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Multisensoral Remote Sensing Based Modelling of the Water Balance of Endorheic Lakes on the Tibetan Plateau

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Abstract The water balance of endorheic lakes on the Tibetan Plateau plays an important role in the assessment of hydrological system dynamics such as glacier retreat or changing patterns of monsoonal precipitation in relation to global warming effects. Since those lakes are remote and hard to access, multisensoral remote sensing seems to be a valuable tool to generate hydrological relevant information as modelling input (land cover, trends in mountain lake ice cover, etc.) or validation base (lake level changes). Integrative methodological approaches linking state-of-the-art remote sensing with distributed hydrological modelling are the only way to quantify the water balance and to provide a forecast of the future water availability on the Tibetan Plateau.

Key words multisensoral remote sensing; satellite altimetry; multi-temporal land cover classifications; snow cover mapping; lake ice monitoring; in-situ field measurements; GIS-based HRU-delineation; distributed hydrological modelling; J2000

INTRODUCTION

This integrative study investigates the driving forces of the water balance of endorheic lakes on Asian high altitude environments in relation to changing climate and monsoonal dynamics (Du et al. 2004, Kang et al. 2010, Liu et al. 2010). It is part of the German DFG Priority Program 1372 (TiP), which focuses on the formation of the Tibetan Plateau as well as its recent and future climate and ecosystem dynamics. Although there have been various studies on single hydrological cycle components (Yao et al. 2007), also using remote sensing data (Xu et al. 2008, Che et al. 2009), an integrative hydrological modelling approach was not applied within this region.

To address this deficit, an interdisciplinary research was initiated to acquire reliable information on spatially and temporally variable hydrological processes and storage compartments integrating field investigations and spatial hydrological parameter derivation from multisensoral remote sensing data as well as statistical analysis of hydro-meteorological data and the delineation of Hydrological Response Units (HRUs) with GIS technology. Finally a sophisticated water balance modelling had to be carried out using the data as input and validation base within the distributed hydrological model J2000.

The investigations have been carried out within the Nam Co Basin (10 800 km²), an endorheic catchment in central Tibet, about 300 km northwest of Lhasa. Slightly salty Nam Co (4718 m a.s.l.), which is one of the largest lakes on the Tibetan Plateau (2009: 2020 km²), was selected as being representative due to its geographical position, land cover, soils and hydro-ecological dynamics. The research was also motivated by available hydro-meteorological data, which are measured since 2005 by the partner scientists of the Institute of Tibetan Plateau Research (ITP) at the Nam Co Station for Multisphere Observation and Research (NAMOR).

Distributed modelling of such large lake ecosystems require spatial information on precipitation patterns, snow cover distribution, the amount of snow and glacier melt runoff, evapotranspiration as well as information on the dynamics of wetlands and permafrost linked through soil moisture to receive estimates of the total runoff into the lake. The study presented here summarizes the efforts undertaken to develop the spatio-temporal data set for the subsequent, distributed hydrological modelling and first model results.

REMOTE SENSING DATA EVALUATIONS

Spatial input for vast and remote areas on the Tibetan Plateau could only be provided by remote sensing data. Numerous sensors have been evaluated for the derivation of different hydrological parameters, for example a multiscale DEM derivation for hydrological relief analysis and geomorphologic classifications due to surface roughness, meanwhile the research focus is on three major fields:

- mapping of wetlands and Multitemporal land cover classifications
- Lake ice and snow cover monitoring with MODIS and ENVISAT A-SAR data,
- Evaluation of time series of satellite altimetry data (Envisat, GFO, IceSat)

Land Cover and Wetland Mapping

Being an important input layer for the delineation of spatial model entities (HRUs), a land cover map was provided based on multitemporal acquisitions of two adjacing LANDSAT scenes from a short period around the year 2000, which was used as modelling input since the land cover determines many hydrological processes: grassland is a base for the estimation of evapotranspiration rates, melting snow and glaciers are presumably important sources of melt water and a resulting lake level increase.

A robust hybrid classification approach that combines a maximum likelihood classifier with a decision tree approach was applied. The decision rules are based on thresholds of multispectral bands and on terrain properties derived from the available digital elevation model (SRTM DEM). Separate spectral signatures were used from each scene, which were extracted from identical training areas located in the overlap area of the two satellite image areas. This analytical approach considered different atmospheric conditions, different periods in the phenological cycle, different moisture conditions etc. The resulting LANDSAT classifications were merged utilizing a majority selection in which the class that occurs most often is selected as resulting class. Rules based on inherited properties of classes were applied in a decision tree, which regard the occurrence of wetlands and water bodies with respect to slope inclination.

Information on spatial extent, the distribution and the characteristics of high elevation wetlands in the Nam Co basin is an important input for hydrological modelling. For this purpose we tested several methods that are based on various optical and SAR remote sensing data (Kropacek et al. 2009, Leiterer et al. 2009). There were dual polarization TerraSAR-X scenes and quad-polarization ALOS/PALSAR data used in order to understand the backscattering properties of the high elevation wetlands in X-band and L-band. Pauli decomposition of the full-polarization dataset features a good discrimination of wetlands. Time series of LANDSAT data were complemented by a CORONA image from 1965 and used to analyze changes of the wetland area. All in all the wetlands tend to be stable in extent in general, though small changes of wetland area were identified in wetlands close to the lake shore. Wetlands are closely connected to the occurrence of permafrost in this area.

Lake Ice and Snow Cover Monitoring

In order to understand the spatial and temporal variability of the snow cover in the Nam Co Basin, a time series of high temporal resolution MODIS data was analysed. Therefore a method for the visualization of the spatial and temporal snow cover distribution was developed by RGB synthesis. The data were divided into three groups according to the season they belong to and weighted averages of these particular seasons were then visualized in the RGB display: Jan-Mar - Winter (red), the warmer part of the year from Apr-Sep - Spring/Summer (green) and Oct-Dec - Autumn (blue). The primary colors represent dominant snow cover in a single season. Secondary colors correspond to dominant snow cover in two seasons. The colour intensity represents the duration of the snow cover. The RGB syntheses were generated for the years 2003 to 2008. The Southern part of the basin is dominated by the summer monsoon with snow precipitations at higher altitudes. The Eastern part of Nam Co is snow covered mainly in autumn and winter. This effect occurs when cold north-westerly winds pass over the relatively warmer lake water and lead to snowfall on the opposite side of the lake. When the lake is frozen, snowfall stops due to missing humidity. This pronounced “lake-effect” of

Nam Co on the snow cover was described by Li et al. (2009) and its spatial and temporal patterns were analysed by RGB synthesis of MODIS snow data. For understanding of broader context of the Nam Co Basin on the Tibetan Plateau, analogous syntheses were generated for the whole plateau based on the lower resolution MODIS snow product.

Lake Level Measurements using Satellite Altimetry

Fluctuation of endorheic lakes is a valuable indicator of climate change and an important parameter for understanding the water balance in the drainage basin. Fluctuations of Nam Co in the last decade were retrieved from available satellite altimeter data between 2001 and 2009. The water table of Nam Co is crossed by the ground tracks of ENVISAT RA-2 and GFO, which were corrected for ionospheric, atmospheric and tidal effects using the BRAT freeware provided by ESA. All the data were converted to the common base of the WGS-84 Ellipsoid in order to retrieve the correct altitudes.

A time series of LANDSAT images have been assembled for comparison and possible extrapolation of the trend of Nam Co lake level extension. The lake area was delineated by the application of a threshold in the NIR band. The result shows that Nam Co Lake area increased from 1938.3 km^2 in 1976 to 2006.8 km^2 in 2006, which gives a mean annual increase of 2.2 km^2/yr. Since the year 2000 there is an area enlargement of up to 5.4 km^2/yr.

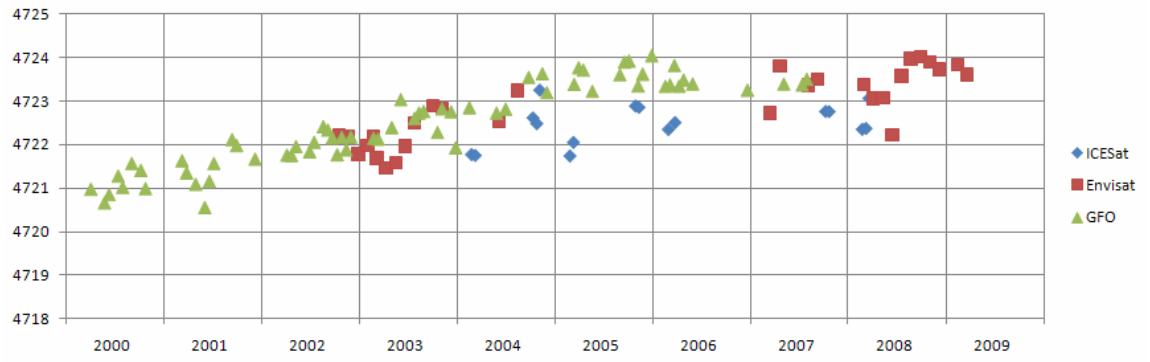

Fig. 1 Lake level of Nam Co in the period from 2000 to 2009 measured by combination of three different satellite altimeters.

The multi sensor analysis of the altimetry data revealed a steady increase of water level from 2000 to 2005. This is obvious from the GFO and ENVISAT data. The lake level of Nam Co was increasing by 2.55 m, equal to an annual increase of 0.51 m (Fig. 1). From 2006 to 2009 the level was rather stable. This can be seen in the GFO and ENVISAT data and it is supported also by the lake shore position stagnated in that period. Changes of areal extent of the lake and shore movements indicate a continuous lake level rise since 1965. Assuming that the shift of the shoreline is linearly dependant on the difference of the lake level, one can estimate an average rise in the period from 1965 to 2009 of 0.2 m/yr. Considering the evapotranspiration, this result is an excellent validation base for the modelling of the catchment since Nam Co has no superficial outflow.

HYDROLOGICAL MODEL APPLICATION

Before using more detailed process descriptions a simple model application was set up to provide estimations of the water balance of the Nam Co basin based on downscaled 0.5° gridded ECHAM5 data. Simplified modelling entities were created by overlay of the ECHAM5 grid cells and land use types to be used with the hydrological model J2000g which was extended and adapted to be used in the Nam Co Basin.

The model was applied for the time period of November 1961 to October 2010. From the simulation results the most important climate and water balance state variables were extracted and analysed as long term means or sums but also for the single decades of the 50yr long period (Krause et al. 2010). The comparison between the simulated lake level rise of 35 cm per year and the estimated lake level

rise of 27cm/yr for 2000 to 2009 from radar altimetry showed that the observed increasing rate is matched well by the model.

CONCLUSIONS

Even if the preliminary study contains a large amount of uncertainty, the model could be used for the simulation and analysis of the lake level rise of Nam Co. It seems that the melt water from the glaciers together with increasing summer precipitations are the most important components to explain this lake level rise. However, much model developmental work remains to be done to understand the hydrological processes which influence lake level rising and how the lake level may change in the future.Although the changing permafrost and wetland conditions are not considered by the recent model version yet (Krause et al. 2010), the remote sensing data show that the wetlands are relatively stable in extent. It is nice to see, that the independent water balance model result and the lake level estimation from satellite altimetry coincide so well. The multisensoral remote sensing data in general provide reliable spatial input data on land cover, wetland extension, lake ice and snow cover as well as altimetry data for validation on the development of the lake level itself. There will be even more relevant remote sensing based information (evaporation, interferometry) in the future.

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