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

Pierre Spandre

Ecole Doctorale Terre, Univers, Environnement

5 Décembre 2016
Introduction
Development and industrialisation of winter tourism


1924 Chamonix Olympics
1927 Plan Praz (Chamonix)
1933 Rochebrune (Megève)
1936 First button lift (Val d'Isère)

1936 French Annual Leave (2 weeks)

WW2
Introduction
Development and industrialisation of winter tourism

- WW2
- 1936 French Annual Leave (2 weeks)
- INITIAL DEVELOPMENT (Villages)

Timeline:
Introduction
Development and industrialisation of winter tourism

- WW2
- 1936 French Annual Leave (2 weeks) Trente Glorieuses
- 1956 3 weeks
- 1969 4 weeks
- 1982 5 weeks

INITIAL DEVELOPMENT (Villages)

Introduction
Development and industrialisation of winter tourism

- WW2
- 1936 French Annual Leave (2 weeks)
  - Trente Glorieuses
- 1956 3 weeks
- 1969 4 weeks
- 1982 5 weeks

Initial Development
(Villages)


End of French school winter holidays
Start of French school winter holidays
Introduction
Development and industrialisation of winter tourism


GROWTH IN TOURISM DEMAND

INITIAL DEVELOPMENT
(Villages)

WW2
Introduction
Development and industrialisation of winter tourism
Introduction
Development and industrialisation of winter tourism

GROWTH IN TOURISM DEMAND

INITIAL DEVELOPMENT (Villages)

1950 Courchevel ski resort development
1961 La Plagne ski resort
1968 Grenoble Olympics
1970 Val d'Isère Avalanche
1971 ANENA (Creation)
1979 Valmorel ski resort


Season duration (days)
Introduction
Development and industrialisation of winter tourism

- WW2
- Growth in tourism demand
- Initial development (Villages)
- Second development (Growth)

Timeline:
- 1920
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

Graph:
- Season duration (days)
Introduction
Development and industrialisation of winter tourism

Development and industrialisation of winter tourism have been driven by factors such as the growth in tourism demand and the initial development of villages. The growth of tourism was particularly significant in the post-WW2 period and accelerated with the advent of the Albertville Olympics in 1992.

The graph illustrates the seasonal duration of the winter tourism season, showing peaks and troughs that correspond to the development phases of tourism infrastructure.
Introduction
Development and industrialisation of winter tourism

- **WW2**
- **GROWTH IN TOURISM DEMAND**
- **INITIAL DEVELOPMENT (Villages)**
- **SECOND DEVELOPMENT (Growth)**
  - 1992 Albertville Olympics
  - Poor snow seasons


- **Season duration (days)**

- 0 50 100 150
Introduction
Development and industrialisation of winter tourism
Introduction

Development and industrialisation of winter tourism

- WW2
- GROWTH IN TOURISM DEMAND
- INITIAL DEVELOPMENT (Villages)
- SECOND DEVELOPMENT (Growth)
- STAGNATION CONSOLIDATION

- Season duration (days)
- Surface equipped with snowmaking facilities (%)
Introduction
Development and industrialisation of winter tourism

- WW2
- United Nations CC Conferences
  - Kyoto (Japan, COP3) 1997
  - Protocol Effective 2005
- INITIAL DEVELOPMENT (Villages)
- SECOND DEVELOPMENT (Growth)
- GROWTH IN TOURISM DEMAND
- STAGNATION CONSOLIDATION

- Season duration (days)
- Surface equipped with snowmaking facilities (%)
Introduction

Development and industrialisation of winter tourism

Trawöger (2014), “Convinced, ambivalent or annoyed [...]” in Tourism Management
Introduction
Climate Change challenges for winter tourism

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

³Lesaffre et al. (2012), "Impact du changement climatique sur l’enneigement de moyenne montagne[...]")
Introduction
Development and industrialisation of winter tourism

Winter tourism: a major economy of French mountain regions

- 20% of the GDP in Savoie (73) and Haute-Savoie (74)
- 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 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
Introduction
Development and industrialisation of winter tourism

A major industry in mountain regions
×
Vulnerable to snow conditions
×
Climate Change challenges
=
A critical societal issue
+
A rising interest for scientific investigations
Definitions⁷:

- **“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 tourism in the Swiss Alps” in *Journal of Sustainable Tourism*
Based on NATURAL SNOW

- **Computation** of the Snow Reliability Line
  
  e.g. 1200 m.a.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

⁹Gilaberte-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
Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
- Transfer/generalization may not be possible
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
- Transfer/generalization may not be possible
- Grooming impact on snow properties may not be considered
- Machine made snow properties may not be considered
Accounting for SNOWMAKING: major limitations

- French Alps are not covered
- Spatial representations of ski resorts may be coarse
- Transfer/generalization may not be possible
- Grooming impact on snow properties may not be considered
- Machine made snow properties may not be considered
- Key periods (Christmas, February) may not be considered
- 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
- Transfer/generalization may not be possible
- Grooming impact on snow properties may not be considered
- Machine made snow properties may not be considered
- Key periods (Christmas, February) may not be considered
- Specificities of French ski industry may not be considered
Initial state based on NATURAL SNOW\textsuperscript{10}

- French Alps
- Transfer/generalization

\textbf{SAFRAN - Crocus model}

Initial state based on a SOCIO - ECONOMIC DATABASE\textsuperscript{11}

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

\textbf{BD STATIONS Database}\textsuperscript{12}

\textsuperscript{11}Marcelpoil et al. (2012), \textit{Atlas des stations du massif des Alpes}

\textsuperscript{12}Example: Sept Laux ski resort (Belledonne, France)
Initial state based on a SOCIO - ECONOMIC DATABASE

- French Alps
- Spatial representations of ski resorts\(^\text{13}\)
- Transfer/generalization

\(^{13}\text{Francois et al. (2016), "Croisement de simulations numériques des conditions d’enneigement […]" in La Houille Blanche} \)
A proof of concept based on **NATURAL SNOW conditions**

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

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

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

Francois et al. (2014), “Crossing numerical simulations […]” in Cold Regions Science and Technology
Problematic
Present investigation: major challenges

Remaining MAJOR CHALLENGES

- French Alps
- Spatial representations of ski resorts
- Transfer/generalization
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
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\textsuperscript{17}

\textsuperscript{17}Vionnet et al. (2012), “The detailed snowpack scheme Crocus [...]” in Geosci. Model. Dev.
SAFRAN - Crocus Resort\textsuperscript{18}

\textsuperscript{18}Spandre et al. (2016), “Integration of snow management [...]” in \textit{Cold Regions Science and Technology}
Physical Impact
Observations and modelling of snow management in ski resorts

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!!

Spandre et al. (2016), “Integration of snow management [...]” in Cold Regions Science and Technology
What is GROOMING?
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$^{-2}$

---

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
Observations and modelling of snow management in ski resorts
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$^{-2}$)

---

Spandre et al. (2016), “Integration of snow management [...]” in Cold Regions Science and Technology
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
Dedicated field campaign
Differences in water volumes (2015 - 2016)

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

Overall 40% (±10%) differences

---

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

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*
Professional approaches
Professional snow management operations in French ski resorts

**Technical means**

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

---

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

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

- 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\textsuperscript{28}

- Grooming every day

\textsuperscript{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

Step 1
Defining resorts villages

Step 2
Select Lifts and Slopes

Step 3
Adjust to target

Sept Laux ski resort, Belledonne, France

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

- **Natural Snow**
- **Groomed Snow**
- **Groomed + MM Snow**

| 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

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

---

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

---

Spandre et al. (In Prep), “Investigations on socio economic indicators of French Alps [...]” in *Journal of the Total environment*
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!**
Conclusion
Interactions between snow conditions and ski resorts activity

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 regarding natural snow conditions

[Map image]

35 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 thanks to snow management

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
Outlooks
Interactions between snow conditions and ski resorts activity

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)
Outlooks
Interactions between snow conditions and ski resorts activity

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!!