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INVESTIGATION OF CAUCASIAN GLACIERS BY SATELLITE DATE

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The main objective of present work is the investigation of glaciers melting including significant ecological risks especially in connection with climate change issues. Long term satellite monitoring objectives toward the climate are:

- Determination of the processes related with climate and glaciers interaction.
- Detection of climate and environmental changes provided through glaciers changes;
- Validation of global and regional climate models, sensitivity studies, climate change scenarios specification, etc.

Satellite monitoring of glaciers has the well expressed potential to facilitate measurements that traditionally were performed using field techniques or ground based observations in one or several spots. High resolution space borne data allow glacier length change measurements along the entire glacier tongues, and in that way complement or even replace ground-based measurements.

Using the remote sensing data it can be determined:

- The ice snow border;
- Glaciers movement speed;
- The glacier elevation model and area of contours;
- Glaciers mass balance.

The surface of a glacier can be roughly divided into accumulation and ablation areas, separated by the equilibrium line where accumulation is exactly equal to ablation. The equilibrium line is generally more or less coincident with the snow line. In winter, before any ablation starts, practically the whole glacier is accumulation area and is summer, at the end of the glacier's year; the accumulation area is at its smallest. The end of the glacier's year is the time when the greatest amount of the previous winter's snow has melted (the ablation area is at its maximum) and new snow has not yet fallen. This occurs typically in September or October in the Alps, so that the mass balance year begins on the first of October, by convention in the so called fixed date system. Further north, in Scandinavia and Svalbard, the moment is approximately a month earlier, while on the glaciers in the southern hemisphere it is in March or April according to the geographical location and altitude [1]. Tropical glaciers, such as the glaciers of Mount Kilimanjaro, are defined by the global circulation patterns of the Inter Tropical Convergence Zone (ITCZ) and have low thermal seasonality which leads to ablation all year round, while the occurrence of accumulation varies between the humid inner tropics, the outer tropics and the subtropics. The investigation of glacier zones is typically carried out at the end of the glacier's year at a time when snow cover on the glacier and in the surrounding is at its minimum.

A glacier can be divided (see fig.1) into a number of specific zones (or facies). Starting from upper elevation and using Paterson's [2] nomenclature, the uppermost zone is dry snow zone in which no melting occurs. This zone exists only in the highest elevations of the ice sheets and on the highest (and coldest) mountain glaciers, where the annual average temperature is lower than the threshold value of -11^{o} C.

Below the snow zone, the dry snow line separates from the percolation zone in which some melting takes place during the summer. The wet snow line separates the percolation zone from the wet snow zone in which all the current year's snow melts. Below this, and separated from in by the snow line, is the superimposed ice zone, in which melt water refreezes onto the colder glacier ice surface. As the superimposed ice is created by melting and refreezing of the current year's snow this zone is still considered to be part of the accumulation area. The equilibrium line (EL) separates the accumulation and ablation areas and is located at the lower boundary of the superimposed ice zone and the bare-ice zone. At the equilibrium line, accumulation is exactly equal to ablation, and the EL is more or less coincident with the snow line. Below the snow line is the firn zone, which represents last year's snow.

The various zones to be detected by remote sensing were first proposed by Ostrem [3] and they have since been mapped with optical sensors, passive microwave sensors and synthetic aperture radar (SAR). The zones can be detected by various remote sensing data based on the surface wetness, grain size and purity of the glacier surface. Some attempts at glacier mapping have been made using multiangular satellite imagery (MISR, Multi-angle Imaging Spectroradiometer).

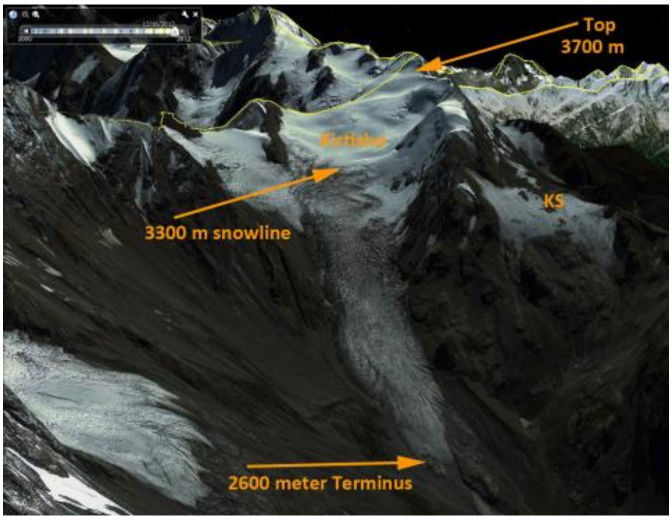

Fig. 1. Glacier Zones on example of the Kirtisho Glacier

The glacier zones can be mapped using radar data from the ablation period using the microwave backscattering properties of the surface. In summer, the accumulation area is in general covered with wet snow, surface scattering is controlled by the water content and surface roughness dominates. Typically the backscattering coefficient is low over a smooth snow surface. Surface scattering is high in ablation areas controlled by surface roughness, which is typically higher than in accumulation areas [4] and increases downward or through-out the summer as a result of melting. Crevassed areas give high backscatter values depending on the orientation of the crevasses relative to the look- direction of the radar. This use of summer SAR data for glacier zone mapping is based on distinguishing areas of contrasting backscatter on glaciers. So called radar glacier zones are defined as follows: the dry snow zone, frozen-percolation radar zone, wet snow radar zone, phase 2 melt radar zones, superimposed radar zone and the bare glacier ice radar zone. However, there zones do not necessarily coincide with the classical glaciological zone described earlier [2]. Winter radar images may be applied to glacier zone mapping as the radar radiation is able to penetrate through dry snow.

A fairly new and promising approach to assessing surface zones is to use laser scanner data. Modern laser scanners also retrieve an intensity signal from the surface, as well as the travel time which is used for elevation determination, and this can be used for mapping surface characteristics. Some preliminary classifications using the intensity signal have been made in Norway.

The mean specific mass balance *b* (expressed in metres water equivalent per year) results from averaging the accumulation and ablation of the various glacier locations. Usually *b* is averaged over 100 m elevation bands as *b* (z). Multiplying *b* (z) by the area of the respective elevations bands *s* (z) and adding over all elevations gives the volume balance *B* (m^3 w. e. per year). The equilibrium line altitude (ELA) is assessed from glaciological field a study as that is altitude where *b* (z) is equal to zero. The equilibrium line is close to the snow line at the end of glacier's year. However, in this case one has to use term averaged snow line, since the snow line separating snow and firn does not follow the contour lines, so that it does not have a unique altitude.

The accumulation area S_c is defined not as the area above the EL, but as the area of the glacier surface where $b>0$, and *the* ablation area is defined correspondingly. The accumulation area ratio (AAR, Equation 3.1) is characteristic of the glacier's status.

$$AAR = S_c / S \quad (1),$$

where S_c is the accumulation area and S is whole glacier area.

AAR has values between 0.6 and 0.7 on stationary glaciers. Values above or below are for positive or negative mean specific mass balance values, respectively.

Using remote sensing methods, the AAR can be determined at the end of the glacier year by mapping the glacier zones and dividing the snow covered area of the glacier by the whole glacier area [1]. Imprecision in this method may be caused by the non-optimal data of the remote sensing image (taken before the timing of the maximum ablation area) or inaccuracies in the classification itself. The EL may also be determined by detecting averaged snow line, a border between snow and firn , simply by manual delineation. Based on the high correlation between AAR and mean specific mass balance, classification of glacier surface characteristics into snow, firn and ice calculation of AAR from the results gives an approximation of the mean specific mass balance for the glacier in certain year. Some uncertainties exist since same AAR can still give values of specific mass balance (b) spreading over several hundred mm of water equivalent as presented for glacier Hintereisferner in Kuhn et al. [3].

The snow line and AAR can be monitored by various optical remote sensing data based on spectral signature differences between snow and firn. In 2007 was applied object oriented classification of snow, firn and ice areas of land-sat TM or ETM+ satellite images at the end of glaciological years. The resulting AAR and snow line altitude were compared with AAR and ELA determined by glaciological method. The results were satisfactory as the correlation between the remote sensing and glaciological methods for AAR was 0.64 and for snow line and ELA was 0.56. Heiskanen et al. (2003) produced AAR by pixel-based classification and studied the location of the snow line using Land-sat TM/ETM+ imagery in Engabreen, Norway. The classification produced a measure of AAR that considered spatial variations of ablation better than the one calculated from field measurements. On Engabreen the boundary between firn and snow corresponded well to the equilibrium line derived from mass balance measurements. Also AAR showed a good fit in the mass balance years studied. Another study on Engabreen was performed by Braun et al. (2005), in
which unsupervised classification of Landsat TM/ETM + images was used for mass balance modeling.

Assessing mass balance by AAR is useful for remote glaciers for which mass balance, ELA and AAR are difficult to assess using conventional methods. Aniya et al. (1996) used a Landsat TM mosaic of the Southern Patagonian Ice–field, South America, and supervised classification methods for TM bands1,4, and 5, for dividing various glacier drainage basins into accumulation and ablation areas, thereby determining the position of the snow line. It was found that the snow line could be taken as the equilibrium line and by comparing topographic maps the ELA was determined.

Mass balance is most typically determined by the glaciological method, but also using hydrological and geodetic methods. The use of the geodetic method, applying elevation models with greater accuracy than previously available, is gaining popularity especially with the success of airborne laser scanning. The use of remote sensing data for the geodetic method of using the determination or ELA and AAR by classification procedures would increase the number of glaciers for which the mass balance is estimated.

The area of Glacier is a basic property in a glacier inventory that is frequently used for upscaling of only of overall are change or sea level rise).The land surface area covered by glaciers is also important boundary condition for climate models that calculate the energy fluxes according to surface type. As the globally available data sets of glacier covered area are either not complete or very rough, new initiatives like Global Land Ice Measurement from Space (GLIMS) have started to compile a global glacier inventory (location, size, digital outlines) from satellite data.

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Glacier area change (percent per year) could be compared on a global scale to quantify regional climate change effects. However, glacier specific changes could only be determined when the same entities are compared. This is quite troublesome when only point information from the former World Glacier Inventory (WGI) is available. Glacier area changes as obtained from satellite data over large regions do also help to assess representativeness of the sparser sample of field –based length change and mass balance measurements or to identify what else is going on. In South Caucasus such down casting (i.e. stationary thinning) and disintegrating glaciers with little change at the terminus could be observed widely using space borne sensors.

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კავკასიონის მყინვარების კვლევა თანამგზავრული ინფორმაციის გამოყენებით/გ.კორძახია, ლ.შენგელია, გ.თვაური/ საქართველოს ტექნიკური უნივერსიტეტის ჰიდრომეტეოროლოგიის ინსტიტუტის შრომათა კრებული-2013.-ტ.119.-გვ.193-196-ინგლ., რეზ. ქართ., ინგლ., რუს.

სამუშაოს მიზანია განხილული და შესწავლილ იქნას მყინვარების დნობა, რაც მნიშვნელოვან ეკოლოგიურ საფრთხეებს მოიცავს განსაკუთრებით კლიმატის ცვლილების პრობლემატიკასთან დაკავშირებით. კერძოდ, კლიმატთან დაკავშირებით მყინვარების გრძელვადიანი მონიტორინგის მიზანია: პროცესების დადგენა, რომლებიც დაკავშირებულია მყინვარებისა და კლიმატის ურთიერთმოქმედებასთან; კლიმატისა და გარემოს მოსალოდნელი ცვლილება, განპირობებული მყინვარების ცვლილებით; კლიმატის გლობალური და რეგიონალური მოდელების ვალიდაცია მყინვარების მონიტორინგის შედეგებით; სენსიტიურობის შესწავლა; კლიმატის ცვლილების სცენარების დაზუსტება და სხვა;

მყინვარების თანამგზავრულ მონიტორინგს აქვს ნათლად გამოხატული პოტენციალი იმისა, რომ ემსახუროს იმ საქმეს, რაც ადრე ტრადიციულად წარმოებდა ექსპედიციური გზით, ან მიწისპირა დაკვირვებებით, როგორც წესი ერთ ან რამდენიმე წერტილში. მაღალი გარჩევადობის დისტანციური ზონდირების სივრცითი მონაცემები საშუალებას იძლევა, რათა გაიზომოს მყინვარის სიგრძის ცვლილება მყინვარის მთლიან ენასთან ერთად. ამ გზით შესაძლებელია მიწისპირა დაკვირვებები შეივსოს ან მთლიანად შეიცვალოს დისტანციური ზონდირების ინფორმაციით.

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Using the remote sensing data it can be determined: the ice snow border; glaciers movement speed; the glacier elevation model and area of contours.

The final objectives, based on the remote sensing, hydrometeorological network and glaciological observation data are: glacier monitoring technological line improvement and glacier properties determination; river Enguri pilot basin glacier runoff investigation based on determined values: creation of the Caucasian glacier models using the glacier characterizing data and glacier development forecast using these models.

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ИССЛЕДОВАНИЕ КАВКАЗСКИХ ЛЕДНИКОВ С ИСПОЛЬЗОВАНИЕМ СПУТНИКОВОЙ ИНФОРМАЦИИ/ Г.И. Кордзахия, Л.Д. Шенгелия, Г.А. Тваури/ Сб. Трудов Института Гидрометеорологии Грузинского Технического Университета. -2013.-т.119.-с.193-196 - Англ., Рез. Груз., Англ., Рус.

Основной целью работы является рассмотрение и исследование таяния ледников, что включает в себе значительные экологические риски, особенно в связи с проблемами изменения климата. Долгосрочными целями спутникового мониторинга ледников относительно климата, являются: определение процессов, которые связаны с взаимодействием между ледниками и климатом; обнаружение изменений климата и окружающей среды, что обеспечивается за счет изменении ледников; проверка глобальных и региональных климатических моделей; исследования восприимчивости, определение сценариев изменения климата и т.д.

Дистанционное зондирование с помощью спутников применительно к мониторингу ледников имеет хорошо выраженый потенциал, способствующий измерениям, которые традиционно проводились с использованием экспедиционных работ или наземными наблюдениями в одной или нескольких точках. Высокое пространственное разрешение спутниковых данных позволяет измерять изменения длины ледника, и таким образом, дополнять или даже полностью заменять наземные измерения.