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Snow and landscape: multi-scale and multi-disciplinary aspects of snow cover

M. Breiling[1], P. Charamza[1], D. Frolov[2], L. Holko[3], V. Golubev[2], V. Khan[4], Z. Kostka[3], M. Petrov[5], M. Petrushina[2], M. Phillips[6], V. Popova[7], K. Rubinstein[4], U. Schwarz[1], E. Semakova[5], A. Shmakin[7], S. Sokratov[3], A. Yakovlev[5], M. Zoloeva[4], et al.

[1]Technical University Vienna, E260L, Austria
[2]Faculty of Geography, Moscow State University, Russia
[3]Institute of Hydrology, Slovak Academy of Sciences, Slovakia,
[4]Hydrometeorological Center of Russia, Russia
[5]Institute of Geology and Geophysics, Uzbekistan Academy of Sciences, Uzbekistan
[6]Swiss Federal Institute for Snow and Avalanches Research, Switzerland
[7]Institute of Geography, Russian Academy of Sciences, Russia

Abstract

The project focused on multi-scale and multi-disciplinary aspects of seasonal snow cover in the landscape. The snow physics parameterization takes into account snow structure for use in the Global Circulation Models (GCM). The geographic classification of snow classes is based on snow types, snow layers and crystal types. Numerical experiments with a GCM are performed. The outputs of the large-scale models are linked to regional models and compared with measured data. The correlations between snow and hydrology are studied. The economic aspects of the snow, e.g. in tourism and transport, are analyzed. Three years of working together was not enough to answer all the questions that we originally posed. We could explore the potential of a longer lasting cooperation and, with some specific steps, contributed to the exploration of the interrelations of landscape and snow in different spatial scales. Research of this kind should continue in future.

Introduction

Figure 1: The macro scale of the project with extension of Northern Eurasia

The project region covers the entire former USSR (FSU) and participating countries outside this area: Austria, Slovakia and Switzerland. All in all, 180 administrative units (oblasts, republics, autonomous territories of the former USSR plus three countries outside the FSU) are included. The total project area extends over 25 million km². Some 40 major river basins or groups of smaller river basins are situated within the macro region. Large-scale studies within the project show how different the principal relationship between snow and the landscape can be.

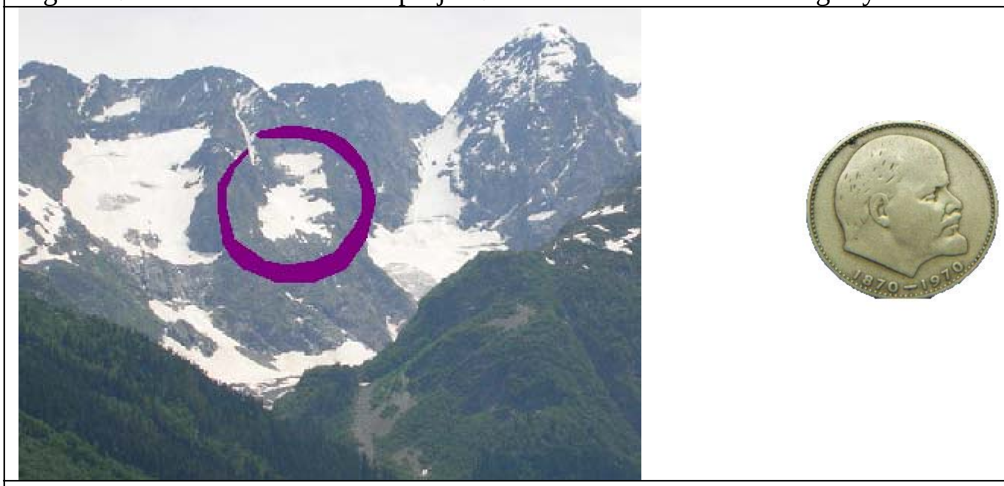
From May 2004 to April 2007, the INTAS project was undertaken by seven teams from Austria, Russia, Slovakia, Switzerland and Uzbekistan. The first results were presented with the publication of the SNOW conference proceedings in Vienna which collected a wide spectrum of disciplines related to snow on different spatial scales (Breiling and Stiles 2004). Here, the contribution provides an overview of the results of the INTAS core project which was also supported by a NATO project from April 2006 to December 2007.

Snow and the landscape are strongly related to each other. Landscapes of high mountain regions and regions in the higher latitudes are especially dependent on snow. Snow stores water and protects plants. Snow contributes to landscape identity and is an important feature of most landscape related processes. However, in an era of climate change, this pattern is likely to alter and there are many possible directions.

Seasonal snow cover is an important natural phenomenon. It substantially influences mass and energy exchanges between the surface of the earth and the atmosphere, and human life in general, in many parts of the world. The snow-related processes occur on a variety of spatial and temporal scales. For example, snow albedo and effective heat conductivity are the main snow parameters to be accounted for in the global circulation models (GCM) that are used to simulate climate on the scale of hemispheres. While the snow albedo is the characteristic of the surface (i.e. can be considered as the macro-scale characteristic), the effective heat conductivity depends on the structure of snow layers, i.e. the micro-scale. Hence, application of a GCM involves an important multi-scale aspect.

In the meso-scale landscape, snow has certain traditionally returning patterns which relate to scenery; the Japanese called it "yukigata" (snow figure, e.g. as described by Nohguchi and Izumi 2006). Snow provided "signs" in the landscape for starting certain work and activities at certain dates. Currently, such knowledge is not used, but it could be a rather cheap way of protection from certain threats related to snow. We do not know how the snow pattern is related to landscape stability, landslides, mudflows, etc. The expansion of snow redistribution, either artificial through snow making or snow removal, and the corresponding redistribution of water resources to produce the snow may change the properties of landscapes and vegetations.

Figure 2: The meso-scale of the project: the snow of a mountain range symbolized as yukigata

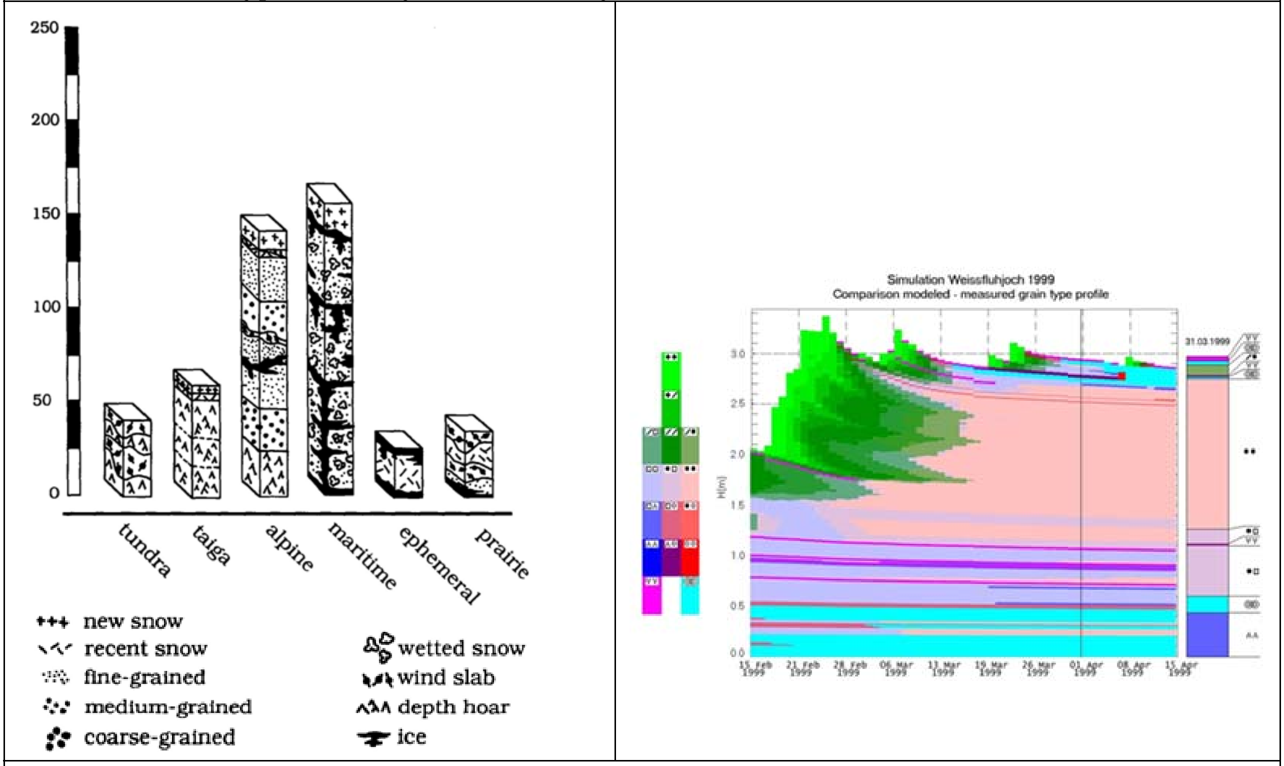


Particularly in mountain landscapes, snow is distributed unevenly. Snow can bring wealth in the form of spring melt water or death in the form of avalanches. Therefore, snow observations started many centuries ago. One of the oldest forms of snow data collection originated in Japan. Certain patterns of snow and non-snow appearing in the landscape at particular times of the year gave the signals to start certain types of work, e.g. in rice cultivation, or informed about natural hazards in the landscape. Here, a landscape in the Caucasus is depicted and the yukigata resembles Lenin before he lost his hair. Other examples of meso-scale investigations are studies of snow in urban environments. The cost of removing snow and preparing for it can be very high. Promotion of winter sports often results in transporting masses of snow to so-called winter openings at the end of autumn.

Snow is not evenly distributed locally. Many micro-climatic landscape factors including the roughness of territory, wind-exposed or wind-protected locations, sun-exposed or shadow sides of the landscape, forests or other vegetation, influence the snow cover. In general, the combination of these factors results in the local variations in snow cover.

This multi-scale aspect of seasonal snow can be supplemented by its multidisciplinary aspect. Spatial and seasonal variability of snow cover not only influences natural processes (e.g. floods, avalanches, landslides), but also human life (hazards, transport, tourism, etc.). Thus, both the snow cover evolution and its effects have a multidisciplinary character. The aim of this paper is to inform about some partial results of the effort of an international team devoted to climatic and economical aspects of snow cover in Northern Eurasia.

Figure 3: The micro-scale: vertical snow structure, expressed as snow stratigraphy, combined with snow classes with snow types, snow layers and snow crystals



Many questions related to the heat transfer and the thermal budget of earth and landscapes are related to snow cover. Snow density and the snow water equivalent (SWE) are just two relevant features for thermal processes in the vertical structure of snow. The static snow classification after Sturm (1995, left side) improved the previous snow classification after Rikhter (1954) based on classes of the former USSR. Sturm derived six snow classes from a situation typical for the end of February – usually the period of snow maximum in the northern hemisphere. Each snow pack has a particular mixture of snow types resulting from the composition of different – up to several hundred – snow layers. Snow classes and snow types are still simplifications of the real situation. Snow research developed increasingly on the smaller scale. At SLF Davos, sophisticated snow analysis goes beyond this scale (1999, right side) and uses computer tomography to get further details.

The project had the following objectives and main tasks:

1. Creation of a database of snow, snow stratigraphy and long-term meteorological time series in various regions of Northern Eurasia;
2. Development of parameterization schemes of the snow cover stratigraphy classes for climate and hydrological models and their testing against the observed data;
3. The role of snow stratigraphy on mean and extreme hydrothermal regimes in Northern Eurasia;
4. Modelling snow cover more precisely for the territory of Northern Eurasia;
5. Estimation of the economic effect of the snow cover's spatial and temporal variability in Northern Eurasia and future climate change.

In the following sections we describe the main achievements and non-achievements in the time period given.

Overview of the results

<u>1. Database</u>
The database contains meteorological, snow, hydrological and economic data from Russia, Uzbekistan, Slovakia, Austria, and Switzerland. The main meteorological data from Russia include two data series – the short term synoptic data from 222 stations for the period 1990-2000 and the long-term daily data from 223 stations. Climatic data from Slovakia include 19 stations from the period 1990-2000, one station with long-term data (1951-1998) and two stations with data from the last winters. Snow data covers arctic

stations, regular snow observations from the former Soviet Union (1881-2001; the number of stations in particular years varies between 1 and 220), snow course data with mean depth, density and water equivalent for the years 1966-2000 (545 and 1313 stations) and snow pits from Russia, Slovakia, Switzerland and Uzbekistan. Hydrological data include monthly and annual runoffs of major Russian rivers (e.g. Lena, Amur, Yenisei, Ob, Volga, Don, and Kamchatka) and one small mountain catchment in Slovakia. A basic description of a major Russian river basin was provided by Krenke and Shmakin. Based on this information, Schwarz generated 40 first order river districts of Northern Eurasia ready for GIS systems. Topographic data were downloaded from the USGS website and analyzed by Schwarz. This gave the altitude relations according to each oblast, which would be needed for further meso-scale and local-scale modelling. Economic data contain various types of data from Russia and the former Soviet Union and Slovakia, e.g. administration units, number of overnight stays in accommodation facilities, ski lifts, etc. according to oblast information.

Achievements:

- Download possibilities of some data at INTAS 03-51-5296 snow data base site: http://www.landscape.tuwien.ac.at/intas
- Evaluation report of data used
- Links to the original sites of databases with freely available data used but not compiled by the INTAS group

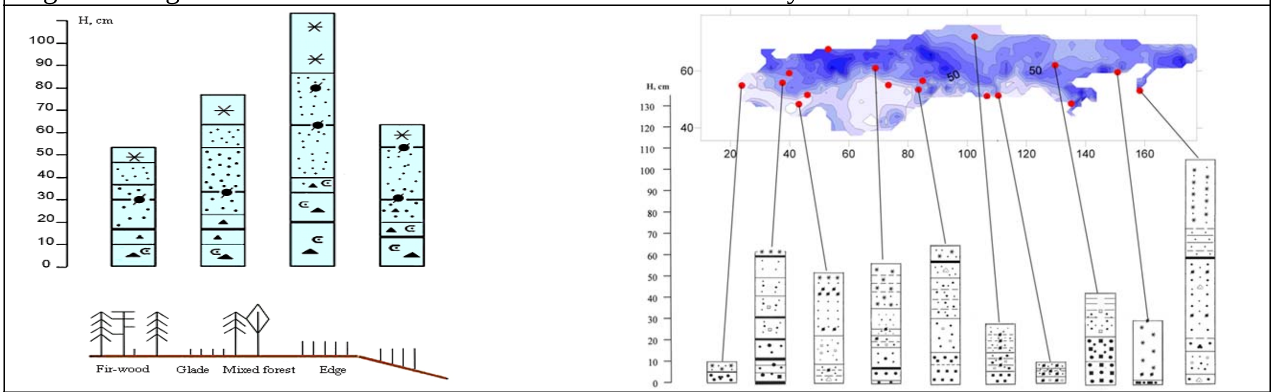
Non -achievements:

- Provision of economic data for the non-Russian territories of the former Soviet Union at the oblast scale.

<u>2. Study of spatial and temporal variability of the structural properties of snow; development of parameterization scheme</u>

Based on their analysis of 225 selected snow stations, Petrushina, Golubev and Frolov constructed maps of snow depth and snow water equivalent (SWE) distribution over the territory of the former Soviet Union for 3 winters with very different winter meteorological conditions. The investigation was based on large-scale fieldwork, physical and mathematical modelling and the analysis of meteorological data. They concluded that regional-scale snow structure is mainly determined by a meteorological pattern. Several types of snow structures were identified and modelled. The most complicated snow structure is formed in mountains where the slope morphology plays a crucial role. A simple algorithm of internal snow-structure time evolution was developed based on 25 Russian sites with different climatic conditions (Fig 4, right). It is planned to elaborate this algorithm in a global climate model at a later date. Locally, major variations are possible at each station (Fig 4, left).

Figure 4: Regional variations of snow cover at the end of February 2005



Snow depth varies at the local level according to vegetation and land-use cover. The four columns depicting February 2005 snow in different vegetation zones in Moscow – see left side – are all represented by column 2 on the right side. The degree of local variation is uniform from year to year and, therefore, the regional picture is representative despite the local variations. New snow and thawing events generate particular snow types that constitute snow classes. Global circulation models cannot produce the vertical structure of snow. By introducing snow classes into global circulation models, climate change forecasts can be considerably improved in future.

Popova (2006a, 2006b) studied the inter-annual variability of winter snow accumulation using long-term data and focusing on the relationships with the North Atlantic Oscillation (NAO) anomalies and global warming. She has found that, with respect to snow depth inter-annual variations, there are several spatially homogeneous regions in Northern Eurasia. The inter-annual variations of snow depth in the regions correspond to changes in certain atmospheric circulation modes. For the major portion of the Eurasian territory north of 55°N between the White Sea and River Lena basin, the snow-depth increase during the period 1975-1995 can be explained by the positive NAO trend. Positive trends in runoff in the Volga and Yenisei rivers since the 1970s have been caused by increased snow accumulation associated with the positive NAO phase.

Breiling and Charamza provided a statistical testing of climate data and multiple regression analysis of how ground-based snow cover height depends on latitude in Northern Eurasia. This was undertaken for the reference period 1970 to 2000. In a next step, the changes which can be expected in snow cover height with a rise of temperature were modelled. This, in turn, shows how northern landscapes flow towards the "south" with regard to snow depth and a particular warming. This was undertaken in order to assess critical snow heights for the economic analysis.

Achievements:

- Finding certain regularities in large-scale snow cover distribution, independent of the total amount of snow, even in extreme years.
- Production of an algorithm on snow stratigraphy evolution dependent on meteorological conditions.

Non-achievements:

- Adjustment of the developed algorithm for the needs of GCMs
- Incorporation of altitude data into multiple regression analysis of snow height

<u>3. Snow stratigraphy and its role in the hydrothermal regime in Northern Eurasia</u>

Based on the existing SPONSOR model (Shmakin 1998), Shmakin, Sokratov, Golubev and Petrov (2006) analyzed the effect of snow cover structure on the thermal regime of the underlying soil, as well as the effect of snow structure on melting and appropriate time scales. The idea was to use these results to estimate the necessary parameters in Global Circulation Models. The modelling results for several testing sites in Eurasia showed that using effective parameters based on the snow vertical structure classification leads to a better evaluation of the energy/water balance.

Phillips analyzed the effect of snow on the development of mountain permafrost (Phillips et al. 2003), and related the findings to the territory of the former Soviet Union where permafrost exists in more than 50% of the region. Due to its particular physical properties, snow cover is one of the main factors influencing the distribution and evolution of permafrost. Modifications in snow cover distribution caused by climate change can lead to a warming or cooling of the ground. In the former case, the geotechnical properties of the ground can change, particularly if it contains ice. A reduction of the bearing capacity of thawing permafrost can have costly and dangerous consequences for any infrastructure located on the permafrost.

Achievements:

- Finding the way to represent the internal structure of snow cover in terms of effective snow cover parameters required for Global Circulation Models.
- Estimation of possible ranges of these snow cover parameters.
- Construction of a link between the snow cover properties and soil condition, the latter affecting requirements for infrastructure development and maintenance in permafrost regions

Non-achievements:

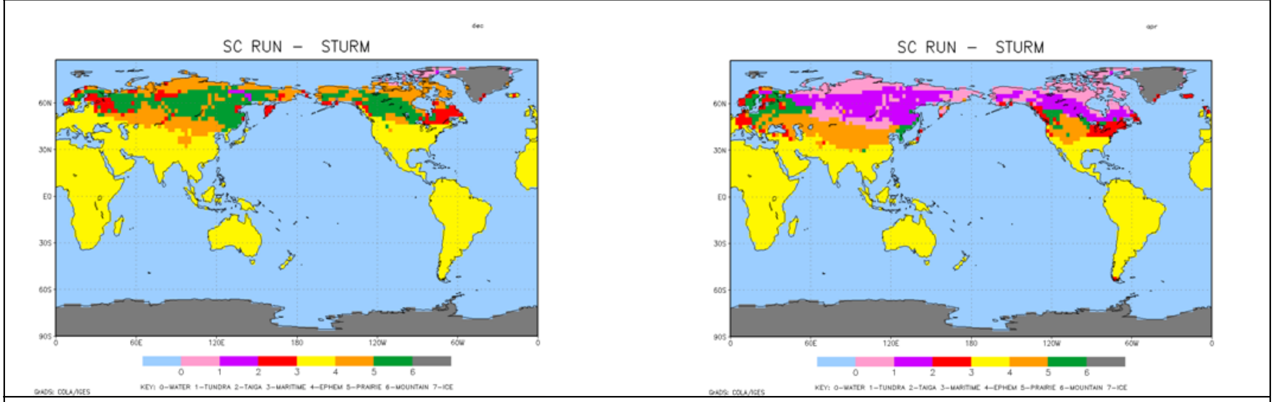
- Due to lacking data, it could not be investigated / confirmed for different climate zones.
- Parameters have not yet been incorporated into GCMs

<u>4. Modelling snow cover more precisely for the territory of the Northern Eurasia</u>

In addition to the normal dual procedure in GCMs of "snow yes" or "snow no" (explaining if snow exists/ does not exist at a certain observation point), Rubinstein, Gromov, Ignatov (2006) and Khan, Rubinstein, Shmakin (2007) compared the amount of snow produced by several general circulation models with the actually observed variability of snow cover and snow water equivalent (SWE) or amount of snow. Due to the drastic reduction of measurements in Northern Eurasia in the 1990s, the reanalysis and satellite data can often only be the surrogates of the measured data. The quality of the reanalysis of snow products varies for different regions and periods. It was found that the best performance for the territory of Northern Eurasia corresponded to the Hydro Meteorological Centre of Russia (HMC) model. Major uncertainties were found in areas with complex topography, and significant disagreements with observational data were observed during the period of intensive snowmelt in spring.

In addition to the amount of snow, Rubinstein, Gromov, Zoloeva (2006) introduced classes of snow. The Sturm classification of 1995 was used as a base and altered by intra seasonal change of snow classes in each surface pixel of the climate model (see Fig. 5; left, December and right, April). The inclusion of the combined spatial and temporal variability of snow cover allowed the introduction of varying parameters of thermal properties of land surface as a boundary condition of GCM. The first experiments with varying albedo displayed the model's great sensitivity to the snow cover parameterization scheme. The estimation of the other snow cover parameters' effects requires the construction of a scheme of snow-cover feedback to the climate system.

Fig. 5 Modification of static snow classification after Sturm (1995) into a dynamic one (2006)



Sturm (1995) based his snow classification on the typical snow depth at the end of February usually the maximum of snow in the northern hemisphere. Rubinstein et al. (2006) made this approach dynamic according to month. The December snow classes on the left look different from those in April. This means a considerable improvement with regard to global climate modelling. The feedback of changed albedo to snow cover is not yet included and a topic of further research.

Achievements:

- Finding the way to represent spatial and temporal variability of snow cover in large-scale climate models.

Non-achievements:

- Not yet developed feed back of snow cover to the climate system
- The intra-seasonal snow cover properties change in GCMs is not yet linked to data responsible for the snow-cover evolution (under 2,3)

<u>Economic aspects of snow cover</u>

There were trials to link this information on snow cover with the economic sectors in Russian oblasts and countries of the former Soviet Union similar to previous work on the economic importance of snow in Austria (Breiling, Charamza 1999). Agriculture, forestry, tourism and transport are all snow-sensitive sectors. Particular problems can be expected in the transport sector in northern latitudes, where snowfall may increase and change the properties of permafrost soils. Major damage to the transport infrastructure of the gas and oil supply can be expected in this case. Other problems are related to agriculture and irrigation.

River runoff is one of the important economic aspects of Northern Eurasia. Khan et al. (2007a and 2007b), related the snow cover modelling results to the main Russian river basins' run-off and to river discharge into the Aral Sea basin. The analysis showed the discrepancy between the increasing trend of runoff in the Amudarya and the Syrdarya Rivers – assumingly from shrinking glaciers of the Western Tien Shan Mountains – and the decreasing trends in precipitation and snow depth. Popova (2006a, 2006a) also related her snow cover distributional studies to river runoff in four river basins in Northern Eurasia (Volga, Ob, Yenisei and Lena). The positive trends in runoff in the Volga and Yenisei rivers since the 1970s are caused by increased snow accumulation associated with a positive phase of the North Atlantic Oscillation weather system. The analysis showed a lower correlation between annual runoff and snow depth in the Ob and Lena river basins due to the higher importance of summer precipitation.

Figure 6. The importance of snow in the economy

Snow is crucial for winter sports and the national income of Austria (right side, Kaprun Glacier), Switzerland and Slovakia amounting to several percent of the GDP. Even some parts in the FSU, e.g. the Caucasus or Uzbekistan, depend on the availability of snow for winter tourism. Floods caused by sudden melting of snow are a huge problem (left side flooding in the Danube Delta, end of April 2000) and can result in expensive damage.

Holko and Kostka analysed the relationship between tourism and snow in Slovakia. Statistical data from the district of Liptovský Mikuláš (which is the district with the highest number of the overnight stays in the Zilina region) showed that – although summer remains the main tourist season in Slovakia – winter tourism is almost equally important. Further analysis can be focused on the assessment of the impacts of changed climatic conditions on this business.

Shmakin, Popova, Chernavskaya, Chernkova (2006) compared the February snow depth for each of the 89 Russian administrative units in 1951-80 (mid-century period) and 1989-2001 (the contemporary warming). In the western and south-western parts of East European plain, the amount of snow has decreased, while in most of the country there has been a significant increase. In addition, the volume of snow falling on roads (which has to be removed by cleaning) was calculated for each of the administrative units. The largest increase in the expenses for snow removal from the roads occurs in the oil production regions of the Urals and Western Siberia (Tyumen, Bashkortostan, and others), where both the length of the roads and snow depth are increasing. Some reduction in expenses is taking place in north-western regions (Tver, Pskov and others).

Achievements:

- Comparing the overall economic situation of Russian oblasts with national data from the former USSR countries and a first assessment of the importance of snow
- Comparing snow related problems in Russian oblasts

Non-achievements:

- Comparison of different river basins in Northern Eurasia and an economic evaluation of snow related risks
- Comparison of snow related economic impacts of non-Russian oblast/territories in Northern Eurasia

Discussion & Outlook

There is an observed discrepancy between large scale, regional and local studies and it is not easy to combine the different assessments. Questions related to beauty and landscape perceptions are not yet major issues of snow research. Incorporating the physical processes in snow cover into climate modelling, and assessing the snow cover impacts on society and the economy, is a long process. We indicated some points where the required data is still missing or the tension between the different approaches and different interests of the individual scientific groups involved is most pronounced.

Recently, snow issues have received much more attention than previously as a result of two unusual winters that brought abundant snow in the season 2005/06 and scarce snow in the season 2006/07. Along with climate change, such abnormal situations are likely to occur more often. Particularly in richer locations, adaptations to lacking or over-abundant snow are under further consideration and widen the spectrum of snow-related applications. Snow science and the development of snow-related technologies will become even more important in future.

While natural snow cover is likely to diminish with global warming, snow in the city can become much more important in future. In case of the abundant snow, the city often becomes polluted very quickly.

Snow masses have to be transported out of the cities to avoid the generation of ice layers on snow and the occurrence of related health and traffic risks. On the other hand, starting in October, snow is transported from mountain regions to city centres to promote skiing and accompany the opening of ski resorts. The actual winter tourist season is no longer necessarily orientated on the natural availability of snow.

The current structure of ski resorts is likely to change. During warm winters we find small tracks with artificial snow in an otherwise green landscape. Artificial snow making is becoming more and more important, but not everyone can afford it. The price of one cubic meter of snow can be as high as five Euros in Austria. This means that some resorts cannot cope with providing artificial snow, while others might come into existence in densely populated urban areas. The existence and development of new artificial snow making methods that may solve problems related to extraordinary resource use are in progress. However, despite the technical possibilities, many people dislike skiing without the feeling of winter.

The terms snow science, snow planning, snow engineering or snow architecture are used, but so far they are part of other fields and not individual disciplines. We believe that considerable progress will occur in the near future. The interaction between snow and the landscape – until recently solely dominated by natural processes – will become increasingly more dominated by humans. Many questions developed in the areas of landscape planning and landscape architecture can be perceived as being relevant in the context of snow and landscape and one should try to strengthen this link. In this context we are happy to be able to take the opportunity of the ECLAS conference for presenting this research to a larger public.

Acknowledgement

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References

Breiling M., R. Stiles, eds. 2004: Technology.Tourism.Landscape: SNOW. Proceedings with extended abstracts to International Conference at TU Vienna. 128 pp., ISBN 3-900804-10-9

Breiling M., P. Charamza 1999: The impact of global warming on winter tourism and skiing: a regionalised model for Austrian snow conditions. Regional Environmental Change Journal. Volume 1.1. pp. 4-14. ISSN 1436-3798.

Holko and Kostka 2006:

Khan, V., Holko, L., Rubinstein, K., Petrov, M., Breiling, M. 2007a: Snow Cover Characteristics Over Aral Sea Basin from Different Data Sets and their Relationship with River Runoff Changes. *Journal of Marine Systems* submitted

Khan, V., Rubinstein, K., Holko, L., Breiling, M., 2007b: Snow Cover Characteristics Over the Main Russian River Basins as Represented by Reanalysis and Measured Data. *Journal of Applied Meteorology and Climatology* submitted

Khan, V., Rubinstein, K., Shmakin, A, 2007: Comparison of snow cover characteristics over territory of Russia based on observational and reanalysis data. *Physics of Atmosphere and Ocean*, 1

Nohguchi Y., K. Izumi, 2006: Yukigata – natural art on mountain visualized by snow. In Proceedings 12TH INTERNATIONAL SYMPOSIUM ON FLOW VISUALIZATION September 10-14, 2006, German Aerospace Center (DLR), Göttingen, Germany

Petrushina, M.N., Sokratov, A.S., Golubev, V.N., 2006: Effect of physico-geographical conditions on snow structure. Geophysical Research Abstracts, Vol. 8, 03229

Phillips M., Springman S.M. Arenson L.U., editors, 2003: Permafrost: Proceedings of the 8th International Conference on Permafrost: Proceedings of the 8th International Conference on Permafrost, Zurich, Switzerland, 21-25 July 2003

Popova, V. 2006a: Interannual Variability of Winter Snow Accumulation and Runoff in Four River Basins of Northern Eurasia.

Popova, V. 2006b: Winter snow depth variability over Northern Eurasia in relation to recent atmosphere circulation changes. *International Journal of Climatology*. submitted

Rikhter, G.D., 1954: Snow cover, its formation and properties. U.S. Army CRREL, Transl. 6, NTIS AD 045950, Hanover, NH, 66 pp.

Rubinstein K.G., Gromov S.S., Ignatov R.Yu., 2006: Otsenka vosproizvedeniya characteristik snezhnogo pokrova v modelyakh obshchei tsirkulyatsii atmosfery [Evaluation of results of simulation of snow cover characteristics in general circulation models]. *Izvestiya Russian Academy of Sciences, ser. Physics of Atmosphere and Ocean*. 43(3) 1-15

Rubinstein, K.G., Gromov, S. Zoloeva M., 2006: Dinamicheskaya klassifikatsiya snezhnogo pokrova [A dynamic snow cover classification]. *Vychislitel'nye tekhnologii [Computing Technologies]*, 11(3), 31-37

Shmakin, A.B., 1998: The updated version of SPONSOR land surface scheme: PILPS-influenced improvements. In Global and Planetary Change Volume 19, Issues 1-4, pp 49-62.

Shmakin, A.B., Popova, V.V., Chernavskaya, M.M., Cherenkova, E.A., 2006: Estimates of climate change influence on economy branches in regions of Russia. International Conference on the problems of hydrometeorological safety (prediction and adaptation of the society to the extreme climate changes). September 26-29, 2006. Moscow, Russia. Poster session abstracts, p. 279.

Shmakin, A.B., Sokratov, S.A., Golubev, V.N., Petrov, M.A., 2006: Evaluation of snow properties for use in climate modeling applications. Geophysical Research Abstracts, Vol. 8, 04636

Sturm, M., Holmgren, J., Liston, G.E., 1995: A seasonal snow cover classification for local to global applications, *Journal of Climate*, 8(5), 1261-1283.