River Flow 2010 - Dittrich, Koll, Aberle & Geisenhainer (eds) - © 2010 Bundesanstalt für Wasserbau ISBN 978-3-939230-00-7

Space-time ice monitoring of Danube in Hungary by multiple web-cameras

G. Keve
Division of Hydrology, Lower-Danube-valley Environmental and Water Directorate (ADUKÖVIZIG), Széchenyi u. 2/C., H-6500 Baja, Hungary

ABSTRACT: In spite of the process of global warming, that can be concluded by analyzing the data of the past couple of decades; an unfortunate constellation of hydro-meteorological factors can anytime cause serious frosts, and consequently ice floods on River Danube. In 2001, based on earlier experience obtained in the 70s by conventional photography, a web-camera was installed on top of a high building at the riverbank at the town of Baja. Based on the first surveys success and their analysis 5 further cameras were mounted in 2008. The sites to be monitored in such a way are placed at 30-40 km distance from each other, so 130 km reach of the river could be observed. In January 2009 a two week long prevailing ice period was successfully recorded at the 5 sites. Coupled with morphological data as well as with the hydro-meteorological data of the observation period, even a primary analysis showed the potential to derive space-time characteristics of the floating ice, including size composition, motion and rearrangement due to secondary currents and occasional packing or release at places. Efforts are being done on quantifying the above mentioned features, furthermore, improving the recording quality.

Keywords: Ice flow, Floe, Web-camera, Monitoring

1 INTRODUCTION

The importance of exploratory work in the field of river ice has recently been intensified in the southern Hungarian reach of river Danube by using up-to-date technology. The reason for that, in fact, is that the most severe floods of the reach in the past were caused by ice jam (Lászlóffy, 1934). In the last 170 years serious ice flood occurred on Danube in 1838, 1839, 1850, 1876, 1878, 1883, 1891, 1920, 1923, 1926, 1929, 1940 and in 1941, and the highest ever experienced in 1956. This used to be so for two main reasons, out of which one is a hydro-meteorological, the other is a morphological factor. River training works in the investigated reach have been completed, only maintenance and small corrections are done from time to time (Keve, 2002).

By investigating the ice data of the river reach, though most of them are mainly simple estimation of the observer, some conclusions of the past can be drawn. The frequency of any kind of ice appearance decreased in the last 40 years (Figure 1). Even the date of the highest probability, when ice could be seen on the investigated area occurred earlier. It is between 14-19 January (26%) to see ice on the Danube at the highest chance, based on the period 1971-2009, while this value was 60% and occurred between 19-25 January in the first seven decades of the last century.

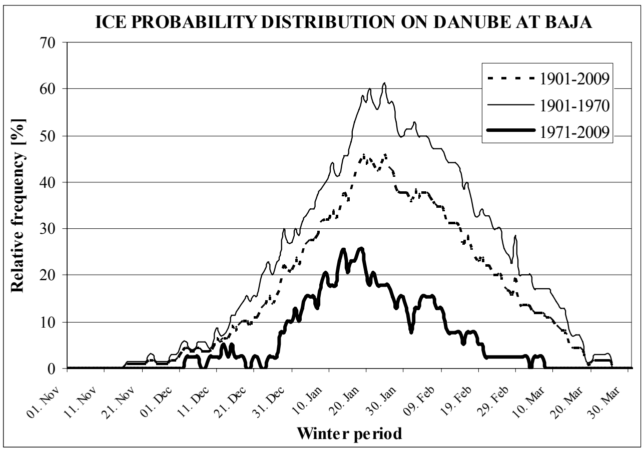

Figure 1. Probability of ice phenomena on Danube at Baja

In spite of the process of global warming, that can be concluded by analyzing the data of the past couple of decades, an unfortunate constellation of hydro-meteorological factors can anytime cause serious frosts, and consequently, ice floods.

Flood prevention and defence is one of the main tasks of the Hungarian water management service, therefore the importance of reliable hydrological observations is extremely high (Starosolszky, 1987). However, the fluvial ice monitoring is a field not easy to handle in hydrology. In many cases only estimations are done by the observers during frozen periods. But only objective measurements could provide data for detailed investigations of the whole freezing, floating and jamming processes.

As an initial step, in 2001, based on earlier experience obtained in the 70s by conventional photography, a web-camera was installed (Figure 2) on top of a high building at the riverbank at the town of Baja. Based on the success of the first surveys and their analysis 5 further cameras were mounted in 2008.

Figure 2. First web-camera at the bank of Danube

The sites to be monitored in such a way are placed at 30-40 km distance from each other, so an altogether 130 km reach of the river could be observed. As a fortunate occurrence, even in the first winter in January 2009 a two week long prevailing ice period was successfully recorded at the 5 sites. Coupled with morphological data as well as with the hydro-meteorological data of the observation period, even a primary analysis showed the potential to derive space-time characteristics of the floating ice, including size composition, motion and rearrangement due to secondary currents and occasional packing or release at places. Efforts are being done on quantifying the above mentioned features, furthermore, improving the recording quality thus the image processing results of the observations.

2 INSTALLATION OF WEB-CAMERAS

2.1 *Placing*

In 1978 Zsuffa wrote a technical study about the appropriate methods of ice measuring on rivers. It declares that there are two main tasks for proper ice observation.

One of them is the qualitative watching of ice, which is done by ice guard person in a way very similar all over the world. This is a rather subjective observation which is then coded and recorded in hydrological databases. Basically these data can be used later for further investigations. These information are mostly limited to the surroundings of gauges. Based on these one can see the appearance of ice, ice drift, stopping of ice floes, breaking up, ice jams, disappearance of ice. The percentage of ice cover zones to total area is also recorded, but it highly depends on the viewpoint and estimation ability of the observer.

Second is the qualitative measurement of ice phenomena. This technique is not really widespread. In this case based on measurements and counting objective quantities describe properly the observed ice phenomenon. Such quantities are the percentage of ice cover to the uncovered part of section, percentage of drift floe to the standing ones, velocity of drifting floes, ice surface discharge [m^2/s], thickness of ice, ice discharge [m^3/s] (Zsuffa, 1978).

This quantitative observation can be assisted with web-cameras in a very effective way, a task performed earlier by photo cameras. The way to make undistorted computer images from the pictures of any kind of camera by photogrammetric methods depends on the location observation point where the camera installed. The best would be a location in the middle of the observed section and to look perpendicularly at the river. In this case the perspective error would be minimal. Of course, satellite images or aerial photos would be fine to use, but they are still too expensive if we take under consideration the required resolution and frame-capturing frequency of the pictures.

A rule of thumb is that as observation height 5-10 % of the total width of river is sufficient for our purpose, but as close to the river as possible. The best installation is when the objective can see both river banks and the vision is right angle to the stream (Zsuffa, 1984). Out of this elevation some of the errors of low perspective can be eliminated (Figure 3-4). It is recommended that the quotient of the length of viewed river reach and the frame capturing time step is in proportion to the average surface velocity of the river, as in this case the surface velocity distribution can be easily determined (or estimated) from the two subsequent frames. In the investigated reach of Danube the average surface velocity is 0.8-1.0 m/s, thus a 60 m section which can be seen on both banks and 1 frame per minute must be enough for measuring conditions. If it is possible one should use marks on the banks to indicate the section, big enough in size to be recognized on the images. With this preparatory work, overlapping two subsequent pictures make easy to draw surface velocity distribution. If the displacement of a floe identified on both frames took 60 m the velocity would be exactly 1 m/s.

There are several limitations to install web-cameras on the banks of river, namely the electric supply and the network connection to transmit computer signal. Even at the best preparation and design it can happen that the electric supply will pause just when we would need the camera mostly. To avoid this UPS and separate electric connection is recommended. In our case it happened that the electricity was turned off in the whole building because of a serious flood inundating the place. It is better to think about these facts in the planning period and take prevention measures.

Figure 3-4. Different views at the same time and section

To place our camera in a proper place described above has a lot of practical obstacles. For example in flat lowland it is hard to find a high natural or artificial place on the banks where all conditions can be fulfilled. Grain towers, high buildings or large bridges along the river are the best places. Natural hills or highlands are good to make movies or take photos about the river, but the electric supply is hard to get if there are no houses in the vicinity. So to install web-cams is very difficult in most of the cases. Wireless connection can be used but sufficient and continuous electric supply is still crucial for these equipments. For outdoor cameras heating is a very important fact especially in cold winter just when we want to use them. Power is needed for signaling, zooming or moving of recently developed cameras.

The objectives of these outdoor web-cams sometimes become dirty, thus the lens require regular cleaning. The places which are difficult to reach even in summer can hardly have an access in a frozen winter. Snow or sleet are the worst cases when the cleaning must be taken.

If we can solve all the above mentioned problems and we have the best and only place, an antenna or any kind of structure can still form an obstacle for viewing our river, covering part of the vision. Wrong reflection of the sun or the water during most of the day also makes the work difficult. Due to these reasons even custom designed placing of cameras is recommended.

Recently Gálai (2010) investigated the distortion of such cameras in operation. In his work the perspective distortion and the camera's self-distortion were both analyzed. With simple linear algebraic methods all the distortions could be eliminated.

2.2 *Types of Web-Camera*

There are many web-cams available in the market, but the one we are going to use should be properly chosen for the above defined purpose. For quantitative basic monitoring even a simple fixed camera is sufficient, serving as a reference site. It is like a "0" point of a water level gauge, as for the rest of time this camera will continuously provide pictures exactly from the same viewpoint. However, experiments with movable and zoomable cameras proved the advantages of this new technology, too.

For example such an advanced technology camera was installed on the steel structure of a bridge right in the middle, facing upstream. Here the main stream is placed at the right bank which is on the left side in the camera's picture. But the ice drift occurred on the left and on the right side periodically. The turning and zooming facility made it possible to follow this alternation in the floes' behaviour. Naturally, we had to renounce some of the measurement information in favour of tracking the changes in the phenomenon.

The resolution of digital cameras becomes better and better, but we need to transfer the captured frames, which needs then larger and larger bandwidth. Transferring or FTP the pictures can be done online to several addresses at the same time. In fact, these are the main reasons underlining the use of webserver-cams. In this case there is no need for an extra PC to control the camera, instead, everything can be commanded from a remote place. Hopefully the progress in file and image compressing techniques will solve many of these problems. Furthermore, mobile phones can be soon applied for taking adequate pictures and making use of their fast, multiple and cheap forwarding capability.

A number of problems can be experienced during the operations of cameras. Insufficiently closed outdoor cover can offer hiding place for insects, which is hard to clean then. Pigeons, falcons can sit on the camera (shaking problem) if there is no higher place in the vicinity. Electrical short circuit can also make operating troubles. But the most significant problem in efficiently using the cameras is usually the occasional high limitation of the daytime visibility conditions by the actual weather.

During the night and in foggy situations or bad reflection conditions we have practically no information about the monitored river reach. As to our knowledge infra cameras for this particular purpose have not been developed yet, or if they have a camera handling more than 500 m distance must be rather expensive. Small capacity infra cameras with own infra lamp up to 10-20 m reach are far not sufficient for our goals.

2.3 *Advantages of online river observation*

Our first ice observing web-cam was installed in 2001. Since then many, not ice-related phenomena have been recorded, important also for river management purposes. For example a ship crashing a bridge pier and mortal canoeing tour accident were recorded. Based on our images the police could have a real picture about the accidents. Some oil spill pollution were also detected and the ship was identified which released its waste oil during the night. High-speed replay of movies about on significant flow regime variations could provide novel information, as well. Water quality experts tried to find correlation between the colour of water and its characteristic parameters. Water management and navigation experts, water police, catastrophe service, meteorology service (cloud and weather image) have been the main users so far. But some of the civil internet users have also utilized the operation of our online camera. Well before the widespread free internet IP telephone technology some local people waved their hands when passing by in a boat in front of the camera and talked on their mobile phone to send picture and voice at the same time to their friends or relatives even to a different continent. Moreover, people even from remote places visited frequently our web site and were happy to watch the river.

In the initial period right after the first installation ice phenomena occurred seldom and only for short time in the investigated Danube reach. These records were, nevertheless, sent to the University of Iowa for processing by PIV method (Jasek, 1999), to generate velocity vector fields based on the subsequent images. Unfortunately without knowing the exact position of the camera and some well identified reference points, further calculations could not be done (Figure 5). Ettema (2002) and Jasek (1999) investigated the relationship between surface velocity distribution, determined by ice web-cams and PIV (Particle Image Velocimetry) and the average velocity of the total cross-section. It is an important technique to discharge estimation of the river as there is hardly any method in icy conditions more reliable and feasible than that.

Kimura et al (2005) developed a method using current meters, remote water level gauging, wind sensors and web-cam to measure factors determining the velocity field in such a way estimating the discharge in a known cross-section.

Figure 5. PIV-reconstructed surface velocity vector field

To find a reliable relationship between the surface velocity distribution and cross-sectional average velocity needs more detailed investigations. Moreover, floes in high drifting time can clash to each other, disturbs the path and speed of the individual elements. It is, however, known that the displacement velocity surface of such inertial floating bodies does not entirely match the one of the water. Sokoray-Varga and Józsa (2008) used PTV (Particle Tracking Velocimetry) method in laboratory conditions to reconstruct surface flow fields. According to their experience there is always some slip of the tracers as compared to the underlying flow field, resulting in some error in the water velocity estimation.

When the floe drift is not significant, often just part of the section carries ice (usually in the main stream), so there is no velocity information about the rest of the section. Several years of own experience shows that evenly distributed floe drifts occur very seldom in the investigated reach of Danube.

Another experience is that the drift is a continuously space-time varying process, even in steady-state base conditions. This is why Zsuffa (1978) classified this phenomenon as an inherently stochastic process where the description and quantification can be done preferably by proper statistical parameters drawn from the measurements. The outcome of web-cam based monitoring should be with no doubt suitable for such a purpose. Up to now, however, a software ready to use for such a data processing and offering a complete statistical evaluation has not been known to the present author, not even safely estimating the ice cover percentage.

It is known how much well documented historical water level observations can be utilized by modern time processing technologies. It may be in a way similar with web-cam based ice monitoring, in which a primary task is to well document and archive prevailing phenomena both for present and hopefully much more advanced future processing and evaluation.

2.4 *One or more web-cameras*

The first experience with our single web-cam and the increasing number of arising questions made evident that the ice observation in time in one single section has to be extended in space. After seven years operation of our first web-cam an EU INTERREG III/A project provided good opportunity to develop our system with 5 more web-cams. By this a 130 km long Danube reach could be monitored (Figure 6).

All this provided a new, substantially more sound, at the same time more comfortable way to investigate fluvial ice processes. It made it possible to watch the whole reach on-line in real-time remotely from the Water Directorate headquarters. Thus decision makers were given a new reliable tool, compared to the past when subjective reports of ice inspectors (or dike keepers) formed the basis of decision making. Anyway, traditional observers walking along the river bank could collect locally instantaneous thus areally less precise information about the observed process. The decisions have serious economical effects as ice defence is a costly action. It means that ice breaker ships must be fuelled and moved with their stuff or at least they have to be kept ready to act. These costs were mostly saved even in the first winter after the installation of the new cameras. In fact, sufficient qualitative and quantitative information on the drifting floes in the monitored Danube reach were provided to the decision makers not to order redundant ice defence work. Furthermore, based on web-cam monitoring field inspectors can be directed to the icy hotspots of the river, eliminating longish walks all along the riverbank.

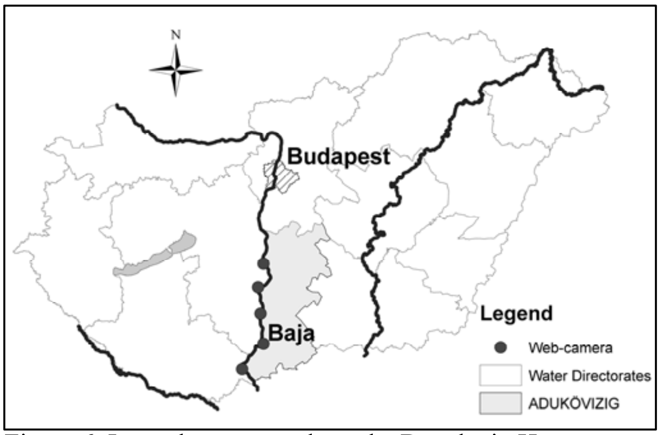

Figure 6. Ice web-cameras along the Danube in Hungary

To put web-cam information straight on the internet has got many advantages as well. The recorded images can be analysed anywhere around the world, involving a number of experts in such a way in real-time discussion, e.g. on the prevention of ice jam formation or opening of a developing one. Ice breaker ships can also be ordered based on sound decision.

Space-time ice monitoring gives a good opportunity to understand and investigate the phenomena at a higher level. Based on the new experience the ice forecast and ice modelling technology will hopefully also develop.

2.5 *Further developments*

Vuyovich et al. (2009) also studied how web-cameras can be used to investigate river ice processes. Hourly images were taken over three winters at the confluence of the Allegheny River and Oil Creek in Oil City. Each image was manually processed and classified according to surface ice conditions. This laborious analysis has to be automated as much as possible.

There are hotspots along the river where the floes could form junction. It would be good to install cameras at these spots, besides the ones at regular spacing. Furthermore, the monitoring system must also cover cross-country border regions as detailed investigations there need particularly high quality data. As an example to that, successful ice defence work in the investigated Danube reach has always depended on the good cooperation with Serbian partners next to the border.

Satellite images and infrared pictures will not be probably used in this field in the near future, but the chance of using them in the future is in scope.

To investigate the drifting processes environmental friendly floe painting would be a new way, first of all because the painted floe is much easier to identify on the pictures. This marking technology could be done e.g. from bridges. In this way the drifting speed and course could be monitored at least between web-cams.

A method is needed to measure floe width, because to do it from a ship is hard and too slow. If we only knew the thickness of ice the ice discharge could be calculated.

Implementing all the above mentioned developments the establishment of a warning system would be the ultimate goal. Such warning systems work on airports where cameras watch and record all the actions. An automatic software checks the difference between sequenced pictures, and if e.g. a luggage is left alone somewhere an alarm signal warns the guards.

3 OBSERVATIONS

3.1 *Typing Tables*

A lot of conditions influence the ice forming on the investigated reach of Danube. As was mentioned in the introduction, ice development is influenced mainly by hydrometeorological processes. River training and the resultant river bed morphology as well as other anthropogenic impacts affect ice phenomena. Such effects are e.g. the outfalls of waste water treatment plants and a nuclear power plant cooling water system operated within the investigated area, the latter giving the most considerable thermal pollution to the river. This outfall is situated at 30-40 km upstream, responsible for moat of the melting of the blocked ice (Keve, 2003).

Hirling (1981) developed a simple ice forecasting method for the Hungarian rivers. This is done by the cumulative sum of negative daily average air temperature. The sum contains the daily temperatures below zero with no positive temperature interval in the period. Though this method has been proven reasonably good, but the occurrence of ice is not the function of the local temperature, only. For the Danube section at Baja approximately -70 ˚C negative sum of air temperature and river water temperature below 0.5 ˚C must prevail to have even a piece of ice. The negative sum must consist of elements cooler than -5 ˚C. If the daily average higher than -5 ˚C no ice occurs even at higher negative sum.

In some cases there are floes which formed in upstream side-branches of the river or released from reservoirs. To forecast this kind of drifting has not been conceived yet. Upstream barrages on river Danube have got their own operational rules. They generally release ice from the upstream part at melting or breaking-up time. These kinds of floes slowly disappear then while moving downstream.

Unfortunately the hydrological service does not record these different types of ice phenomena. The only traditionally available information is to note the presence of near-shore ice, drifting floe, blocked floe and ice jam. These qualitative data, though useful to know, do not give room for further quantitative analyses.

Air and river water temperature data are usually accurate enough to do calculations and forecast on the ice forming or the probability of occurrence. These methods could be hopefully further improved by using the records of web-cams from a longer river reach.

3.2 *Experiences*

Using even one single camera offers a huge advantage as the whole ice forming and melting period can be followed in the viewed section. Multiple cameras are of course even better so it is worth searching on the internet and find shared web-cams. Some of them can provide useful information for our research. Once it happened that a city site camera in Budapest helped us to identify ice at that section of Danube. Now, with our installed web-cam system the situation is even better. According to our experience there are mainly three types of drifting floe at the Baja section of River Danube.

In the first case a long reach of river freezes at the same time. This type of freezing has got huge (football field size), thin and sharp edged floes. These big floes then soon brake apart by crashing bridge piers of or river training works. If the navigation did not stop yet even the waves generated by the ships can destroy these ice floes. Waves induced by the wind can also crumble the ice, because of which these great floes occur mostly early in the morning after a calm cold night. In fact, the calm but chilly weather can freeze the over-cooled water on large surfaces.

In the second case the ice forms in the river bed. It can be either river bottom ice or floes detaching from the bank. In this situation the floes are not always flat, but under the water they are cone-shaped. Naturally freak forms and colours can be also present. The colour depends on the material where the water got frozen. Suspended ice pieces are in the water body. This means that buoyancy force can lift up the ice mixed with river bed material but not able to keep it on the surface. These blocks flow in the middle of river downstream and can seldom be seen on the surface.

In the third situation the floes form in the upstream regions of the river or in side branches. The floe sizes are very different, but the edges of them keep debris ice. These small broken ice pieces are originated from the great number of crashes between floes. Big floes are not flat because they are usually formed from small floes.

In the Hungarian water management practice the drifting floe is characterized primarily with its estimated percentage to the total section width. From the recorded movies it is clear that the distribution of floes changes dynamically in time. It has daily and even smaller scale quasi-periodical changes. Therefore a fast estimation can not be correct, but an observer person can not spend much time in a section. The drifting has got the same space-time characteristics as the stream velocity. As traditional velocimetry in a measurement point can not be shorter than 1 minute, the floe observation could be handled in the same way.

Next, the observer usually views the river from a lower altitude place and is not able to distinguish stopped ice from the moving one. So he or she can easily overestimate the drift flux. For this reason automatic image processing of the pictures of web-cams is recommended. Based on this

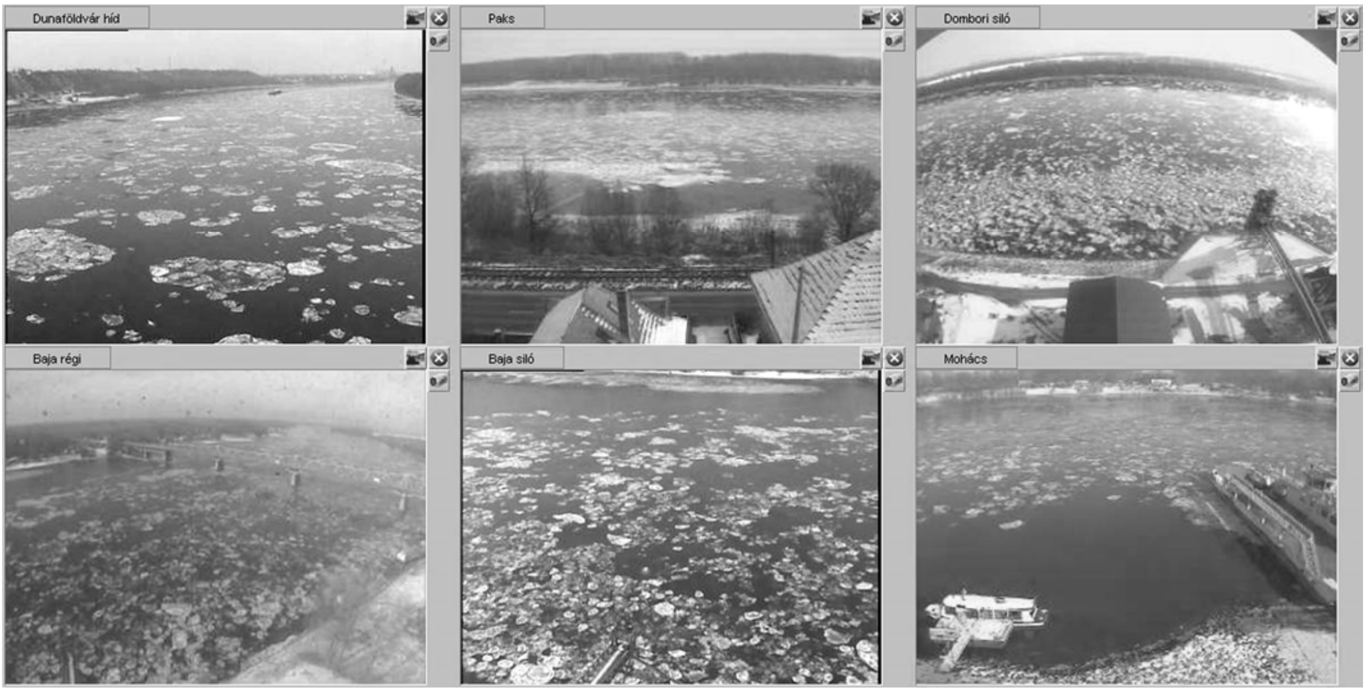

Figure 7. Pictures of the web-cam observation system

In Figure 7 the third case is presented. Six pictures were taken at six different sections of the river at the same time. From left to right and from top down the images represent the downstream flow. Upstream the floes are big but at the most downstream section they are already broken into pieces and almost disappear. There are 120 km between the site of the first and the last picture. In our example the coming ice in fact met a warm melting weather.

Any combination of the described three base types of ice can occur. The distinction of types can help to classify ice phenomena and can lead us to make accurate forecast for them.

process hourly statistics can be done providing more acceptable results.

3.3 *Hydrodynamic cases*

In spite of the new installation of cameras even in the first winter some hydrodynamic cases were recorded. All of these recorded movies about ice on River Danube were investigated. Experience was collected in a table where the rows represented the places of cameras and the columns showed the time. With no exception, in all the sections a daily periodicity was detected. Drifting in the morning was always more intensive than in the afternoon.

Uniform distribution of floes in the investigated sections occurred very seldom, mostly the main stream conveyed the ice pieces downstream.

But in some cases the drift changed its structure and from one side of the river it moved to the other side. The main stream follows the concave bank as was expected, and floes are conveyed here in most of the time. Though the reason is not exactly clear, in certain cases the floes moved just at the convex bank. There were cases when there was near-shore ice on both sides in the same manner, and nothing was seen in the middle of river.

Ships or ferries waiting in front of the cameras also formed obstacle against drifting floe. Arched jam developed suddenly and helped to investigate this process. This real phenomenon could help us to understand the developing stage of ice jams, to formulate the defence against them and to model all this complexity.

4 RESULTS

Although only two week long prevailing ice period was successfully recorded by our web-cams at 5 sites in the first winter, nevertheless, coupled with morphological data as well as with the hydro-meteorological data of the observation period, even a primary analysis showed the potential to derive space-time characteristics of the floating ice, including size composition, motion and rearrangement due to secondary currents and occasional packing or release at places. Efforts are been done on quantifying the above mentioned features, furthermore, improving the recording quality. As a summary promising experience can be reported about the web-cam monitoring of rivers, for which new ways of observation and investigations have been implemented.

REFERENCES

Ettema, R., Muste, M., Kruger, A. 1999. Ice Jams in River Confluences. CRREL Report, US Army Corps of Engineers

Ettema, R. 2002. Review of Alluvial-channel Responses to River Ice. Journal of Cold Regions Engineering, Vol. 16, No. 4.

Gálai, A., 2010. River Ice Inspection by Webcameras. Periodica Polytechnica – Civil Engineering, 54(2). in Press

Hirling, Gy. 1981. Forecast of the ice phenomena in river Danube and Tisza. VIZDOK. Budapest. (In Hungarian)

Keve, G. 2002. Improvement and up-to-date development of ice observations. Vízügyi Közlemények, 3. (In Hungarian)

Kimura Y., Iida, S., Mori H., et al. 2005. River flow information system with RF current sensors, Yokogawa Denshikiki Co., Ltd

Lászlóffy, W. 1934. Ice conditions in rivers, in particular in river Danube in Hungary. Vízügyi Közlemények,. 3. (In Hungarian)

Jasek, M. 1999. LSPIV and Numerical-Model Estimation of Yukon River Discharge During an Ice Jam Near Dawson. Iowa University.

Sokoray-Varga, B., Józsa, J., 2008. Particle tracking velocimetry (PTV) and its application to analyse free surface flows in laboratory scale models. Periodica Polytechnica – Civil Engineering, 52(2), 63-71.

Starosolszky, Ö. 1987. Ice phenomena and ice conditions in the Hungarian rivers. ÁRVÍZVÉDELEM, OVH. (In Hungarian)

Starosolszky, Ö 1969. Ice in hydraulic engineering. VITUKI. (In Hungarian)

Vuyovich C. M., Idia, H., Daly, S. F., Gagnon, J. J., Weyrick, P., Zaitsoff, M., 2009. Monitoring River Ice Conditions Using Web-Based Cameras, J. Cold Reg. Engrg. Volume 23, Issue 1, pp. 1-17.

Zsuffa, I. 1978. Hydrological measurements: ice observation. Vízügyi Műszaki Segédlet, VMS 231/6-T/78.01/G70. (in Hungarian)

Zsuffa, I. 1984. Applied hydrology. Tankönyvkiadó. Budapest. (in Hungarian)