Advances in the process-related understanding of atmosphere-cryosphere-hydrosphere couplings on the Tibetan Plateau

C. Schneider[1], T. Yao[2], D. Scherer[3], S. Kang[2], M. Buchroithner[4], M. Fink[5], V. Hochschild[6], J. Bendix[7], J. Kropáček[4,6], F. Maussion[3], W. Yang[2], E. Huintjes[1], S. Biskop[5], J. Curio[3], G. Zhang[2], F. Ruethrich[7], B. Thies[7], M. Spiess[1], N. Neckel[6], N. Holzer[4], B. Schroeter[4]

1 Department of Geography, RWTH Aachen University
2 Institute for Tibetan Plateau Research, Chinese Academy of Sciences
3 Department of Ecology, TU Berlin
4 Institute for Cartography, TU Dresden
5 Department of Geography, Friedrich-Schiller-University Jena
6 Department of Geosciences, University of Tuebingen
7 Faculty of Geography, Philipps-University Marburg
Christoph.Schneider@geo.rwth-aachen.de

Interdisciplinary research within the joint German-Sino research group constituted by the authors of this abstract regarding atmosphere-cryosphere-hydrosphere couplings on the Tibetan Plateau has led to a series of remarkable advancements regarding our understanding of the coupling between sub-systems in atmosphere, cryosphere and hydrosphere at various scales in time and space.

The High Asia Reanalysis datasets (HAR) at 30 and 10 km resolution were generated for the period 2001 to 2011 using a state-of-the art atmospheric model driven by global observations. In combination with glacier surface mass balance and hydrological models, they allow an unprecedented understanding of atmosphere-related processes in this data-scarce region of complex topography. In particular, they made it possible to quantify the impact of the often quoted "interplay" between the Monsoons and the Westerlies on glaciers in the south-central Tibetan Plateau.

A newly developed integrated gross cloud retrieval based on Meteosat and CloudSat combines the advantages of the high spatio-temporal resolution available from geostationary Meteosat satellites with the benefits of the active sensor on board of CloudSat. The new algorithm outperforms the existing product of the International Satellite Cloud Climatology Project for the Tibetan Plateau in terms of resolution and skill scores. It was used to identify the nocturnal formation of mesoscale convective systems on the southern foothills of the Himalayas and can nicely be combined with the HAR dataset for cross validation. In combination, mesoscale convective cloud systems are better resolved with satellite retrievals while low stratus representation might be improved with HAR data, due to the poor spectral resolution of Meteosat First Generation imagery.

For investigating decadal glacier changes we used declassified high resolution stereo satellite photography of the US Keyhole (KH-9) mission dating back until the 1970s as well as recently recorded high resolution stereo remote sensing data to study glacier variations. By comparing multi-temporal glacier outlines and surface dynamics, as well as glacier thickness changes over time, we could observe rather heterogeneous glacier variations over approximately the last 40 years in the more western Tibetan Plateau . Many glaciers lost area and mass throughout since the 1070s. We could also observe stable and several advancing glaciers with indications of surges.

For the more recent period, ICESat measurements revealed a mass loss of most Tibetan glaciers between 2003 and 2009. Most negative mass budgets of -0.66±0.25 m w.e./a were estimated for the central and eastern Tibetan Himalayas while a slight mass gain of +0.13±0.07 m w.e./a was found in the Westerly-dominated north-central part of the Tibetan Plateau. A total annual mass loss of -13.3±6.2 Gt/a was estimated for eight sub-regions sufficiently covered by ICESat data which represent roughly 80% of the total glacier area on the Tibetan Plateau.

The shift of the equilibrium line altitude of a glacier can be used as an indication of its mass balance variations. As a proxy for the equilibrium line altitude of glaciers the end-of-summer snow line is used. By means of Moderate-resolution Imaging Spectroradiometer (MODIS) satellite imagery we investigate the multi-annual migration of the snow line during recent years in several mountain ranges distributed along an east west transect.

In May 2010 we installed two terrestrial time-lapse cameras at Zhadang Glacier (southern-central Tibetan Plateau) generating six stereo photographs of the glacier every day. These high resolution images allow conclusions about the effects of different climatic parameters related to the glacier on a four-hour time scale from May 2010 until September 2012. A remarkable result is the proof of the existence of ablation due to heavy snow drift and sublimation on the glacier during the winter months (DJFM) which could not be detected by the automatic weather station (AWS) on Zhadang Glacier because of the glacier's topography. Furthermore, all images were orthorectified and the mean altitude of the snowline was detected.

A physically based, coupled energy balance and multilayer snow model was developed and evaluated against multi-year ablation stake measurements and the time-lapse camera images for Zhadang Glacier. Forced by meteorological data from the HAR, the model was then applied on Purogangri Ice Cap (central Tibetan Plateau) and on a glacier near Halji (western Nepal Himalayas). The detailed calculation of atmospheric energy fluxes and subsurface processes like refreezing, allows reproducing the results obtained from remote sensing techniques and to explain and analyse the variability in glaciological and hydrological parameters in the different regions on the Tibetan Plateau. Furthermore, model runs tuned in order to reproduce the equilibrium line altitudes on glaciers as retrieved from remote sensing allow to assess the spatial pattern of summertime cold-bias within the HAR dataset.

The ice phenology of 59 large lakes on the Tibetan Plateau was derived from MODIS 8-day composite data for the period from 2001 to 2010. Ice cover duration appears to have a high variability in the studied regions due to both climatic and local factors. A correlation of ice phenology variables with parameters describing local climatic conditions showed a high thermal dependency of the ice regime. For the studied lakes, it appears that the freeze-up tends are more thermally determined than the break-up.

Radar altimetry data from different space born instruments provided an insight to the lake systems of Mapam Yumco and La'nga Co in the south-western part of the Tibetan Plateau which obviously were connected sometime in the past. It appears that the elevation of Mapam Yumco was stable in the period 2002-2010. There was likely no significant overflow to La'nga Co which was 23 m lower during this period.

Lake level fluctuations of endorheic lakes on the Tibetan Plateau serve as a sensible indicator for the climate induced impacts on the regional water balance. For a better understanding of the spatio-temporal patterns the contribution of several hydrological components to the water balance is quantified for selected benchmark basins representing different hydro-climatic and physical basin characteristics on the Tibetan Plateau. HAR data are used as meteorological drivers for the process-oriented conceptual hydrological model built within the Jena Adaptable Modelling system. Available ground measurements, earth observations or independent model data of snow and glacier dynamics are used for a multiple-response validation approach, respectively plausibility checks.

Model results show that despite glacier shrinkage the contribution of ice melt to total runoff plays a minor role compared to precipitation and snow melt runoff components. However, wind-induced sublimation (blowing snowdrift) is supposed to be a main factor strongly controlling the spatio-temporal evolution of snow cover during the winter season and consequently for snow and glacier melt throughout the summer season.

The work is part of research projects funded by the DFG Priority Programme 1372: "Tibetan Plateau: Formation-Climate-Ecosystems" (TiP) and the BMBF research program "Central Asia and Tibet: Monsoon dynamics and geo-ecosystems" (CAME).

Keywords: Tibetan Plateau, Atmosphere, Cryosphere, Hydrosphere, Coupling, Global and Regional Change, Remote sensing, Modelling