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USING AVHRR (AND MODIS) DATA FOR MONITORING OF SNOW COVER AND SNOW MELTING PROCESSES

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Abstract: *Satellite remote sensing has become increasingly important to snow hydrologists because the data provide information on the spatial distribution of parameters of hydrologic importance and the possibility for this data to be incorporated into runoff forecasting and management systems.*

There are many remote sensing instruments applicable for snow detection and monitoring - the selection of the appropriate sensor depends on the specific aims and goals, as well as on the compromise between spatial and temporal resolution.

This report presents the results obtained for snow cover monitoring and snow melting processes on the territory of Bulgaria for the winter season 2007-2008, using AVHRR and MODIS data. Satellite images and data products, as well as meteorological forecast and ground-based data are used for snow cover depth. An attempt for using these data for flood hazards is done.

Snow AVHRR NDSI indexes for automated snow mapping procedure are created and proposed.

1. Theoretical Background

The main data and underlying information used may be summarized in: optical properties and spectral reflectance of snow; NOAA AVHRR and MODIS images – between 5 and 10 images per twenty-four hours; ground data for snow cover depth and meteorological forecast. Below, in very shortly is presented the theoretical background for remote sensing of snow

1.1. Optical Properties of Ice and Water

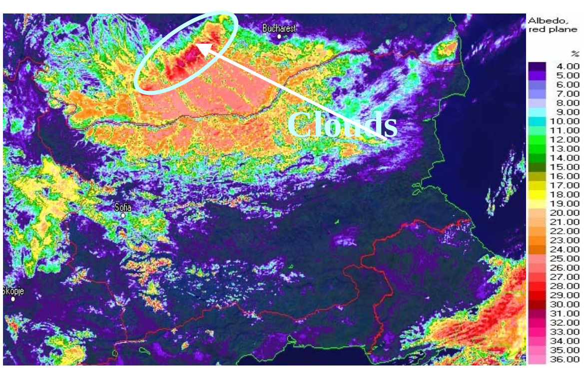
Snow is a collection of ice grains and air, and, when at 0 degrees C, it also has a significant fraction of liquid water. Snow also often includes particulate and chemical impurities - dust, soot, pollen and other plant material, and small amounts of the major cations and anions. Thus the optical properties of snow depend on the bulk optical properties and the geometry of the ice grains, the liquid water inclusions, and the solid and soluble impurities. (Dozier,1989)

In the visible and near-infrared wavelengths the optical properties of ice and water are very similar, so the reflectance and transmittance of the snowpack in this region of the electromagnetic spectrum depend on the wavelength variation of the refractive index of ice, the grain size distribution of the snow, the depth and density of the snowpack, and the size and amount of those impurities whose refractive indices are substantially different from those of ice and water. The reflectance of wet snow in the near-infrared is lower than that of dry snow, but mainly because of microstructural changes caused by the water, except in some narrow spectral regions where the optical properties of water are different than those of ice. Similarly, the reflectance and transmittance of clouds depend on the geometric thickness, the number density of the droplets, and their size distribution. (Dozier,1989)

The most important optical property of ice and water, which causes spectral variation in the reflectance of snow and clouds in visible and nearinfrared wavelengths, is that the absorption coefficient (i.e., the imaginary part of the refractive index) varies by 7 orders of magnitude in the wavelengths from 0.4 to 2.5 btm. (Dozier,1989)

Ice is very weakly absorptive in the visible (minimum absorption at 0.46 micrometer) but has strong absorption bands in the near infrared (near IR). The near-IR solar irradiance thus plays an important role in snowmelt and in the energy balance at a snow surface. The near-IR albedo is very sensitive to snow grain size and moderately sensitive to solar zenith angle (Warren at all, 1982). The visible albedo (for pure snow) is not sensitive to these parameters. Grain size normally increases as the snow ages, causing a reduction in albedo. If the grain increases as a function of depth, the albedo may suffer more reduction in the visible or in the near IR, depending on the rate of grain size increase. The presence of liquid water has little effect per se on snow optical properties in the solar spectrum, in contrast to its enormous effect on microwave emissivity. Snow albedo increases at all wavelengths as the solar zenith angle (fig.1 and 2).

Cloud cover affects snow albedo both by converting direct radiation into diffuse radiation and also by altering the spectral distribution of the radiation. (Warren at all, 1982)



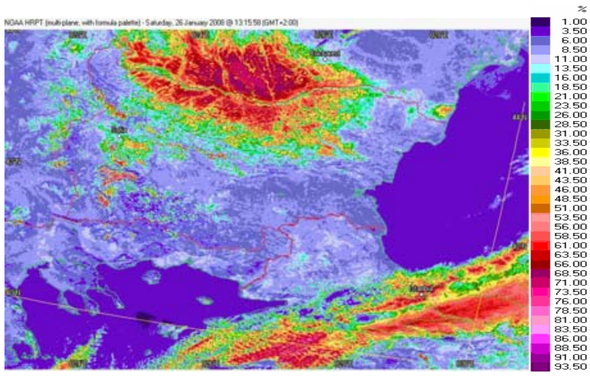


Fig. 1. Left - albedo dependence of the sun zenith angle and snow depth (channel 1, NOAA, 26.01.2008, 10:42 h)
Fig. 2. Right - albedo dependence of the sun zenith angle and snow depth (channel 1, NOAA, 26.01.2008, 13:15 h)

1.2. Spectral Reflectance of Snow

In the visible wavelengths ice is highly transparent, so the albedo of snow is sensitive to small amounts of absorbing impurities. In the near-infrared wavelengths ice is more absorptive, so the albedo depends primarily on grain size (Dozier, 1989)
Because snow/ice is so transparent in the visible wavelengths, increasing the grain size does not appreciably affect the reflectance. The probability that a photon will be absorbed, once it enters an ice grain, is small, and that probability is not increased very much if the ice grain is larger. (Dozier,1989) In the near-infrared, however, ice is moderately absorptive. Therefore, the reflectance is sensitive to grain size, and the sensitivity is greatest at wavelengths from 1.0 to 1.3 µm. Because the ice grains are strongly forward-scattering in the near-infrared, reflectance increases with illumination angle, especially for larger grains (Dozier, 1989).

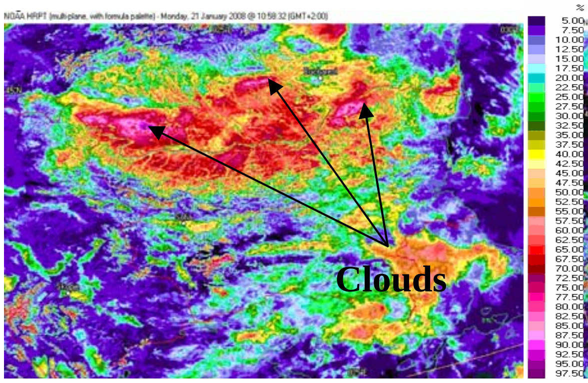
Because the complex indices of refraction of ice and water are similar, liquid water *per se* has little effect on the reflectance of snow. Except where meltwater ponds in depressions when melting snow overlies an impermeable substrate, or when rain falls on fine-grained snow. The decreases in reflectance that occur as snow melts result from the effective size-increase caused by the grain clusters that form in wet, unsaturated snow. These apparently behave optically as single grains. (Dozier,1989)

Although the reflectance in the visible wavelengths is insensitive to grain size, it is affected by two variables, finite depth and the presence of absorbing impurities (fig1, 2 and 3).

In the 8–14 µm region of the spectrum snow emissivity decreases with both increasing particle size and increasing density due to packing or grain welding; while snow emissivity increases due to the presence of meltwater (Salisbury, *et al.*, 1994). It is obvious that snow has lower temperature in infrared part of electromagnetic spectrum in comparison with surroundings (fig.10 and 11).

Water, ice, and snow generally have a high emissivity in 0.86 to 0.99 µm, across the thermal infrared region. Snow emissivity is in the range 0.9- 1.00 for all grain sizes and viewing angles. However, there is a conflict between the published theories of the emissivity of snow. Moreover, accompanying measurements show a decrease in emissivity in the presence of liquid water (Dozier and Painter, 2004).

Snow is unusual in that it has a high reflectance in the visible region (where most of the downwelling energy is during the day) very high in NIR and very low emissity in region around 3-5 µm. (fig.6). The near-IR albedo is sensitive to grain size and zenith angle; the visible albedo is sensitive to snow depth and impurities observed 30% differences in between clean and dusty snow. (Dozier and Painter, 2004; Hall et al., 1995). In additional, albedo in VIS is much higher then albedo in NIR at the same solar zenith angel (fig. 3 and 4). The albedo is dependent on snow cleanness and presence of different impurities and increase with increasing the depth and purity of snow. (fig.3,4).



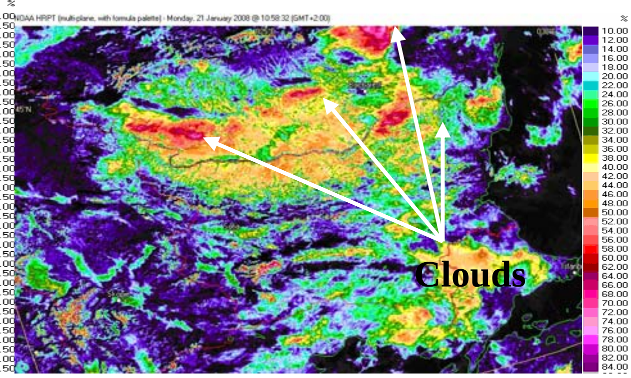


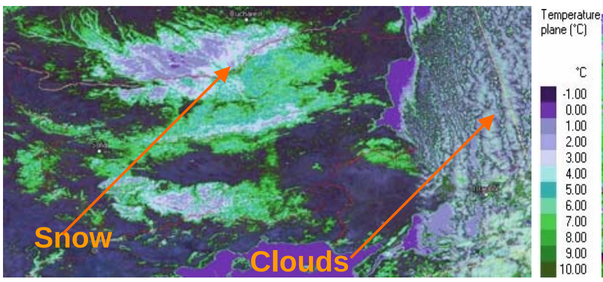
Fig. 3. Left -NOAA channel 1 albedo product; 21.01.2008, 10:58 h   0.58 - 0.68 µm
Fig. 4. Right - NOAA channel 2 albedo product ; 21.01.2008, 10:58 h 0.725 - 1.10 µm
Albedo in channel 1 (VIS) is much higher then albedo in channel 2 (NIR)

2. Primary results from monitoring of snow cover and snow melting processes using NOAA AVHRR (and MODIS) data

2.1. Distinguish between snow and cloud cover

In visible satellite images, clouds can usually be distinguished from snow by texture, but there is a many cases when distinguish between snow and clouds may be difficult and inaccurately. In the thermal wavelengths clouds may be either warmer or colder than the snow surface, but in most cases the snow and clouds have the same spectral characteristic. (fig. 9 and 10)

As is stated above, the snow has very low albedo (emissity), (around 0-6 %) in region around 3-4 µm, as the albedo decrease with increasing of snow depth (fig.6,8). The differences in albedo values between snow and cloud can be reached over 40 – 50 % (fig.6) In this region of electromagnetic spectrum, snow and clouds have different spectral signatures and consequently this wavelengths can be used for of snow and cloud cover distinguish.



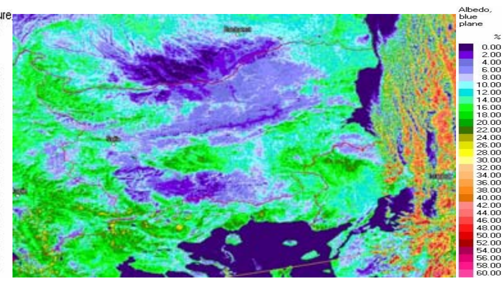
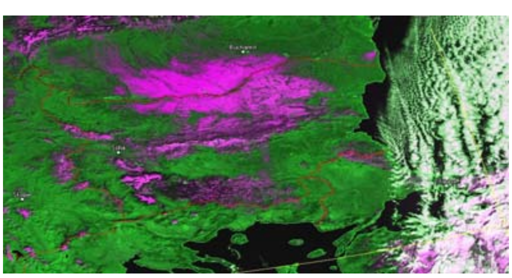


Fig. 5. Left - NOAA channel 3 temperature product, 30.01.2008, 10:50 h
Fig. 6. Right - NOAA image channel 3 albedo product, 30.01.2008, 10:50 h



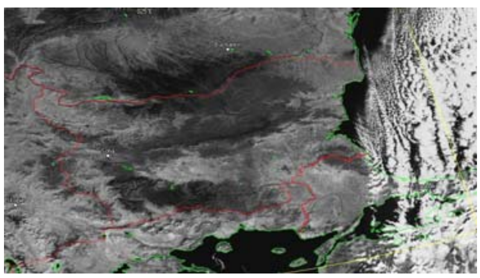
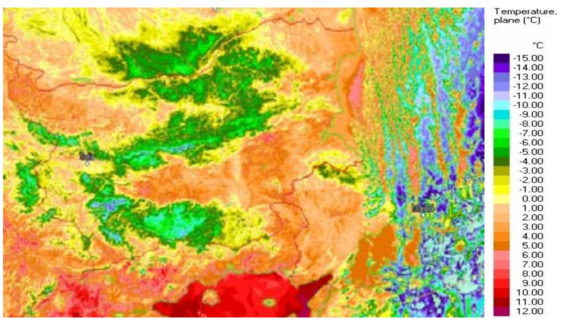


Fig. 7. Left - NOAA image, channel 1 and 3, 30.01.2008,10:50 h
Fig. 8. Right - NOAA image, channel 3, 30.01.2008,10:50 h



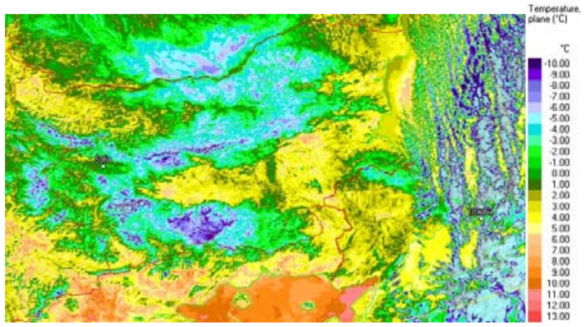


Fig. 9. Left - NOAA channel 4 temperature product, 30.01.2008, 10:50 h
Fig. 10. Right - NOAA channel 5, temperature pproduct, 30.01.2008, 10:50 h

2.2. Monitoring of snow cover and snow melting processes using remote sensing data and Normalized Difference Snow Index (NDSI)

Satellite image from NOAA AVHRR and MODIS are used for monitoring of snow cover and snow melting processes. Snow and clouds distinguish is done taking into consideration physical and spectral characteristics of ice (snow) and clouds.

For our purpose image products such as albedo, brightness temperature, density slice, NDSI ect. from NOAA AVHRR data are created.

Density slicing is a digital data interpretation method (image enhancement procedure), based on combining digital data (DNs) of different values within a specified range or interval into a single value. The density slice (also called "level slice") method works best on single band images (fig.13). The objective of density slicing is to deduce the number of grey scales in an image be redistributing the levels into given number of specified slices to facilitate visualization of features in the image (Cracknell *at al*, 1993).

A suite of normalized band differences for mapping snow (with Landsat TM band) are presented in Dozier (1989). The current scheme in NASA's Earth Observing System (EOS) applies this method to the MODIS (Moderate-Resolution Imaging Spectrometer) instrument for its standard snow map product (Hall *et al*. 1995, 2002). The NDSI helps distinguish snow from similarly bright soil, rock and cloud (Dozier, 1989). This has been shown to be an effective index for mapping snow cover in rugged terrain (Hall *et al*, 1995).

A normalized difference snow index (NDSI) is calculated from reflectance in bands at wavelengths where snow is bright (AVHRR band 1) and where it is dark (AVHRR band 3):

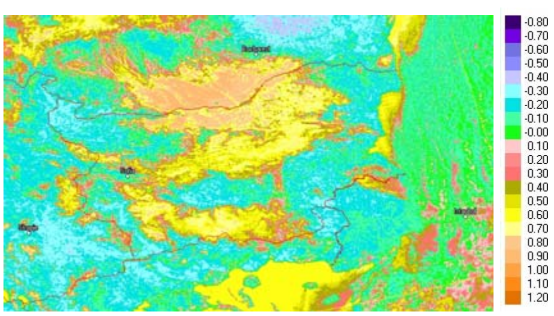
(1) NDSI = AVHRR band1 – AVHRR band3 / AVHRR band1 + AVHRR band3

For our purpose, the other NDSI products are proposed:

(2) NDSI = AVHRR band2 – AVHRR band3 / AVHRR band2 + AVHRR band3

(3) NDSI = AVHRR band2 + AVHRR band3 / AVHRR band2 - AVHRR band3

(4) NDSI = AVHRR band1 + AVHRR band3 / AVHRR band1 - AVHRR band3



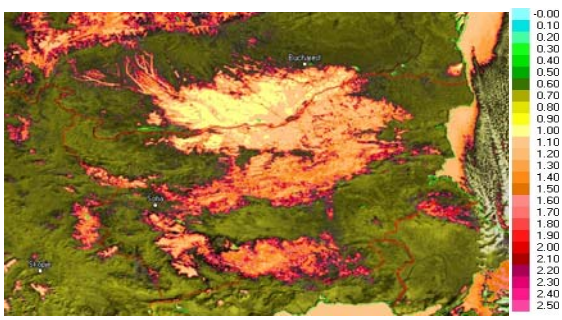


Fig. 11. Left - NOAA HRPT, 30.01.2008, 10:50:25 (GMT + 2:00), NDSI product (Channel 2 and 3)
A pixel is mapped as snowcovered when NSDI>0, formula (2).
Fig. 12. Right - NOAA HRPT, 30.01.2008, 10:50:25 (GMT + 2:00), NDSI product (Channel 1 and 3)
A pixel is mapped as snowcovered when NSDI>0.9, formula (4).

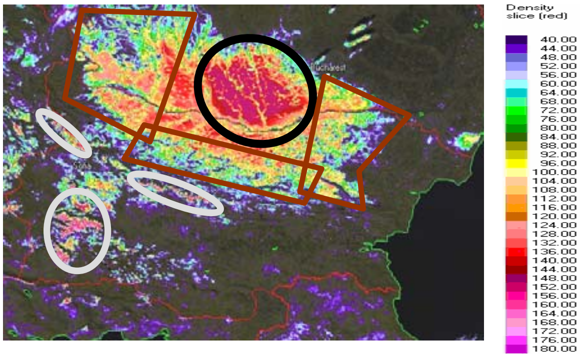
In additional, for satellite images analysis and interpretation are used image processing functions, such as image enhancement with different enhancement profiles. Such products and image processing functions are used for snowpack monitoring and mapping and determination of areas with snow melting processes and the areas with snow cover that is expected to hold longer. For visualization and better interpretation satellite images and products are integrated and GIS.

Image processing, interpretation and analyses shows that the areas covered with snow that is going to melt first are characterized in low albedo, higher temperature in the thermal region and low density slice. And vice versa, snow cover that is going to hold for a longer period of time is characterized with high albedo, high values of density slice, and lower brightness temperature.

It has to be noted that highest mountain region is not taken into consideration (in analysis), because it is obliviously that snow in these areas will melt in late springtime.The snow pack in the high mountain region is characterized with high albedo (in VIS and NIR), high density slice and very low temperate in thermal region (in comparison with surroundings), because of elevation, purity and depth.

The preliminary results obtained from snow cover monitoring and snow melting processes (after image interpretation and analysis) are presented on fig.13. On the image are shown areas with snow that going to melt first and the areas that is going to hold for a longer period of time.

Further down are shown a few chosen images for the period from 26.01.2008 to 25.02.2008. The snow melting process is presented on the figures 13,14,15, and 16.



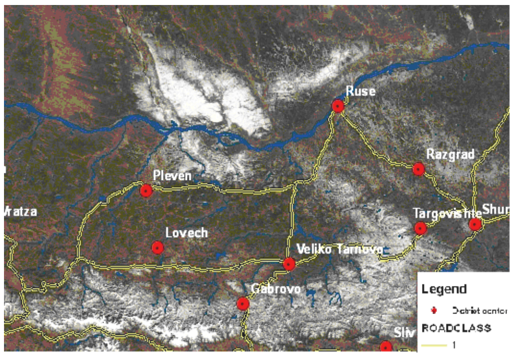
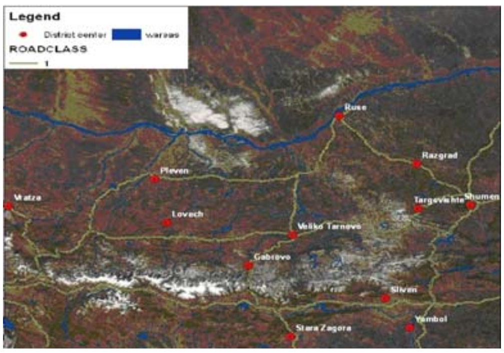


Fig. 13. Left - Channel 2 NOAA density slice product. 26.01.2008 13:15 h. The snow that going to melt first if framed in red rectangular, and the one that is going to hold for a longer period of time is circled in black ellipses. White circle shows the snow in the highest mountain areas

Fig. 14. Right - Snow cover on the territory on the country , 20.02.2008. MODIS image from USDA integrated in GIS. (http://www.pecad.fas.usda.gov)



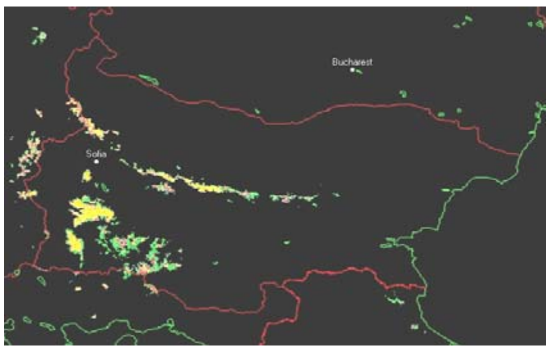


Fig. 15. Snow cover on the territory on the country, 22.02.2008. Image from USDA integrated in GIS (*http://www.pecad.fas.usda.gov*)

Fig. 16. Snow cover , 25.02.2008, NDSI product, NOAA image

2.3. Snow Water Equivalent

Snow Water Equivalent (SWE) is a measurement of the amount of water contained in snow pack. Snow Water Equivalent (SWE) is the product of snow depth and snow density.

(5) SWE (m) = snow depth (m) x snow density (kg/m^3) / water density (kg/m^3)

A satellite and variety of surface-based methods can be used to measure SWE, but because of the small penetration distance of light in the wavelengths where the absorption coefficients of ice and water differ, any information about liquid water in snow from multyspectral data is restricted to the near-surface layer (Shi, 1995).

Because of lack of data about snow density, for our purpose the theoretical is used. It can be seen because of small depth (fig. 17) and low SWE there is no floods hazard caused by snowmelt for existing environmental conditions. (Springtime floods with long duration in Danube river region caused by high flows in Danube catchment is not under consideration)

Attention has to be paid to south and south-western part of Bulgaria - here are located the highest mountain in Bulgaria with snow cover in the highest mountain regions between one and two meters.

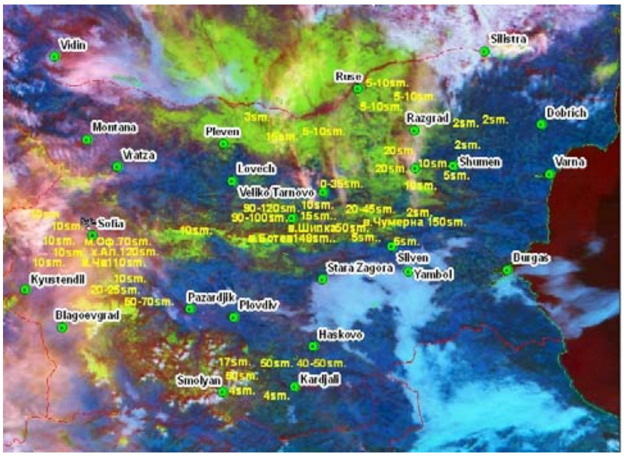


Fig. 17. Snows cover depth on 03/04.02.2008

Conclusion

The results obtained for snow cover monitoring and snow melting processes using AVHRR and MODIS data are presented. Satellite images, data products, meteorological forecast and ground data are used, as well as different techniques for image analysis and interpretation. An attempt for using the results for flood hazards is done. A snow AVHRR NDSI indexes for automated snow mapping procedure are created and proposed. There is a good correlation of primary results obtained and actual environmental condition. The accurate results require satellite data to be combined with weather forecast and hydro-meteorological ground data.

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