University of Wollongong
Research Online

SMART Infrastructure Facility - Papers

Faculty of Engineering and Information Sciences

2010

A spatial agent-based model to explore scenarios of adaptation to climate change in an alpine tourism destination

Stefano Balbi

Pascal Perez
University of Wollongong, pascal@uow.edu.au

Carlo Giupponi

Publication Details

Balbi, S., Perez, P. & Giupponi, C. (2010). A spatial agent-based model to explore scenarios of adaptation to climate change in an alpine tourism destination. In A. Ernst & S. Kuhn (Eds.), 3rd World Congress on Social Simulation

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

A spatial agent-based model to explore scenarios of adaptation to climate change in an alpine tourism destination

Abstract
A vast body of literature suggests that the European Alpine region may be one of the most sensitive to climate change impacts. Adaptation to climate change of Alpine socioecosystems is increasingly becoming an issue of interest for the scientific community while the people of the Alps are often unaware of or simply ignore the problem. ClimAlpTour is a European research project of the Alpine Space Programme, bringing together institutions and scholars from all countries of the Alpine arch, in view of dealing with the expected decrease in snow and ice cover, which may lead to a rethinking of tourism development beyond the traditional vision of winter sports. The research reported herein analyses the municipality of Auronzo di Cadore (22,000 ha) in the Dolomites under the famous peaks of the "Tre Cime di Lavaredo". The local economy depends on tourism which is currently focused on the summer season, while the winter season is weak. Since recently the Community Council is considering options on how to stimulate a further development of the winter tourism. This paper refers to a prototype agent-based model, called AuronzoWinSim, for the assessment of alternative scenarios of future local development strategies, taking into account complex spatial and social dynamics and interactions. Different typologies of winter tourists compose the set of human agents. Climate change scenarios are used to produce temperature and snow cover projections. The model is mainly informed by secondary sources, including demographic and economic time series, and biophysical data which feed-in its spatial dimension. Primary data from field surveys are used to calibrate the main parameters. AuronzoWinSim is planned for use in a participatory context with groups of local stakeholders.

Keywords
agent, scenarios, spatial, adaptation, explore, model, destination, tourism, alpine, change, climate

Disciplines
Engineering | Physical Sciences and Mathematics

Publication Details
Balbi, S., Perez, P. & Giupponi, C. (2010). A spatial agent-based model to explore scenarios of adaptation to climate change in an alpine tourism destination. In A. Ernst & S. Kuhn (Eds.), 3rd World Congress on Social Simulation

This conference paper is available at Research Online: http://ro.uow.edu.au/smartpapers/9

A Spatial Agent-Based Model to Explore Scenarios of Adaptation to Climate Change in an Alpine Tourism Destination

Stefano Balbi [a], **Pascal Perez** [b d], **Carlo Giupponi** [a c]
[a] *CEEM, Department of Economics, Ca' Foscari University of Venice (stefano.balbi@unive.it)*
[b] *RMAP, Australian National University, Canberra (pascal.perez@anu.edu.au)*
[c] *Foundation Eni Enrico Mattei (carlo.giupponi@feem.it)*
[d] *CSIRO*

Abstract: A vast body of literature suggests that the European Alpine region may be one of the most sensitive to climate change impacts. Adaptation to climate change of Alpine socio-ecosystems is increasingly becoming an issue of interest for the scientific community while the people of the Alps are often unaware of or simply ignore the problem. ClimAlpTour is a European research project of the Alpine Space Programme, bringing together institutions and scholars from all countries of the Alpine arch, in view of dealing with the expected decrease in snow and ice cover, which may lead to a rethinking of tourism development beyond the traditional vision of winter sports. The research reported herein analyses the municipality of Auronzo di Cadore (22,000 ha) in the Dolomites under the famous peaks of the "Tre Cime di Lavaredo". The local economy depends on tourism which is currently focused on the summer season, while the winter season is weak. Since recently the Community Council is considering options on how to stimulate a further development of the winter tourism. This paper refers to a prototype agent-based model, called AuronzoWinSim, for the assessment of alternative scenarios of future local development strategies, taking into account complex spatial and social dynamics and interactions. Different typologies of winter tourists compose the set of human agents. Climate change scenarios are used to produce temperature and snow cover projections. The model is mainly informed by secondary sources, including demographic and economic time series, and biophysical data which feed-in its spatial dimension. Primary data from field surveys are used to calibrate the main parameters. AuronzoWinSim is planned for use in a participatory context with groups of local stakeholders.

Keywords: alpine winter tourism; spatial agent-based model; climate change adaptation

1. INTRODUCTION

The Alpine region in Europe is among the areas that are most rapidly affected by climate change. In general, the mean temperature of this region has increased up to +2°C for some high altitude sites over the 1900-1990 period against +0.78°C in the last 100 years at a global level [IPCC, 2007; ESFR ClimChAlp, 2008]. With a certain degree of local variability, glaciers have lost 50% of their volume since 1850 and snow cover is decreasing especially at the lowest altitudes and in fall and spring. A clear signal of climate change about precipitations is not detectable yet, but increasing risks of extreme events have been projected including floods, debris flows, avalanches, glacial hazards, and mountain mass movements [Castellari, 2008]. The main expected impacts on the Alps concern the hydrological conditions and water management, forests and biodiversity, agriculture, energy management, and eventually tourism, which is the focus of this paper. While summer tourism is most probably going to be favored by climate change [Bourdeau, 2009], the World Tourism Organization started warning about the possible negative implications for winter tourism and sports in 2003 [UNWTO, 2003]. Nowadays already 57 of the main 666 ski resorts of the European Alps are considered to not be

snow-reliable[1] [OECD, 2007]. However, climate change is also an opportunity for those resorts that are snow-reliable, as they will face less competition in the future [Simpson et al., 2008].
The Alpine people are often unaware of or simply ignore the problem, which is a common problem of climate change adaptation. Perhaps, at a very local level, climate patterns are not evident enough to question the development model based on the "white dream" which has prevailed since the seventies. Indeed, a model of development based on snow, no matter if natural or artificial, is still somehow surviving notwithstanding the maturity of the traditional ski product and the stagnation of the market demand [Macchiavelli, 2009]. At this point very careful assessments should be carried on before any further snow-based development plan [WWF, 2007].
ClimAlpTour is a European project of the Alpine Space Programme, bringing together institutions and scholars from all countries of the Alpine arch, in view of dealing with the expected decrease in snow and ice cover[2]. The research reported herein analyses the municipality of Auronzo di Cadore located in the province of Belluno, in the Veneto region, in the north-east of Italy. It covers a vast area (22.000 ha) which includes Misurina (1754m above sea level) with its lake and the most famous mountain of the Dolomites, namely the "Tre Cime di Lavaredo", part of the UNESCO world heritage since 2009. The village of Auronzo (866m above sea level) hosts almost the entire population of the municipality of approximately 3,600 inhabitants. The local economy depends on tourism which is currently focused on the summer season, while the winter season is weak, with only 25% of arrivals [Regione Veneto, 2009]. The main problem at stake is how to develop winter tourism in the next 40 years, in a context of climate change and market demand that is not favorable. In particular, the spatial heterogeneity given by the bipolarity of the case study, suggested the elaboration of a spatially explicit agent-based model (ABM).
This paper explores the conceptualization phase of an ABM capable of gathering the available heterogeneous information and assessing different scenarios of future local development, and eventually tourist supply, taking into account complex spatial and social dynamics and interactions. We drew inspiration from previous ABM applications that have already proven to be successful in the field of natural resource management [i.e. Werner and McNamara, 2007; Sax et al, 2007; Barthel, 2008; Perez et al., 2009]. To our knowledge, this is one of the first attempts to explore the interactions between climate change and winter mountain tourism by means of an agent-oriented approach. Our work is still in progress and is meant to complement a decision support system (DSS) [see Giupponi and Sgobbi, 2008], which will be implemented during a series of participatory workshops.

2. MODEL DEVELOPMENT

The development of a conceptual model has been carried out to support the design of the ABM by integrating three methods gravitating around different research groups of the heterogeneous agent-based modelling scientific community. The ARDI (Actor, Resources, Dynamics, and Interactions) method belongs to the companion modeling tradition, mainly applied to natural research management. It can be extremely efficient for jumpstarting the process of visual formalization of the domain model [Etienne, 2006]. The ODD (Overview, Design concepts, Details) protocol belongs to the individual-based modeling branch of ecology, but is gaining further diffusion in social science. Differently from the other methods, it consists of a narrative description of the various elements of an ABM, contributing to a more rigorous formulation phase [Grimm et al., 2006]. Finally, the UML (Unified Modeling Language) belongs to the computer science tradition and is probably the most effective method, preceding the coding phase, which can guarantee the full replicability of the model [Boch et al., 1999].

---

[1] In general, a ski resort is considered to be snow-reliable if, in 7 out of 10 winters, a sufficient snow covering of at least 30 to 50 cm is available for ski sport on at least 100 days between December 1 and April 15 [Burki at al., 2007].
[2] The project website is www.climalptour.eu

These methods have been firstly applied in the order in which are presented, subsequently leading to a more iterative approach. By means of ARDI we identified the tourist facilities as the main resources of the system, the winter tourists as the acting agents and the meta-economic agents as the economic units in charge of accounting the economic flows for each tourism sub-sector. The application of ODD led to the definition of the tourists' heterogenic behavior and of the future scenarios. Finally, through UML, we were able to formalize in diagrams all the details. The clear advantage is that the modeler is endowed with a set of tools mutually checking the model internal consistency with regards to both its static and the dynamic aspects.

2.1 Representing Heterogeneous Market Behavior

Even though winter sports, and especially downhill skiing, are still the essence of winter mountain tourism the market has reached its maturity and is challenged by (a) loss of shares in the tourist market in the Alpine countries throughout Europe, (b) competition from other tourist destinations, (c) the growing economic and territorial divide between large and small resorts, (d) the need for huge new investments against the background of a reduction of public funding, (e) new recreational practices (freestyle and freeride), (f) the ageing of the tourist population, (g) demand for environmental quality, (h) the changed notion of resort, (i) the inclination toward shortened and repeated holidays, (j) behavioral unpredictability, due to weather forecasts, and finally (k) the search for new markets [Minghetti, 2002; Daidola, 2006; Bourdeau 2009; Macchiavelli 2009]. However, according to Camanni [2002] and Daidola [2007], a new light ski industry, with less investments and more flexibility with regard to climate conditions, is possible and the small resorts may thus be advantaged.
ABMs can be of great value in dealing with such dynamics because they are particularly well suited to incorporate heterogeneity of behavior. Drawing on the above cited literature and especially on secondary data from marketing surveys of the tourism statistical observatories of Trentino and Alto Adige[3] [Provincia Autonoma di Trento, 2007; Provincia Autonoma di Bolzano, 2009], we created a set of eight tourist profiles which is rich enough to take into account (1) the actual winter tourists of Auronzo, (2) the actual winter tourist visiting Auronzo's main competitors, and (3) the potential winter tourist of tomorrow.
In this first release we focus on the simulation of tourists' response (demand-side) to alternative and exogenously modelled strategies of development of tourism facilities of the destination (supply-side) in order to provide the local stakeholders (residents, entrepreneurs, local tourism organizations, community council), with quantitative indicators of possible futures which depend on their collective decisions. These strategies are infrastructure oriented and consider snow and non snow related facilities.

2.2 Representing Alternative Futures

Every simulation run requires the users to make three choices: (1) the development strategy to be tested; (2) the societal scenario that sets the conditional context in terms of number of tourists that could be available to choose the destination; and (3) the climate projection, in terms of snow cover and temperature. The combination of these choices defines the future conditions, from 2011 to 2050, under which the tourists' response is simulated. The underlying idea that has inspired the model is to identify the most robust development strategy. In this regard, we have defined four spatially explicit alternative strategies which are able to take into account various orientation towards tourism and the perception of climate change from the local stakeholders' point of view. The first strategy is the pursue of the traditional ski intensive paradigm. Indeed, one of the most familiar measures in the struggle against snow-deficient winters is the construction of high cost artificial snowmaking facilities [Burki et al., 2007]. However, in this strategy Auronzo not only maintains its original ski areas, but also develops two new ski areas with snowpark, which have different spatial conditions. The overall hosting capacity remains untouched while a minor increase concerning restaurants and retailers supply

[3] These are the two most important winter tourism regions of the Italian Alps.

is included. The second strategy embraces the vision of Daidola [2006] and Burdeau [2009] of an alternative light ski oriented and post-modern development. It integrates the wilderness and the playground concepts increasing the supply of controlled off-piste tracks, cross-country itineraries and snow parks. These are assisted by a very limited development of the existing ski lifts and a more sober artificial snowmaking behavior. The third is the non-snow strategy that is the well established, but often not self-sustaining, process of diversification and enlargement of tourist offer by means of higher quality hotels, shopping, gastronomy, pubs and bars, and, most of all, wellness and spa centers. The ski areas remain in function without the support of artificial snow. Finally the fatalistic strategy consists of no changes in the supply behavior, which could also be described as "business as usual".

The societal scenarios serve the purpose of both considering the overall alpine winter tourism trend and the level of competition with other neighboring winter destinations. We include scenarios that allow us to take into account two situations, where market demand is decreasing and competition high (conservative) and where the demand for alpine winter tourism is stable and competition less decisive (optimistic). Given the extremely low number of winter tourists in Auronzo, compared to the number of winter tourists in other destinations of the Dolomites, the number of tourist agents is calibrated on neighboring destinations with similar hosting capacity.

The climate projections (temperature, precipitation and snow cover) are based on the SkiSim model [Steiger, 20009] and represent four scenarios based on three regional climate models, REMO UBA A1B and B1, from the Max Planck Institute of Hamburg, and Ensembles CLM A1B and Aladin A1B, from the Ensembles European project[4]).

Table 1. Narratives describing the tourist profiles

Traditional Ski Intensive (TSI). Mainly motivated by the practice of downhill skiing (3/4) and snowboarding (1/4). Primarily interested about the ski-lifts and trails. Appreciates gastronomy. Not satisfied by the scarce presence of bars and pubs. Has a middle-low profile of expense (110 Euros/day). Has one or more winter holidays every year, often in the same destination. The booking process is often intermediated and the time unit of reference is 7 days. Books his holidays in February and March. Travels in company with one or more friends or with the family.

Ski Part-Time (SPT). Mainly motivated by the natural environment and by the practice of downhill skiing (2/3) and snowboarding (1/3), with a softer approach. The trend towards snowboard is more evident. Interested about ski-lifts and trails, but also about other winter sports. Dedicates to traditional ski activities not more than half of the day. Often novices, mainly with family. Not interested in gastronomy. Not satisfied by the scarce presence of children facilities. Has a low profile of expense (100 Euros/day). Visits the same destination, often for the Christmas holidays. The time unit of reference is 7 days. Tend to book directly to the hospitality structure. Booking is less predictable and more subjected to weather conditions and forecasts.

Sporty Alternative. Mainly motivated by the natural environment and the practice of alternative winter sports. Often in group and on a day trip. Often adult or elder. Highly dependent on weather conditions and forecasts. Has the lower profile of expense (under 100 Euros/day). This typology is composed of two profiles: the practitioners of cross-country skiing **(SAX)** and the practitioners of backcountry skiing and ski touring **(SAW)**.

Idle (ID). Mainly motivated by the natural environment. Scarcely interested by any intensive sport activities. Appreciates easy trekking in the snow, children facilities and wellness and spa services. Not satisfied by the scarce presence bars and pubs and other sport facilities. Often females, accompanying skiers. Often with family. Tends to book for the Christmas holidays. Has a middle-high profile of expense (130 Euros/day).

Eclectic (EC). Mainly motivated by the idea of having fun by means of a set diversified activities not related to traditional skiing. Interested in gastronomy, wellness and spa and shopping. Appreciates minor winter activities (i.e. ice skating, hockey, sled-dog…). The natural environment remains important. Has the highest profile of expense (over 150 Euros/day) but the shorter average stay. Not satisfied by the scarce presence of bars and pubs and other sports facilities.

Counter culture. Mainly motivated by the desire of having deep and authentic experiences, merging wilderness and playground, nature and adrenaline. Mainly sporty and expert in their discipline. Composed of two profiles: practitioners of freestyle **(CCP)** and of freeride **(CCW)**. Often travelling with friends practicing the same activity. Interested in natural snow, very dependent on wheater conditions and forecasts. CCP is interested in dedicated facilities as snowparks. CCW appreciates the organization of the natural environment into off-piste trails and the presence of small ski-lifts and security services. Both are sensitive to environmental issues. Have a medium-high profile of expense according to the services that are offered.

3. MODEL DESCRIPTION

This concise model description loosely follows the ODD protocol [Grimm et al., 2006]. While a simplified class diagram is proposed in Figure 1, we also provide the complete UML class, sequence and activities diagrams in the project's website http://www.dse.unive.it/clim/climalptour.htm.

[4] See the Ensembles project's website: http://ensembles-eu.metoffice.com/

The model *purpose* is to analyze alternative winter development strategies for the case study simulating the tourists' response under different climate scenarios.
Entities and *state variables* are visually presented in the UML class diagram. The main entities are the tourists, the tourism facilities and the meta-economic agents. According to the profile they belong to (variable "type"), tourist agents have different preferences and behavior with regards to the tourism facilities. The tourism facilities, which in turn compose the destination supply structure, are divided in eight types: four are snow related (facilities dedicated to downhill skiing, snowparks, cross-country skiing and off-piste skiing) and four are non-snow related (accommodations, restaurants, retailers, and other facilities including those for kids, wellness and spa, and other sports). The meta-economic agents are the accountants of the tourism facilities. One meta-economic agent is in charge of managing one type of tourism facility. They keep track of the investment required to put in place their facilities, defined by the development strategy to be analyzed, and of their money flow. The development strategies are set exogenously by the model.
Concerning the *scales,* both the snow and the non-snow related facilities are located in a spatial grid of approximately 10.000 cells which represent the destination. Each cell represents a 150 x 150 meters square and contains the actual geographical information of the area. Nine weather stations, named reference points, have been identified in order to represent the different snow conditions under alternative climate scenarios. A simulation is composed of 40 cycles, which are the winter seasons from 2011 to 2050. Each cycle consists of 126 days (time steps) that represent the 18 weeks from the 1st of December to the 6th of April. Summing up, every simulation takes into account 720 weeks and 5040 time steps.
Process overview and scheduling are captured in the UML sequence diagram, which shows the sequence of operations performed by each class. Every operation is then further described as activity diagram. Initially, the spatial units (patches) update their attributes and configure the tourism facilities presence as per selected development strategy. Each of the meta-economic agent is assigned with the investment needed to meet that configuration. The reference points read snow cover and temperature from the climate data which describe the selected climate projection. They also perform three kinds of forecasts concerning snow cover, at short and medium term, and snow security, at short term. Then, the snow facilities check those forecasts and store the information that they will subsequently pass to the tourists. Downhill and snowparks can decide to produce artificial snow. After that, the tourists, whose total amount is taken by the societal scenario, can check the destination in order to become visitors, if their requirements are met. According to their behavior, they can check the forecasts and go to the planning phase, in which they decide their day of arrival. If they are in the destination they enter into a loop of operations which describe the use of the tourism facilities. Then, every facility can check its own users and passes the information to the patches that can visually describe the tourists density on the grid. The meta-economic agents calculate the return associated to the facilities use and update their balance sheet. Finally, the tourists in their last day of vacation calculate their overall satisfaction. If this is negative they exit from the simulation, if it is positive they remain among the potential visitors and can plan a further vacation.
Input data is provided in various forms. The spatial units are georeferenced, based on GIS (geographical information system) layers concerning elevation, slope, aspect, land use and a thematic differentiation in areas of the destination. The reference points are provided with climate data in form of time series of snow cover and temperature, according to the selected climate projection. Finally, the demographic data provides the total number of tourist agents available for each of the 40 cycles during every simulation.
Most of the operations make use of *submodels* in form of simple algorithms and logical tests which are presented in detail in the activity diagrams. For instance, the calculation of return performed by the meta-economic agents is based on several parameters referred to the facility they are in charge of, including a tag price, the cost of labor and the cost of energy associated to the use by one tourist, and the seasonal investments requested by the development strategy. Most of the parameters used in the activity diagrams are calibrated on the case study, by means of field surveys. The rest are retrieved from the literature. The model *initialization* represents

the destination winter tourism conditions in 2011 concerning the actual amount, type and spatial configuration of the tourism facilities.

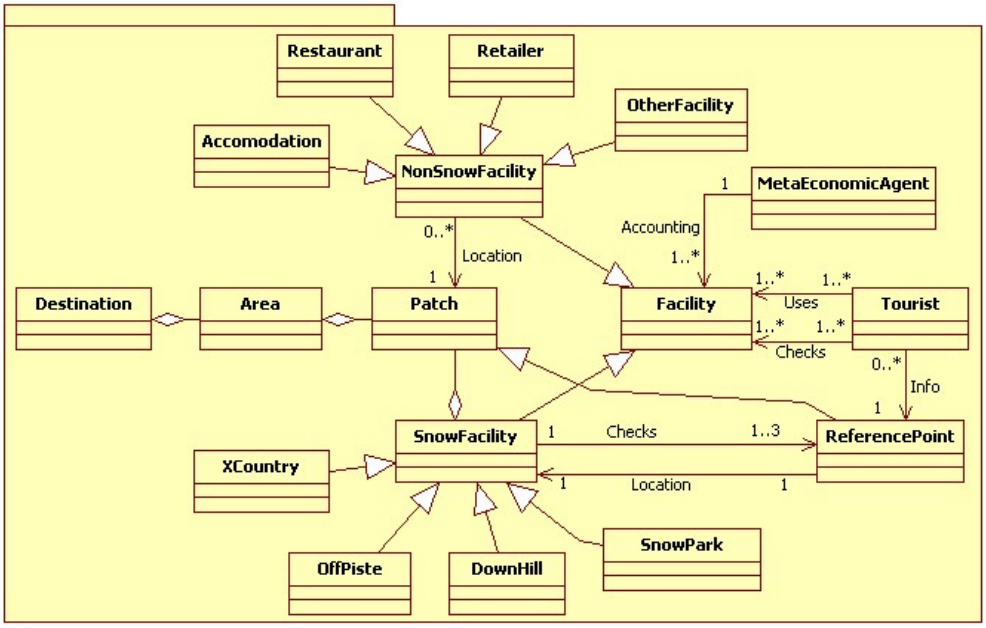

Figure 1. AuronzoWinSim Simplified UML Class Diagram

3.1 ABM Design Concepts

Emergence. Once the boundary conditions of possible futures are set by the 3 choices on the scenarios for any model run, then the performance of the destination is a phenomenon that emerges from the tourists' behavior. This is numerically expressed in terms of tourist attracted and money flow produced by each facility type (see updateUsers and updateBalance activity diagrams) and visualized on the spatial grid at each time step in terms of tourists' density (see checkOccupation activity diagram).
Objectives. The tourists can choose whether to go or not to the destination, according to their preferences about the destination supply and to the weather forecasts. The objective function is expressed in form of sequential tests on certain conditions. During the operation named checkDestination every type of tourist compare the destination's dotation with their own desires. For instance a traditional ski intensive tourist is looking for a minimum amount of groomed slopes. If the condition is satisfied the agent becomes a potential tourist (see checkDestination activity diagram). In order to effectively book the vacation every agent have to consider the climatic forecasts, according to the agent's behavior (see initPlanning, checkForecast, and doPlanning activity diagrams).
Prediction. Tourists' expectations are based on the facilities available and their spatial configuration in the destination and on the snow cover and security forecasts. For long-term planners snow cover conditions are guessed on the basis of historic data (see doMidTermForecast activity diagram), while short-term planners are endowed with knowledge about next day projections with a certain error (see doShortTermForecast activity diagram).
Sensing. The tourists are fully aware of the destination's facilities and spatial attributes before the vacation, but they perceive the environmental conditions of the facilities they use only *in loco*.
Learning. Each day of their vacation the tourists calculate their satisfaction which depends on the effective environmental conditions encountered in terms of snow cover and tourists' density, so that their availability to a subsequent vacation depends on the memories of the previous one (see calcSatisfaction activity diagram).

Adaptation. The tourists adapt by not visiting Auronzo again once their satisfaction goes negative, in favor of other competing destinations (see updateSatisfaction activity diagram).
Interaction. The tourists directly receive stimuli, through sensing, from the destination's facilities and spatial attributes, which affect their eligibility to book their vacation. They also indirectly interact among each other with negative effects on their respective satisfaction, over certain density thresholds.
Stocasticity is used to reproduce variability in the various agents' decision processes, primarily by means of normal distributions, as showed in the activity diagrams.
Observation. The model collects data on the economic performance of the eight types of facilities and on the spatially distributed tourist fruition of the destination.

4. DISCUSSION AND CONCLUSION

Our work is still in progress but it can already provide some interesting insights on the modeling of climate change and tourism. First of all, the scale of analysis and the level of detail represent a significant improvement in the climate change research, which is normally performed at a much higher level of spatial and temporal aggregation. This scale perfectly fits the crucial socioeconomic dynamics of local adaptation that have to be investigated. Second, to our knowledge this is one of the first attempts to formalize the supply structure of a winter tourism destination in classes by means of UML. The result is simple and clear but is able to represent complex interactions, for alternative development strategies, in a spatially explicit way. This conceptualization can eventually become a generic ontology, if it will be proved to fit the application to other case studies. Third, the simulation focuses on the feed-backs of the demand side of tourism, which is often missing in the existing tourism models. However, the tourists are the ultimate judges of a destination adaptation strategy, because they will decide the winners and losers of the future. This is why we regarded as fundamental to focus on their agency in an heterogeneous way, drawing from disciplines such as customer behavior, which could only be done by means of an the agent-based approach. Fourth, the model development itself is a novelty because we integrated some of the main practices of the ABM community which are never found together but can mutually benefit each other.
One main existing limitation of our approach is that it has proven to be quite demanding in terms of field work needed to retrieve some calibrated parameters. The next steps of our work include the implementation of the UML model into software for computer simulation. We are also planning to test the model on historic data, and eventually explore the relationship between the climatic conditions and the economic performances of the system. AuronzoWinSim will then be used in a participatory context with groups of local stakeholders, in two ways. Initially, it will support the collective discussion on possible adaptation and development strategies, and the criteria to assess their robustness. Secondly, it will incorporate the strategic adjustments proposed by the stakeholders.

REFERENCES

AuronzoWinSim Model Website, http://www.dse.unive.it/clim/climalptour.htm.

Barthel, R., S. Janisch, N. Schwarz, A. Trifkovic, D. Nickel, C. Schulz, and W. Mauser, An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain, *Environmental Modelling and Software 23*: 1095-1121, 2008.

Boch, G., J. Rumbaugh and I. Jacobson, The unified modeling language user guide, Addison-Wesley, 1999.

Bourdeau, P., Mountain tourism in a climate of change. In Alpine space - man & environment, vol. 7: Global Change and Sustainable Development in Mountain Regions, Innsbruck University Press, Innsbruck, Austria, 2009.

Burki, R., B. Abegg, and H. Elsasser, Climate change and tourism in the alpine region of Switzerland. In B. Amelung et al., Climate change and tourism: assessment and coping strategies, 165-172, Maastricht, 2007.

Camanni, E., La nuova vita delle Alpi, Bollati Boringhieri, Torino, Italia, 2002.

Castellari, S., Climate change, impacts and adaptation strategies in the Alpine Space: some results from the INTERREG III B project ClimChAlp, Proceedings of the conference on Mountains as Early Indicators of Climate Change, Padova, Italy, 17-18 April 2008.

Daidola G., Il corto circuito dello sci di massa. In WWF, Alpi e turismo: trovare il punto di equilibrio, WWF Italia, February, 2006.

ESFR ClimChAlp, Extended Scientific Final Report of the ClimChAlp project, 2008, The Climate Change Assessment Report. Available at http://www.climchalp.org/ .

Etienne, M., Companion modelling: a tool for dialogue and concertation in Biosphere Reserves. UNESCO-MAB, Technical Notes 1 :44-52, Paris, France, 2006.

Giupponi, C. and A. Sgobbi, Models and decisions support systems for participatory decision making in integrated water resource management. In P. Koundouri, Coping with Water Deficiency, 165-186, Springer, 2008.

Grimm, V., U. Berger, F. Bastiansen, S. Eliassen, V. Ginot, J. Giske, J. Goss-Custard, T. Grand, S. K. Heinz, and G. Huse, A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, *198*(1-2): 115–126, 2006.

IPCC, Contribution of Working Group I to the Fourth Assessment Report of the IPCC: The Physical Science Basis, Cambridge University Press, United Kingdom, 996 pp, 2007.

Macchiavelli, A., Alpine tourism: development contradictions and conditions for innovation, *Journal of Alpine Research*, 97-1, 2009. Available at http://rga.revues.org/index843.html.

Minghetti, V., Il turista della neve in Italia: profilo, esigenze, nuovi modelli di consumo, Touring Club Italiano, Milano, Italia, 2002.

OECD, Climate change and the European Alps: adapting winter tourism and natural hazard management, January, 2007.

Perez, P., A. Dray, D. Cheland, and J.E. Ariaz-Gonzalez**,** An agent-based model to address coastal management issues in the Yucatan Peninsula, Mexico. In 18th World IMACS and MODSIM09 Congress on Modelling and Simulation, Cairns, Australia, 13-17 July, 2009.

Provincia Autonoma di Bolzano, ASTAT, Profilo dei turisti in Alto Adige: anno turistico 2007/08, May, 2009. Available at http://www.provinz.bz.it/astat/it/mobilita-turismo/474.asp

Provincia Autonoma di Trento, Osservatorio Provinciale per il Turismo, La stagione turistica invernale 2006/07 in Trentino, December, 2007. Available at http://www.turismo.provincia.tn.it/osservatorio/pubblicazioni/pubblicazioni_report/report_andamenti_stagionali/

Regione Veneto, online database of the department of statistics, last access January, 2010. Available at http://statistica.regione.veneto.it/dati_settoriali_turismo.jsp

Sax, M., J. Schmude, and A. Dingeldey, Water and tourism – simulating the tourist water use in the Upper Danube catchment area. In Reducing the vulnerabilities of societies to water related risks at the basin scale, IAHS Publ. 317, 2007.

Simpson, M.C., S. Gössling, D. Scott, C.M. Hall, and E. Gladin, Climate change adaptation and mitigation in the tourism sector: frameworks, tools and practices, UNEP, University of Oxford, UNWTO, WMO, Paris, France, 2008.

Steiger, R., SkiSim - A tool to assess the impact of climate change on ski season length and snowmaking, International Snow Science Workshop, Davos, Switzerland, 27 September - 2 October, 2008.

UNWTO, Climate change and tourism, Proceedings of the 1st International Conference on Climate Change and Tourism, Djerba, Tunisia, 9-11 April, 2003.

Werner, B. T., and D. E. McNamara, Dynamics of coupled human-landscape systems, *Geomorphology 91*(3-4): 393-407, 2007.

WWF, Alpi e turismo: trovare il punto di equilibrio, WWF Italia, February, 2006.