Observation et modélisation des interactions entre conditions d'enneigement et activité des stations de sports d'hiver dans les Alpes Françaises

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5 Décembre 2016

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or 45 minutes in a glance

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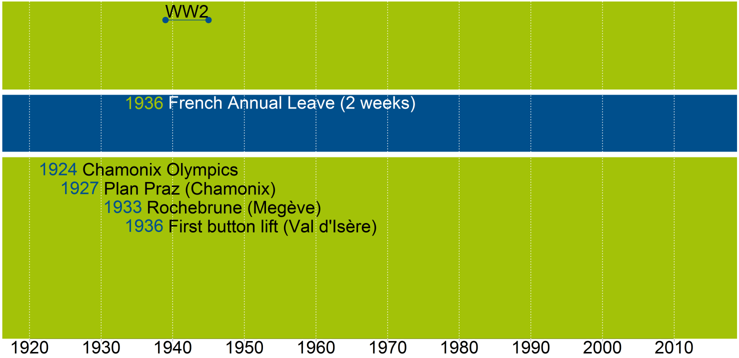
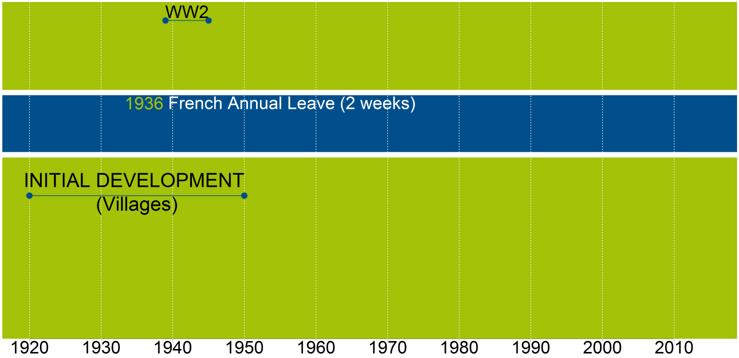
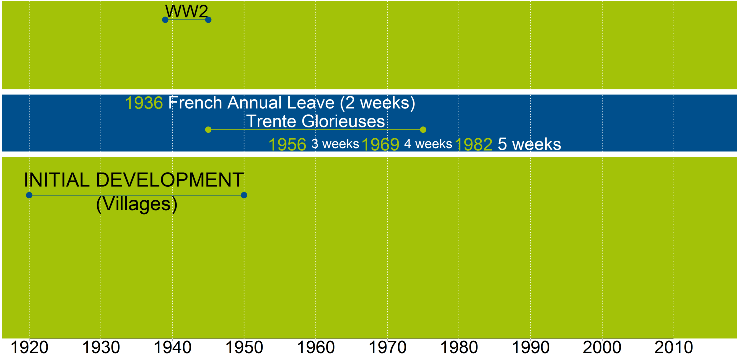
Development and industrialisation of winter tourism

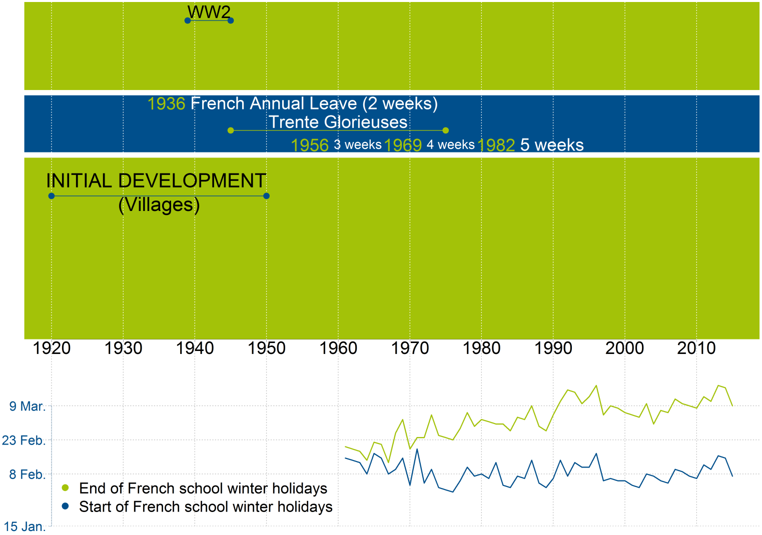



WW2
1936 French Annual Leave (2 weeks)
INITIAL DEVELOPMENT
(Villages)
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

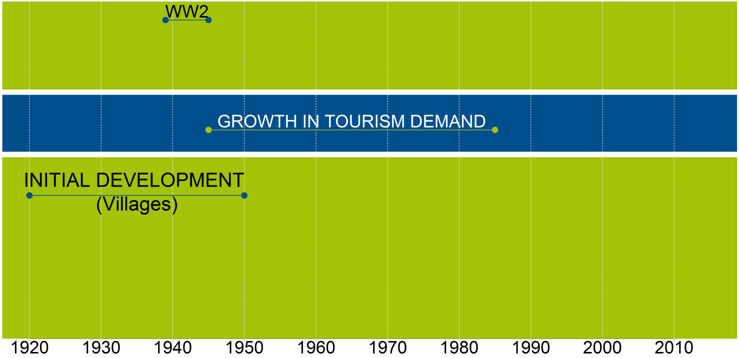
Introduction

Development and industrialisation of winter tourism





EducationNationale (2016), "Records of the academic calendar (1959 - 2015)"


WW2
GROWTH IN TOURISM DEMAND
INITIAL DEVELOPMENT
(Villages)
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

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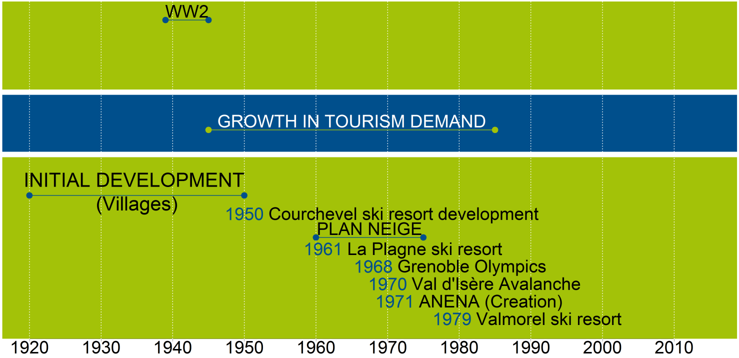

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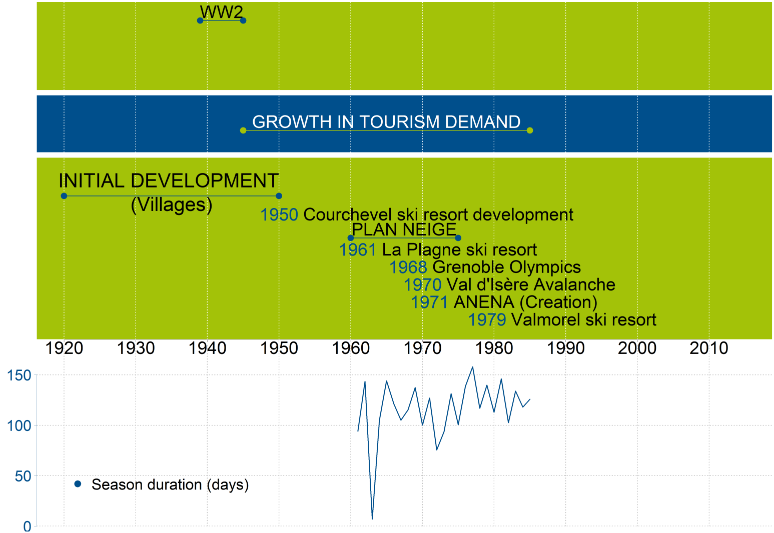

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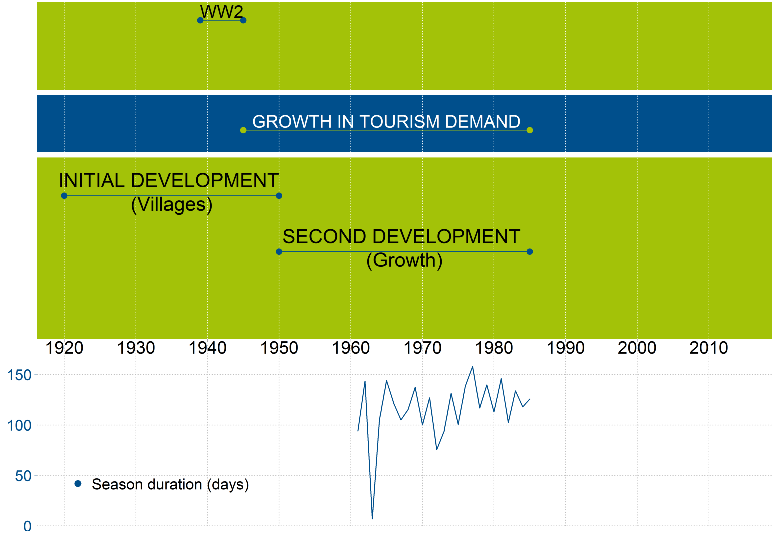

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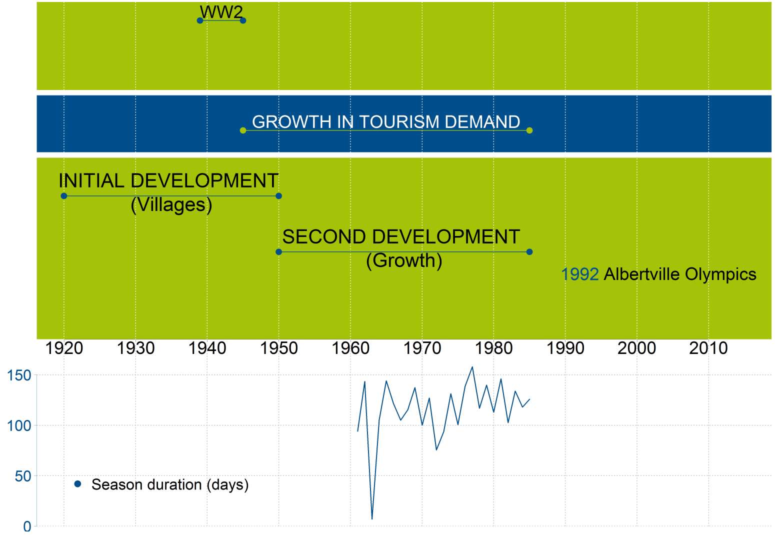
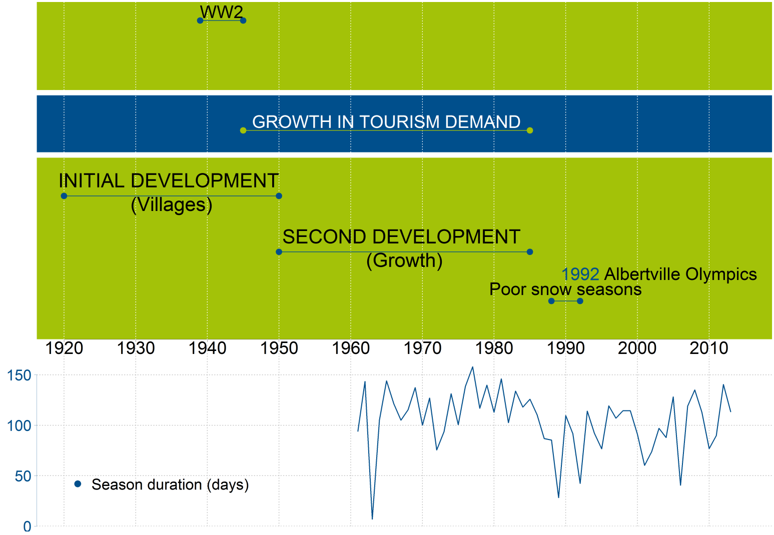
Development and industrialisation of winter tourism

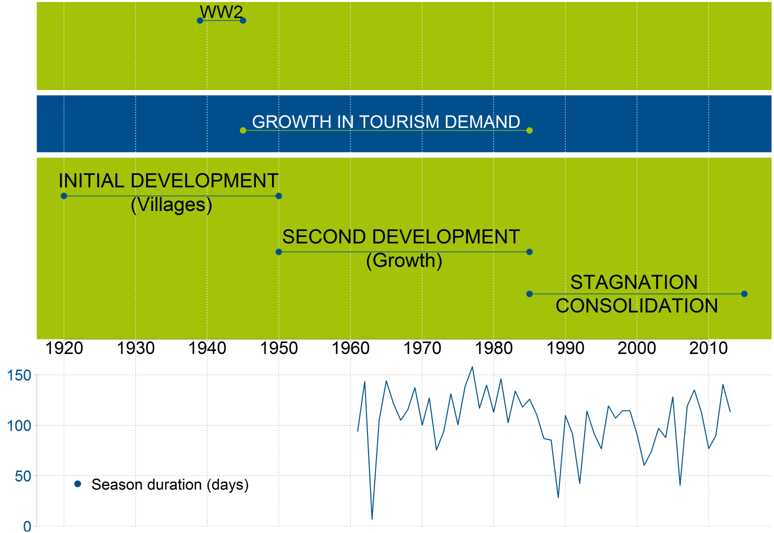


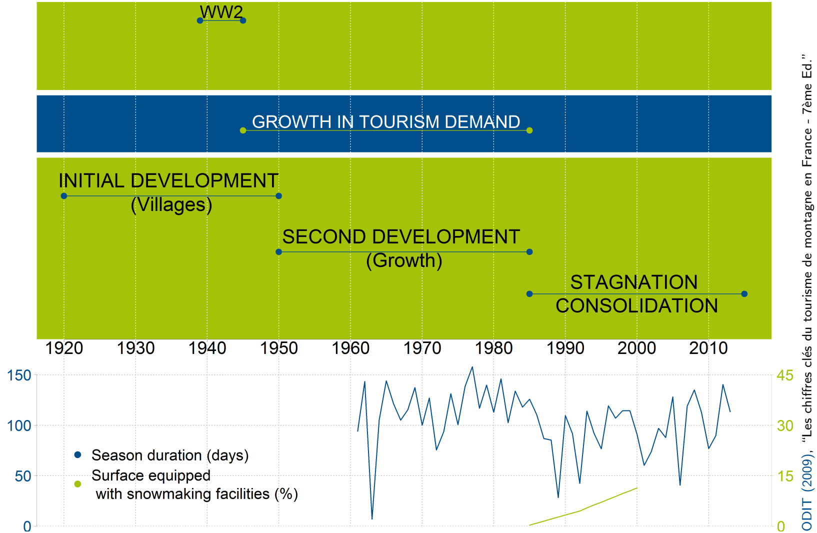
Fablet (2013), "Real Estate Development [...]" in *Journal of Alpine Research*


WW2
GROWTH IN TOURISM DEMAND
INITIAL DEVELOPMENT
(Villages)
SECOND DEVELOPMENT
(Growth)
1992 Albertville Olympics
Poor snow seasons
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
150
100
50
0
Season duration (days)

Introduction

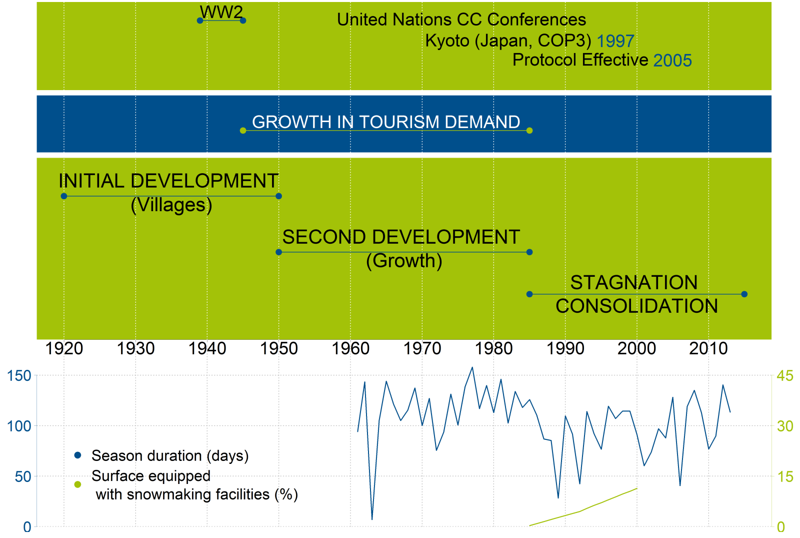
Development and industrialisation of winter tourism




WW2
GROWTH IN TOURISM DEMAND
INITIAL DEVELOPMENT
(Villages)
SECOND DEVELOPMENT
(Growth)
STAGNATION
CONSOLIDATION
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
150
100
50
0
45
30
15
0
Season duration (days)
Surface equipped
with snowmaking facilities (%)
ODIT (2009), "Les chiffres clés du tourisme de montagne en France - 7ème Ed."

Introduction

Development and industrialisation of winter tourism



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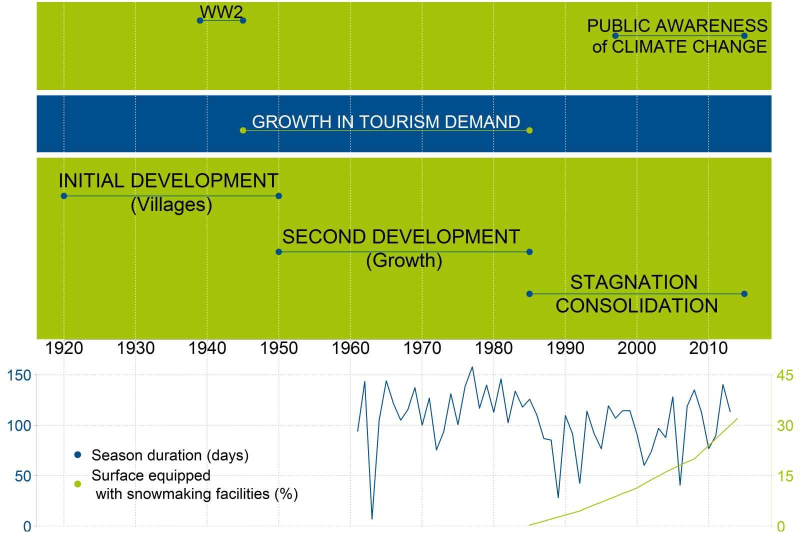
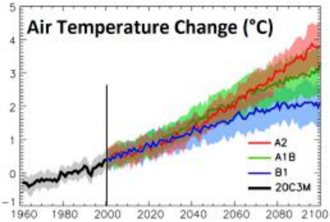
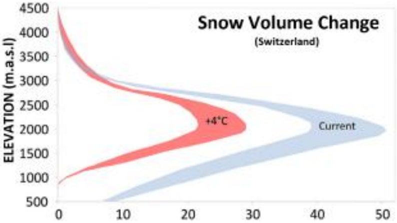


Trawöger (2014), "Convinced, ambivalent or annoyed [...]" in *Tourism Management*





Climate Change Challenges[1]

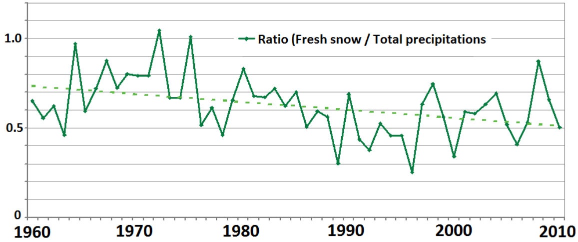
- Outstanding global increase of greenhouse gases concentrations since 1950
- $+ 0.85^\circ$C global temperature increase since pre industrial era [2]
- In the European Alps, a twice higher rate of increase
- Importance of the Snow/Rain elevation limit

[1] Gobiet et al. (2014), "21st century climate change in the European Alps" in *Science of the Total Environment*

[2] IPCC (2014), *Climate Change 2014: Impacts, Adaptation, and Vulnerability [...]*

An example at the Col de Porte (1325 m.a.s.l, Chartreuse, France)[3]

- Season duration diminished by -6 days per decade over 1960 - 2012
- Average Snow depth diminished by -13 cm per decade over 1960 - 2012



[3] Lesaffre et al. (2012), "Impact du changement climatique sur l'enneigement de moyenne montagne[...]"

Winter tourism: a major economy

of French mountain regions[4]

- 20% of the GDP in Savoie (73) and Haute-Savoie (74)[5]
- 10 out of the 30 largest ski resorts in the world are located in the French Alps
- 150 000 employments

An economy **based on key periods**

- 20% of revenues[6] during Christmas Holidays (2 weeks)
- 33% of revenues during February School break (4 weeks)

4 DSF (2014), *Indicateurs et Analyses*

5 Lecuret et al. (2014), *Tourism monitor. Savoie Mont Blanc facts and figures*

6 skier days and overnight stays in Savoie and Haute-Savoie

A major industry in mountain regions

x

Vulnerable to snow conditions

x

Climate Change challenges

=

A **critical societal issue**

+

A **rising interest for scientific investigations**

Definitions[7]:

- "100 days" rule

  Skiing requires a **minimum 30 cm** deep snow during **100 days or more** to be economically viable

- Snow Reliability Line

  the **minimum elevation** fulfilling the "100 days" rule

[7] Koenig and Abegg (1997), "Impacts of climate change on winter tousim in the Swiss Alps" in *Journal of Sustainable Tourism*

Based on NATURAL SNOW[8]

- **Computation** of the Snow Reliability Line

  e.g. 1200 ma.s.l (French Northern Alps) | 1500 m.a.s.l (French Southern Alps)

- **Impact of Climate Change** on the Snow Reliability Line

  e.g. 150m rise for a $+1^{\circ}$C increase in temperature

- **Reliability of ski resorts** by comparing elevations

  e.g. 97% of French resorts currently snow reliable | 83% under a $+1^{\circ}$C | 65% under a $+2^{\circ}$C increase in temperature

- **Computation of snowmaking requirements** to fulfill the "100 days" rule at resorts' elevation

[8] Abegg et al. (2007), "Climate change impacts and adaptation in winter tourism" in *Climate Change in the European Alps*

Accounting for SNOWMAKING [9]

- U.S.A
- Austria
- Switzerland
- Canada
- Spanish and French Pyrenees
- Germany
- Andorra
- Australia
- New-Zealand

[9] Gilaberte-Búrdalo et al. (2014), "Impacts of climate change on ski industry" in *Environmental Science & Policy*

Accounting for SNOWMAKING: major limitations

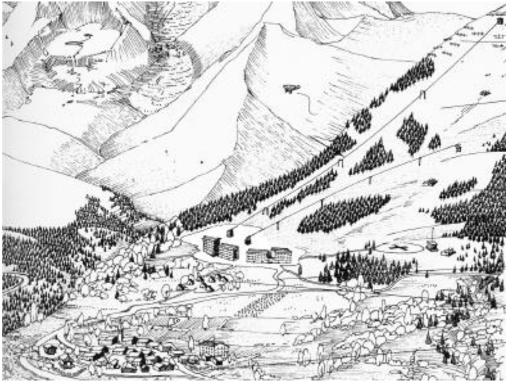
- French Alps are not covered
- Spatial representations of ski resorts may be coarse

Research publications

Impact studies accounting for snowmaking: major limitations

Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse



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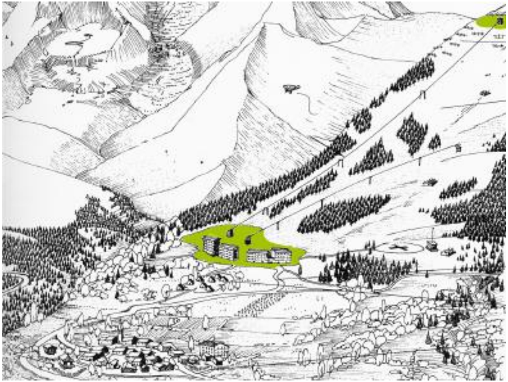

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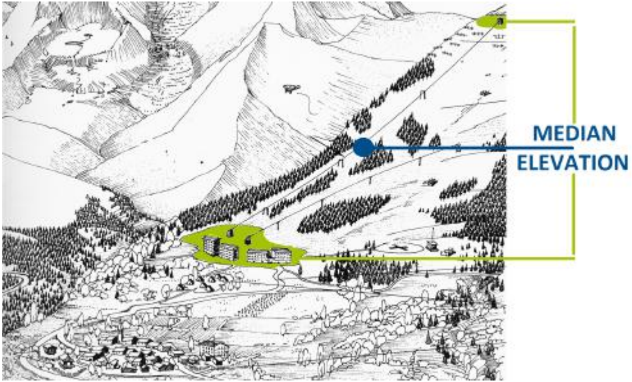

Accounting for SNOWMAKING: major limitations

- French Alps are not covered
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- Transfer/generalization may not be possible

Accounting for SNOWMAKING: major limitations

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- Grooming impact on snow properties may not be considered
- Machine made snow properties may not be considered

Research publications

Impact studies accounting for snowmaking: major limitations

Accounting for SNOWMAKING: major limitations

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- Specificities of French ski industry may not be considered

Remaining MAJOR CHALLENGES

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
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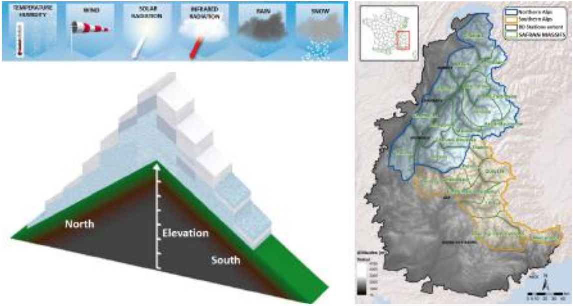
Research publications
Present investigation: initial state

Initial state based on NATURAL SNOW[10]

- French Alps
- Transfer/generalization

SAFRAN - **Crocus** model

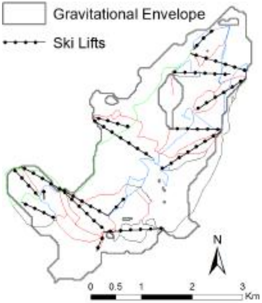


[10] Vionnet et al. (2012), "The detailed snowpack scheme Crocus [...]" in *Geosci. Model. Dev.*

Initial state based on a SOCIO - ECONOMIC DATABASE[11]

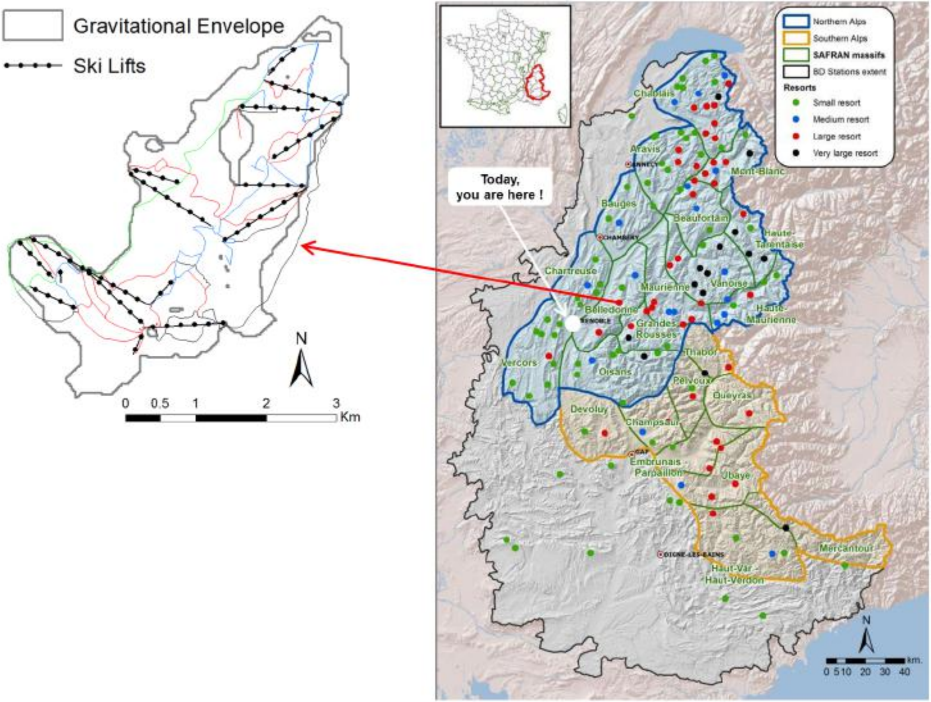
- French Alps
- Spatial representations of ski resorts
- Transfer/generalization

BD STATIONS Database[12]

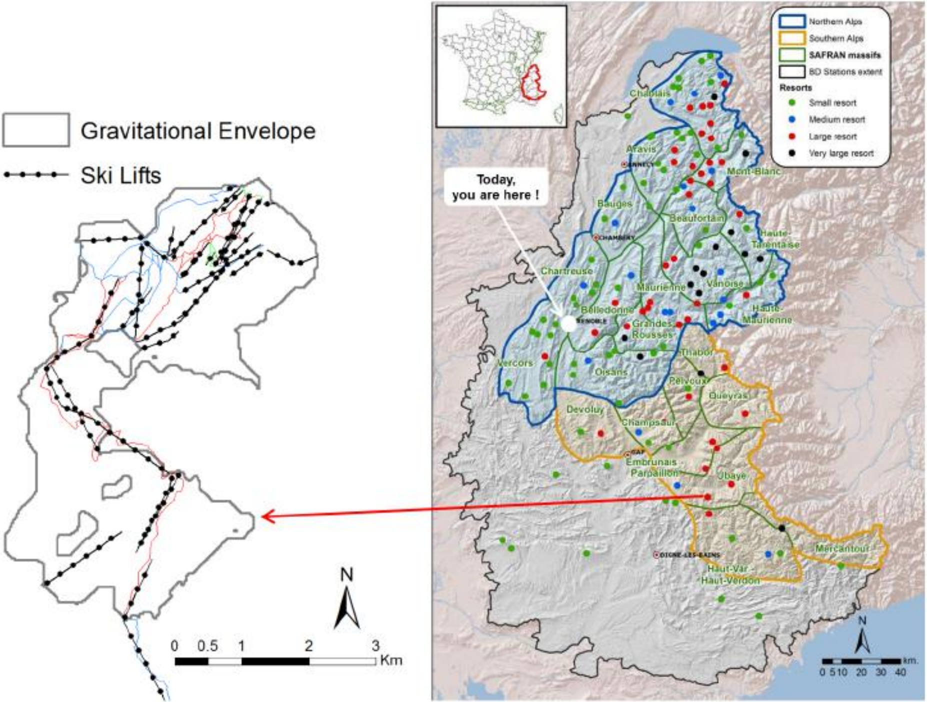


[11] Marcelpoil et al. (2012), *Atlas des stations du massif des Alpes*

[12] Example: Sept Laux ski resort (Belledonne, France)



Gravitational Envelope
Ski Lifts
N
0 0.5 1 2 3
Km
Northern Alps
Southern Alps
SAFRAN massifs
BD Stations extent
Resorts
Small resort
Medium resort
Large resort
Very large resort
Today,
you are here !
Chablais
Aravis
ANNECY
Mont-Blanc
Bauges
Beaufortain
CHAMBERY
Haute-
Tarentaise
Chartreuse
Maurienne
Vanoise
Belledonne
Grandes
Rousses
Haute-
Maurienne
Thabor
Vercors
Oisans
Pelvoux
Queyras
Devoluy
Champsaur
GAP
Embrunais
Parpaillon
Ubaye
Mercantour
DIGNE-LES-BAINS
Haut-Var -
Haut-Verdon
N
km.
0 5 10 20 30 40



Gravitational Envelope
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Southern Alps
SAFRAN massifs
BD Stations extent
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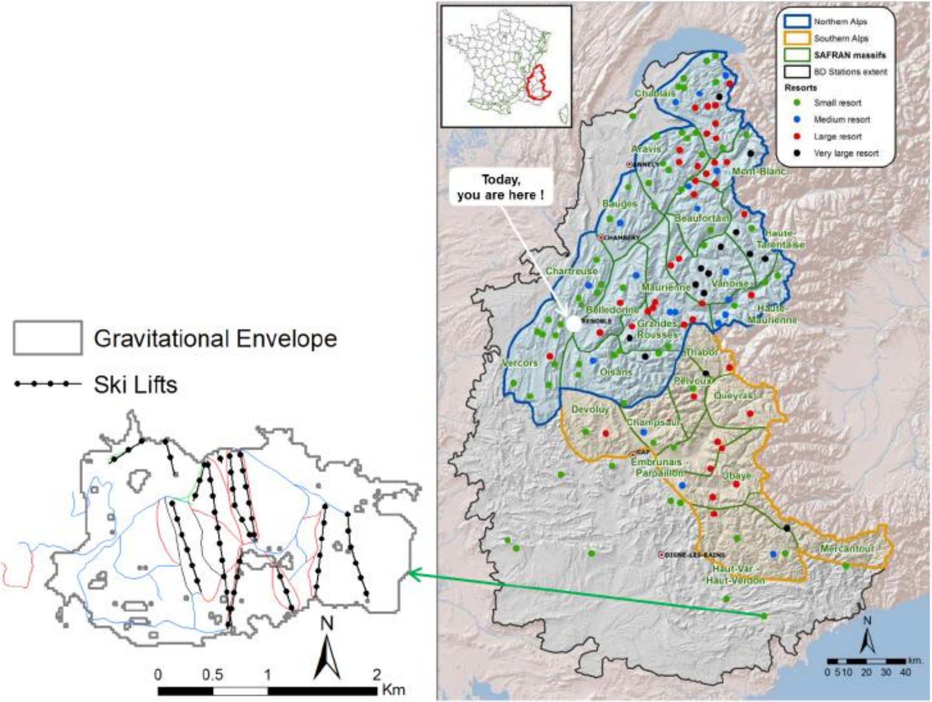
Chartreuse
Maurienne
Vanoise
Belledonne
Haute-Maurienne
Grandes-Rousses
Thabor
Vercors
Oisans
Pelvoux
Queyras
Devoluy
Champsaur
Embrunais - Parpaillon
Ubaye
Mercantour
Haut-Var - Haut-Verdon
N
km
0 5 10 20 30 40



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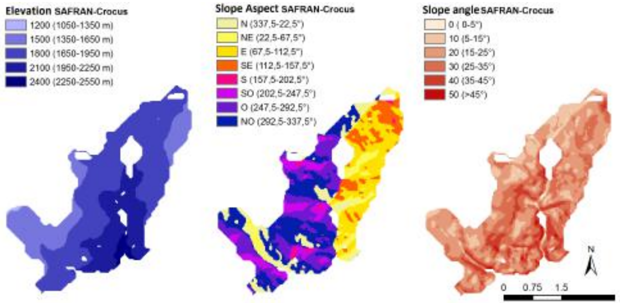
Pelvoux
Queyras
Devoluy
Champsaur
Embrunais Parpaillon
Ubaye
Mercantour
Haut-Var - Haut-Verdon
DIGNE-LES-BAINS
N
km
0 5 10 20 30 40

Research publications
Present investigation: initial state

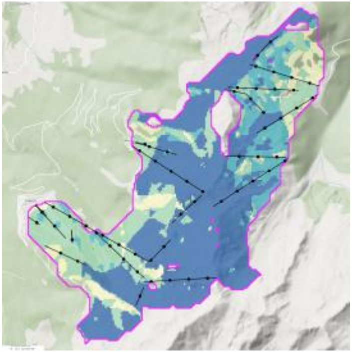
Initial state based on a SOCIO - ECONOMIC DATABASE

- French Alps
- Spatial representations of ski resorts[13]
- Transfer/generalization



[13] Francois et al. (2016), "Croisement de simulations numériques des conditions d'enneigement [...]" in *La Houille Blanche*

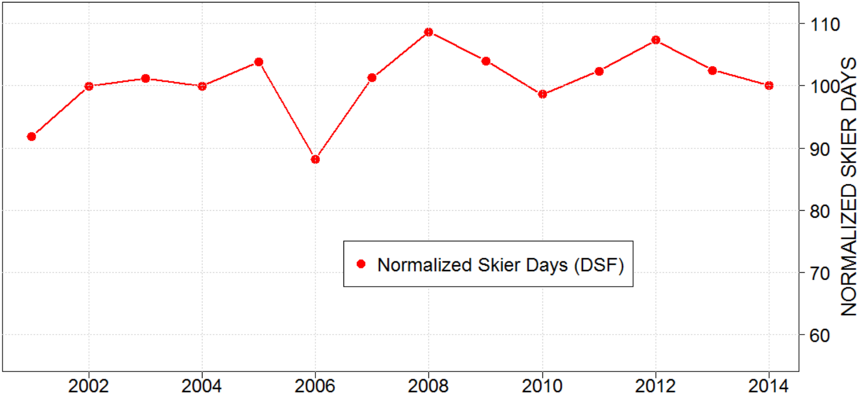
A proof of concept based on **NATURAL SNOW conditions**[14]



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

[14] François et al. (2014), "Crossing numerical simulations [...]" in *Cold Regions Science and Technology*

Initial state
Proportion of a ski resort fulfilling the "100 days" rule
weighed by resorts ski lift power



[15] François et al. (2014), "Crossing numerical simulations [...]" in *Cold Regions Science and Technology*

Initial state
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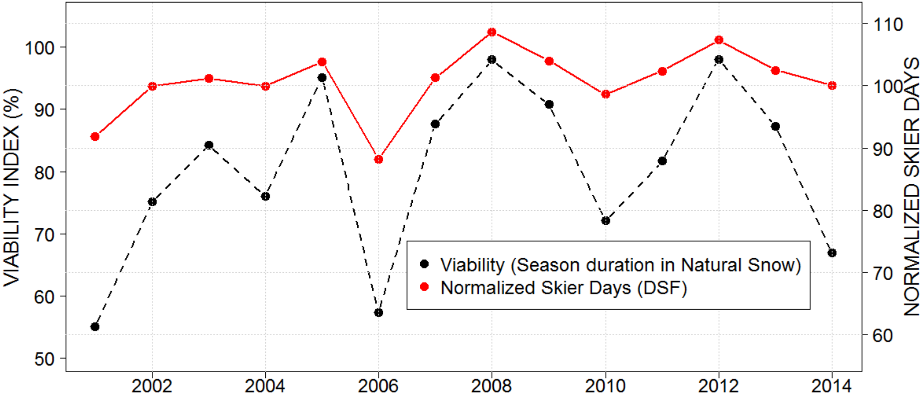


[16] François et al. (2014), "Crossing numerical simulations [...]" in *Cold Regions Science and Technology*

Remaining MAJOR CHALLENGES

- French Alps
- Spatial representations of ski resorts
- Transfer/generalization

Remaining MAJOR CHALLENGES

- French Alps
- Spatial representations of ski resorts
- Transfer/generalization
- Grooming impact on snow properties
- Machine made snow properties

Problematic

Present investigation: major challenges

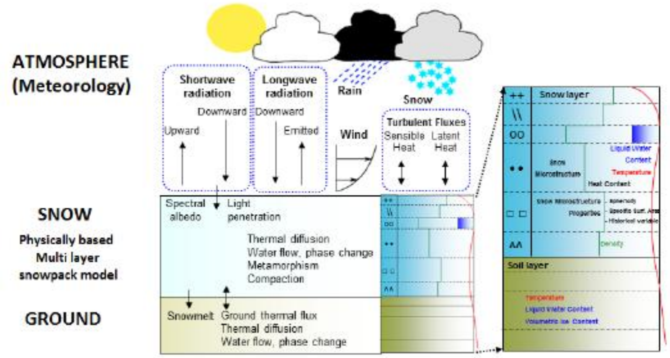
Remaining MAJOR CHALLENGES

- French Alps
- Spatial representations of ski resorts
- Transfer/generalization
- Grooming impact on snow properties
- Machine made snow properties
- Key periods (Christmas, February)
- Analysis and specificities of French ski industry

Part 1

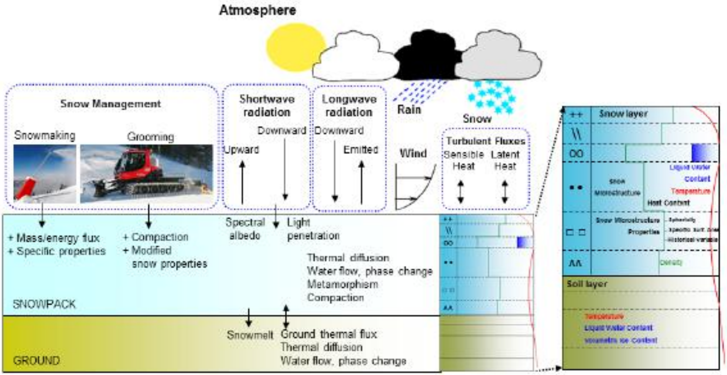
Observations and modelling of snow management impact on snow properties

SAFRAN - Crocus model[17]



[17] Vionnet et al. (2012), "The detailed snowpack scheme Crocus [...]" in *Geosci. Model. Dev.*

SAFRAN - Crocus Resort[18]



[18] Spandre et al. (2016), "Integration of snow management [...]" in *Cold Regions Science and Technology*

Physical Impact

Observations and modelling of snow management in ski resorts[19]

Observations in four ski resorts

Autrans, Chamrousse, Les 2 Alpes, Tignes

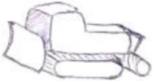
over two winter seasons

- 19 ski patrollers involved
- 64 observations by ski patrollers
- 45 additional observations

Many thanks to all of them!!

[19] Spandre et al. (2016), "Integration of snow management [...]" in *Cold Regions Science and Technology*

What is GROOMING?



Physical Impact of GROOMING
Observations and modelling of snow management in ski resorts[20]

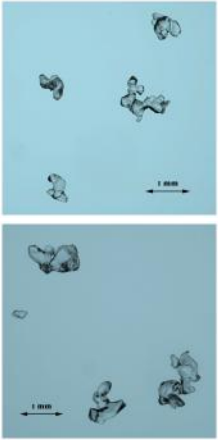
What is grooming? 

Physical impact

- Static weight 
- Mixing and evolution effect 

Grooming schedule

- From November 1 to April 15
- From 20 p.m to 21 p.m
- Minimum 20 kg m^{-2}



[20] Spandre et al. (2016), "Integration of snow management [...]" in *Cold Regions Science and Technology*

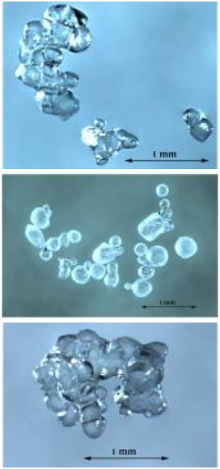
Autrans (Vercors) | 1300 m.a.s.l | 2015 - 2016

Physical impact of SNOWMAKING

Physical Impact of SNOWMAKING

Observations and modelling of snow management in ski resorts[21]

- **Machine Made snow properties**
- **Production conditions**
  - Start and End dates
  - From 6 p.m to 8 a.m
  - Wet bulb temperature threshold (°C)
  - Precipitation rate (kg m^{-2} s^{-1})
- **Production duration (s)**
  Or threshold snow depth (m)
  Or threshold snow mass (kg m^{-2})



[21] Spandre et al. (2016), "Integration of snow management [...]" in *Cold Regions Science and Technology*

Physical Impact of SNOWMAKING

Observations and modelling of snow management in ski resorts[22]

Differences in water volumes

(2014 - 2015)

- >25% in Tignes
- ±50% in Les 2 Alpes
- >50% in Chamrousse, Autrans

[22] Spandre et al. (2016), "Integration of snow management [...]" in *Cold Regions Science and Technology*

Physical Impact of SNOWMAKING

Observations and modelling of snow management in ski resorts [23]

Dedicated field campaign

Differences in water volumes (2015 - 2016)

- $<$10% due to thermodynamic losses (evaporation, sublimation)
- 30% unexplained (wind, obstacles, etc.)

Overall 40% ($\pm$10%) differences

[23] Spandre et al. (2016), "Seasonal evolution of a ski slope under natural and artificial snow [...]" in *The Cryosphere Discussions*

Part 2

Professional snow management operations in French ski resorts

Major priorities for resorts operators[24]

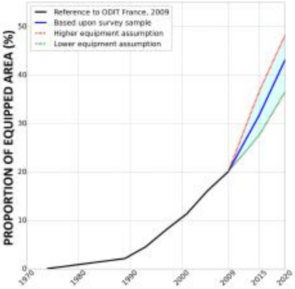
1. **The satisfaction of skiers expectations**
   - To provide comfortable skiing conditions (9.0/10)
   - To return back down the village by ski (8.8/10)
2. **The guarantee of skiable conditions**
   - To build a snowpack resistant against erosion (8.2/10)
   - To reach a threshold snow depth (8.1/10)

     Average: February = 63cm | Minimum= 45cm
3. **The promotion of the resort**
   - To have visually appealing slopes every morning (8.1/10)

[24] Spandre et al. (2016), "Panel based assessment of snow management [...]" in *Journal of Outdoor Recreation and Tourism*

Technical means[25]

- 70% of ski slopes groomed every day
- Increasing snowmaking requirements [26]



[25] Our survey was realized before the 2015 announcement from "Auvergne Rhône Alpes" region of an investment plan in snowmaking facilities

[26] Spandre et al. (2015), "Snowmaking in the French Alps. Climatic context [...]" in *Journal of Alpine Research*

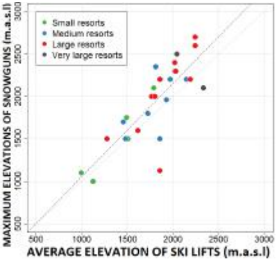
Professional approaches

Professional snow management operations in French ski resorts

- **Water supply**
  - Dedicated reservoirs (70% of resorts)

    Average capacity **30 to 36 cm** Machine Made (MM) snow (1500 to 1800 m^3 ha^{-1})
  - 31% have this only source of water

    Average capacity **38 cm** MM snow (1900 m^3 ha^{-1})
- **Priority for snowguns set up**
  - To low elevation areas (excepted Very Large resorts)
  - To slopes turned towards the village



Conclusions[27]

- Frameworks for the production of MM snow and snow grooming

  (i.e. periods, threshold snow depth, grooming frequency)

- Indications for the spatial modelling of ski slopes covered by snowmaking facilities

  (i.e. % of equipment, slopes aspect, elevations)

[27] Based on survey's results, interviews with professional snowmakers and literature

Part 3

Integration of professional snow management operations

Frameworks for the production of MM snow and snow grooming[28]

- Grooming every day

[28] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

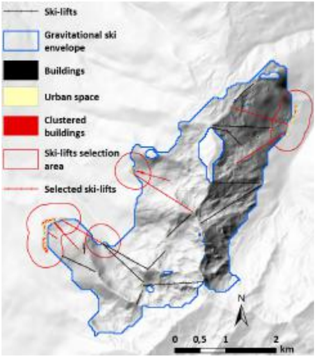
Frameworks for the production of MM snow and snow grooming[29]

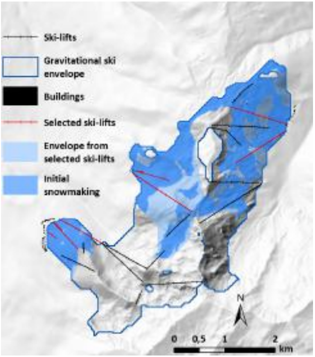
- Grooming every day
- November 1 to December 15:
  "base layer" (150 kg m^{-2} or 30 cm MM snow)
- December 15 to February 28:
  reach a threshold of 60 cm total snow depth
- March 1: STOP!

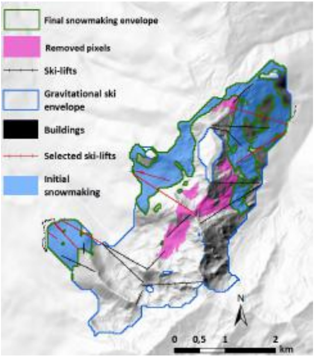
[29] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Spatial modelling of ski slopes covered by **snowmaking facilities**[30]

Step 1	**Step 2**	**Step 3**
Defining resorts villages	Select Lifts and Slopes	Adjust to target







Sept Laux ski resort, Belledonne, France

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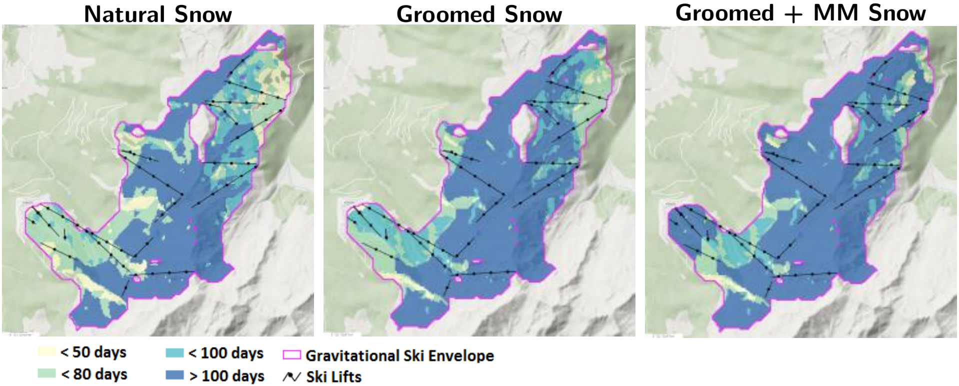
[30] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Explicit spatial modelling of managed snow on ski slopes



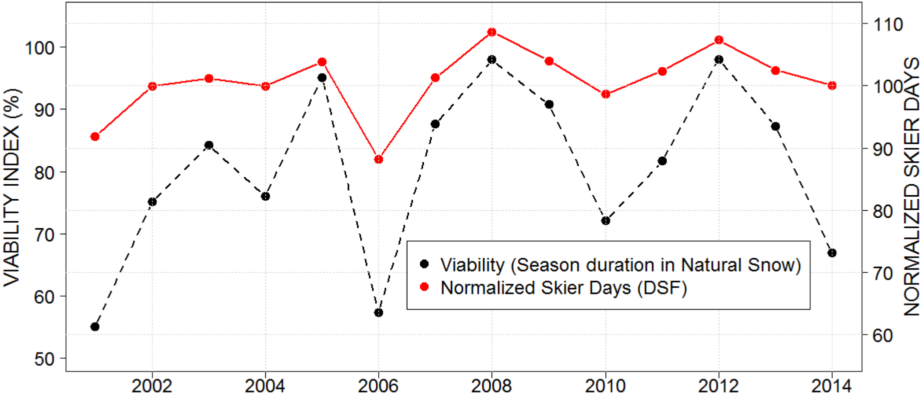
Sept Laux ski resort | Season duration (days) | 2006-2007

Interactions

Snow reliability indicators for the economic activity of ski resorts

Initial state

Proportion of a ski resort fulfilling the "100 days" rule weighed by resorts ski lift power



[31] François et al. (2014), "Crossing numerical simulations [...]" in *Cold Regions Science and Technology*

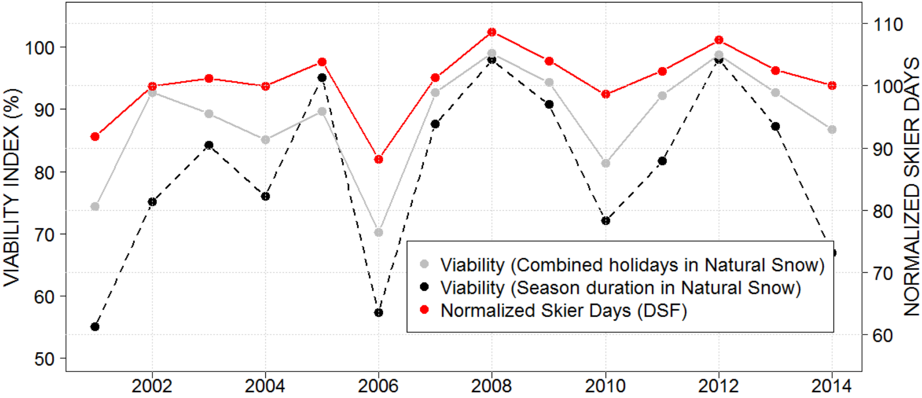
Step 2

Accounting for the **key periods**

- Daily viability for every resort
- Computed for Christmas Holidays and February school break
- "Combined Holidays" viability = 15% Christmas + 85% February

Step 2

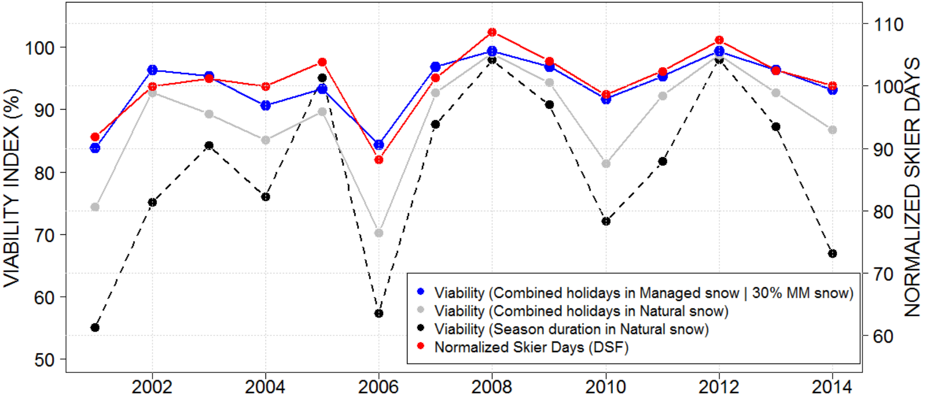
Accounting for the **key periods**
weighed by resorts ski lift power



[32] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Step 3

Accounting for the key periods and **snow management** weighed by resorts ski lift power



[33] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Time!

General conclusions

Conclusion

Interactions between snow conditions and ski resorts activity

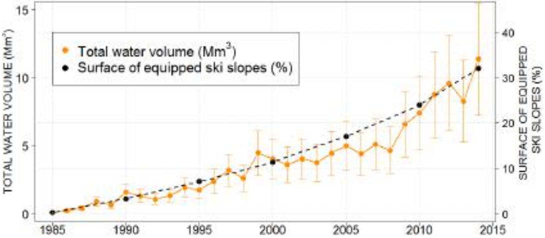
Integrated approach, accounting for:

- **Spatial representations** of ski resorts
- **Physical impacts** of snow management
- **Professional approaches** of snow management
- **Specificities of the ski industry economy**

Leading to a wide range of applications!

An innovative approach to

- Compute **water and energy requirements** for snowmaking[34]

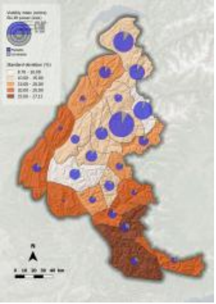


[34] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Conclusion
Interactions between snow conditions and ski resorts activity

An innovative approach to

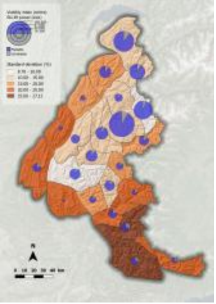
- Compute water requirements for snowmaking
- Investigate **spatial and resorts categories variabilities**[35] regarding natural snow conditions

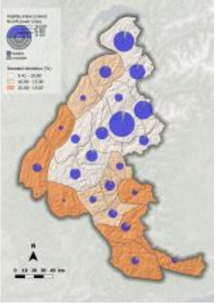


[35] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

An innovative approach to

- Compute water requirements for snowmaking
- Investigate spatial and resorts categories variabilities
- Assess the **evolution of snow conditions** thanks to snow management[36]





[36] Spandre et al. (In Prep), "Investigations on socio economic indicators of French Alps [...]" in *Journal of the Total environment*

Conclusion

Interactions between snow conditions and ski resorts activity

An innovative approach to

- Compute water requirements for snowmaking
- Investigate spatial and resorts categories variabilities
- Assess the evolution of snow conditions
- Provide **relevant and objective information** for fruitful debates on local development in mountain regions

Time!

Outlooks

Additional applications

- Generalization to all French mountain regions

  (i.e. Pyrenees, Massif Central, Vosges, Jura)

- Ecological impact studies

  (cf. grooming impact on ground temperatures)

- Hydrological applications

  (i.e. water requirements)

Additional applications

- Generalization to all French mountain regions

  (i.e. Pyrenees, Massif Central, Vosges, Jura)

- Ecological impact studies

  (cf. grooming impact on ground temperatures)

- Hydrological applications

  (i.e. water requirements)

- Climate change impact studies

  (i.e. evolution of resorts reliability, water requirements)

- Diagnosis for policy makers and resorts stakeholders


THANK YOU!! MERCI!!