

THE IMPACTS OF CLIMATE CHANGE ON SKI RESORTS AND TOURIST TRAFFIC

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ABSTRACT We analyze possible impacts of climate change on the traffic dynamics on access roads to ski resorts. We applied a discrete choice model for day tourism (1) to the hydrological catchment of the Upper Danube, covering parts of southern Germany, Austria and Switzerland. As a consequence of the spatial concentration of ski resorts, the current infrastructure is prone to traffic jams. We apply a macroscopic traffic model (2) in order to simulate the traffic dynamics on the road network. In different scenarios we systematically study the traffic dynamics on the access roads to the ski areas, varying the shift of the lower limit of snow-reliability (3) and hence the concentration of ski resorts. We analyze the total length of the resulting traffic jams. The results show that with increasing lower limit of snow-reliability traffic jams will become significantly more frequent on the access roads to the ski resorts.

KEYWORDS: *Climate change, traffic dynamics, traffic jam, ski tourists, discrete choice model*

INTRODUCTION

Little is known about the potential impacts of climate change on the traffic dynamics. The decreased risk of traffic-restricting factors in winter, such as frost and snow, road and rail traffic is expected to have a slightly positive impact on the transportation sector. It is further expected, that streams of traffic will relocate due to changes in recreational and holiday behavior (Zebisch et al., 2005).

The impact of climate change on winter tourism has been examined in several studies (Elsasser and Bürki, 2002). It is expected that the percentage of snow-reliable ski resorts in Switzerland will drop from 85 % to 44 % if the elevation above which the snow cover is reliable increases from 1200 m a.s.l. to 1800 m a.s.l. (Elsasser and Bürki, 2002). In this paper we will call the elevation above which the snow cover is reliable “lower limit of snow-

reliability“. Given the possibility of artificial snow production the situation is less dramatic. This was shown for the skiing industry in Southern Ontario (Canada) (Scott et al., 2003).

As a consequence of the spatial clustering of ski resorts at the higher elevations, the current traffic infrastructure is prone to traffic jams. We study the traffic dynamics on the access roads to the ski areas in different scenarios, varying the shift of the lower limit of snow-reliability and hence the concentration of ski resorts. We analyze the total length of the resulting traffic jams.

SKI RESORTS AND TRAFFIC DYNAMICS

We use a discrete choice model for day tourism to ski resorts in order to calculate the number of sold tickets for each ski area (Tepfenhart et al., 2006). The model takes into account the displacement of the lower limit of snow-reliability, the attractiveness due to existing infrastructure and the travel times between the places of residence of day tourists and the ski areas.

We apply DaTraM (Siebel and Mauser, 2007) in order to simulate the traffic dynamics on the road network. DaTraM is a macroscopic model for vehicular traffic flow in a network with multi – destinations and is based on the classic Lighthill-Whitham model.

The OriDestination - flows (OD – flows) determined by the model for day tourism serve as input data for DaTraM. We assume that the traffic dynamics in the network are caused solely by day tourism to ski resorts. We further assume that tourists leave their home between 07:00 and 11:00 am, the corresponding OD-flows are equally distributed over the considered period of time. For performance reasons, we only used major street types for the simulations.

We work on a grid with the dimensions 425 km × 430 km. Our area under investigation, which is shown in Fig. 1, corresponds the hydrological catchment of the Upper Danube (~75000 km²) Catchment (Zebisch et al., 2005) and contains 237 ski resorts with maximum altitudes between 557 m a.s.l. and 3440 m a.s.l. and lift capacities between 500 persons/h and 77500 persons/h. The ski resorts are numbered in ascending order according to their maximal height. The travel times used by the model for day tourism are calculated with DaTraM for ideal conditions, i.e. for empty roads. Fig. 2 shows the network - the width represents the street type and the color the corresponding degree of utilization. The figure corresponds to the traffic situation after two hours simulation time.

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The rise of the lower limit of snow-reliability leads to the closure of ski resorts at lower altitudes. While the lower limit of snow-reliability shifts up from 555 m a.s.l. to 1200, 1500, 1800 and 2100 m a.s.l. the number (percentage) of closed ski areas increases from 0 to 45 (19 %), 76 (32 %), 129 (54.4 %) and 172 (71.7 %). At first the ski resorts in the Bavarian Forreest will close, then those of the Bavarian Prealps. Finally only ski resorts in the Alps will have a sufficient snow cover.

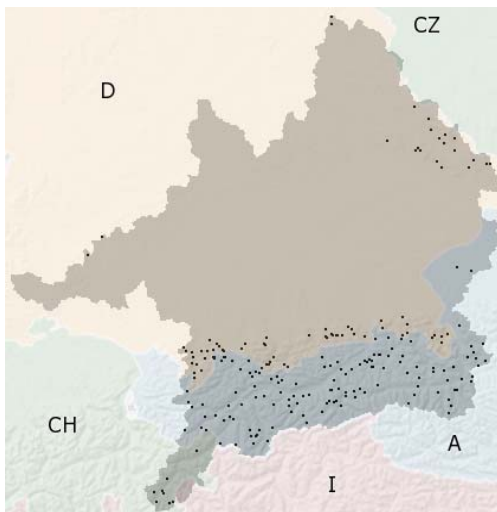


Figure 1: Distribution of the 237 ski resorts (black dots) in the Upper Danube catchment (gray area)

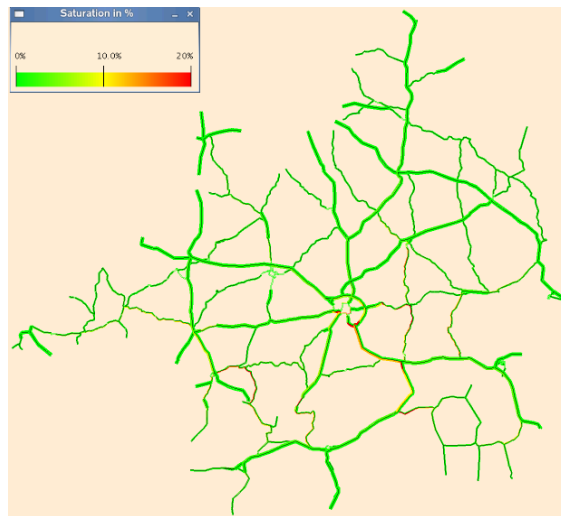


Figure 2: Traffic network at 09:00 am for a lower limit of snow-reliability of 1200 m a.s.l. The color bar indicates the total saturation of roads in per cent

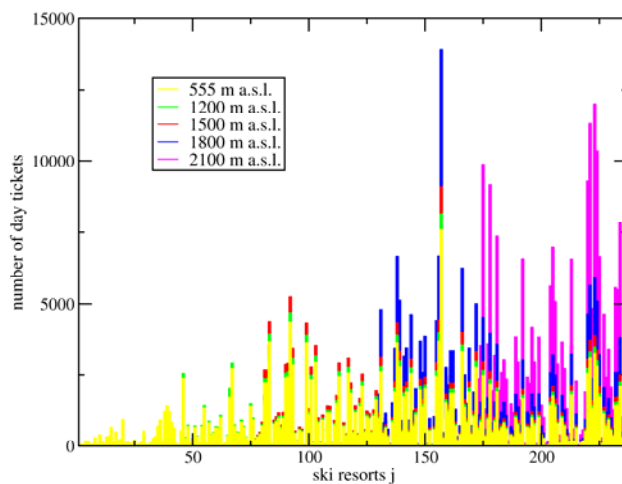


Figure 3: Number of sold tickets for each ski resort at the examined lower limits of snow-reliability 555 m a.s.l., 1200 m a.s.l., 1500 m a.s.l., 1800 m a.s.l., and 2100 m a.s.l.

We determined the number of sold tickets for five different lower limits of snow-reliability. At each shift of the lower limit of the snow-reliability towards higher altitudes the number of ski areas decreases. The number of sold tickets will increase in the remaining ski resorts for

the same number of ski tourists. Fig. 3 shows the quantitative growth in the number of sold tickets for each ski resort.

The increased number of ski tourists in the remaining ski resorts leads to changes in the OD-Flows. We simulated the traffic dynamics with DaTraM at each examined lower limit of snow-reliability with the corresponding OD-flows. Moreover we systematically analyzed the length of the resulting traffic jams on the access roads to the ski areas. According to traffic theory (Kerner, 2004) traffic flow can be subdivided into two traffic phases, *free flow* and *congestion*. The transition zone between these two phases corresponds to a traffic density of about 20-30 % of the maximum density. Hence we use a value of 20 or 30 % in the total utilization to define traffic jams. Fig. 4 and 5 shows the time evolution of the total length of traffic jams in the entire network, respectively.

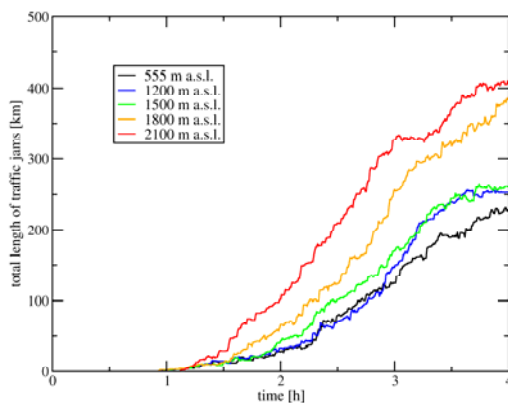


Figure 4: Total length of traffic jams vs. time for the examined lower limits of snow-reliability, under the assumption that traffic jams exist for a saturation above 20 %

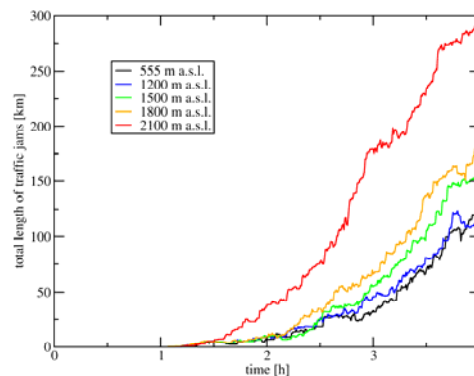


Figure 5: Total length of traffic jams vs. time for the examined lower limits of snow-reliability, under the assumption that traffic jams exist for a saturation above 30 %

The curves in the figures are to a great extent monotonously increasing. The maximum total length of traffic jams increases as the lower limit of snow-reliability rises. We examined the relative increments of the length of the traffic jams for each simulated density and for each lower limit of snow-reliability, that is we examined the ratio $L(srl)/L(555)$, where $L(srl)$ is the length of the traffic jam at the corresponding lower limit of snow-reliability srl . Obviously, its definition also depends on the definition of traffic jams. Table 2 shows the maximum total length of traffic and the mean values of the relative increments of the length of the traffic jams for the simulated lower limits of snow-reliability. The higher the relative increment of traffic jams, the lower the limit of snow-reliability.

CONCLUSIONS AND OUTLOOK

We analyzed possible impacts of climate change on the traffic dynamics on access roads to ski resorts. We used a general model for day tourism (Tepfenhart et al., 2006) to ski resorts, which calculates the number of sold tickets in each ski area. We applied the model to the Upper Danube Catchment (Ludwig et al., 2003). Currently 81 % of the ski resorts in the Upper Danube catchment can be considered as snow-reliable, if we assume that the lower limit of snow-reliability is at 1200 m a.s.l. (Tepfenhart et al., 2006). We expect that the rising lower limit of snow-reliability to 1500, 1800 and 2100 m a.s.l. will cause 32 %, 54.4 % and 71.7 % of the ski resorts to close.

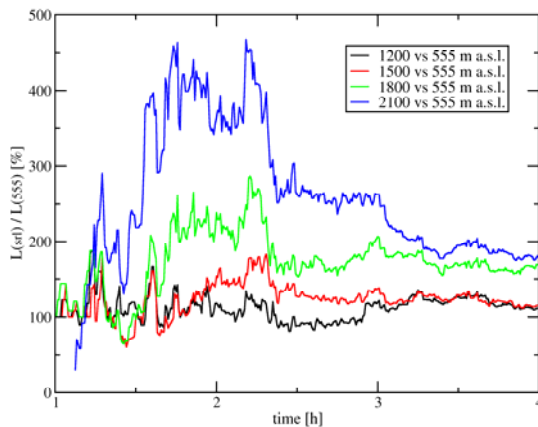


Figure 6: Relative increments of the length of the traffic jams vs. time, for a saturation above 20 %

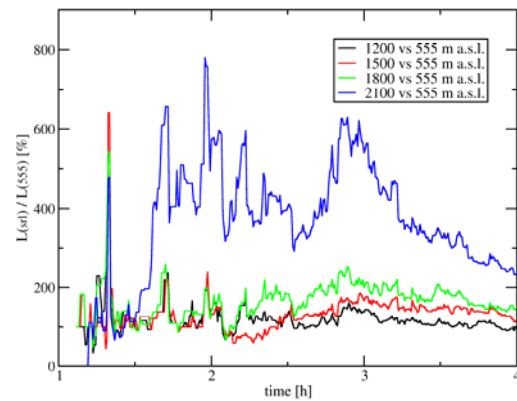


Figure 7: Relative increments of the length of the traffic jams vs. time, for a saturation above 30%

Table 2: The maximum total length of traffic jams and the corresponding mean values of the relative increments $\overline{L(sr)/L(555)}$ in per cent for a definition of jam densities of 20% and 30% and examined lower limits of snow-reliability

<i>srl</i> [m a.s.l.]	20% saturation		30% saturation	
	max. length [km]	$\overline{L(sr)/L(555)}$	max. length [km]	$\overline{L(sr)/L(555)}$
555	231.2	100	125.1	100
1200	256.3	112.2	124.4	121.3
1500	256.2	123	152.5	132.6
1800	386.8	173	182.7	166
2100	410.4	249	291.1	360.2

In order to assess the impact of climate change on the traffic dynamics on access roads to ski resorts we used the results from the model for day tourism and studied several traffic

scenarios with the macroscopic traffic model DaTraM (Siebel and Mauser, 2007). We examined the total length of the traffic jams for different definitions of traffic jams (corresponding to 20 % and 30 % saturation) and for different lower limits of snow-reliability at 555 m a.s.l., 1200 m a.s.l., 1500 m a.s.l., 1800 m a.s.l. and 2100 m a.s.l.. While the lower limit of snow-reliability shifts towards higher altitudes, the maximum total length of traffic jams is likely to increase by a factor of more than two. Moreover, for a given point in time the total length of traffic jams can increase even more severely, due to the highly nonlinear dynamics of traffic flows.

In future studies, we plan to consider feedback effects when determining the travel times of ski tourists.

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