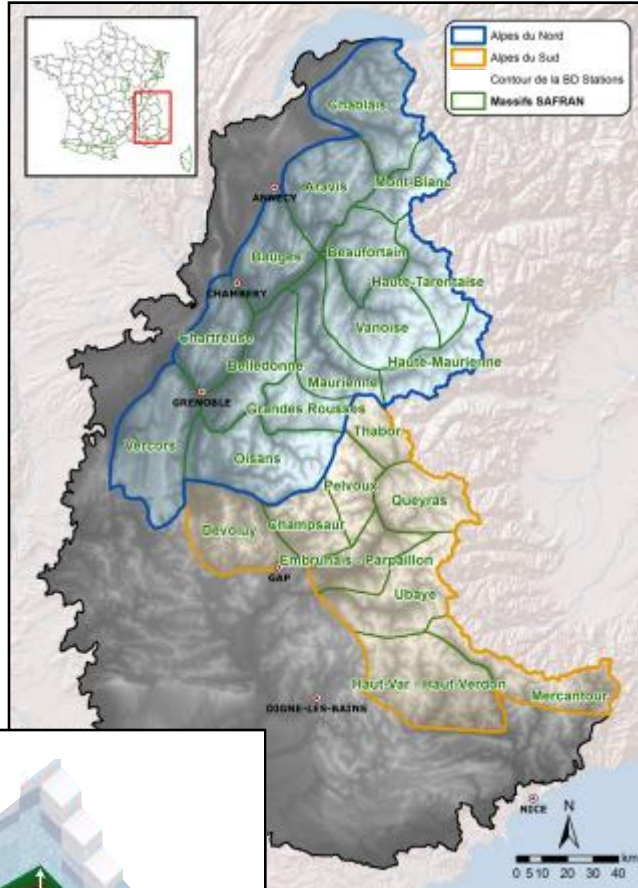
Use of massifs within which meteorological conditions vary by steps of 300m

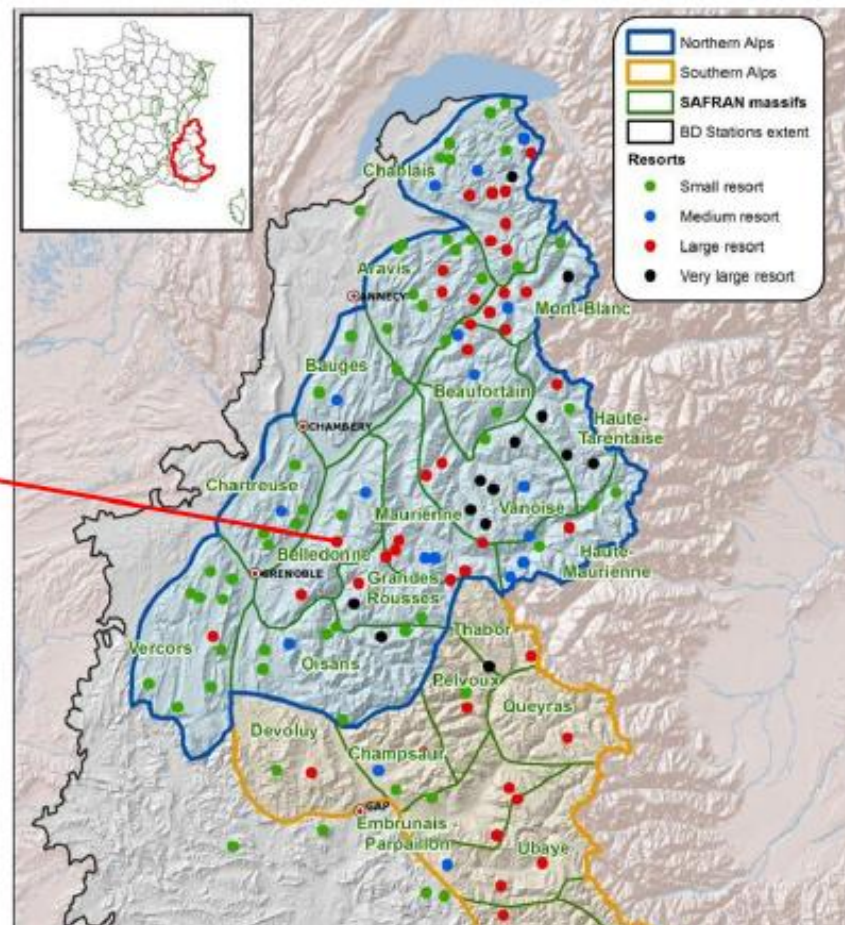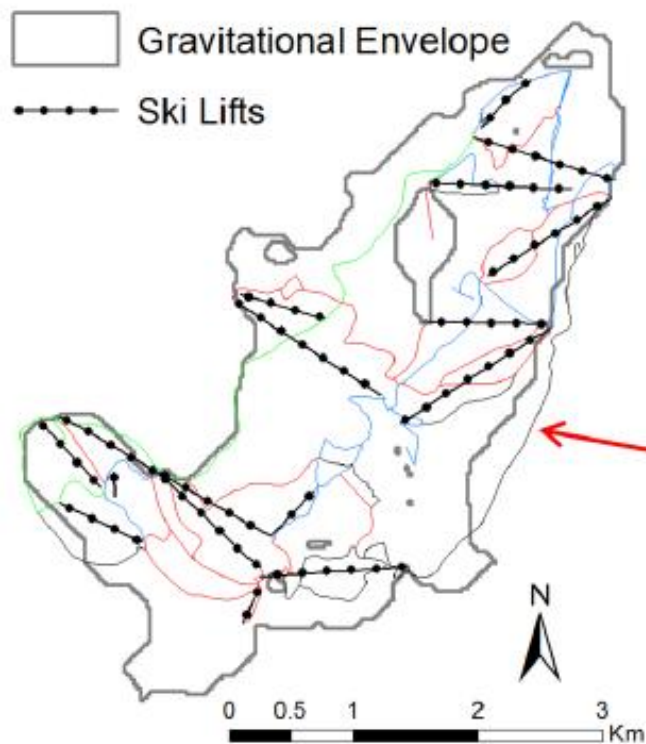**Observations** : in-situ, remotely-sensed, radiosondes

NWP model guess
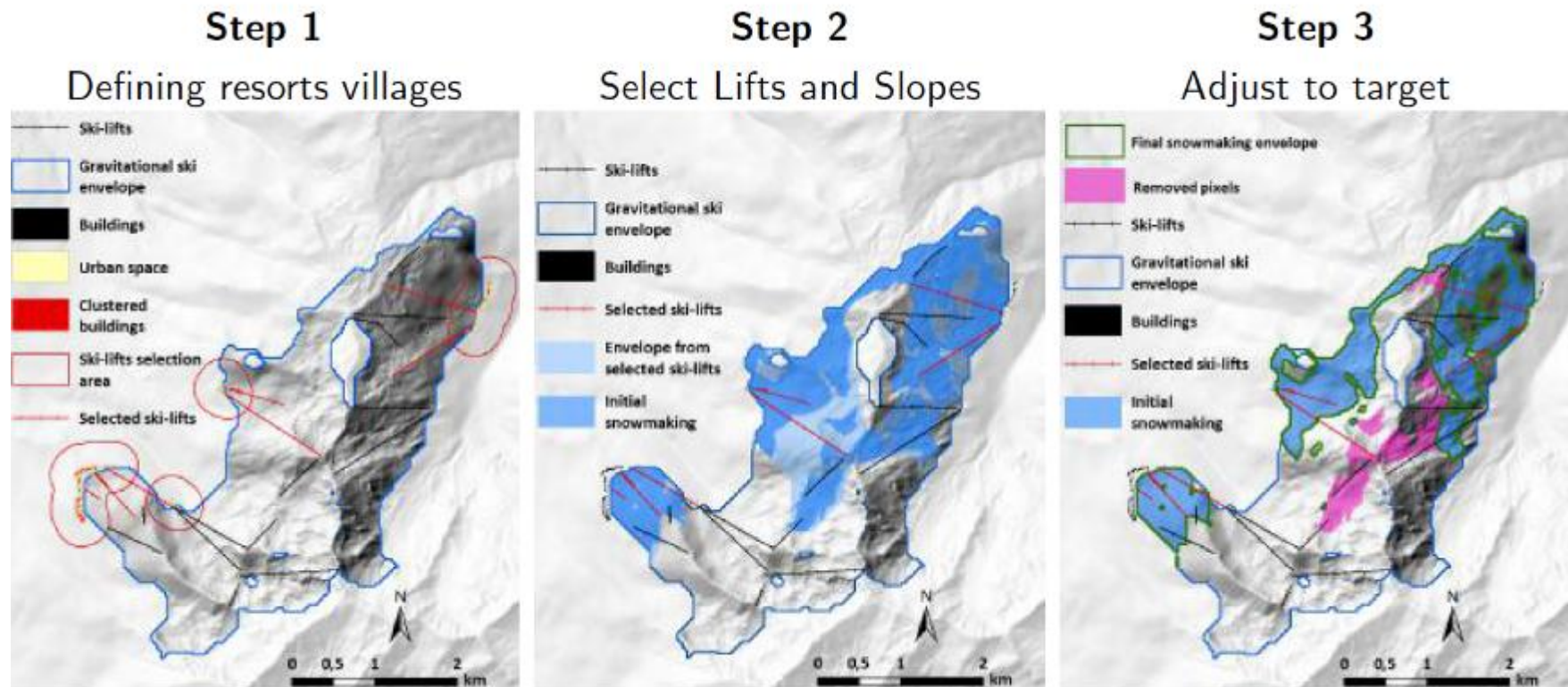

ERA40 1958-2002
ARPEGE 2002 - …

Durand et al., 1999, 2009

11

Resorts spatial representation

- Use of ski-lifts catalogue

François et al., 2014

Computation of snow indicators

- Representation of **snowmaking envelope** in ski resorts (depend on spatial structure and assigned % coverage)

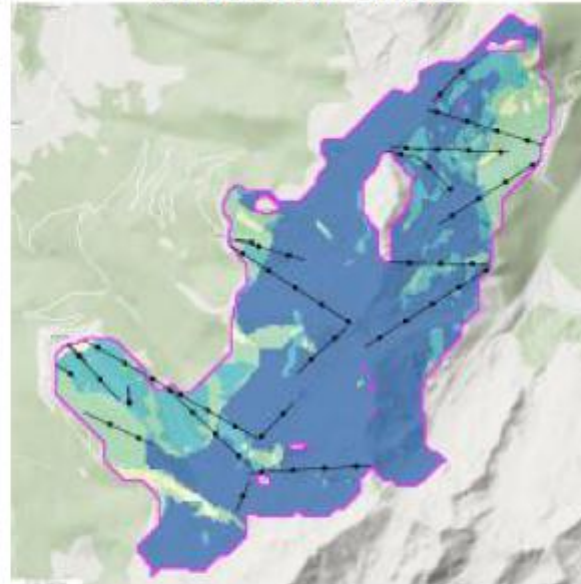Spandre et al., submitted

Sept Laux ski resort, Belledonne, France

Computation of snow indicators

- Explicit representation of snow coverage in a ski resort
- Computation of resort-level **viability indicator** based on thresholds and critical dates (Christmas, winter holidays etc.)
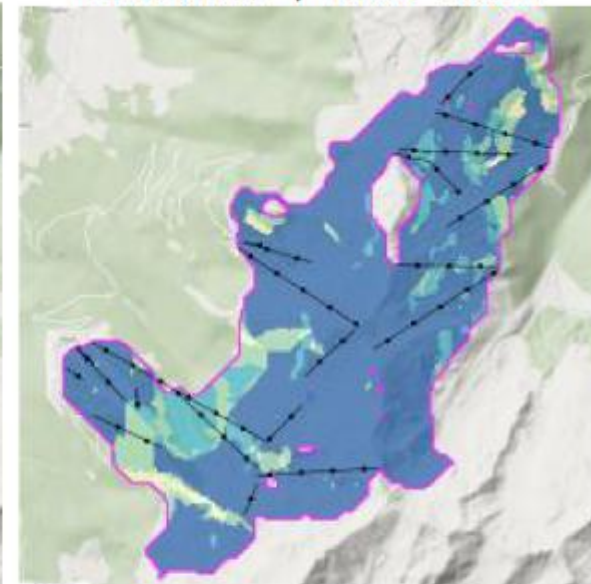
Spandre et al., submitted
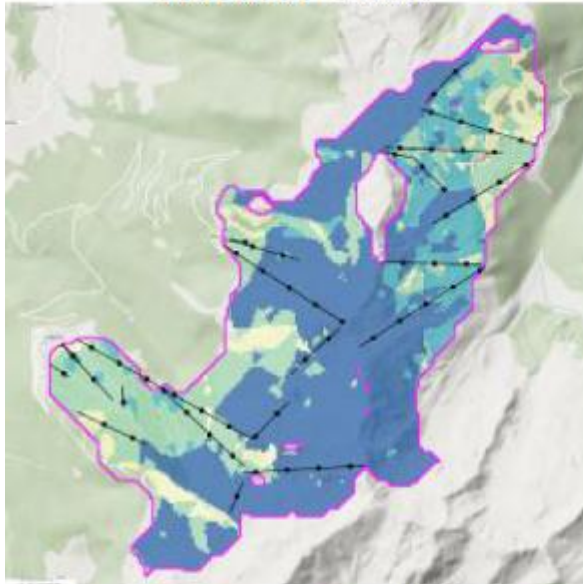
Natural Snow — **Groomed Snow** — **Groomed + MM Snow**

< 50 days < 100 days ☐ Gravitational Ski Envelope
< 80 days > 100 days ∿ Ski Lifts

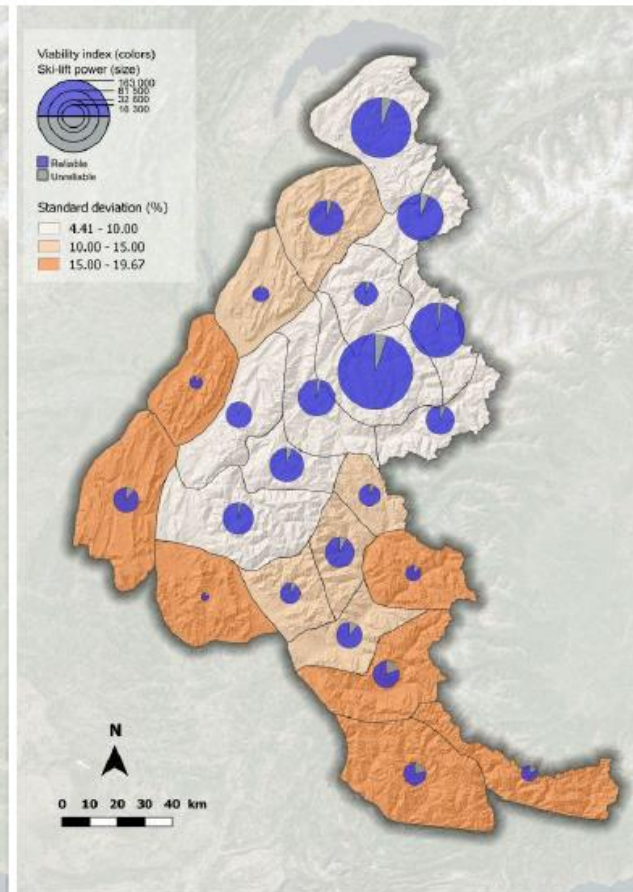Sept Laux ski resort | Season duration (days) | 2006-2007

Large-scale reanalysis

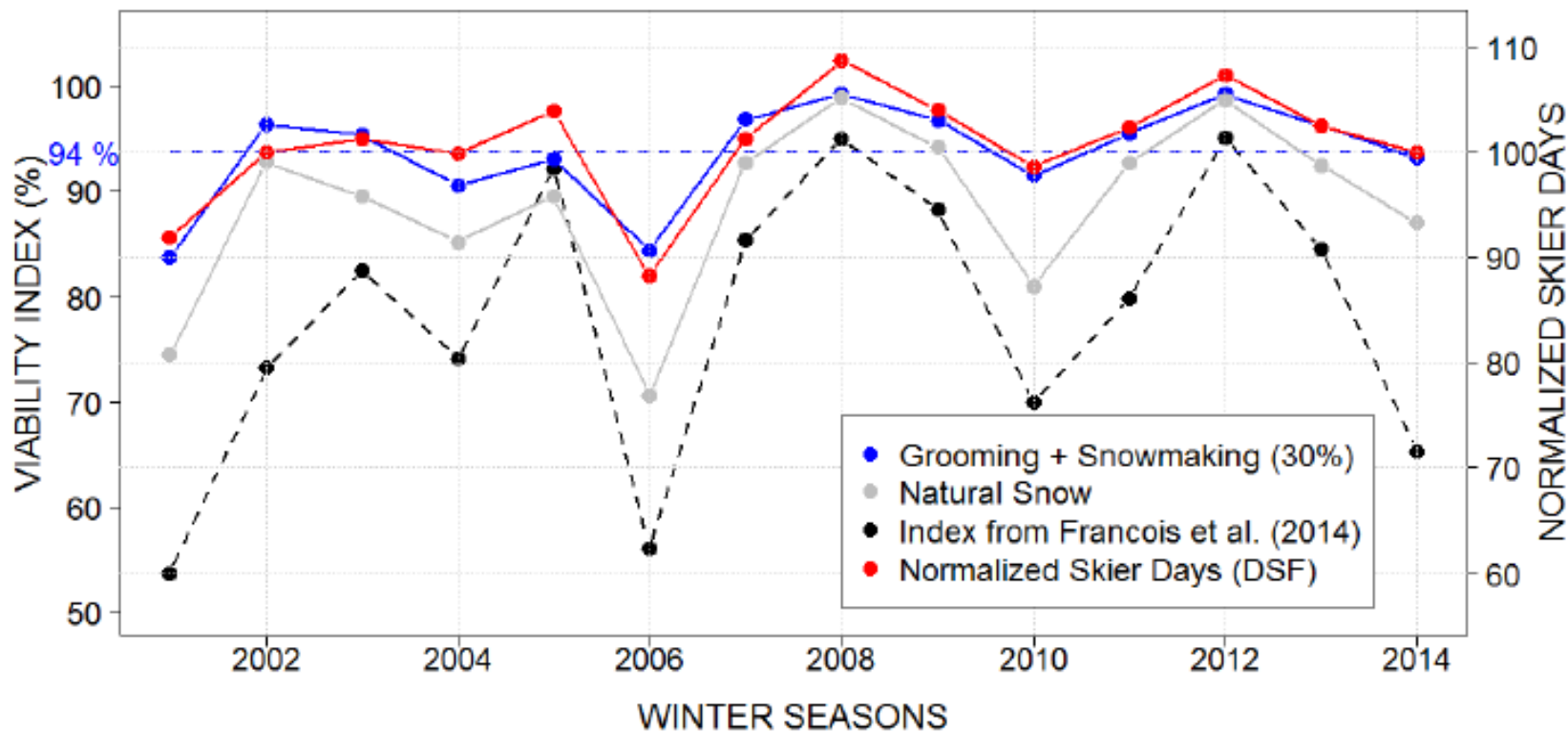- Snow reliability of ski resorts in the French Alps, based on past winter conditions

Natural snow
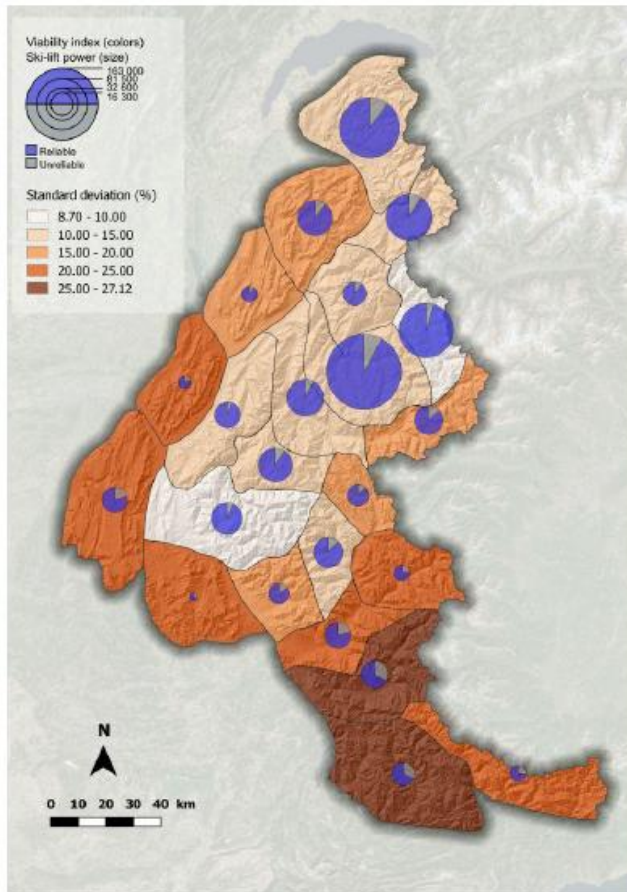
Managed snow (30% snowmaking)

Spandre et al., submitted

Large-scale reanalysis

- Relationship between snow conditions and **socio-economic turnover** (ski pass sales)
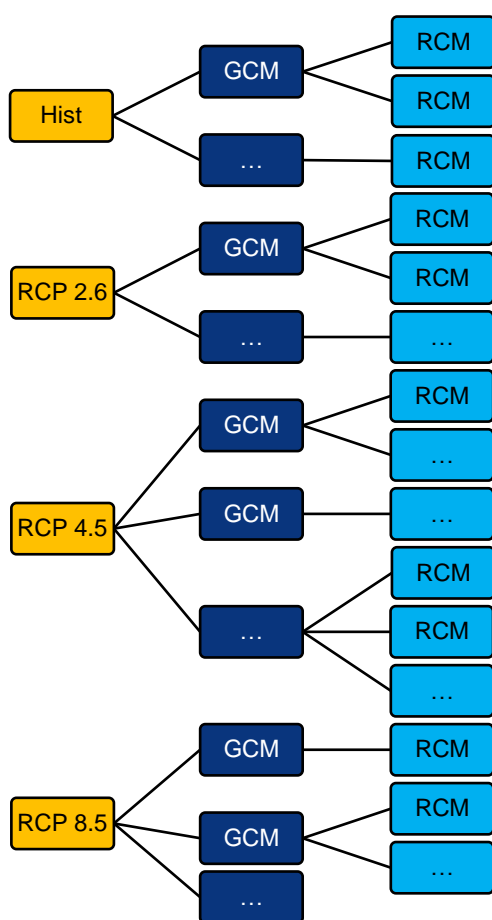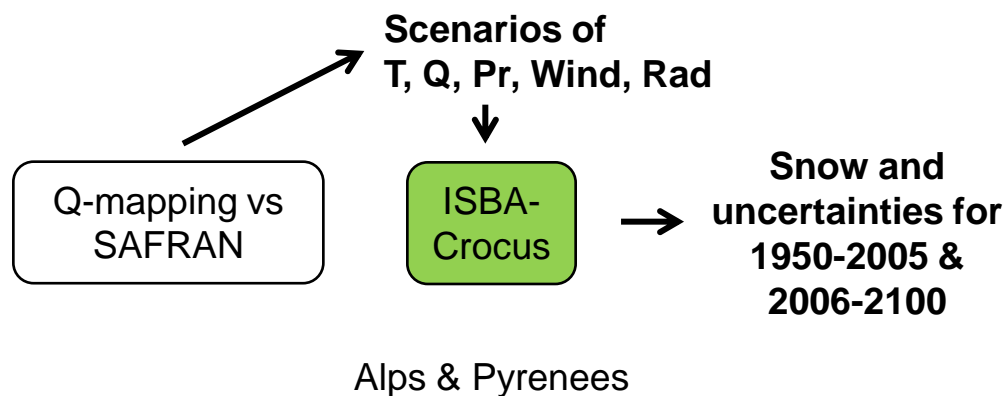

Spandre et al., submitted

Future plans

- Apply the model in reanalysis mode for the **Pyrenees** (France / Spain / Andorra) and **lower lying** French mountain regions with ski resorts (Jura, Vosges, Massif Central, Corsica)

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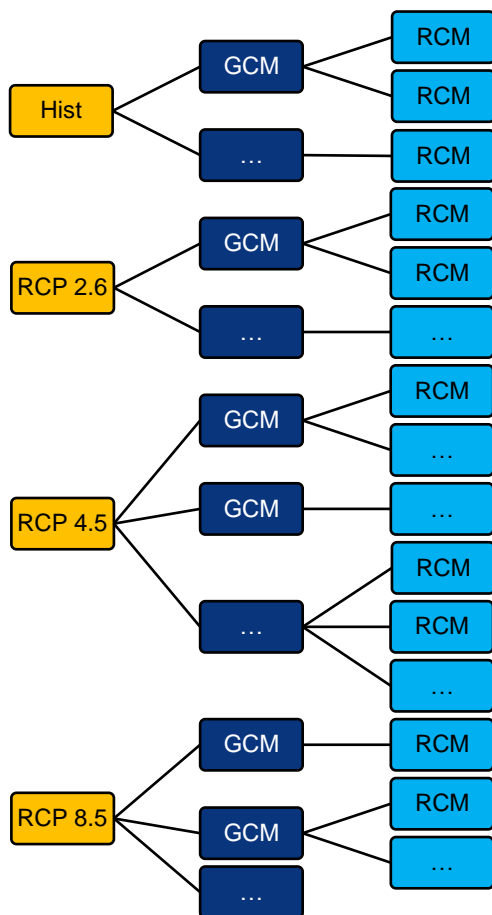# Future plans : ADAMONT

Forcing/Scenarios
EUROCORDEX
12 km simulations

Bias-adjustment method :
- quantile mapping & weather regimes
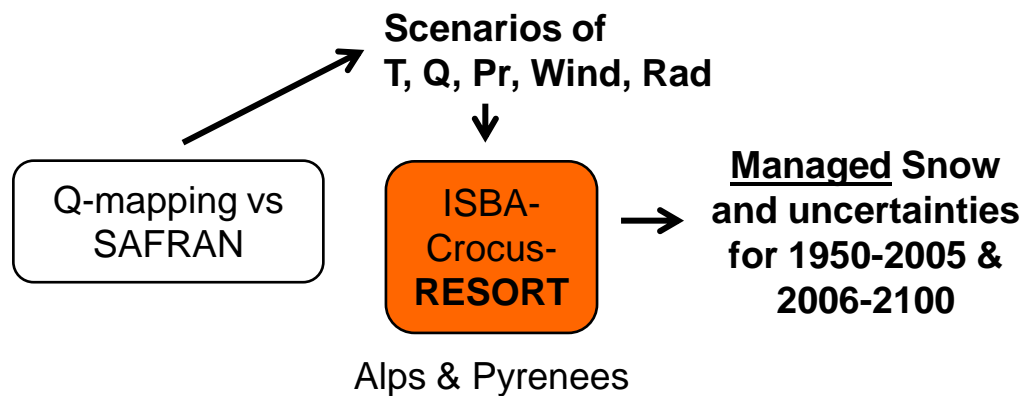- vs. a meteorological reanalysis (SAFRAN)
- multi-variable and hourly

Scenarios of T, Q, Pr, Wind, Rad

Q-mapping vs SAFRAN → ISBA-Crocus → **Snow and uncertainties for 1950-2005 & 2006-2100**

Alps & Pyrenees

Currently, **43 runs in total**

Future plans : ADAMONT

Forcing/ Scenarios — EUROCORDEX 12 km simulations

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Q-mapping vs SAFRAN → ISBA-Crocus-**RESORT** → **Managed** Snow and uncertainties for 1950-2005 & 2006-2100

Alps & Pyrenees

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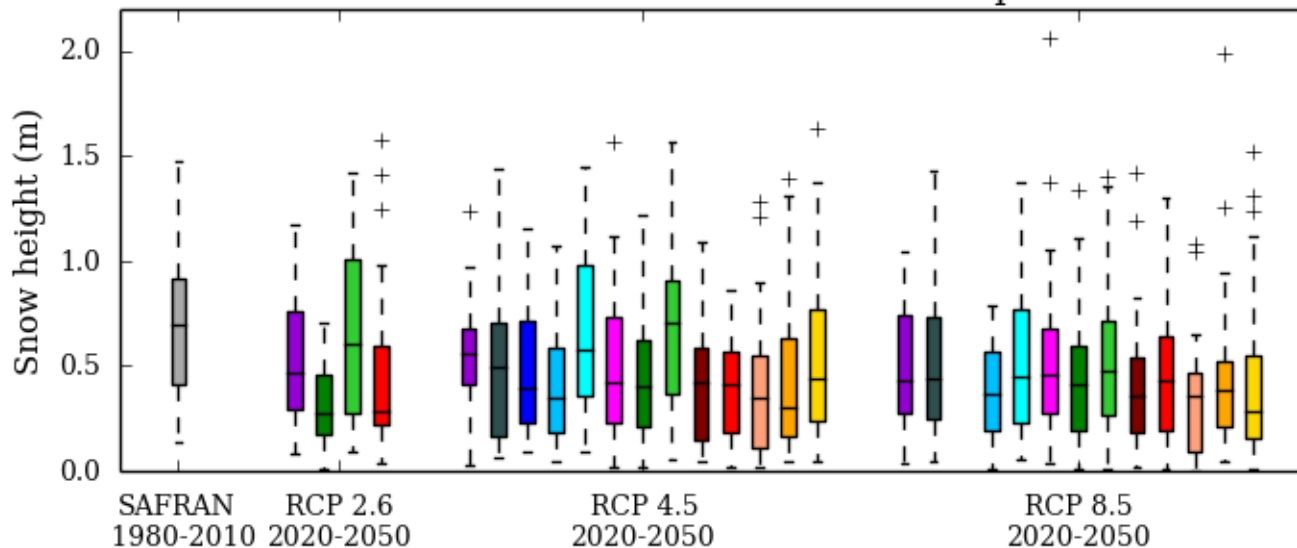
23

- Any SURFEX FORCING file can be used to drive the model !

Thank you !

Example of results

Snow height from Crocus at the INARCH/ GCW site Col de Porte
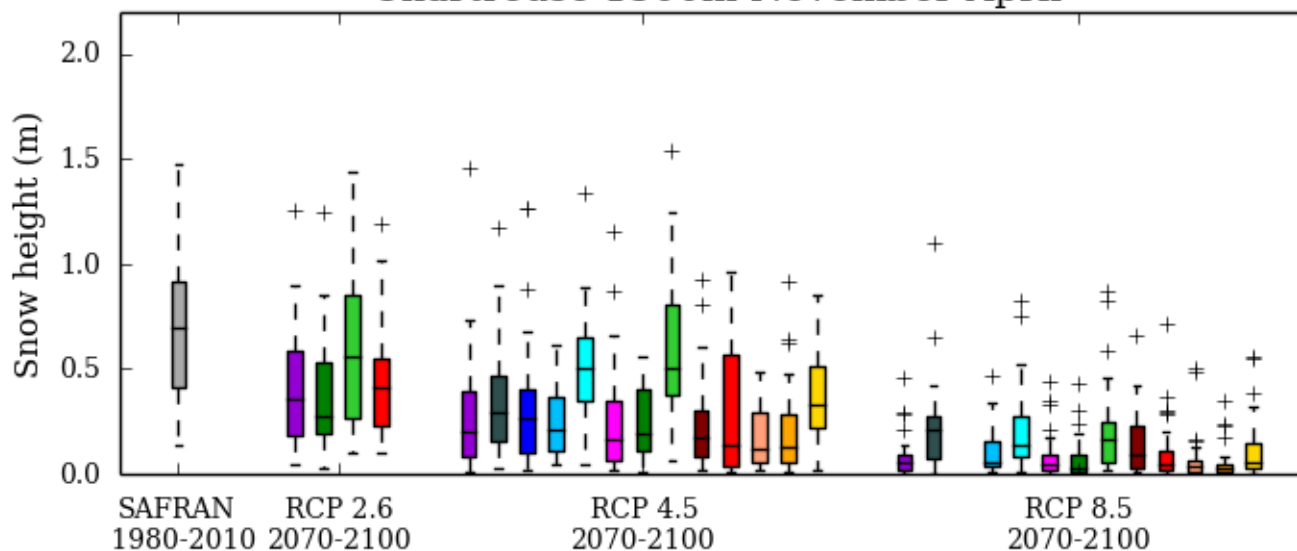

Chartreuse 1500m November-April
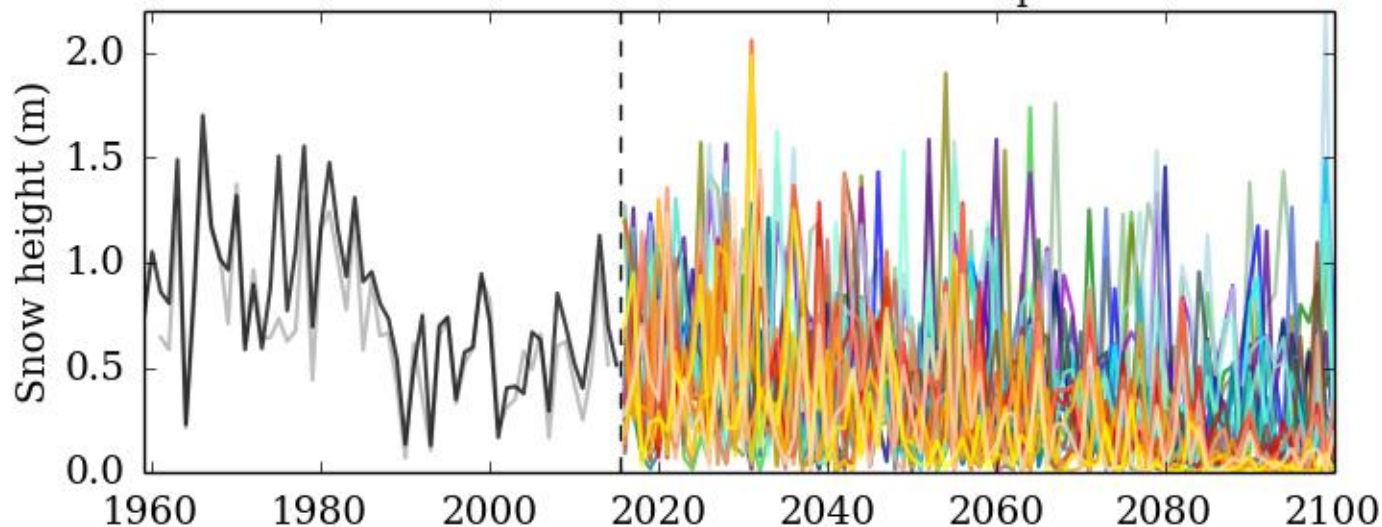
Legend:
- Observations 1960-2014
- SAFRAN reanalysis
- ARPEGE/ALADIN RCP2.6
- HadGEM2-ES/RACMO22E RCP2.6
- MPI-ESM-LR/REMO2009 RCP2.6
- EC-EARTH/RCA4 RCP2.6
- ARPEGE/ALADIN RCP4.5
- ARPEGE/CCLM4-8-17 RCP4.5
- EC-EARTH/CCLM4-8-17 RCP4.5
- HadGEM2-ES/CCLM4-8-17 RCP4.5
- MPI-ESM-LR/CCLM4-8-17 RCP4.5
- IPSL-CM5A-MR/WRF331F RCP4.5
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- IPSL-CM5A-MR/RCA4 RCP4.5
- MPI-ESM-LR/RCA4 RCP4.5
- ARPEGE/ALADIN RCP8.5
- ARPEGE/CCLM4-8-17 RCP8.5
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Example of results

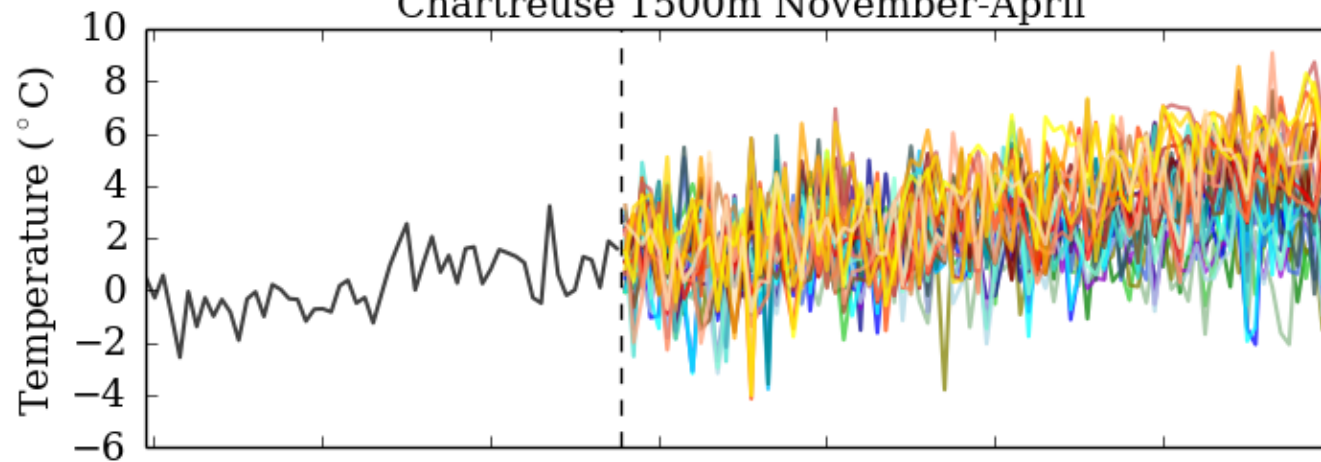Snow height from Crocus at the INARCH/ GCW site Col de Porte

Chartreuse 1500m November-April

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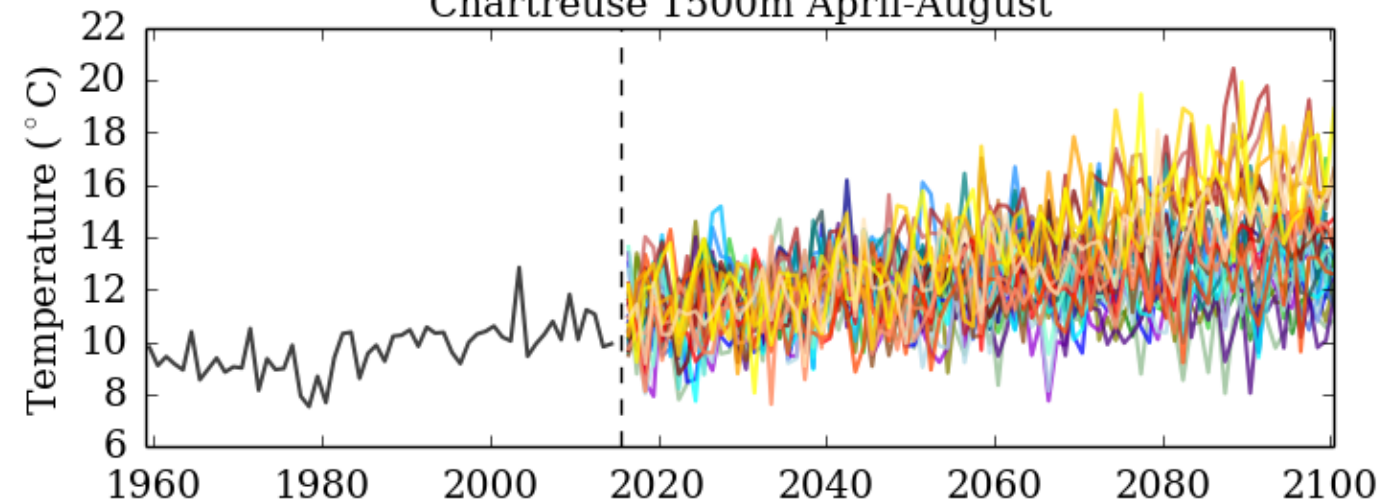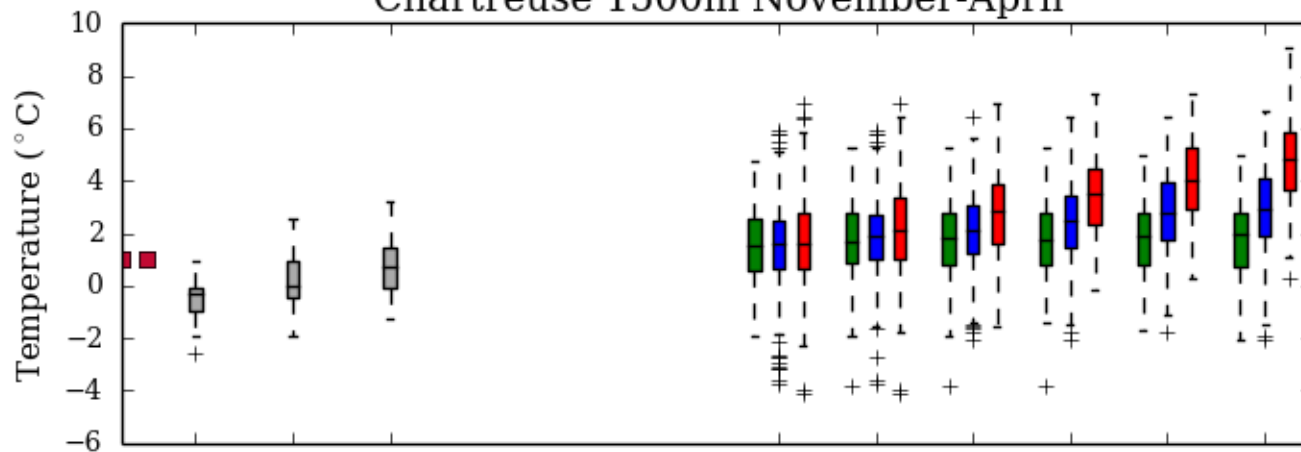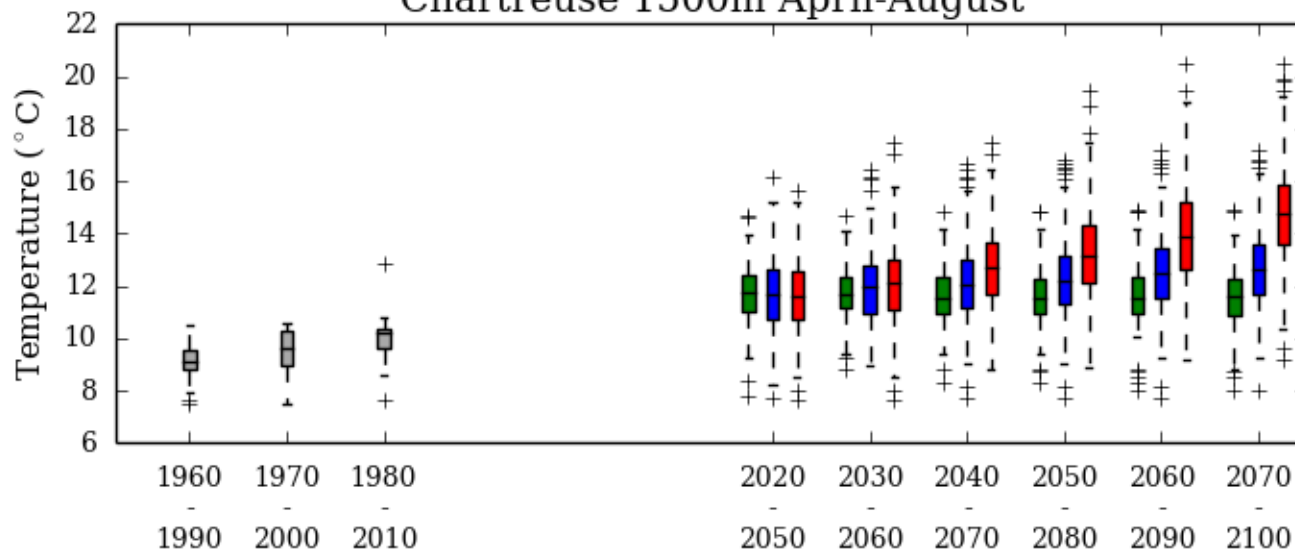- SAFRAN reanalysis
- EUROCORDEX RCP2.6
- EUROCORDEX RCP4.5
- EUROCORDEX RCP8.5

Example of results

Snow height from Crocus at the INARCH/ GCW site Col de Porte

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First results – Meteorological variables

Chartreuse 1500m November-April

Chartreuse 1500m April-August

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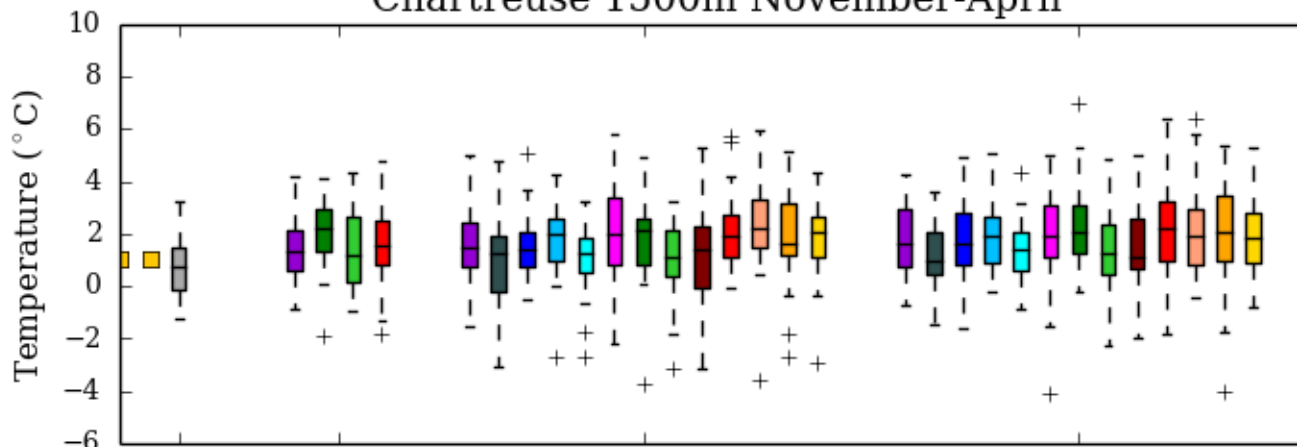
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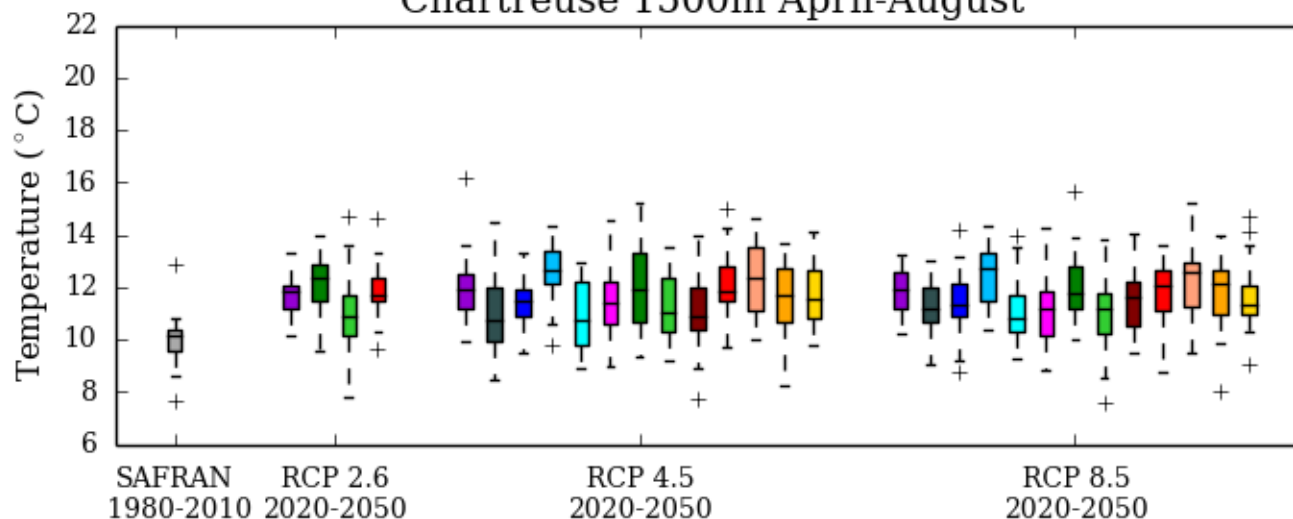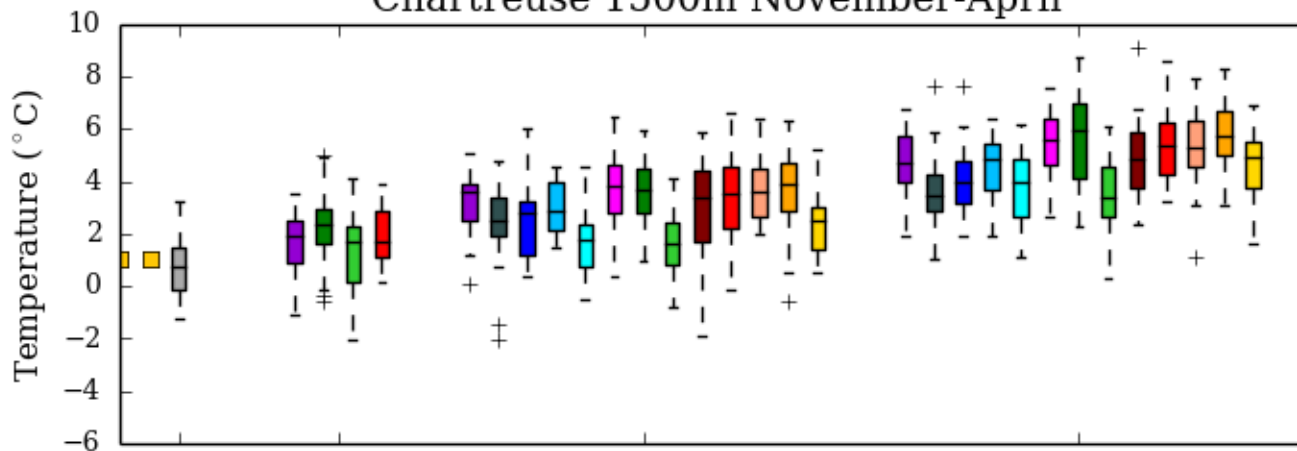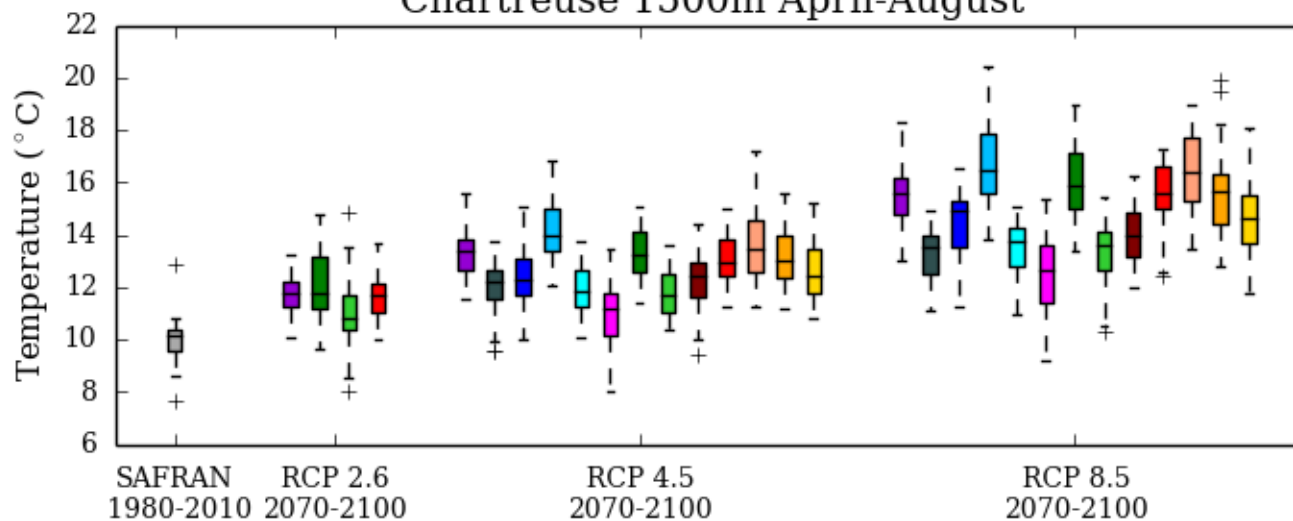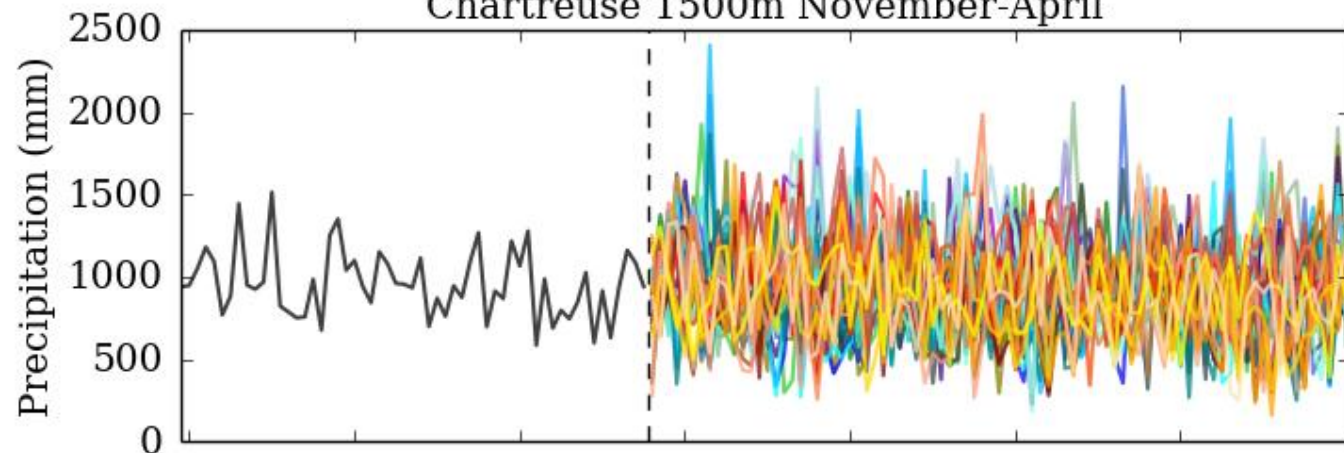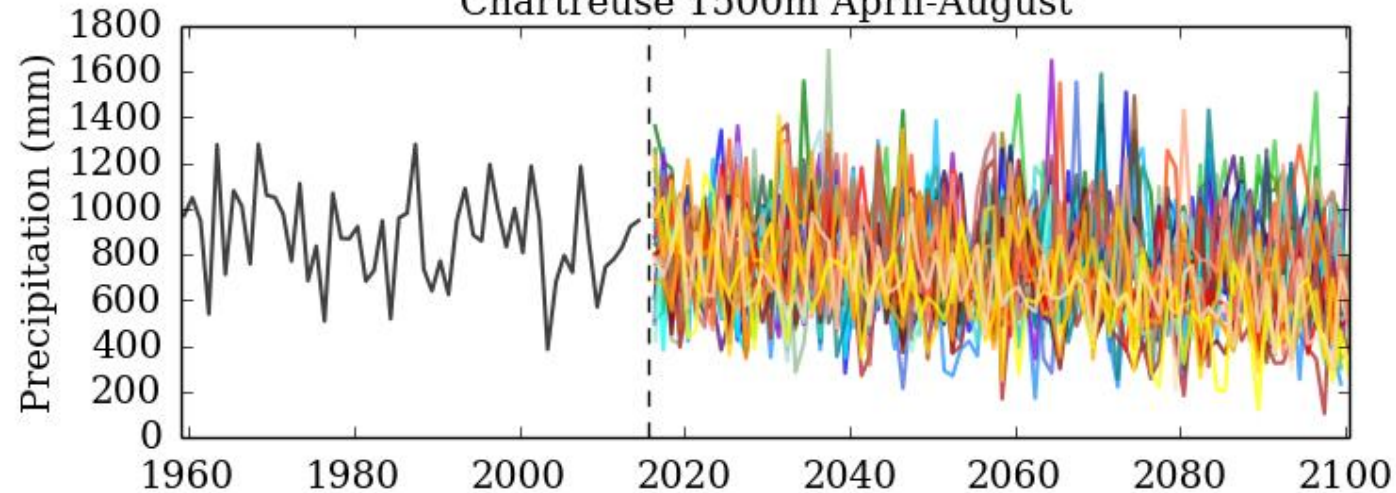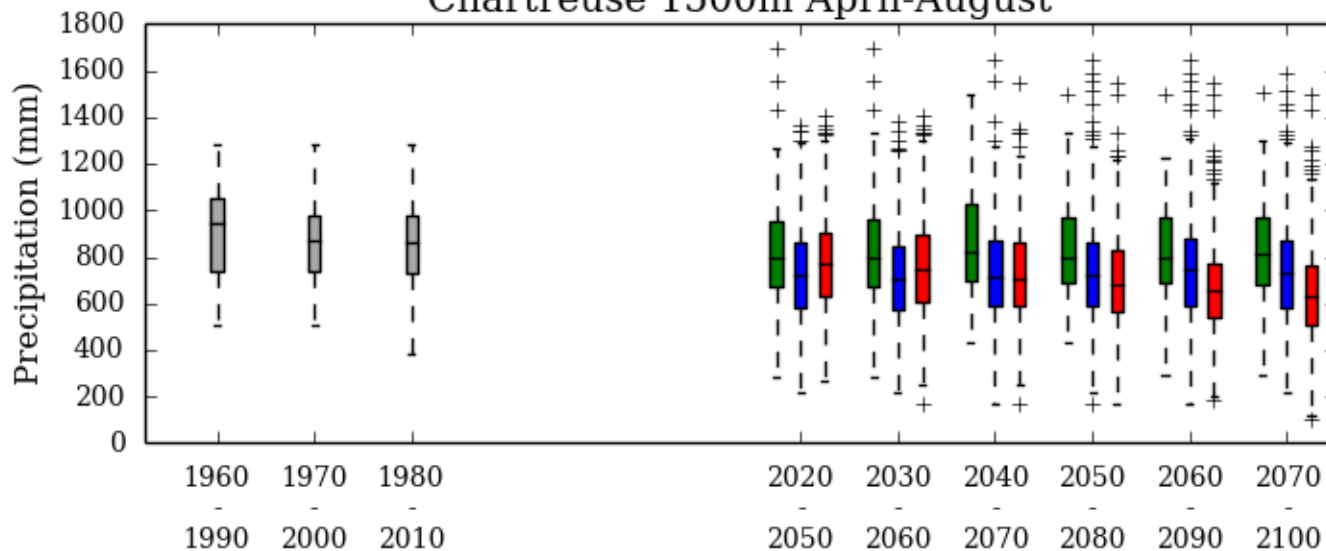
Chartreuse 1500m April-August

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SAFRAN 1980-2010   RCP 2.6 2020-2050   RCP 4.5 2020-2050   RCP 8.5 2020-2050

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SAFRAN 1980-2010   RCP 2.6 2070-2100   RCP 4.5 2070-2100   RCP 8.5 2070-2100

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- EC-EARTH/RCA4
- HadGEM2-ES/RCA4
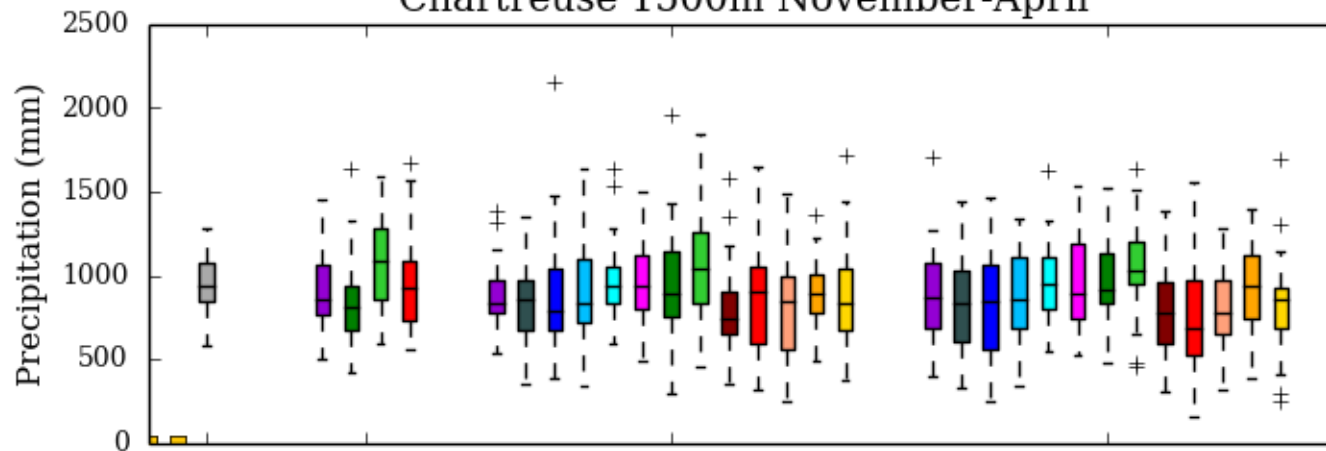- IPSL-CM5A-MR/RCA4
- MPI-ESM-LR/RCA4

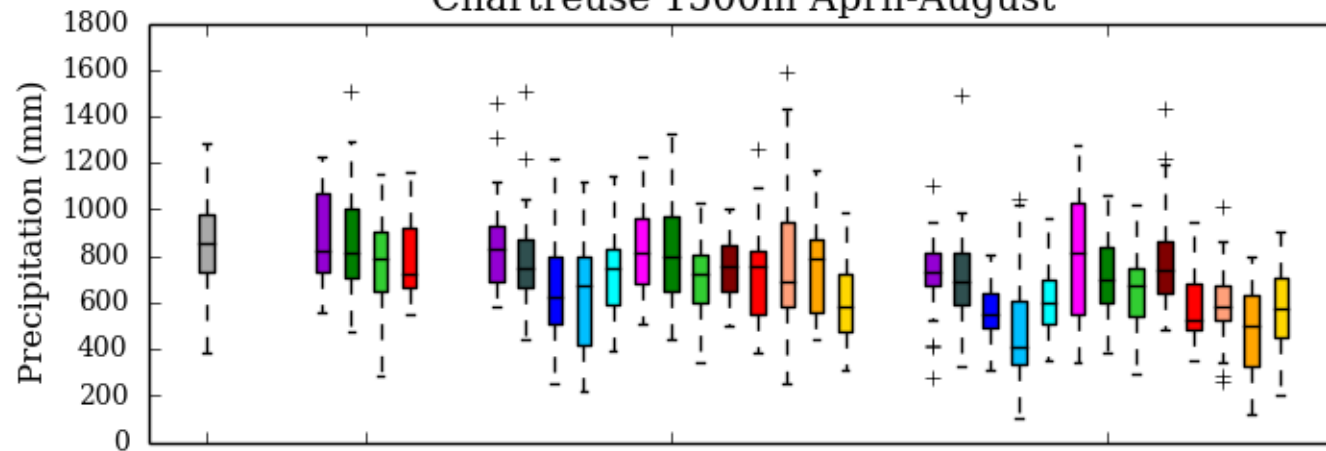SAFRAN 1980-2010   RCP 2.6 2020-2050   RCP 4.5 2020-2050   RCP 8.5 2020-2050

First results – Meteorological variables

First results – Meteorological variables

Chartreuse 1500m November-April

Legend:
- SAFRAN reanalysis
- ARPEGE/ALADIN RCP2.6
- HadGEM2-ES/RACMO22E RCP2.6
- MPI-ESM-LR/REMO2009 RCP2.6
- EC-EARTH/RCA4 RCP2.6
- ARPEGE/ALADIN RCP4.5
- ARPEGE/CCLM4-8-17 RCP4.5
- EC-EARTH/CCLM4-8-17 RCP4.5
- HadGEM2-ES/CCLM4-8-17 RCP4.5
- MPI-ESM-LR/CCLM4-8-17 RCP4.5
- IPSL-CM5A-MR/WRF331F RCP4.5
- HadGEM2-ES/RACMO22E RCP4.5
- MPI-ESM-LR/REMO2009 RCP4.5
- ARPEGE/RCA4 RCP4.5
- EC-EARTH/RCA4 RCP4.5
- HadGEM2-ES/RCA4 RCP4.5
- IPSL-CM5A-MR/RCA4 RCP4.5
- MPI-ESM-LR/RCA4 RCP4.5
- ARPEGE/ALADIN RCP8.5
- ARPEGE/CCLM4-8-17 RCP8.5
- EC-EARTH/CCLM4-8-17 RCP8.5
- HadGEM2-ES/CCLM4-8-17 RCP8.5
- MPI-ESM-LR/CCLM4-8-17 RCP8.5
- IPSL-CM5A-MR/WRF331F RCP8.5
- HadGEM2-ES/RACMO22E RCP8.5
- MPI-ESM-LR/REMO2009 RCP8.5
- ARPEGE/RCA4 RCP8.5
- EC-EARTH/RCA4 RCP8.5
- HadGEM2-ES/RCA4 RCP8.5
- IPSL-CM5A-MR/RCA4 RCP8.5
- MPI-ESM-LR/RCA4 RCP8.5

First results – Meteorological variables

Chartreuse 1500m November-April

First results –
Meteorological variables

Chartreuse 1500m November-April

Legend:
- SAFRAN reanalysis
- ARPEGE/ALADIN
- ARPEGE/CCLM4-8-17
- EC-EARTH/CCLM4-8-17
- HadGEM2-ES/CCLM4-8-17
- MPI-ESM-LR/CCLM4-8-17
- IPSL-CM5A-MR/WRF331F
- HadGEM2-ES/RACMO22E
- MPI-ESM-LR/REMO2009
- ARPEGE/RCA4
- EC-EARTH/RCA4
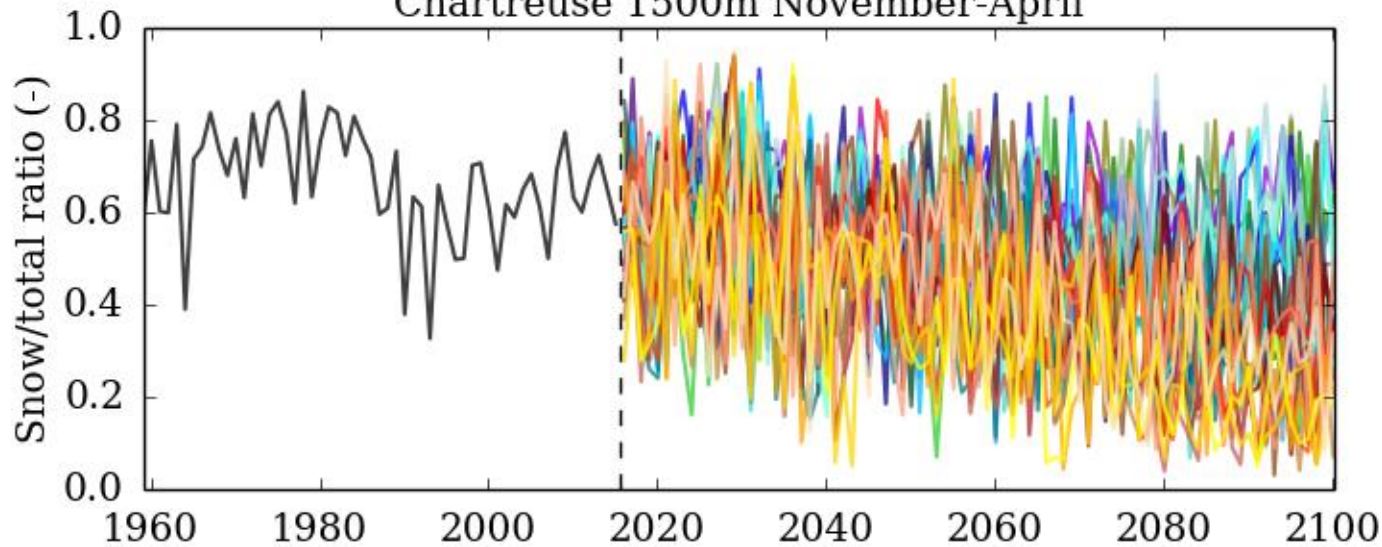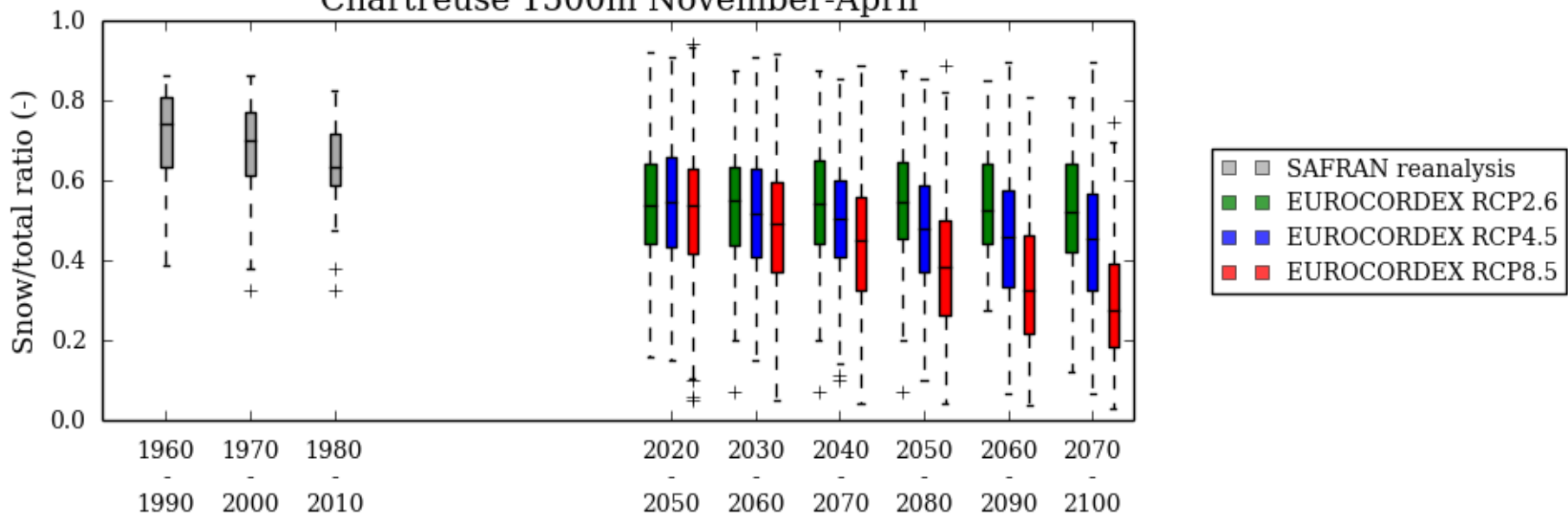- HadGEM2-ES/RCA4
- IPSL-CM5A-MR/RCA4
- MPI-ESM-LR/RCA4

First results – Meteorological variables

Chartreuse 1500m November-April

Legend:
- SAFRAN reanalysis
- ARPEGE/ALADIN
- ARPEGE/CCLM4-8-17
- EC-EARTH/CCLM4-8-17
- HadGEM2-ES/CCLM4-8-17
- MPI-ESM-LR/CCLM4-8-17
- IPSL-CM5A-MR/WRF331F
- HadGEM2-ES/RACMO22E
- MPI-ESM-LR/REMO2009
- ARPEGE/RCA4
- EC-EARTH/RCA4
- HadGEM2-ES/RCA4
- IPSL-CM5A-MR/RCA4
- MPI-ESM-LR/RCA4