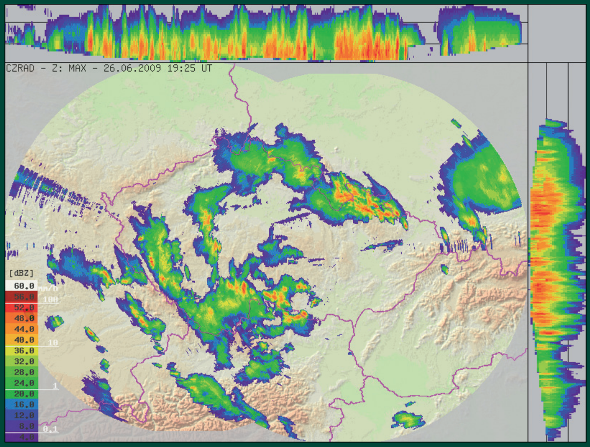
Workshop Proceedings

INTERNATIONAL
WORKSHOP
November 1 to 2, 2010



# EARLY WARNING FOR FLASH FLOODS

Organized by the Czech Hydrometeorological Institute
and the Czech National Committee for Disaster Reduction

Český hydrometeorologický ústav
Český národní výbor pro omezování následků katastrof

# EARLY WARNING
# FOR FLASH FLOODS

## International Workshop

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Editor Ivan Obrusník

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# Contents

### International Workshop

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## Foreword

Flash Floods (FFs) belong to the most destructive types of natural disasters. They might strike with little or practically no warning and could cause losses of lives. The economic losses of FFs by far outweigh investments to prevent or mitigate disasters. They are usually triggered by extreme cloudbursts and storms. Combating FFs is increasingly becoming a high priority in many countries. The losses of lives and property are unacceptable at a time when appropriate technologies and know-how are available to prevent FFs turning into disasters. The Czech Republic was hit by series of flash floods on very large area during the last summer. This disastrous series of FFs showed many problems connected with the speed and very local character of such events. To face better to such dangerous and fast events it is necessary to improve the whole chain beginning with forecasting and warning, followed by dissemination and communication of this information to emergency system at different levels and finally to the prepared and trained public. As FFs have been appearing more and more frequently in other European countries as well as in other parts of the world gathering experienced people in FFs from more countries can always be very helpful.

The special international workshop devoted to the problems of Early Warning for Flash Floods took place in the Czech Hydrometeorological Institute (CHMI) in Prague on November 1-2, 2010. The workshop was organized jointly by CHMI and the Czech National Committee for Disaster Reduction within the activities of the European Network of National Platforms (ENNP) gathering national platforms from France, Germany, Poland and the Czech Republic. The aim of the Workshop was to put together experienced people from the European Network of National Platforms (ENNP) countries with a representative of the United States. Participants in the workshop directly involved in facing FFs like forecasters from NMHSs and operational specialists and crisis managers from Civil Defense or Fire and Rescue Services, regional and local administration and the public could find possibilities of improvement of efficiency and diminishing an impact of such fast and dangerous events like flash floods. A comparison of existing systems for early warning and protection against FFs in ENNP countries and the USA stimulated discussion aiming to find significant improvement of early warning, dissemination and preparedness for these extremely quick floods. The role of national platforms for disaster risk reduction had been stressed and recognized. The activities of the platforms should be directed towards modern and complex protection against FFs leading to minimization of losses of lives and property in their respective countries.

Early warning for flash floods has proved to be very important and at the same time relatively difficult especially with respect to the speed of such floods. Many problems related to flash floods are common and very interesting for specialists not only from countries represented at the workshop but also for many others. Eight participants provided only abstracts gathered in materials available to the workshop. 10 participating authors agreed with a presentation of their contributions as full papers in this collection, French authors joined their contribution into one paper prepared by F. Gerard. I hope this collection of full papers will be very useful to the whole disaster reduction community.

Ivan Obrusník, Chairman of the Organization Committee

# NATIONAL WEATHER SERVICE FLASH FLOOD WARNING PROGRAM

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## ABSTRACT

Timely Warning for flash flooding requires a well-integrated data, modeling, forecast, and dissemination system. The various data systems, models, forecast techniques, and dissemination approaches currently used and under development in the U.S. will be discussed. Specific topics covered in this overview will include: IFLOWS systems, Precipitation Estimation, Precipitation Forecasting, Ensemble Information, Flash Flood and Headwater Guidance, Site Specific Models, Distributed Model Application, Role of the Forecaster and Forecaster Tools, Coordination, Decision Support, and Warning Dissemination. Also, information on the performance of the NWS Flash Flood Warning program will be presented.

The presentation will also summarize outreach and education efforts being undertaken by the National Weather Service and others. This will include the addition of a Service Coordination Hydrologist at each River Forecast Center, use of Customer Advisory Boards, regional and national workshops, training exercises, and production and dissemination of outreach and education materials.

## 1. INTRODUCTION

Effective warning for flash flooding is extremely difficult given the localized nature and rapid onset of intense rainfall and the fast hydrologic response of small basins. Flash floods can occur within minutes or a few hours of excessive rainfall. All the steps in the warning process need to be optimized so they take the least amount of time possible. These steps include: computing the rainfall, modeling the basin response, analyzing the situation, communicating the warning message, and completing life saving actions such as evacuations. For warnings to be effective, only a few precious minutes are available to complete each of these steps. In the United States, progress continues on tools and techniques to improve the end-to-end flash flood warning process (Office of Hydrologic Development 2010).

## 2. COMPUTING THE RAINFALL

The National Weather Service (NWS) relies on a combination of satellites, radars, and gages to provide near real-time rainfall estimates for flash flood forecast and warning. Satellite data are used in some mountainous areas where there are gaps in radar coverage. A national radar network provides updated rainfall estimates (rainfall rates and accumulations) every 4.5 to 6 minutes. Every hour, an updated radar rainfall bias is calculated from radar/gage data pairs. Radar rainfall data are transmitted from the Radar Product Generator computer to Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs) and made available publically in real-time via the internet. Rain gage data, transmitted on a fifteen minute and hourly frequency, includes Automated Surface Observing System (ASOS) gages located mainly at airports and state or locally-operated mesonets that share their data with the NWS.

Substantial resources are dedicated to improving radar rainfall estimates. Over the next 2 years, the radar network will be upgraded to add dual polarization capability. Multi-parameter estimates with polarimetric radar have the potential to substantially improve the accuracy of radar rainfall estimation compared to single polarization radar (Ryzhkov 2005) (Istok 2009). A system for development and real-time testing of enhancements to single-polarization radar is currently in use in some field offices.

In 1979, the NWS first began development of a prototype Integrated Flood Observing and Warning System (IFLOWS) with the intent to susbstantially reduce annual loss of life, property damage, and disruption of commerce and human activities due to flash flooding. IFLOWS consists of rainfall and stream gages reporting to local base stations every 5 to 15 minutes. The data are collected centrally on NWS servers via a wide area network to compute 15 minute or longer rainfall accumulations and track river stages. Because the all-weather gages are solar powered and report via radio, they can be deployed in remote areas prone to excessive rainfall. Today, numerous communities, state and federal agencies are now linked in a wide area communications network using this technology. This Automated Flood Warning Systems (AFWS) (see <http://afws.erh.noaa.gov/afws/national.php> and <http://www.hydrologicwarning.org>) network connects numerous local flood warning systems and integrates and shares information from 1700 sensors across 12 states.

Forecasters often issue flash flood warnings based solely on the rainfall intensity and rainfall accumulations being reported by radar and mesonets. To enhance lead time, forecasters incorporate short term forecasts of rainfall. To aid local forecasters, the National Centers for Environmental Prediction routinely disseminate quantitative precipitation forecasts (QPF), some specifically for rainfall capable of causing flash flooding (see e.g. <http://www.hpc.ncep.noaa.gov/qpf/excess_rain.shtml> and <http://www.hpc.ncep.noaa.gov/qpf/qpf2.shtml> ). Forecaster understanding of the weather patterns and trigger mechanisms causing the heavy rainfall is helpful. The NWS calls this 'situational awareness' and provides training through workshops and web-based modules (see e.g. <http://www.meted.ucar.edu/topics_hydro.php> and <http://www.erh.noaa.gov/bgm/research/ERFFW/>. Forecasters can often make short-term forecasts (Fig. 1) of rainfall with a fair degree of accuracy using the projected evolution of the mesoscale forcings, identifying telling trends in the radar patterns, and understanding conceptual models of convective storm archetypes.

The NWS is also improving quantitative precipitation estimates (QPE) and generating automated 0-6 hour QPF using multi-sensor approaches focused on high-resolution integration of radar, satellite, mesoscale models, surface observations and statistical techniques. [Note: QPE is an estimate of recent precipitation. QPF is a forecast of future precipitation.] An ongoing collaboration among NWS, Institute of Atmospheric Physics ASCR, and Czech Hydrometeorological Institute researchers has resulted in prototype real-time systems for short-range radar-based QPF (Kitzmiller 2010).

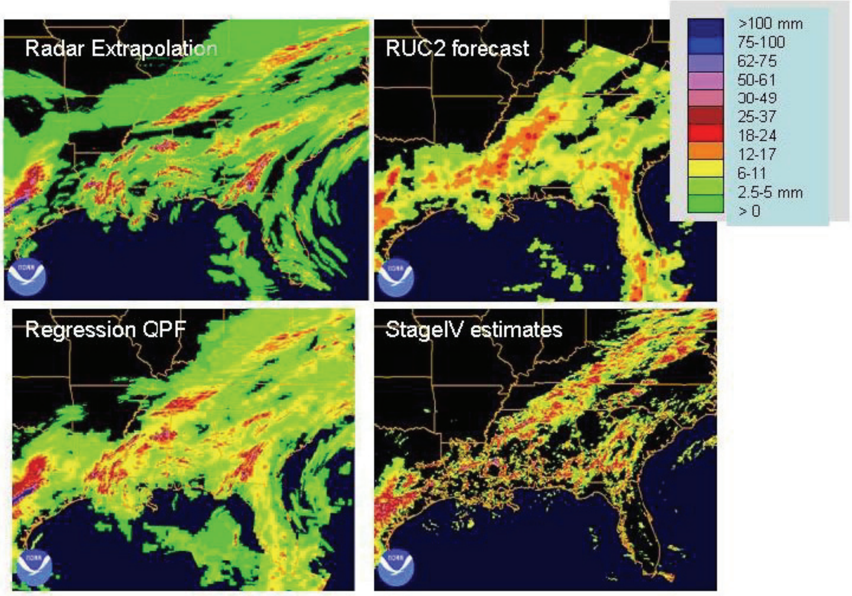


*Fig. 1. Comparison of three short range 6 hour precipitation forecasts over the southeast U.S.A. for the period 1800-0000 UTC, 16-17 May 2009. Forecasts are (upper left) radar extrapolation; (upper right) RUC2 mesoscale model; (lower left) regression based statistical forecast technique.*
*Verifying 6 hour rainfall is at lower right. (Kitzmiller 2010)*

## 3. MODELING THE BASIN RESPONSE

How much rainfall is needed to generate a flash flood? The answer is not straightforward. First, one must define what is meant by a flash flood. Second, the rainfall necessary to produce flash flooding depends on many variables such as previous rainfall (i.e. antecedent conditions), basin size, slope, soil type, urbanization (i.e. impervious area), and vegetation. In use for many years at the NWS, forecasters still depend heavily on Flash Flood Guidance (FFG) and Headwater Guidance (FFH) issued by the RFCs (Ostrowski 2003). FFG, updated 1 to 4 times a day, gives an estimate of the rainfall required in a 1-, 3-, 6-, or 12- hour period to initiate flash flooding on an un-gaged small stream typical of that area. When a new FFG is issued, forecasters and other users such as local emergency officials can examine the guidance before heavy rain begins and have a good estimate for how much rain is needed to trigger flash flooding in their area. Most flash flood warnings in the U.S. today are issued based on rainfall observations (accumulations and intensity), forecaster's short-term estimate of additional rainfall that may fall in the next 30 minutes or so, and Flash Flood Guidance. A recent enhancement in FFG has been to issue higher resolution guidance on a 4km grid as seen in Figure 2. Headwater Guidance is computed in a similar way, but is derived for a gaged point on a specific headwater stream with known antecedent channel contents and a defined flood level. For selected gaged points on small streams, WFOs with assistance from the RFCs, have calibrated and implemented Site Specific lumped hydrologic models running at one hour time steps.

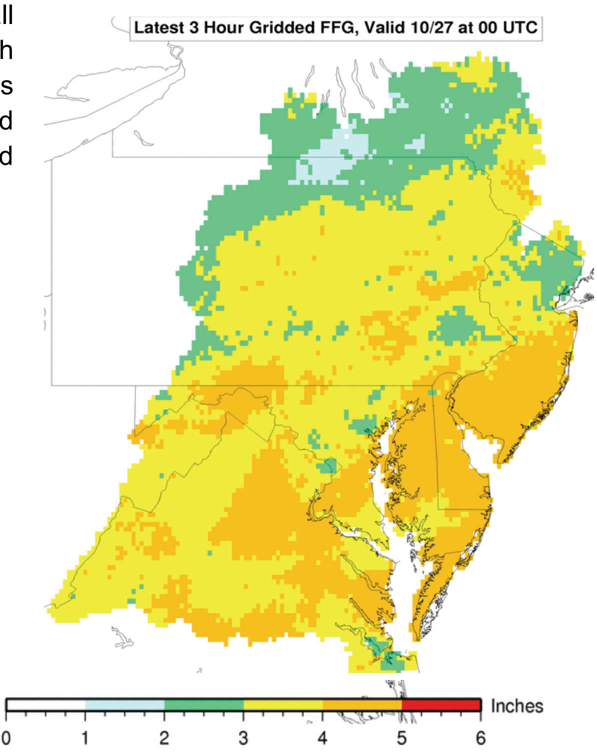


*Fig. 2. National Weather Service 3-hour Flash Flood Guidance on a 4x4km grid for the Mid-Atlantic region.*

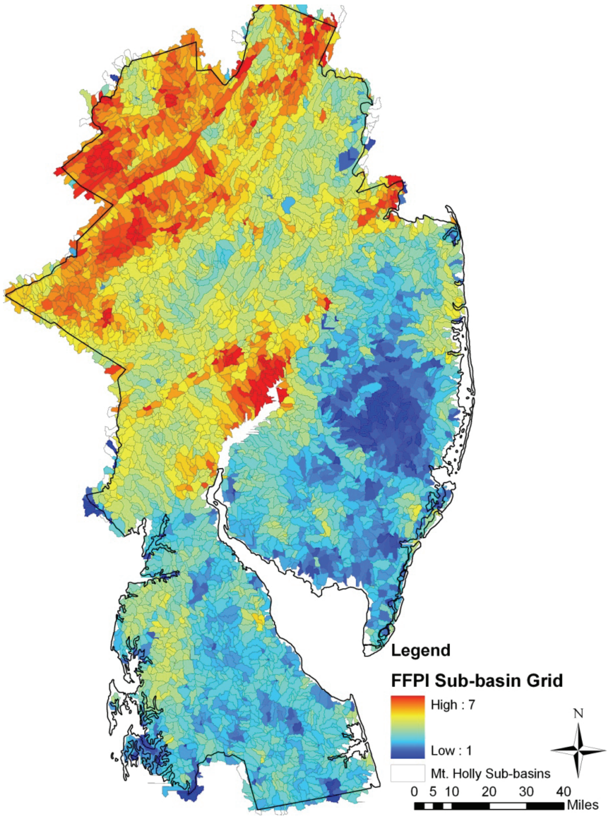
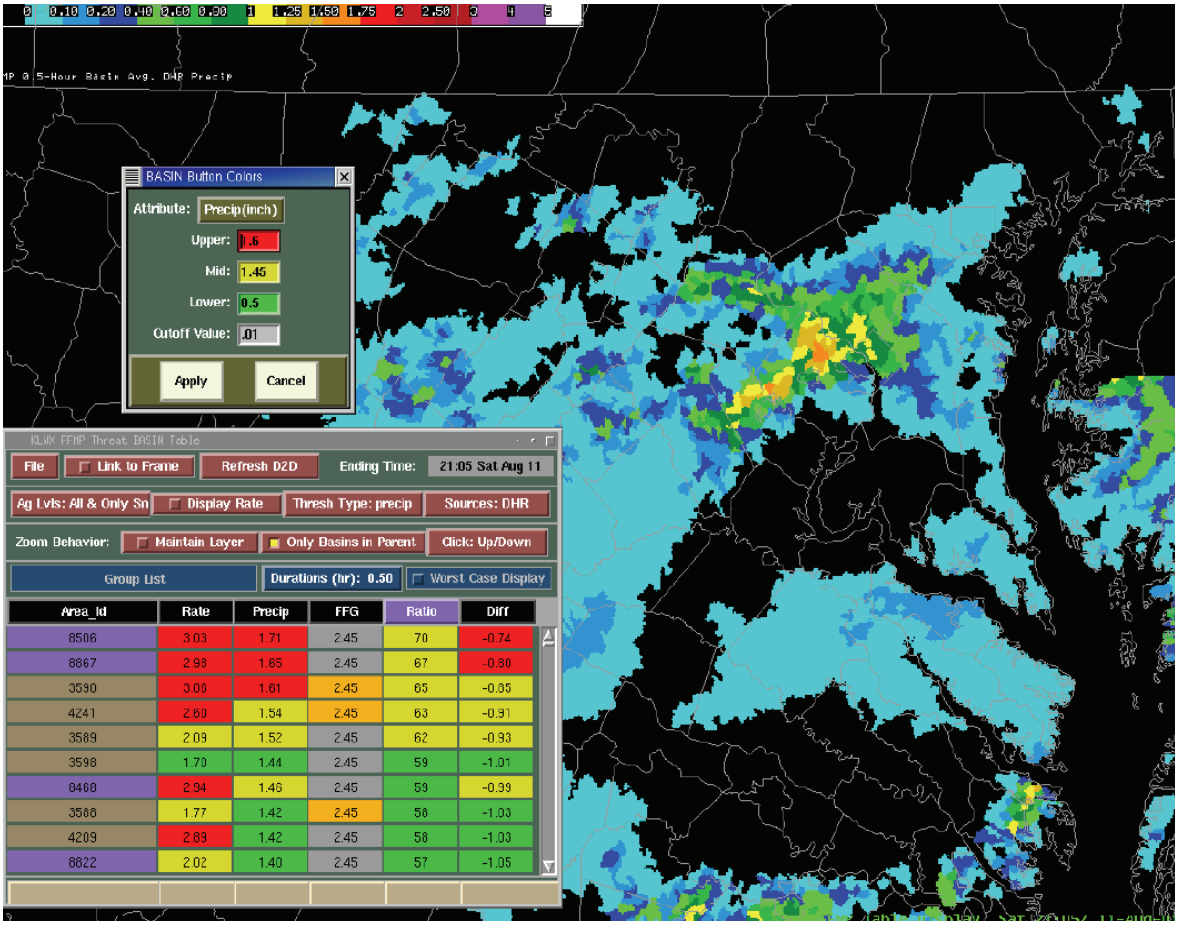


*Fig. 3. Flash Flood Potential Index (FFPI) for the area surrounding Delaware Bay and the New Jersey coastline extending northwest to the Pocono/Catskill mountains. Higher values near the center are the result of the urbanized areas in and around the city of Philadelphia, Pennsylvania. Lowest values near the coast are the result of sandy soils and flat terrain.* (<http://www.erh.noaa.gov/bgm/research/ERFFW/posters/kruzdlo_FlashFloodPotentialIndexforMountHollyHSA.pdf>)

New tools for modeling the basin response are being developed and tested. These include distributed hydrologic models. One interesting approach is the Distributed Hydrologic Model Threshold Frequency Approach (DHM-TF) (Reed 2007). The distributed model is executed using historical data and then frequency distributions are determined from the modeled flow at every grid cell in the basin, whether gaged or not. When a new event occurs, the simulated flow at each grid point is compared to the historical frequency distribution in order to estimate the flow return period. Warnings could then be issued based on an established flow return period threshold for that region that has been associated with flash flooding in the past. For this approach to work, computer resources must be sufficient to provide frequent updates and generate the output displays for forecaster analysis. Another approach originally developed for use in mountainous areas and now being tested in other areas is the Flash Flood Potential Index (FFPI). FFPI is a Geographical Information System (GIS) based approach to map the relative threat of flash flooding based on factors such as terrain slope, land usage, soil type, etc. Such maps (Fig. 3), when overlaid with precipitation estimates can help forecasters quickly identify the highest threat areas where warnings should be issued. A third approach being applied in some areas is a physically-based Kinematic Runoff and Erosion Model (KINEROS) (see <http://www.tucson.ars.ag.gov/kineros/> KINEROS is an event oriented, distributed, physically-based model developed to simulate the runoff response in basins having predominantly overland flow. KINEROS compliments existing modeling tools by providing information beyond the simple issuance of a flash flood warning, such as how high the water will get at the specified outlet or for any channel model element, when the worst flooding will take place, and what will be impacted (Schaffner 2010).

## 4. ANALYZING THE SITUATION

For timely decision making, the forecaster needs an integrated set of tools to perform synoptic and mesoscale analyses, monitor rainfall and stream stages, make short-term forecasts, evaluate flash flood threat, and issue warnings and statements. The tools should be optimized so they provide the needed information without overloading forecasters with too much information. The NWS uses several tools: Display Two Dimensions (D2D) is a graphical software application used to monitor observation data and perform synoptic and mesoscale analyses of model data. WFO Hydrologic Forecast System (WHFS) provides graphical tools to monitor stream and river gages and tools for issuing hydrologic products data (see <http://www.weather.gov/oh/hrl/whfs.htm>); Flash Flood Monitoring and Prediction (FFMP) is a tool specifically designed to help forecasters monitor and evaluate the flash flood threat and decide whether or not to issue flash flood warnings (Smith 2000; Filiaggi, 2002)(see <http://www.nws.noaa.gov/mdl/ffmp/index.php?L=5>). FFMP provides displays, similar to the one shown in Figure 4, comparing observed and predicted rainfall to flash flood guidance for each small basin, and provides information on the names of impacted small streams for inclusion in the text warning. Another tool, Warning Generation for AWIPS (WARNGEN) composes the warning messages. Forecaster training along with the implementation of FFMP has been credited with improving flash flood warning accuracy and lead time.



Attribute: Precip(inch)

Upper: 1.6

Mid: 1.45

Lower: 0.5

Cutoff Value: .01

Ending Time: 21:05 Sat Aug 11

☐ Link to Frame

Ag Lvls: All & Only Sn

☐ Display Rate

Thresh Type: precip

Sources: DHR

Zoom Behavior: ☐ Maintain Layer ☑ Only Basins in Parent

Durations (hr): 0.50

☐ Worst Case Display

| Area_Id | Rate | Precip | FFG | Ratio | Diff |
|---|---|---|---|---|---|
| 8506 | 3.03 | 1.71 | 2.45 | 70 | -0.74 |
| 8867 | 2.98 | 1.65 | 2.45 | 67 | -0.80 |
| 3590 | 3.06 | 1.61 | 2.45 | 65 | -0.85 |
| 4241 | 2.60 | 1.54 | 2.45 | 63 | -0.91 |
| 3589 | 2.09 | 1.52 | 2.45 | 62 | -0.93 |
| 3598 | 1.70 | 1.44 | 2.45 | 59 | -1.01 |
| 8468 | 2.94 | 1.46 | 2.45 | 59 | -0.99 |
| 3566 | 1.77 | 1.42 | 2.45 | 58 | -1.03 |
| 4209 | 2.89 | 1.42 | 2.45 | 58 | -1.03 |
| 8822 | 2.02 | 1.40 | 2.45 | 57 | -1.05 |

*Fig. 4. Flash Flood Monitoring and Prediction tool used by National Weather Service forecasters to track the precipitation rates and accumulations in small basins (typically 5 to 25 square kilometers) as compared to flash flood guidance. Information is updated every 4.5 to 6 minutes. The stream name and county can also be displayed so more specific information can be included in flash flood warning messages.*

Comparison of national verification statistics from the period 1997-2000 before FFMP implementation and 2006-2009 after FFMP implementation (Tab. 1) shows a significant improvement in both the probability of detection (0.85 improving to 0.91) and the percentage of warnings with lead times greater than zero minutes (66% improving to 79%). While average lead time improved from 47 minutes to 64 minutes, false alarm rates have worsened, increasing from 0.42 to 0.56. One possible explanation for the increase in the false alarm rate is FFMP makes it more likely forecasters will issue warnings for remote areas before any flash flood observations are received. The true false alarm rate is probably lower since some flash floods in remote areas are unlikely to be observed or reported.

*Tab. 1. Comparison of National Weather Service flash flood warning verification statistics from the 4 year periods 1997-2000 and 2006-2009. Green numbers show improvement between periods. Improvement in POD and average lead time has been attributed in part to the implementation of FFMP across the country between 2001 and 2005.*

| Years of Study | Probability of Detection (POD) | % of warnings with > 0 min lead time | Average lead time for warnings | False Alarm Ratio (FAR) |
|---|---|---|---|---|
| **1997-2000** | 0.85 | 66% | 47 min | 0.42 |
| **2006-2009** | 0.91 | 79% | 64 min | 0.56 |

Ideally, forecasters should have access to real-time information on flash flooding and flood impacts such as: streams out of their banks, roads and homes flooded, bridges overtopped, status of dams (releases, spills, emergency situations). Obtaining this information as it is happening is often extremely difficult, especially at night and in remote areas. Without this type of feedback, forecasters are often left wondering if anything is happening. This is cited by some NWS forecasters as the biggest weakness in the flash flood program. To improve access to information, WFOs are recruiting volunteer severe weather spotters, exploring the use of the web and social media such as Twitter and Facebook, establishing chat rooms for emergency management and the media, and installing situational awareness displays to monitor local and national media outlets.

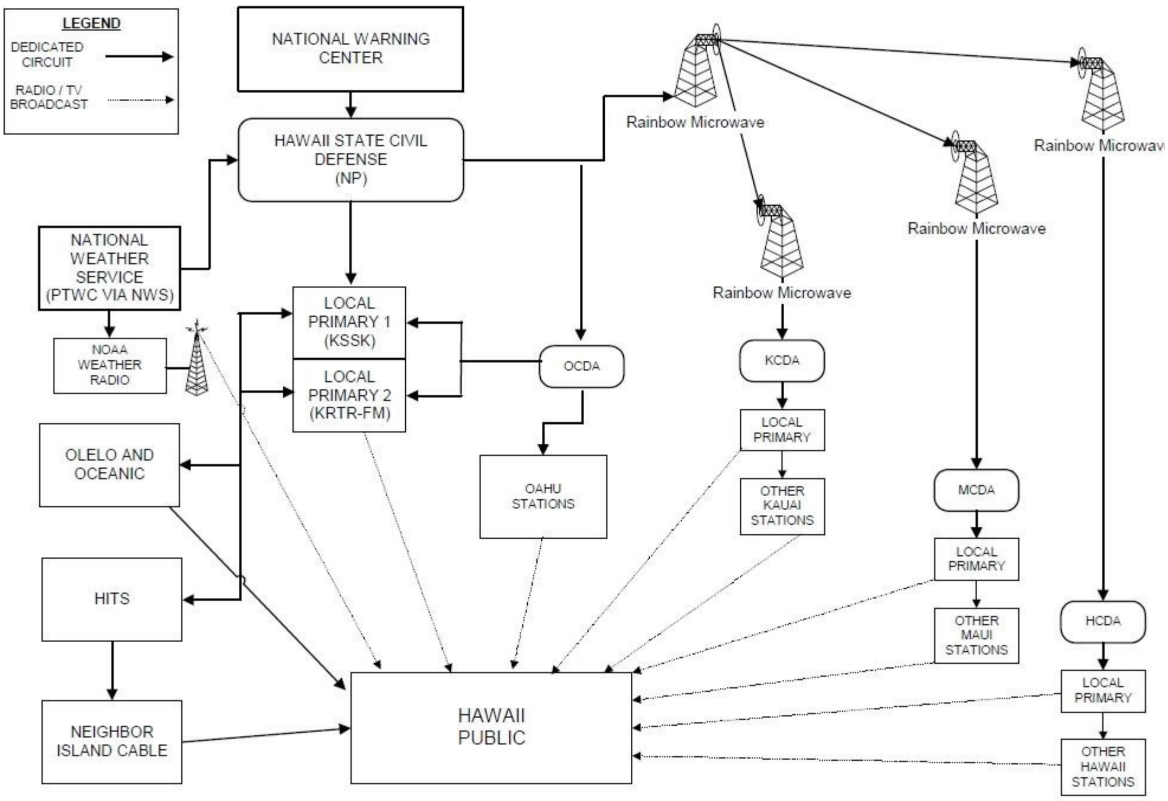
## 5. COMMUNICATING THE WARNING MESSAGE

Warnings have no benefit unless the people that need to protect themselves get the warning in time and understand its meaning so they can act. The end user can be a homeowner, a business owner, a vehicle driver, a local fireman, emergency medical technician, local transportation department, local emergency official, etc. Given the diversity of end users, a fully automated dissemination system with multiple communication paths and some redundancy is best (see <http://www.weather.gov/om/disemsys.shtml>). Whenever possible, communication systems should incorporate back-up power sources because electric utility power often fails during severe storms. In the U.S., a federal system called the Emergency Alert System (EAS) is used to transmit flash flood warnings (see <http://www.fcc.gov/pshs/services/eas/ > and <http://www.weather.gov/os/NWS_EAS.shtml>).

A schematic of a state EAS is shown in Figure 5. Television and radio stations have decoders that automatically or manually, at the discretion of the station staff, interrupt normal programming to broadcast the warnings. For many years, the NWS has operated NOAA Weather Radio (NWR) which is a network of over 1000 radio transmitters continuously broadcasting environmental information and timely warnings of weather and non-weather events and emergencies (see <http://www.weather.gov/nwr/>). NWR also serves as the primary NWS path into the EAS system. Weather radio receivers are extensively used in schools, hospitals, nursing homes, and by government agencies and large businesses in their emergency operations centers. However, less than 20% of individual households choose to own weather radios and a survey in one state revealed that fewer than 7% of individual households would get an emergency notification via weather radios (Redmond 1995). Cell phone technology and the internet have led to several new privately operated subscription services where people can sign up to receive warnings issued for a particular area. The NWS has a new experimental subscription service for emergency responders and other core partners called Mobile Decision Support Services (MDSS) interactive NWS (iNWS) (see <http://inws.wrh.noaa.gov/>).

The Federal Emergency Management Agency (FEMA) is currently developing an Integrated Public Alert and Warning System (IPAWS) designed to expand upon the traditional EAS by allowing emergency management officials to reach as many people as possible over as many communications devices as possible, such as cell phones, radio, television, personal computers and other communications devices (see <http://www.fema.gov/emergency/ipaws/projects.shtm >). The first major IPAWS project to leverage this new push technology is the Commercial Mobile Alert System (CMAS). CMAS is a cell tower broadcast (point to multi-point) of imminent threat alerts to cell phones. It will be an opt-out service and the alerts will be geo-targeted based on the Common Alert Protocol warning message. CMAS is scheduled for implementation in early 2012 and will include flash flood warnings.

In addition to relying on NWS warnings, some communities with their own AFWS networks of rain and stream gages have employees or volunteers monitor conditions and warn flood-prone neighborhoods and initiate evacuations (see <http://www.highwater.org/Brittany/temp%20site/temp_fws.html>). Since people have access to different communications linkages at different times, the number of people who hear a warning message can be maximized by disseminating warning messages over the full range of public communications networks (Mileti 1990).



**State Level of Emergency Alert System (EAS)**

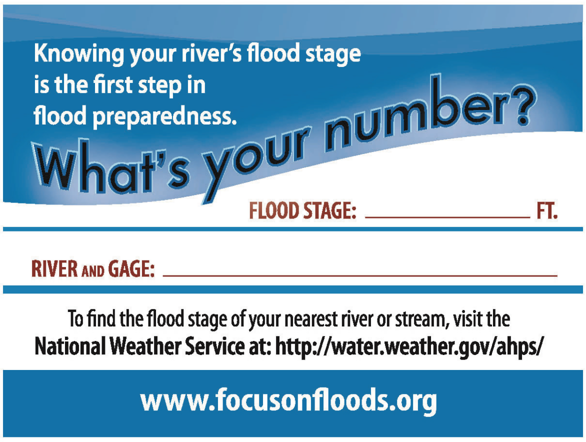
*Fig. 5. Hawaii Emergency Alert System (EAS) for communicating warnings to response officials and the general public. Note the multiple redundant channels of communications to the public including State Civil Defence network, NOAA Weather Radio, Cable and Broadcast Television, and Commercial FM and AM radio stations. Plans are being developed to include the capability to transmit warnings to hand held devices and cell phones.*

## 6. COMPLETING LIFE SAVING ACTIONS

For various reasons, people don't always make good decisions to protect themselves and others from harm even when they have received a warning or they see a developing flash flood situation. Social scientists and hazard response planners have identified multiple factors that influence how people respond (Mileti 1975). These include their past experience, their understanding and assessment of the immediate threat to themselves and their loved ones, and their evaluation of (and trust in) the sources of information. Very often, after getting a warning, people will look for additional clues or confirming information to help them assess their immediate risk (Leik 1981). For example, what are neighbors doing in response and what are local police and fire departments saying about the situation? Many people will drive across a flooding roadway if the person driving in front of them makes it across.

People are less likely to act in response to a warning if they have never discussed the dangers of flash flooding in their local area or have never seen educational videos on the dangers of flash flooding. For this reason, education is needed at the federal, state, and local levels on the risks posed by high water including flash floods. These educational messages need to be repeated often and school children need to be taught as well. The NWS places emphasis on outreach and education about weather and flood hazards (see <http://www.weather.gov/education.php>).

*Fig. 6. Turn Around Don't Drown street sign used to remind motorists of the deadly dangers of driving across flooded roadways.*



**Knowing your river's flood stage is the first step in flood preparedness.**

**What's your number?**

**FLOOD STAGE:** ______________ **FT.**

**RIVER AND GAGE:** ______________________________

To find the flood stage of your nearest river or stream, visit the
**National Weather Service at: http://water.weather.gov/ahps/**

**www.focusonfloods.org**

*Fig. 7. Refrigerator magnet distributed at flood outreach events to encourage the public to go to the National Weather Service river forecast pages and look-up their local flood stage.*

In addition to publications and videos produced by NWS in association with other partners, NWS staff routinely give presentations to local groups and schools on the dangers of flash floods. One such outreach initiative is called 'Turn Around – Don't Drown' (see <http://www.nws.noaa.gov/floodsafety/index.shtml>). The NWS has been working with other agencies and the non-profit foundation Nurture Nature Foundation on a flood safety campaign in the Delaware River basin (see <http://www.focusonfloods.org/>). During flood season, short 30 or 60 second public service announcements play on radio and television to remind people of the dangers. Most states hold annual flood safety awareness weeks, during which the NWS, state and local officials, and the media work together to educate the public about flood dangers. Some counties and cities hold tabletop flood exercises or functional exercises (Federal Emergency Management Agency 2010a, 2010b, 2010c) every 1-3 years during which all agencies involved in flood warning and flood response work through a flood scenario and simulate communication and decision making. Each WFO is staffed with a Warning Coordination Meteorologist and a Hydrologic Service Program Manager. Recently, every RFC added to their staff a Service Coordination Hydrologist. These people work with their staffs on projects and activities designed to educate the public about the dangers of hazardous weather such as flash flooding.

## 7. CONCLUSIONS

Given enough rainfall in a short enough period of time, flash flooding can occur anywhere. Flash flood risk increases in areas of steep terrain, bare non-vegetated ground (e.g. recent wildfire burns), poor draining soils, and urbanization. A substantial flood awareness and education program is the key to the success of any warning and response system. Local officials and the general public need to be informed regarding the causes of flash floods, their risks, the warning system, emergency safety measures they need to be ready to take, and inherent uncertainty in the forecast and warning process. Local warning plans need to be reviewed and practiced on a regular basis. This knowledge needs to be prevalent in the community, so that when a warning is issued or flash flood development is observed, time critical safety measures are implemented without delay. The highest priority must be taking actions to prevent loss of life, with secondary attention to saving property. The warning system

*Fig. 8. Still image from animated 9 minute flood safety story developed by Nurture Nature Foundation and funded through a NOAA grant. This animated story has no copyright restrictions and is available at <www.focusonfloods.org> and <http://www.youtube.com/watch?v=iOjEtowTGag>*

*Fig. 9. National Weather Service flood outreach and education exhibit using a flood model to demonstrate the factors that influence flood severity.*

should relay warnings via multiple robust communication paths that aren't prone to failure in severe weather. Local officials and the general public have a need to get warnings reliably and nearly instantaneously, since every additional minute of warning is critical. Seconds can mean the difference between life and death. Because of the uncertainty in the forecast and warning processes, everyone must be educated concerning the expected percentages of false alarm warnings. When false alarms occur, they should be viewed positively as an unavoidable fact of life and an opportunity to have tested the warning and response system. Significant improvements in lead time are possible as better short-term (0-3 hour) precipitation forecasting systems are further developed and implemented into the warning system. Continued sharing of successful flash flood warning technologies and best practices amongst countries will help all cooperating nations improve their warning systems so that fewer lives are lost during future destructive storms.

## 8. ACKNOWLEDGEMENTS

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### *References:*

[1] FEDERAL EMERGENCY MANAGMENT AGENCY, 2010a. Floods Pathfinder, A Guide to the Literature. Available online at: <http://www.lrc.fema.gov/path_flood.html> (accessed 2010).

[2] —. 2010b. IS-39 Exercise Design, Unit 10: The Functional Exercise.
[Available online at: <http://www.training.fema.gov/EMIweb/downloads/is139Unit10.doc>]
[Course available at: <http://training.fema.gov/EMIweb/IS/is139.asp>] (accessed 2010).

[3] —. 2010c. IS-39 Exercise Design, Unit 5: The Tabletop Exercise.
[Available online at: <http://www.training.fema.gov/EMIweb/downloads/is139Unit5.doc>]
[Course available at: <http://training.fema.gov/EMIweb/IS/is139.asp>] (accessed 2010).

[4] FILIAGGI, T. - SMITH, S. - CHURMA, M. - XIN, L. - GLAUDEMANS, M., 2002. "Flash Flood Monitoring and Prediction Version 2.0: Continued AWIPS Modernization." Orlando: Preprints, 18th Conf. on International Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Amer. Meteor.Soc., January 2002.

[5] ISTOK, M. - FRESCH, M. - SMITH, S. - JING, Z - MURNAN, R. - RYZHKOV, A. - KRAUSE, J - JAIN, M. - FERREE, J. - SCHLATTER, P. - KLEIN, B. - STEIN, D. - CATE, G. - SAFFLE, R., 2009. "WSR-88D Dual Polarization Initial Operational Capabilities." Phoenix: Preprints, 25th Conf. on International Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Amer. Meteor. Soc., January 2009.

[6] KITZMILLER, D. - WU, W. - WU, S. - SOKOL, Z. - PESICE, P., 2010. Quantitative precipitation forecasts from radar extrapolation and physical-dynamical prediction models: Strategies for blending of information from multiple prediction systems. Available online at: <http://www.erad2010.org/pdf/oral/thursday/nwp1/05_ERAD2010_0074.pdf>.

[7] LEIK, R.K. - CARTER, T.M. - CLARK, J.P., 1981. Community response to natural hazard warnings: Final Report. Mineapolis, MN: University of Minnesota. 77pp.

[8] MILETI, D.S., 1975. Natural hazard warning systems in the United States. Boulder, CO: Program on Technology, Environment, and Man, Institute of Behavioral Science, University of Colorado. 97pp.

[9] MILETI, D.S. - SORENSEN, J.H., 1990. Communication of emergency public warnings: A social science perspective and state-of-the-art assessment. Oak Ridge, TN: Oak Ridge National Laboratory. 166pp.

[10] OFFICE OF HYDROLOGIC DEVELOPMENT, 2010. Hydrology Laboratory Strategic Science Plan. Available online at: <http://www.nws.noaa.gov/oh/src/docs/Strategic_Science_Plan2010.pdf>.

[11] OSTROWSKI, J. - BALK, B. - DERNER, G. - DEWEESE, M. - MCINERNEY, B. - MERCER, M. - STORY, G. - REED, S., 2003. Flash Flood Guidance Improvement Team - Final Report: February 6, 2003. National Weather Service Office of Hydrologic Development. Available online at: <http://www.nws.noaa.gov/ohd/rfcdev/docs/ffgitreport.pdf>.

[12] REDMOND, JAMES W., 1995. "NOAA Weather Radio as an Emergency Communication Vehicle in West Tennessee." (Weather and Forecasting) 10, no. 485-497.

[13] REED, S. - SCHAAKE, J. - ZHANG, Z., 2007. "A distributed hydrologic model and threshold frequency-based method for flash flood forecasting at ungaged locations." (Journal of Hydrology) 337, no. 402-420.

[14] RYZHKOV, A., - SCHUUR, T. - BURGESS, D. - HEINSELMAN, P. - GIANGRANDE, S. - ZRNIC, D., 2005. "The Joint Polarization Experiment: Polarimetric rainfall measurements and hydrometeor classification." (Bull. Amer. Meteor. Soc.) 86, no. 809-824.

[15] SCHAFFNER, M. - UNKRICH, C.L. - GOODRICH, D.C, 2010. "Application of the KINEROS2 Site Specific Model to South-Central NY and Northeast PA: Forecasting Gaged and Ungaged Fast Responding Watersheds." (NWS Eastern Region Technical Attachment) No. 2010-01. Available online at: <http://www.werh.noaa.gov/ssd/erps/ta/ta-list.html>.

[16] SMITH, S. - FILIAGGI, M. - CHURMA, M. - ROE, J. - GLAUDEMANS, M. - ERB, R. - XIN, L., 2000. "Flash Flood monitoring and prediction in AWIPS build 5 and beyond." Long Beach: Preprints, 15th Conference on Hydrology. Amer. Meteor. Soc., no. 229-232.

[17] HANG, J. - HOWARD, K. - VASILOFF, S - LANGSTON, C., KANEY, B. - ARTHUR, A. - VANCOOTEN, S. - KELLEHER, K. - KITZMILLER, D. - DING, F. - MULLUSKY, M. - WELLS, E. - SEO, D. - SCHNEIDER, T. - DEMPSEY, C., 2009. "National Mosaic and QPE (NMQ) System - Description, results and future plans." Williamsburg: Preprints 34th Conference on Radar Meteorology. Amer. Meteor. Soc., 7A1.

# THE WEATHER WARNING SYSTEM OF GERMAN WEATHER SERVICE PROVIDER AND SPECIAL INFORMATION FOR DISASTER CONTROL

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## ABSTRACT

The German Weather Service act from September 1998 defines the role of the German Weather Service Provider as National Weather Service of the Federal Republic of Germany. Main task is publishing official warnings previous to severe weather conditions risking public safety and order, especially impending floods. Furthermore the German Weather Service provides support in disaster control to the federal states.

The German Weather Service has generated a policy of weather forecasts targeting at better numeric models and statistical methods. Models and ensemble using convection have proofed advantageous in forecasting heavy rain. Additionally a multi-level warning management system has been established.

The weather warning system allows for weather warning to be differentiated by region and time. Global models indicate dangerous weather conditions 2 until 7 days ahead. The general office in Offenbach publishes this early warning information on a daily basis. This bulletin represents a week's forecast of dangerous weather conditions and is applicable for the entire area of Federal Republic of Germany. The regional centres release information on weather warning conditions for each federal state five times daily. Depending on the danger of weather conditions warnings are differentiated into several levels of storm warnings like rain, intense rain, continuous rain, thunderstorm with hail or heavy rain. This is levelled down to the administrative districts. An official checklist for each element of weather indicates the warning level once different critical values are reached. The warning contains a free text written by the forecaster, publication time and the duration of validity

Disaster control is based on Germany's political structure and therefore the warning management of German Weather Service Provider is organized along the same structure. Unfortunately riverbeds do not match with political boundaries. Warnings for thunderstorms with heavy rain can usually be given only on very short notice and have a short validity. On days with a high tendency for thunderstorms the warnings might have to be repeated several times per day. As thunderstorms are restricted to a very small geographical area and only a part of the district might experience severe weather conditions. Users not affected by these conditions think of the warnings as false warnings. This proofs dangerous for disaster preparation. A future way out might be warnings with a free graphic configuration depending on the exact location of severe weather conditions.

Free public warning information can be found on the website <www.dwd.de> and also at <www.wettergefahren.de>. There is also a warning module which costumers can integrate on their own website. The information is distributed to users via ftp, Fax, SMS and telephone. Warnings of unfavourable weather conditions are also distributed to the media (television, radio) but with the exception of Bavaria they are not legally obliged to publish these warnings.

A website focussed especially on disaster control has been set-up. It bundles all relevant and important information. The website is the heart of the FeWIS – Weather Information System for fire brigades – a system combining all necessary advisory information from different departments and different authorities, e.g. THW, Red Cross, and various Ministries. FeWIS contains customized warnings and graphics as well as text information, and is updated every two minutes. Over 1490 customers used FeWIS in 2010. WebKONRAD – a thunderstorm prediction module – is integrated in the system. Radar data processing provides the most accurate information on cell intensity and their shifting. WebKONRAD is most important for planning and coordination action forces.

The German Weather Services offers special training courses. The program HEARTS **H**azard **E**stimation for **A**ccidental **R**elease of **T**oxic **S**ubstances calculates the dispersion of toxic substances in case of larger accidents involving toxic materials. The user provides date and location of the disaster in an online standard form; the calculation will be executed in Offenbach. Moreover the user can get information about the forest fire danger index, flood waters, and basic climate information for regional risk analyses. Densely populated urban

areas like Berlin get additional service regarding warnings for severe weather conditions including short texts with local details and updates every 30-60 minutes. Coordinating offices use the FeWIS-system and thus always have access to up to date information on weather and warnings, in advance of and during disaster.
Flood centre Saxony (LWHZ) gives forecast and warning against danger of flooding. DWD and LWHZ exchange measured values, model data, warnings and special forecast. There are consultations together. The Weather Service in Leipzig has created especially forecasts for river areas in 1984. Probability of exceeding threshold values of precipitation will be forecast, demand on level. Forecast is subjective in using all actual available weather models. An objective method of calculation or statistics exists not. The forecast is in table form, forecast time 36 hours. LWHZ is using this information for planning outflow with empiric scenarios. Take more measurements would be useful for better interpretation of radar and better nowcasting.
The most important forecast is the estimate of risk for precipitation more than 100 mm over 2 until 3 days in advance. That way it is possible prepare of flood danger. But the best weather forecast can't anticipate flash flood disaster.

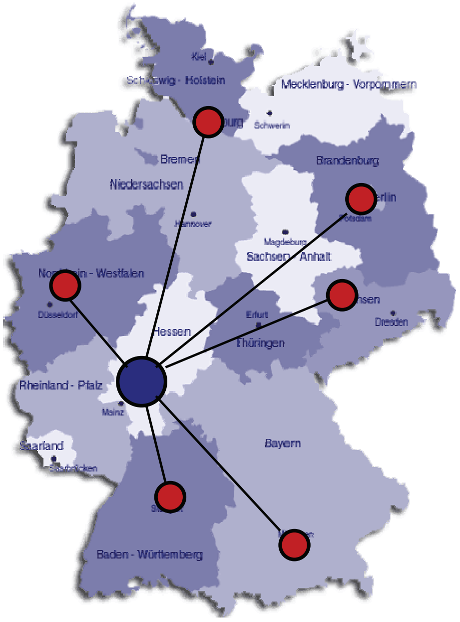
## 1. INTRODUCTION

The Deutscher Wetterdienst (DWD) as the National Meteorological Service of the Federal Republic of Germany is the reference for meteorology for all issues by weather and climate. The DWD is provider of scientific and technical services as well as a competent and reliable partner for public and private partners. Acting as a federal authority under the department of the Federal Ministry of Transport, Building and Urban Development (BMVBS) the DWD is responsible for providing services for life and property in the form of weather and climate information. The legitimate basis for these tasks is embodied in the "Law on the Deutscher Wetterdienst of 10 September 1998". According to the law the DWD assists the German Federal States in carrying out their responsibilities with regard to disaster control and issues official warnings of meteorological events that could endanger for public safety and order. These are the DWD's core tasks.

## 2. THE MANAGEMENT OF WEATHER WARNINGS

### 2.1 The organisational structure

Business Area "Weather Forecasting Services" issues and delivers weather forecasts and weather warnings of severe weather events for the general public and users in special areas such as road traffic, aviation, marine shipping and others. Provisioning the population and the disaster control institutions of the Federation and the Federal States with warnings for the purposes of hazard prevention needs an optimal organisational structure and a multi-level warning system.



●

<u>Offenbach</u>
Weather Forecasting and Advisory Centre (Germany)
and

●

Regional Centre (Hessen, Rheinland-Pfalz, Saarland)
and
Professional Management of Department "Basic Forecasts"

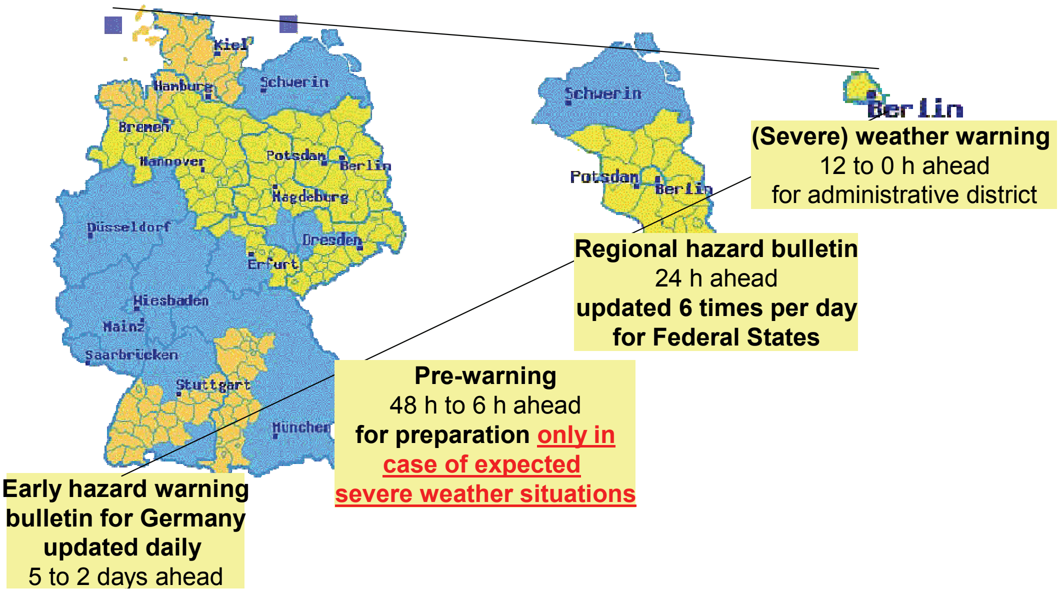
Regional Centres

Hamburg (Hamburg, Niedersachsen, Bremen, Schleswig-Holstein)
Potsdam (Brandenburg, Berlin, Mecklenburg-Vorpommern)
Essen (Nordrhein-Westfalen)
Leipzig (Sachsen, Thüringen, Sachsen-Anhalt)
Stuttgart (Baden- Württemberg)
München (Bayern)

*Fig. 1. Organisational structure, Department "Basic Forecasts"*

### 2.2 The weather warning system

The DWD is using a three level warning system divided into early hazard warnings, pre-warning information and regional hazard bulletins based on the principle of increasing regional and spatiotemporal differentiation.



**(Severe) weather warning**
12 to 0 h ahead
for administrative district

**Regional hazard bulletin**
24 h ahead
**updated 6 times per day**
**for Federal States**

**Pre-warning**
48 h to 6 h ahead
**for preparation only in case of expected severe weather situations**

**Early hazard warning bulletin for Germany updated daily**
5 to 2 days ahead

*Fig. 2. 3-level warning system of DWD, Department "Basic Forecasts"*

In the forecast and advisory centre the supervisor determines an overall warning concept for Germany in consultation with the meteorologists of the day and accordingly manages the issuance of warnings. The centre in Offenbach is also responsible for issuing the weekly weather warning bulletin and the central hazard report.

The meteorologists of the day in the regional DWD offices are responsible for generating, issuing, and monitoring the hazard warning bulletins for the regional states, the rural districts and the urban municipalities.

Early hazard warning information

Any early knowledge of expected weather developments (distinctive hazard situations and situations of (extreme) severe weather on a supra-regional level (250-700 km) are released in the weekly weather warning bulletin. There the weather developments are categorized into probability levels: possible, likely, highly likely. All the weather information is also included in the standard mid-term and short-term (until the second next day) weather forecasts.

Pre-warning information

Pre-warning information includes all knowledge on expected significant weather situations (all warning occurrences) on a regional base (50-250 km). The information is incorporated into the standard short-term weather forecast and is - with a 24h lead-time - also published in the regional hazard warning bulletins.

Regional hazard information (rural districts, urban municipalities)

Concretely issued (severe) weather warnings always relate to administrative districts. In some cases the warnings are further differentiated by altitude. The advance warning time is the time period from the publication of a warning until the beginning of its validity. The advance warning time involves the challenge of managing early and firm information of the clients/customers on one hand and precise geographical and timely differentiation with the needed high accuracy on the other hand.

Warning criteria and thresholds are closely related to the experience and operations of the disaster control authorities. Their definitions are matched accordingly.

To obtain a clear information level, all warnings include the lead time, the validity time and the time of issuing.

This multi-level warning system enables the meteorologists to issue more and more detailed and exact information the further the hazardous situation is advancing.

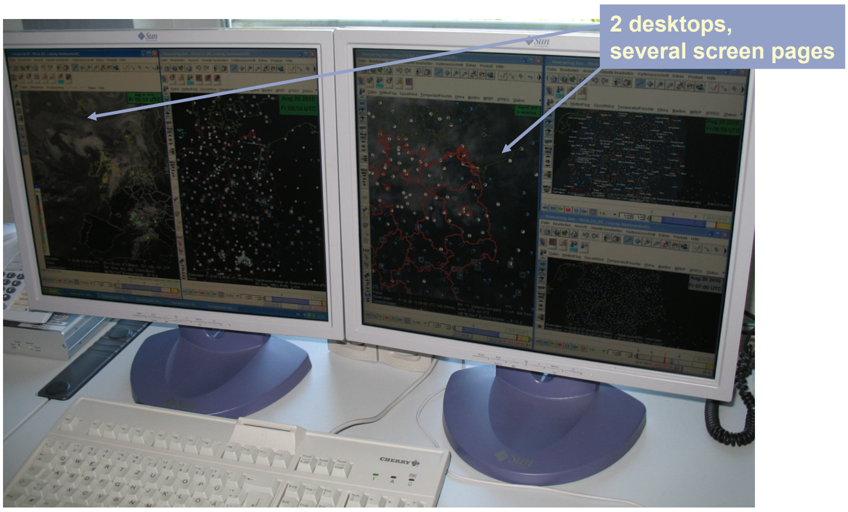
| | |
|---|---|
| 🟨 Warnung vor markantem Wetter | **•High precaution; actions might be necessary** |
| 🟥 Unwetterwarnung | **•serious event, emergency plan is activated** |
| 🟪 Extremes Unwetter | **•extreme event** |

| | | |
|---|---|---|
| intense<br>strong rain | 10 bis 25 l/m² in 1 Stunde<br>20 bis 35 l/m² in 6 Stunden | 🟨 **Starkregen** |
| | ≥ 25 l/m² in 1 Stunde<br>≥ 35 l/m² in 6 Stunden | 🟥 **Heftiger Starkregen** |
| fertile<br>continuous rain | 25 bis 40 l/m² in 12 Stunden<br>30 bis 50 l/m² in 24 Stunden<br>40 bis 60 l/m² in 48 Stunden | 🟨 **Dauerregen** |
| | ≥ 40 l/m² in 12 Stunden<br>≥ 50 l/m² in 24 Stunden<br>≥ 60 l/m² in 48 Stunden | 🟥 **Ergiebiger Dauerregen** |
| extreme fertile<br>continuous rain | ≥ 70 l/m² in 12 Stunden<br>≥ 80 l/m² in 24 Stunden<br>≥ 90 l/m² in 48 Stunden | 🟪 **Extrem ergiebiger Dauerregen** |

*Tab. 1. Warning criteria and thresholds for rain*

In addition there are graded warning thresholds for snowfall, thawing, squalls, hurricanes, thunderstorms incl. hail and/or squalls, frost, fog, etc. in place.

## 2.3 The workstation system NinJo



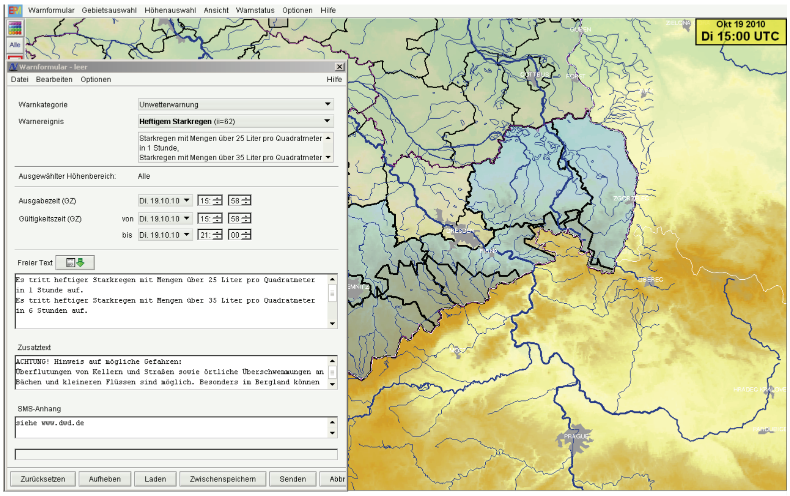
NinJo provides the meteorologist with numerous important data at a glance.

*Fig. 3. Sample picture - NinJo workstation, Regional Centre Leipzig*

In order to monitor the weather and warning situation continuously the forecaster needs a technologically advanced level of the equipment components. A meteorological visualization system for the use of meteorologists on their workstations was developed under the direction of the DWD in co-operation with the Federal Armed Forces Institutions of Denmark, Canada and Switzerland.

NinJo, the innovative workstation system, provides meteorologists in weather forecasting and warning services with a variety of available measured and observed data, satellite and radar data and the results of numerical weather forecasts in visualised graphical form, which can then be used for the production of forecasts and warnings. A configurable modular design allows each user to organise his NinJo workstation individually and to adapt it the task at hand.

The tool for the issuance of warnings – the program EPM – Edition, Prediction, Monitoring – is integrated in NinJo.



Warnkategorie: Unwetterwarnung

Warnereignis: **Heftigem Starkregen** (ii=62)

Starkregen mit Mengen über 25 Liter pro Quadratmeter in 1 Stunde,
Starkregen mit Mengen über 35 Liter pro Quadratmeter

Ausgewählter Höhenbereich: Alle

Ausgabezeit (GZ): Di. 19.10.10 15: 58

Gültigkeitszeit (GZ) von Di. 19.10.10 15: 58

bis Di. 19.10.10 21: 00

Freier Text

```
Es tritt heftiger Starkregen mit Mengen über 25 Liter pro Quadratmeter
in 1 Stunde auf.
Es tritt heftiger Starkregen mit Mengen über 35 Liter pro Quadratmeter
in 6 Stunden auf.
```

Zusatztext

```
ACHTUNG! Hinweis auf mögliche Gefahren:
Überflutungen von Kellern und Straßen sowie örtliche Überschwemmungen an
Bächen und kleineren Flüssen sind möglich. Besonders im Bergland können
```

SMS-Anhang

```
siehe www.dwd.de
```

*Fig. 4. Sample picture - EPM, window to produce warnings of severe weather situations, such as rain, East Saxony: blue – administrative districts*

EPM warning of severe weather conditions can be produced, updated and cancelled in all regional centres according to their area of responsibility. The EPM technology enables the meteorologist to choose between different elements of warning, warning thresholds, durations of validity, and independent phrasing/wording of the warning texts. Weather warnings should be easy to understand and tell the public what to do in case of severe weather.

The DWD issues 27 different types of warnings for about 450 districts in Germany by at most 10 altitude levels. The whole forecast and warning process is certified to ISO 9001.

### 2.4 The future prospects

The DWD will enhance the quality of its weather forecasts and severe weather warnings. The new strategy will be valid until 2015. Strategic plans for the best structure of Business Area “Weather Forecasting Services, Department Basic Forecast” include consolidation of positions in the field of weather forecasting and high quality of warning, improvement of the quality of weather forecasting and warning services with high temporal and spatial resolution and ensuring a high level of operational stability and economic allocation of resources.

In pursuit of this aim the DWD will establish a National Warning Centre in Offenbach with weather monitoring and weather warning services for the whole German State. Based on the information of this centre, the Regional Weather Advice Offices will provide weather consulting services to Federal States Governments, rural district and local administrations (disaster control and flood protection), fire brigades and technical relief organisations and regionally operating media (informing general public) including individual, regional-based real-time weather information.

A major objective of its strategy is to continuously improve the warning management. The recently developed AutoWARN system will combine all available meteorological information, such as observational and radar data, nowcasting products, statistical analyses as well as model forecasts in order to produce automatically generated reliable severe weather warnings. The incoming data are checked for weather events that deserve a warning and, after that, used to automatically suggest warning statuses. The process is supervised by meteorologists who use the suggestions to produce and distribute warnings targeted to specific customers.

The process will also take account of probability estimations of heavy rain or gusts. The introduction of a cell detection and tracking method relying on radar, lightning and model data will contribute significantly to improving thunderstorms, hail, gust and heavy rain warnings. For very short-range up to 18 hours, the numerical weather forecasting model COSMO-DE with its 2,8 km grid and the ensemble forecasts computes the probability of weather events for which warnings should be issued.

Then future warnings, based on polygons or grid points, could better show the region within an administrative area without dangerous weather. The customers will know how likely the severe weather is and so the weather warnings are more reliable.

## 3. THE DISTRUBUTION OF METEOROLOGICAL WARNING INFORMATION

### 3. 1 The DWD Website

The DWD has services for the general public and for selected customer groups. On its website at <www.dwd.de> presents the DWD a rich range of up-to-date weather and climate information is available.

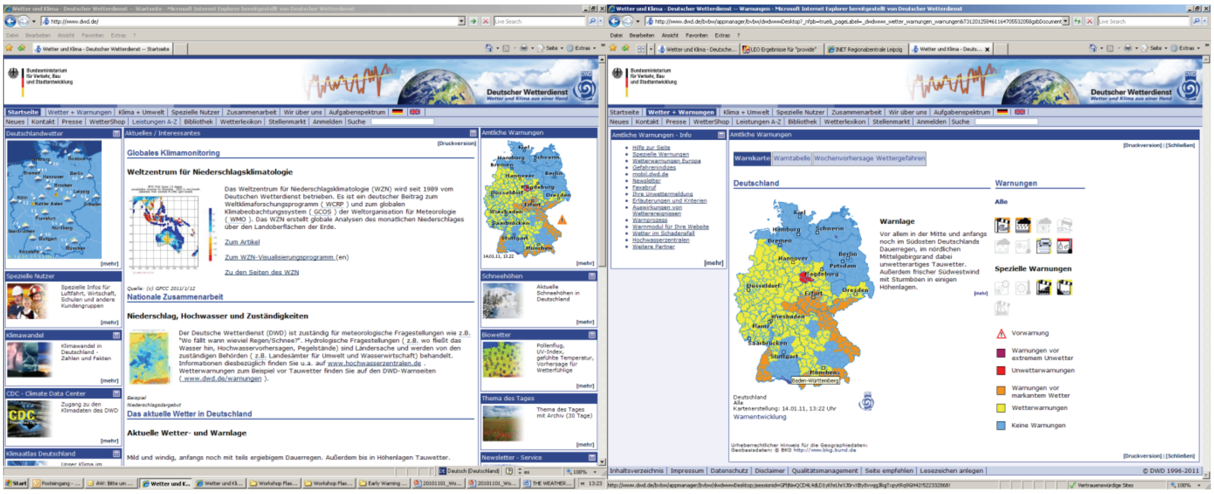
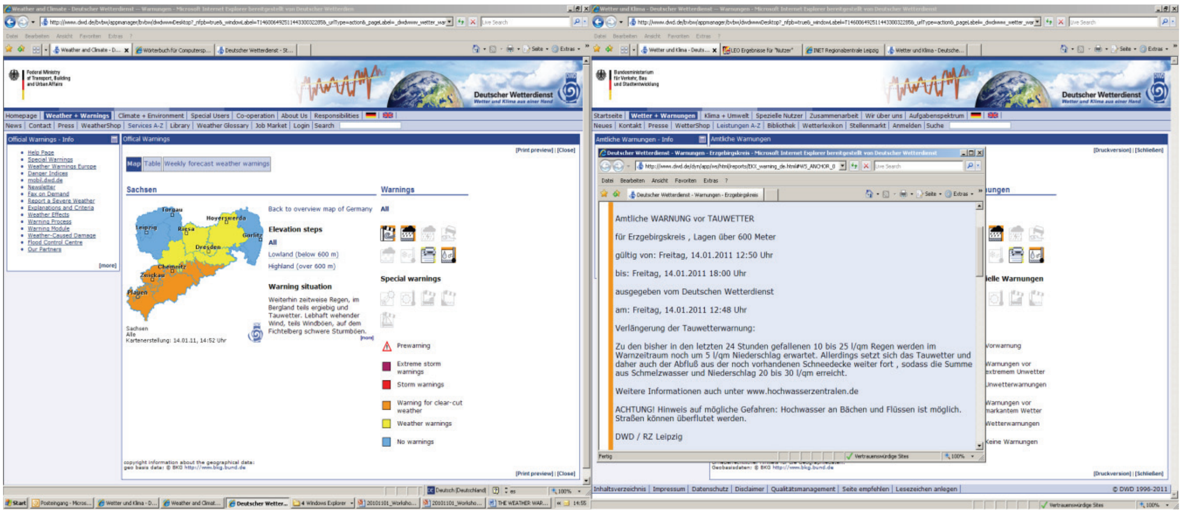


*Fig. 5. Weather, warning and climate information for everybody*

All Germany citizens with Internet access can subscribe to a free newsletter providing detailed severe weather warnings for individual advisory districts. In addition to the sections “Weather Warnings” for Germany and its regions, “Weather in Germany” and “Regional Weather” with basic forecast for all Federal States the DWD web pages provides all kinds of information about current weather including radar and satellite images as well as graphical forecasts.

Visitors of the website find daily updated reports on particular weather events in the “Topic of the Day” section. In order to guarantee accessibility for a very high number of users even in severe weather situations, the DWD has created the warning page <www.wettergefahren.de>. In order to the protect life and property the official storm warnings and extreme storm warnings are free for Television and Radio stations.

The visitors of both websites find the text of all official warnings with a few clicks trough the menu and on choosing the advisory district.



Warning situation

Weiterhin zeitweise Regen, im Bergland teils ergiebig und Tauwetter. Lebhaft wehender Wind, teils Windböen, auf dem Fichtelberg schwere Sturmböen.

Amtliche WARNUNG vor TAUWETTER

für Erzgebirgskreis , Lagen über 600 Meter

gültig von: Freitag, 14.01.2011 12:50 Uhr

bis: Freitag, 14.01.2011 18:00 Uhr

ausgegeben vom Deutschen Wetterdienst

am: Freitag, 14.01.2011 12:48 Uhr

Verlängerung der Tauwetterwarnung:

Zu den bisher in den letzten 24 Stunden gefallenen 10 bis 25 l/qm Regen werden im Warnzeitraum noch um 5 l/qm Niederschlag erwartet. Allerdings setzt sich das Tauwetter und daher auch der Abfluß aus der noch vorhandenen Schneedecke weiter fort , sodass die Summe aus Schmelzwasser und Niederschlag 20 bis 30 l/qm erreicht.

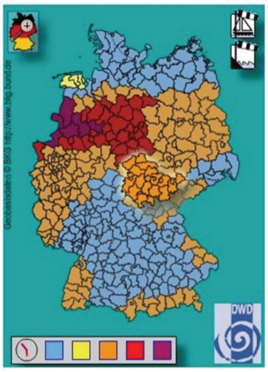
Weitere Informationen auch unter www.hochwasserzentralen.de

ACHTUNG! Hinweis auf mögliche Gefahren: Hochwasser an Bächen und Flüssen ist möglich. Straßen können überflutet werden.

DWD / RZ Leipzig

*Fig. 6. Sample picture - warning situation for Saxony and text information for one advisory district*

### 3. 2 Official warnings for websites



All operators of websites are free to enhance their own sites with graphically refined warning information. A specific warning module has been developed for this purpose. All warnings are constantly updated. The necessary software is available under <www.dwd.de/warnmodul>.

The layout can be individually configured according to the region, picture size, 3D-effects, and colours desired. This enables an extensive adaption of the (graphical) design corresponding to customer's needs.

*Fig. 7. Sample picture warning module*

### 3.3 Official warnings for mobile devices

Official warnings for mobile devices
Users can obtain warnings and warnings of severe weather conditions issued by the DWD optimized for the use on mobile devices on <www.dwd.de/mobil>.

Thus DWD warning information is readily accessible whilst travelling.

Free of charge and everywhere: the user needs not pay any extra charges in addition to his regular costs. This offer has been specifically designed focusing on broadest availability (services working on a very broad range of mobile devices) and thus enabling all citizens to use this service.

*Fig. 8. Sample picture mobile*

## 4. FEWIS – SPECIAL WEATHER INFORMATION SYSTEM FOR DISASTER CONTROL

Disaster control authorities and special user groups such as the professional fire brigades, relief organisations, police and emergency centres have guaranteed access to information via a separate web platform, presented on <www.dwd.de/fewis> or <www.dwd.de> → Button "Special users". The access is password protected.

Since July 2004 DWD has designed a unique weather information system, one system for different authorities. Meanwhile more than 1490 authorities of all sectors of disaster control and civil protection are using this system. FeWIS is one of the most important components of warning management.

FeWIS is an online system which offers all significant weather and severe weather information from DWD at a glance, containing warnings, graphical and textual information, updated online round the clock.

The system is also easy for meteorological laymen to operate after some instruction. The Regional Centres provides training courses for all staff of disaster management authorities and new users.

**Herzlich willkommen in FeWIS,**
dem Wetterinformationssystem für den Katastrophenschutz.

Hiermit steht ihnen ein effektives, auf den jeweiligen Nutzer zugeschnittenes Warnmanagement zur Verfügung.
Vom allgemeinen Warnlagebericht über die Vorwarnung bis hin zur Wetter- und Unwetterwarnung können sie alle wichtigen Daten für ihren Bereich auf einen Blick erfassen.

Zudem liefert FeWIS eine Fülle an Informationen, die ihnen im Ernstfall eine wichtige Entscheidungshilfe sein können:

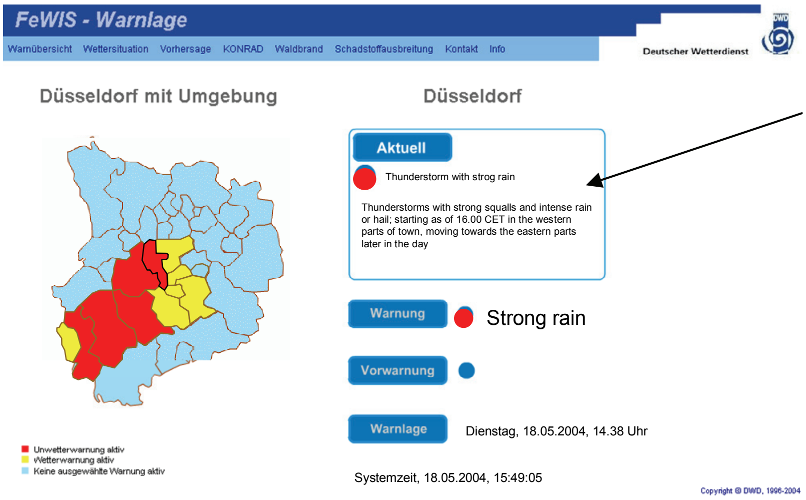
- Informationen zur aktuellen Wettersituation
- aktuelle Vorhersagen
- Zugang zu webKONRAD
- Berechnung von Schadstoffausbreitung
- Klimadaten mit KLIMA-KAT
- Links für Hochwasserinformationen
- Waldbrandgefahrenindex
- Konkrete Ansprechpartner für den Ernstfall

Alle Informationen erreichen sie über das Auswahlmenü oben.

Hinweis: Für eine optimale Nutzung sollte ihr Macromedia-Flashplayer mindestens die Version 9 (9.0.124.00) haben.

The user can select from different information:
warning situation Germany
warning situation Europa
weather situation
weather forecast
WebKONRAD
forest fire index
toxic diffusion
flood waters
climatological data
contact

Fig. 9. Start site for FeWIS – system information



● Thunderstorm with strog rain

Thunderstorms with strong squalls and intense rain or hail; starting as of 16.00 CET in the western parts of town, moving towards the eastern parts later in the day

Warnung ● Strong rain

Warnlage Dienstag, 18.05.2004, 14.38 Uhr

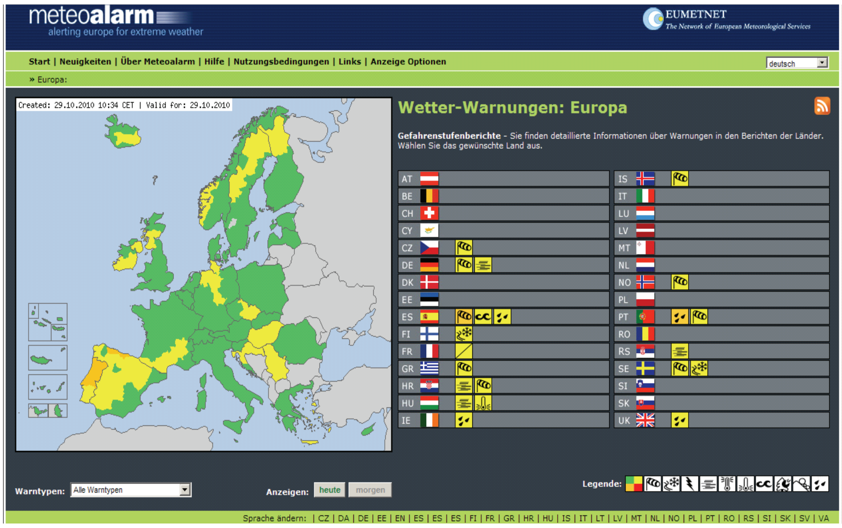
Systemzeit, 18.05.2004, 15:49:05

A separate window shows the latest information from the meteorologist on duty at the nearest DWD Regional Centre and describes, for example, the position of a thunderstorm cell and the course it will takewithin the next one or half hour.

This is a special warning service for urban areas like Berlin, Düsseldorf, München, Frankfurt/M. and others.

For all others the actual meteorological data from the nearest synoptic station is available.

Fig. 10. FeWIS - sample picture - Individual warning situation for the Düsseldorf region



Created: 29.10.2010 10:34 CET | Valid for: 29.10.2010

**Wetter-Warnungen: Europa**

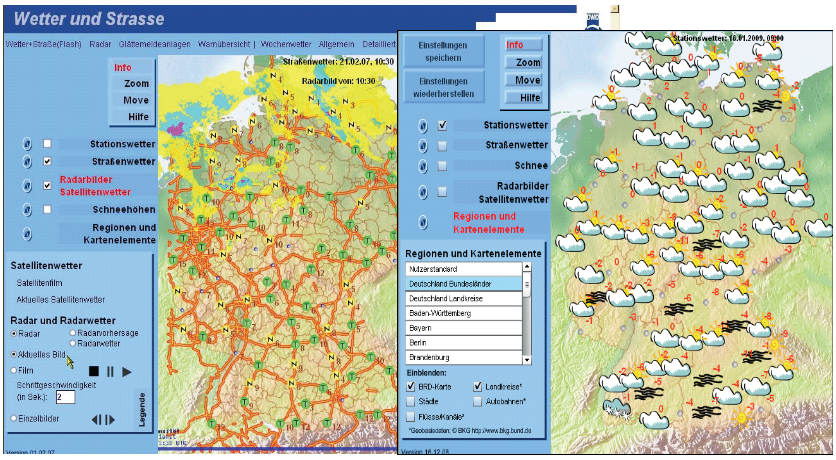
**Gefahrenstufenberichte** - Sie finden detaillierte Informationen über Warnungen in den Berichten der Länder. Wählen Sie das gewünschte Land aus.

**Warntypen:** Alle Warntypen

**Anzeigen:** heute

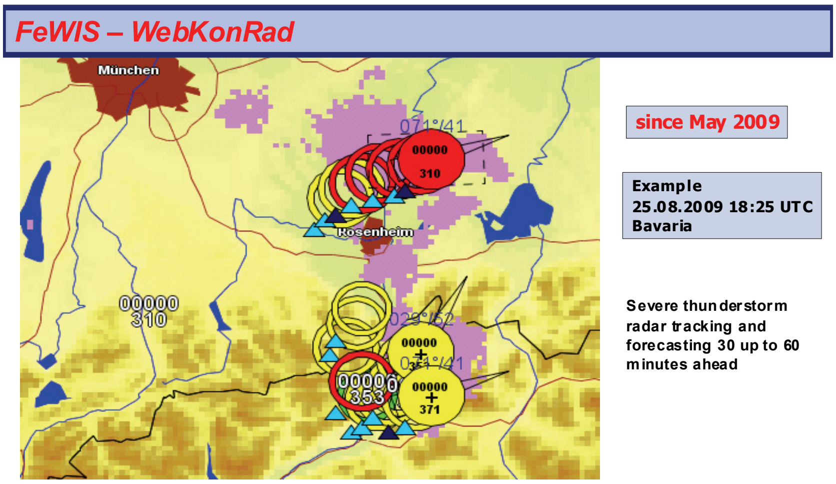
Severe weather does not respect national borders and so relief services such as sea or alpine rescue units and disaster relief organisations benefit from the information at <www.meteoalarm.eu>.
Also general public has free access to the warning web page, which is available in several European languages. The website warns of all types of severe weather risks. The web portal is fed by the various warning systems of the National Meteorological Services.

Fig. 11 FeWIS – sample picture warning information EU (Link)



In addition to radar and satellite pictures (animated) the user can see current weather information (e.g. wind, rain, temperature), information on road weather (e.g. road conditions, temperature of pavement). Also information on depths of snow and calculated snow load is available. The map is freely scalable and all adjustments can be saved.

*Fig. 12 FeWIS – sample picture current weather information*



since May 2009

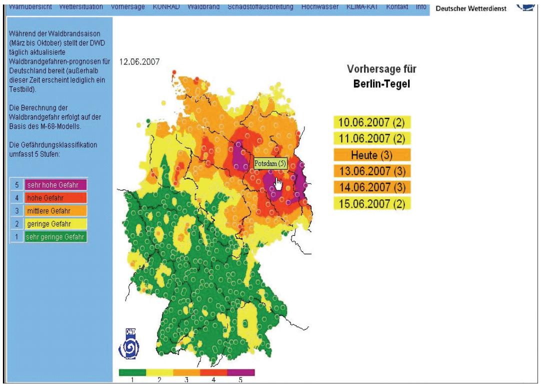
**Example**
**25.08.2009 18:25 UTC**
**Bavaria**

**Severe thunderstorm radar tracking and forecasting 30 up to 60 minutes ahead**

WebKONRAD is an online-tool for fast detection and tracing of thunderstorms (webbased convection development in radar products).
This radar based thunderstorm diagnosis and forecast system is an important component of FeWIS for planning and coordinating all action forces.
The data of all 16 offices of DWD‘s radar network.

*Fig. 13 FeWIS – sample picture WebKONRAD*

WebKONRAD filters the core of thunderstorm cells from the radar pictures. They are evaluated according to echo intensity, surface area and moving direction. Warning signals for hails, intense rain and squalls are derived from the evaluation. The information is depicted in a geographical map using symbols in relation to the actual point of time and the last 30 minutes. The symbols are updated every 5 minutes.
In the time period from March until October the DWD provides forecasts of risks of forest fires updated on a daily basis. The forest fire index comprises of five categories, whereas five equals the highest risk category. Meteorological data like the midday air temperature, relative humidity, wind speed, and rainfall sums of the last 24 hours, as well as vegetation status are included in the calculation. The values are calculated for the weather stations; the results are illustrated in Germany’s map. Trends can be derived from historic and forecasted indices.
The program HEARTS (**H**azard **E**stimation for **A**ccidental **R**elease of **T**oxic **S**ubstancis) calculates the dispersion of toxic substances in case of larger accidents involving toxic materials. The user provides date and location of the disaster in an online standard form, the calculation will be executed in Offenbach. Meteorological forecast data such as wind direction and wind speed are also included in the calculation. This allows forecasting of the dispersion of toxic substances for several hours in advance (standard: 6 hours).



Während der Waldbrandsaison (März bis Oktober) stellt der DWD täglich aktualisierte Waldbrandgefahren-prognosen für Deutschland bereit (außerhalb dieser Zeit erscheint lediglich ein Testbild).

Die Berechnung der Waldbrandgefahr erfolgt auf der Basis des M-68-Modells.

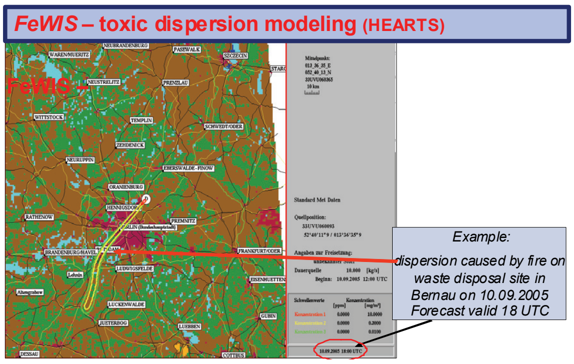
Die Gefährdungsklassifikation umfasst 5 Stufen:

| | |
|---|---|
| 5 | sehr hohe Gefahr |
| 4 | hohe Gefahr |
| 3 | mittlere Gefahr |
| 2 | geringe Gefahr |
| 1 | sehr geringe Gefahr |

Vorhersage für
Berlin-Tegel

10.06.2007 (2)
11.06.2007 (2)
Heute (3)
13.06.2007 (3)
14.06.2007 (3)
15.06.2007 (2)

*Fig. 14 FeWIS – sample picture Forest fire index*



*FeWIS* – toxic dispersion modeling (HEARTS)

*Example:*
*dispersion caused by fire on waste disposal site in Bernau on 10.09.2005*
*Forecast valid 18 UTC*

*Fig. 15 FeWIS – sample picture HEARTS index*

## 5. FLOOD PROTECTION AND SPECIAL FORECAST FOR SAXONY FLOOD CENTRE

With a view to preventive flood protection in Germany, the flood response centres of the Federal States are provided by the DWD with meteorological information as the basis for their flood calculations from which disaster mitigation measures are derived. With the system RADOLAN it is possible to record the precipitation distribution for the whole of Germany in near real-time at hourly intervals and with great accuracy.

RADOLAN combines the precipitation information from the DWD Weather Radar Network (16 Stations) with the precipitation measurements at ground level. In this context, particular importance is attached to small-scale showers which cause the dreaded, rapidly rising flash floods in small catchment areas.

The DWD and the Federal States have agreed that detailed flood forecasts and the related warnings will furthermore issued by the water resources authorities of the Federal States. The DWD supplies the Federal States with warnings of dangerous weather phenomena with heavy rain. In its official severe weather warnings, which are also issued to television and radio channels, the DWD as National Meteorological Service also points out possible flood risks and gives a link to the web site <www.hochwasserzentralen.de>.

The Saxony Flood Centre (LHWZ) gives forecast and warning previous to danger of flooding. DWD, Regional Centre Leipzig and LHWZ exchange measured values, model data, warnings and special forecast. Yearly take place consultations together. The Weather Service in Leipzig issues especially forecasts for river areas, not only for Saxony, also for Federal States Thüringen and Sachsen-Anhalt.

Rain fall averages for river catchments (two altitude levels: upper catchment and lower catchment) for two 6-hour and two 12-hours periods are forecasted. Levels of probability are connected to the forecasts. The amount of rain which is to fall in a certain river area is stated in a 90%, 50% and 10% probability ratio. The forecast is issued twice a day in tabular form. The standard short-term forecast is supplemented with a risk assessment of the amount of rain exceeding 100 mm in a trailing 24-hour period for two to three days in advance. The forecast is essential for the flood centres' management of barrages. In certain cases a preventive dewatering conduit can be undertaken in order to increase the storage capacity of dams in the case of heavy rains.

### *References*

[1] <www.dwd.de/fewis>

[2] DWD Jahresbericht 2004, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2005, s. 6 – 15, s. 24 – 28, ISBN 3-88148-403-5

[3] DWD Jahresbericht 2005, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2006, s. 10 -30, ISBN 3-88148-414-0/979-3-88148-414-5

[4] DWD Jahresbericht 2006, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2007, s. 15 -21, s.38 -40, ISBN 978-3-88148-420-6

[5] DWD Jahresbericht 2007, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2008, s. 26 -39, ISBN 978-3-88148-432-9
[6] DWD Jahresbericht 2008, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2009, s. 32 - 41, ISBN 978-3-88148-439-8
[7] DWD Jahresbericht 2009, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main 2010, s. 18 - 29
[8] DWD, Geschäftsbereich Wettervorhersage, Vorschriften und Betriebsunterlagen Nr. 11, Betriebshandbuch des Wettervorhersage- und Warndienstes im DWD, Stand 12/2010, s. 4 - 7

# LIMITS OF FLASH FLOOD FORECASTING IN THE CONDITIONS OF THE CZECH REPUBLIC

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## ABSTRACT

In June/July 2009 the weather in the Czech Republic was influenced by a 12 days lasting baric low located over Mediterranean, which resulted in a sequence of many flash foods. The total damage was estimated to 200 mil. EUR, 15 people died.

Although flash floods are considered to be extremely difficult to forecast, case studies simulating real-time forecasting indicate that at least some of flash floods can be predicted several tenths of minutes in advance. For successful flash flood forecasting, it is necessary to have precipitation nowcasting together with the hydrological model to be able to estimate the development of the flow in the streams in real time. However, according to case studies, even with these tools some forecasts fail.

The main problem is in the estimation of both measured and predicted precipitation. The heavy rainfalls are caused by severe convection that is very discrete in time and space, thus almost impossible to forecast before its initiation. The high uncertainty in the nowcasting of the convective rainfall leads to so called "variant-approach". The several precipitation scenarios are obtained from several different nowcasting methods. These scenarios are then used for calculation of several discharge scenarios. In such a way the forecaster obtains the spread of expected peak discharges. It is necessary to stress that in flash flood forecasting we are not interested in peak discharge, but in the reaching a predefined category of flood emergency.

This method was tested on several case studies from recent years. Despite each location is different and can require different approach (e.g. mountainous areas where the radar visibility can be very bad), some basic recommendations for flash flood forecasting were set up and will be tested in operation for pilot catchments in following season.

## 1. INTRODUCTION

In June/July 2009 the weather in the Czech Republic was influenced by a 12-day lasting baric low located over eastern Mediterranean and Balkan, which resulted in a sequence of many flash foods. The total damage was estimated to 200mil. EUR, 15 people died.

Although flash floods are considered as hardly predictable phenomena (taking into account exact time and location of its occurrence), first efforts in flash floods forecasting have been already made [1]. Some flash floods can be predicted several tens of minutes in advance. Nowadays, new methods of nowcasting are being developed in CHMI [2,3,4]. Together with the distributed hydrological models they promise a new progress in predicting of these phenomena.

The problem of flash flood forecasting is connected with great uncertainty of the parameters of such phenomena. All the information we have about precipitation causing flash flood is very uncertain, also the rainfall-runoff modeling is only estimation of a real course of the flood in the terrain. This uncertainty is necessary to take into account when the forecaster is deciding whether to issue a warning or not.

In the paper the authors try to describe how we can deal with the uncertainty connected with the flash flood forecasting. The proposed method is tested on several flash floods which occurred in last year in the Czech Republic.

## 2. THE METHOD

The method is based on detail analysis of the state in the catchment. The flash floods typically hit small catchments, so the size of the analyzed catchment should be less than cca 100 km$^2$. Since the flash floods are very quick the analysis must be performed repeatedly in small time steps (usually 5 or 10 minutes).

The repeated analysis can be described by so called "evaluation circle" (see Fig. 1), it consists of several steps:

1. **Precipitation analysis**. In this step the already fallen precipitation are combined with the various precipitation forecasts. In small catchments there is usually no precipitation observation - we must use radar-based quantitative precipitation estimates (QPE). The "merge" QPE based on radar-raingauge merge algorithm [5], which is available in 1 hour step, is supplemented by adjusted-radar QPE available in 5 minute step. The precipitation forecasts are obtained by various nowcasting methods, e.g.:
    a. COTREC – see Novák 2007,
    b. COTREC-ext using also radar data from neighbouring countries [6],
    c. CELLTRACK – see Kyznarová et al. 2009,
    d. PERSISTANCE

    Nowcasting methods, which are based on radar echo extrapolation, are usually adjusted by last available adjustment coefficient (in our case by mean field bias – see [5]). There are many ways how the adjustment coefficient could be obtained. Different methods of adjustment can bring new precipitation forecasts into an ensemble of all available forecasts, which can be used in further analyses [7]. The precipitation analysis can be depicted with the help of a map (see Fig. 2) or a graph, which describes the development of the precipitation in time (see Fig. 3). However this method does not take into account the time and spatial resolution of the precipitation.

2. **Decision point.** We check, whether any of the precipitation scenarios exceeds the certain level of alert or warning. So far we estimated this level from the experience of hydrologists, but this value can be based on some hydrological models, where the actual soil saturation is calculated. If the level is exceeded, we proceed to the hydrological simulations.

3. **Hydrological simulations.** Rainfall-runoff simulations are based on all precipitation scenarios from the precipitation analysis. Thus we obtain the set of various discharge scenarios – and again we check whether the warning level is exceeded. In observed catchments this level is given by so called "3rd flood degree – flood warning". In catchment without observation (without watergauge stations) this level must be estimated, e.g. by a discharge with 5-year return period – which is usually 3rd flood degree in small catchments.

4. **Decision point.** If any of discharge forecast exceeds the dangerous level, the forecaster must decide whether he/she should issue a warning to the threatened areas. The rule for this decision-making is a subject of a long time testing, because due to the high uncertainty of the whole process there can be a great amount of the false alarms.

5. **Proceeding to the next time step.**

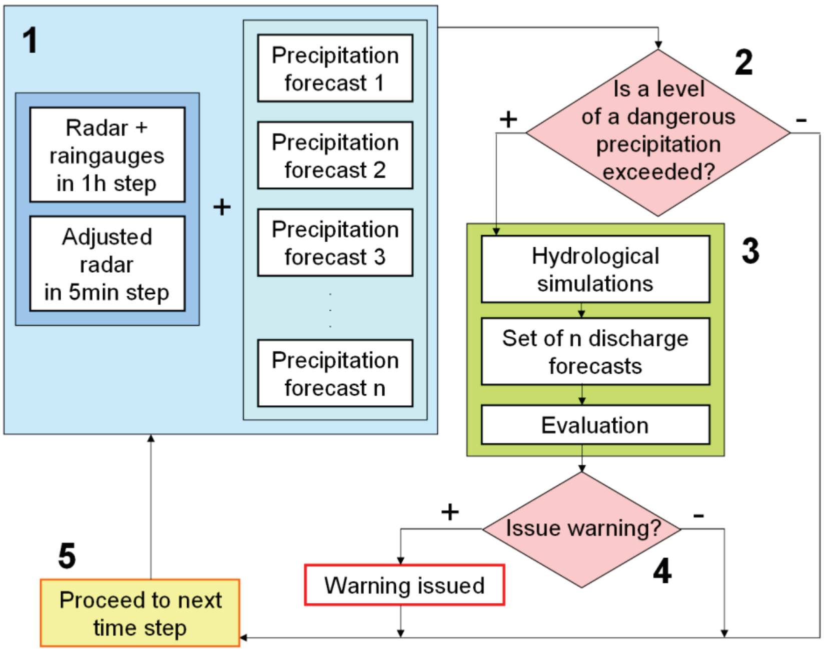

*Fig. 1 Evaluation circle – the principle of flash flood forecasting. 1) Precipitation analysis as depicted on Fig. 2. 2) Comparison of actual measured and forecasted precipitation with a level of “dangerous precipitation”. 3) Hydrological simulations based on various precipitation forecasts (nowcasts). 4) Final decision – to issue warning or not? 5) Proceeding to the next time step. The evaluation circle should be run in 5 or 10 minute step for every catchment.*

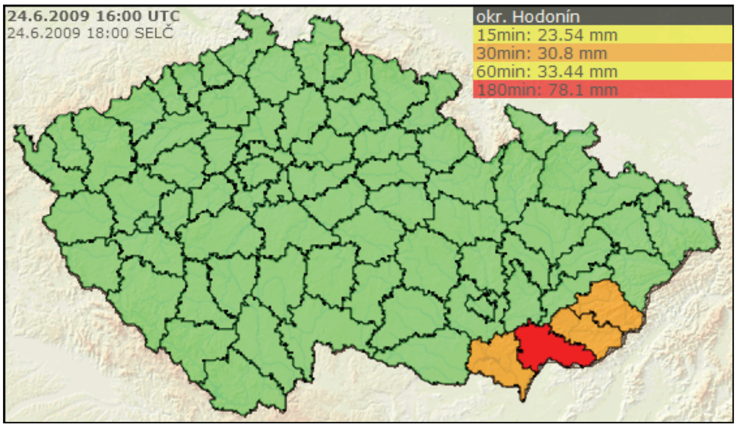

*Fig. 2 Map of precipitation analysis. The levels of dangerous precipitation in dependence of time duration of the precipitation are depicted by various colors (see Novák et al., 2010).*

## 3. HYDROLOGICAL SIMULATIONS – CASE STUDIES

Four case studies were tested. We tried to simulate the flash flood forecasting with the data which would have been available in real time to the forecaster. The hydrological simulations were made by distributed hydrological model HYDROG [8]. The basic information about the tested flash floods together with the achieved results are given in Tab.1

*Tab. 1 Summarization of the results - simulations of flash flood forecasting in the Jičínka river, the Luha river, the Hodonínka river and the Sloup creek catchment*

| **Catchment** | **Jičínka river** | **Luha river** | **Hodonínka river** | **Sloup creek** |
|---|---|---|---|---|
| **Area [km2]** | 95 | 96 | 67 | 50 |
| **Final profile** | Nový Jičín | Jeseník nad Odrou | Štěpánov | Sloup |
| **Level of danger [m3/s]** | 49 | 37 | 32 | 12 |
| **Q100 in final profile [m3/s]** | 178 | 87 | 64 | 35 |
| **Flood extremity** | >>$Q_{100}$ | >>$Q_{100}$ | >>$Q_{100}$ | >>$Q_{50}$ |
| **Time of senseful warning** | 17:40 (UTC) | 19:00 (UTC) | 17:50 (CET) | 13:50 (CET) |
| **Time of possible warning** | 16:40 | 17:40 | 17:20 | 13:20 |
| **Time in advance [min]** | 60 | 80 | 30 | 30 |

## 4. DISCUSSION

The results presented in Tab.1 show that early warning could have been issued from 30 to 80 minutes in advance. But it is important to emphasize that we calculated the discharge forecast to the final profile of the catchment. That means in upper parts of the catchment the flood occurred sooner and probably the early warning for the municipalities located in upper parts is impossible in many cases. In other words, the quick hydrological response to very heavy rainfall from severe convective storm effectively prohibits timely warning at the very beginning of the flash flood. Another problem is nonlinear behaviour of convective storms with back-building, training effects etc that can be captured only with some delay.

## 5. CONCLUSION

The paper shows several case studies of flash floods. The attention is paid to the possibilities of early warning with the help of new 5-minute updated precipitation estimates and nowcasts, The elaborated case studies indicate that new precipitation estimate and nowcasting system that has been introduced in 2009-2010 is definitely improving the possibility of more timely warning. However, the non-linear development of severe convective storm producing heavy rainfall and consecutive flash flood is very difficult to be captured and forecast timely and accurately; it means that in spite to the new warning systems that already proved to be useful there will be non-negligible amount of false alarms and misses.

Following the presented experience, the prediction system consisting of several nowcasting tools combined with the HYDROG rainfall-runoff model will be set up for pre-operational testing in real time.

### Acknowledgement

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***References:***

[1] ŠÁLEK M., BŘEZKOVÁ L., NOVÁK P., 2006: The use of radar in hydrological modelling in the Czech Republic - case studies of flash floods. *Natural Hazards and Earth System Sciences*, 6, 229-236

[2] NOVÁK, P., BŘEZKOVÁ, L., FROLÍK, P., SOKOL, Z., KYZNAROVÁ, H., 2009: Utilization of Radar-Based Precipitation Forecasts for Improvement of Hydrological Forecasts, Proceeding of *„WMO International Symposium on Nowcasting and Very Short Range Forecasting 2009“*, 31. 8. - 4. 9. 2009, Whistler, Kanada.

[3] NOVÁK P., BŘEZKOVÁ L., FROLÍK P., 2009: Quantitative Precipitation Forecast using Radar Echo Extrapolation. *Atmospheric Research*, 93, 328–334.

[4] KYZNAROVÁ H., NOVÁK P., 2009: CELLTRACK – Convective Cell Tracking Algorithm and Its Use for Deriving of Life Cycle Characteristics. *Atmospheric Research*, 93, 317–327.

[5] ŠÁLEK M., NOVÁK P., SEO D.-J., 2004: Operational application of combined radar and raingauges precipitation estimation at the CHMI. ERAD 2004 proceedings, ERAD publication series, Vol. 2, 16-20.

[6] NOVÁK P., FROLÍK P., BŘEZKOVÁ L., JANÁL P., 2010: Improvements of Czech Precipitation Nowcasting System. 6th European Conference On Radar In Meteorology And Hydrology. In: Conference proceedings.

[7] BŘEZKOVÁ, L., JONOV M., NOVÁK, P., ŠÁLEK, M., 2008: Different methods of adjustment of the nowcasting data from the point of view of the hydrological forecasting, In Fifth European Conference on Radar in Meteorology (ERAD) 30.6.-4.7.2008, Helsinki, ERAD publication series. Conference Abstract, full text on enclosed CD.

[8] STARÝ, M., TUREČEK, B., 2000: Operative control and prediction of floods in the River Odra basin. In.: Flood Issues in Contemporary Water Management, NATO Science Series, 2.Enviromental Security - Vol.71, Kluwer Academic Publishers, 2000, s.229-236, ISBN 0-7923-6452-X

# FLASH FLOOD AWARENESS AND PREVENTION IN GERMANY

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## ABSTRACT

During extreme storm events rainfall up to several hundreds of millimeters may precipitate in Europe within a few hours. In many cases, limited soil infiltration results in high surface runoff. These flash flood (FF) events can principally occur at any time and place (e.g. in Germany: Bonn-Mehlem 3/7/2010, Oldenburg, 18/8/2010, Osnabruck/Hanover 26/8/2010). While dedicated counter-measures have been developed during the last decades to improve the management of river floods, attention to FF events has not been given in such a great detail. Moreover, due to the very nature of FFs these measures cannot prevent infrastructure from damage. Still, recent projects (e.g. FLOOD*site* [1] or URBAS [2]) deal with FFs, predominantly focusing on forecasting methods using satellite and radar data (e.g. [3], [4]). Furthermore, real-time guidance for flash flood risk management has been developed [5]. Usually the investigations are based on various case studies after occurred events (e.g. [6], [7], [8]). However, compared to river floods no detailed studies are available on the societal awareness regarding FFs and the necessity of prevention measures. The presented abstract is dealing with this identified research deficit. FF awareness and prevention are two main factors to reduce flood damage in urban regions. Next to general hazard identification processes it is essential to get information on the public's awareness to sensitize flash flood events and to result in effective flash flood prevention as well as management plans.

## 1. INTRODUCTION

Before dealing with flash floods it is essential to distinguish river flood events from flash floods. River floods usually occur in the direct surrounding of watercourses caused by rising river water levels. Hence, their impact area is limited by the topography of the adjoining areas. Return periods can be determined on basis of large data sets and long time-series. Therefore, many counter-measures have been developed during the last decades to improve the management of river floods. These flood types are normally no flash floods.

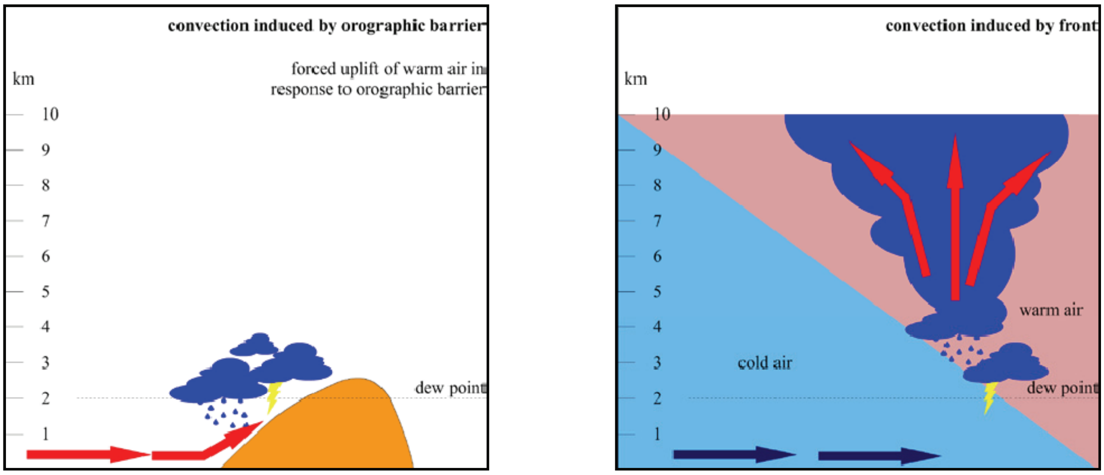
In contrast, flash floods can principally occur at any time and place but are generally intensified in sealed urban areas and thus, involve a high damage potential. The driving forces are usually storm events and resulting extreme rainfall events. During these events rainfall up to several hundreds of millimetres may precipitate in European countries within a few hours. In many cases, limits of soil infiltration, drainage and sewerage capacities result in high surface runoff – so called flash floods.

Flash floods had a worldwide part of around 8 % in all damaging events and 2 % in resulting economic losses during 1980-2003 (MunichRe Foundation). Structural prevention measures and strategies as provided along watercourses against river floods (i.e. dikes/walls and storage reservoirs) do not economically benefit in case of flash floods which are erratic and unpredictable events [9], [10]. Instead, local and very individual protection of buildings with basements and other infrastructure is demanded. Such permanent measures are generally cost-efficient in contrast to potential damages. Benefit-cost analysis for river floods can be arranged at a factor of one, but prevention measures for flash flood events result in a much higher benefit-cost efficiencies.

Vulnerability is likewise intensified by exposing more valuable goods and contents and altered uses of infrastructure. For instance, basements and underground infrastructures are more and more equipped with electrical devices, i.e. washing machines, refrigerators and computers. On the other hand, office buildings often come with a basement garage and elevators operated by controllers installed in the basement. The missing awareness of flash floods may be caused by the apparent low probability of occurrence and the short duration of the event. In contrary, the more common and media-covered river flood events are of longer duration and in most cases forecasted with high accuracy several days before a flood wave imperils the specific region and the maximum water level is reached. Thus, a river flood generally attracts more attention and draws additional precautionary measures than sudden, short-term flash flood events.

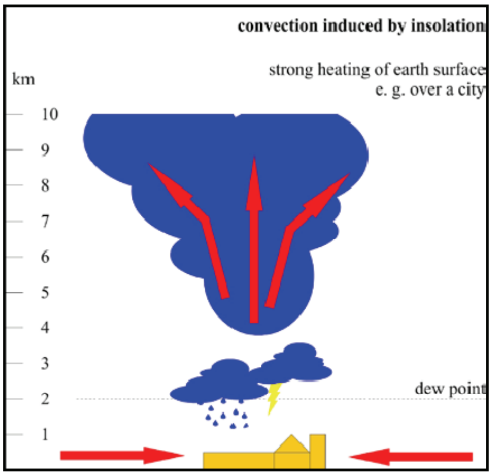
## 2. (HYDRO-) METEOROLOGY

Generally, extreme precipitation scenarios result from storm events with highly concentrated thunder cells running over land areas. Three leading convection scenarios can be defined ([11], see Fig. 1): (a) convection induced by orographic barrier, (b) convection induced by front, and (c) convection induced by insolation. Hybrid occurrences are very likely. In Germany flash floods are mostly induced while storm cells pause unpredictably over indefinite areas and precipitations occur in quasi steady state manner.



a) Convection, orographic barrier

b) Convection, front



c) Convection, insolation

*Fig. 1. Definition of convection scenarios [11]*

Fig. 2 gives an exemplary extreme storm event over Dortmund in July 2008. The region has an average annual precipitation of approximately 750 mm. In summer 2008 more than 200 l/m² were measured within 6 hours.

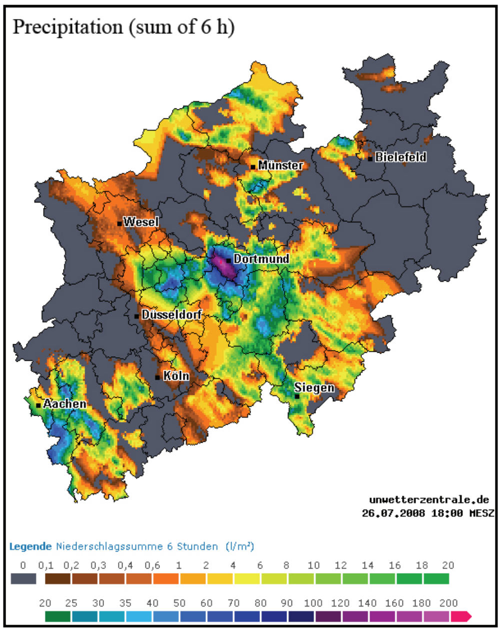


*Fig. 2. Precipitation during 6h extreme storm event in Dortmund/Germany, 20/07/2008 [12]*

## 3. DETERMINATION/CLASSIFICATION

Flash flood events can take place in various ways. Generally two main flash flood types are distinguished [11]: (1) the flat land flash flood and (2) the montane flash flood. Both are characterized by different flow and discharge regimes. The flat land flash flood is generally characterized by exceeding local sewer capacities as well as by surface runoff on sealed areas with low infiltration ratio. Generally, flow velocities are slow and low areas are flooded in a quasi-static way. Montane flash floods occur with high flow velocities and damage potential. Erosion, landslides and debris flow are common events. Drainage and sewer systems are blocked up by transported materials and huge amounts of materials remain as deposition. The montane flash flood is primarily characterized by dynamic pressures and forces.

## 4. AWARENESS – QUESTIONNAIRE CAMPAIGNS

To get a current impression of local awareness levels questionnaire surveys are arranged [13]. The strategy provides two main interest groups: (1) local citizens to research general flash flood knowledge and awareness, and (2) local water authorities, fire departments and federal agencies for technical relief to analyze preventative measures. This paper deals within the first step with questionnaire surveys for local citizens in four regional cities: Wuppertal, Dortmund, Cologne, and Düsseldorf (see Fig. 3). The cities are located in the most populated area in Germany with more than 1,000 inhabitants/km$^2$. All cities, except Dortmund, are located in flat lands close to rivers or tributaries of larger rivers. Results are based on following quantities of questionnaire campaign feedbacks:

*Tab.1. Quantities of questionnaire campaign feedbacks.*

| **Overall** | Wuppertal | Dortmund | Cologne | Düsseldorf |
|---|---|---|---|---|
| **339** | 135 | 60 | 72 | 72 |

A total of 34 questions are asked. These questions are arranged in five blocks: (I) general questions on habitation, (II) general questions on natural phenomena, (III) specified questions on floods and flash floods, (IV) general questions on questionnaire campaigns, and (V) personal questions.

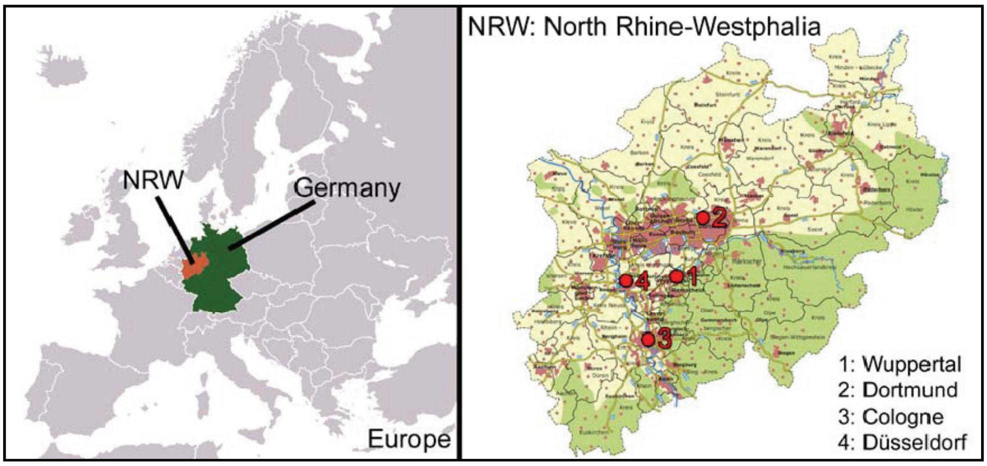


*Fig. 3. Location of questionnaire surveys in Germany in March 2009*

The results show a good spreading in regard to gender, age group and persons per household. To detect possible information sources questions like “Do you read daily newspaper?” and “Are you member of a local club?” were asked. Here 3/4 read the local news in daily newsletters but only 1/4 are members in various clubs. More than 85 % have a main interest in natural phenomena. Questions on residential areas show very good hit rates of local inhabitants, which the questionnaire surveys focused on. Fig. 4 shows the habitation character, where more than 50 % are living in imaginable flash flood affected houses with basements/ground floors – and nearly 60 % of the people are living in their homes for more than 5 years. The question if there is a river or stream around was answered with “no” by 73 % of the interviewed people. Here, it can be assumed that many of them do not know especially about small creeks which might run in underground channels. A main output gives a question dealing with past house flooding events. As illustrated in Fig. 5, nearly 1/4 of the interviewed people already have been affected by flooded basements or ground floors (16 % due to heavy rainfall and only 3 % due to a river flood). Reviewing the city of Dortmund separately (here, an extreme event occurred in 2008, Fig. 2), this value increases up to 25 % only affected by heavy rainfall. Even more dramatically is the number of known affected people. Fig. 6 illustrates that 45 % have affected relatives or neighbors. 44 % of affected people invested in resulting protection measures (Fig. 7) – mostly in backflow flaps, sewer cleaning and pumps. But only 42 % of the damage has been insured (Fig. 9). Damage amounts are generally smaller than 1,000 EUR. But also larger damage amounts were detected. For instance, 6 % of affected people sustained damages of more than 20,000 EUR.

Questions like “Do you think you can be affected by floods / flash floods?” are in the focus of interest in order to detect the people’s awareness. For 41 % of interviewed people think to be generally at risk. Continuatively, the terms “flood” and “flash flood” are prompted to be explained. While 97 % know about “floods” and give the correct answer on the meaning, only 71 % pretend to know about “flash floods” (Fig. 10). In fact, after several personal consultations it can be assumed that many interviewed people never heard about it before. When clarifying the term it was classified the right way (Fig. 11).

Fig. 12 gives the results for detected information sources in regard to flash floods. For flood as well as for flash flood events TV, newspapers and friends are nominated as main sources. Results of questions on informative meetings as a main flood protection measure are given in Fig. 13. For floods 60 % just did not know about the existence of meetings. For flash floods these are 65 %. Here, a large leakage of knowledge has been detected. Mentionable is the number of people which think a flash flood can affect them. 50 % declared “already been affected”, “definitely” or “imaginable” (Fig. 14). But the question on existent insurances has been answered with “no” by approximately 50 % – for floods as well as for flash floods (see Fig. 15). However, more than 50 % remarked the desire for more informative meetings and more general information.

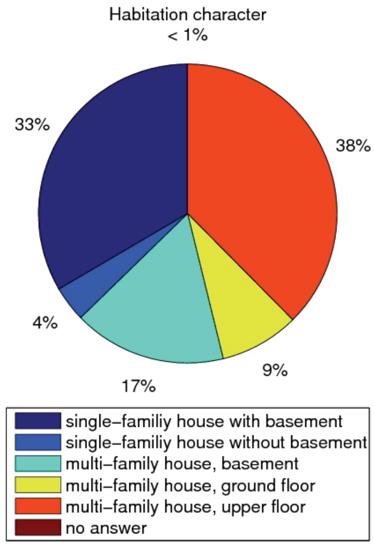


*Fig. 4. Habitation character*

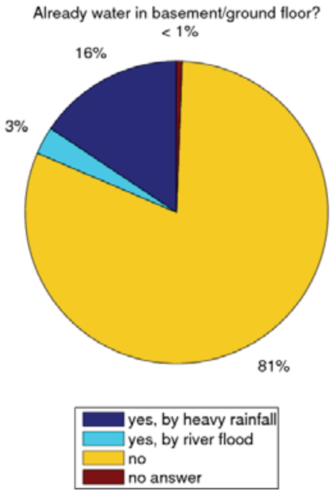


*Fig. 5. Water in house*

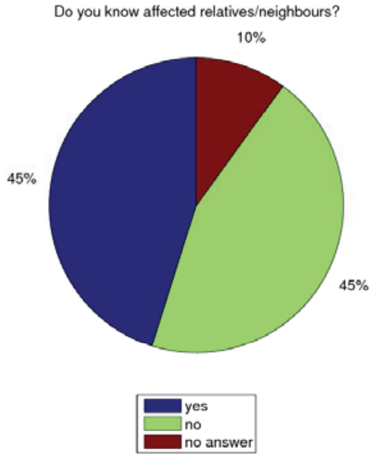


*Fig. 6. Knowing affected*

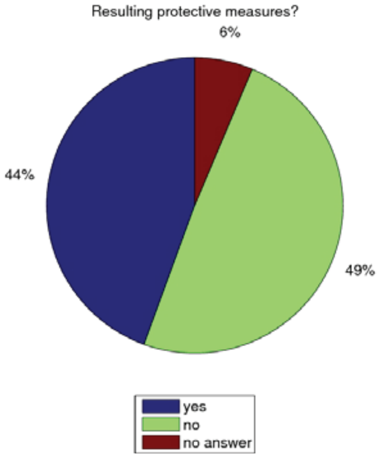


*Fig. 7. Protection measures*

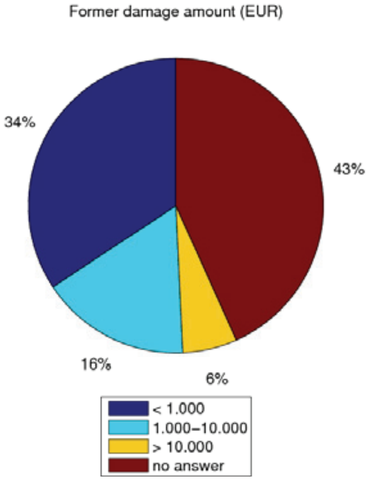


*Fig. 8. Damage amount*

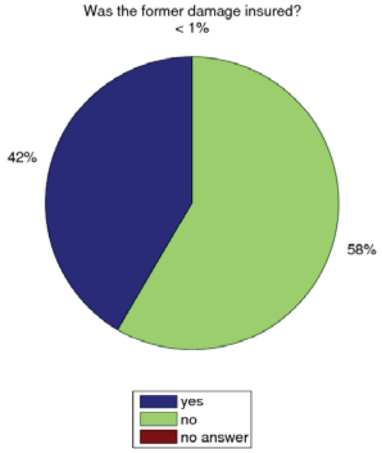


*Fig. 9. Insured damage*

## 5. PREVENTION

To be prepared for flash flood events several measures are conceivable. In accordance with national and European flood protection strategies for river flood events [14], these can be distinguished as follows: (1) technical prevention, (2) flood area management, (3) risk or financial prevention like insurance, (4) information prevention, and (5) building prevention. As a result of the arranged questionnaire surveys there are two main prevention measures for flash flood events which have to be carried out:

1. Clear definition of the term “flash flood” and connection to flood events caused by heavy rain falls, and
2. Arrangement of informative meetings and general information prevention measures (e. g. flyers in daily newspapers, TV documentations etc.) to prepare the people for possible events. Here, information on technical prevention and building prevention measures as well as on financial prevention measures must be discussed in detail.

Hence, main flash flood prevention measures can be arranged in the information prevention methodology in combination with small technical prevention measures. A fundamental knowledge about private sewage systems and technical components (e.g. backflow traps and drainage systems) is absolutely necessary to be protected for lots of flash flood events. These small prevention measures can help reducing resulting damages with only small investigations.

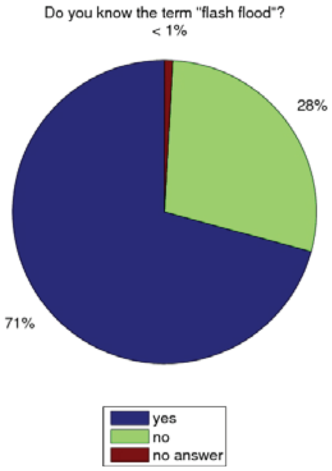


*Fig. 10. Term “flash flood”*

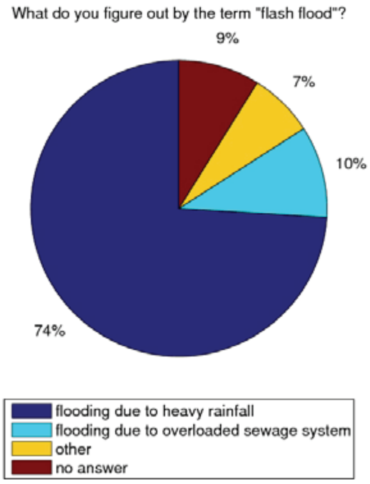


*Fig. 11. Classification*

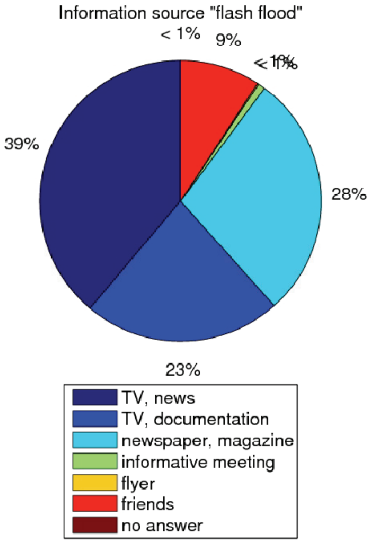


*Fig. 12. Information source*

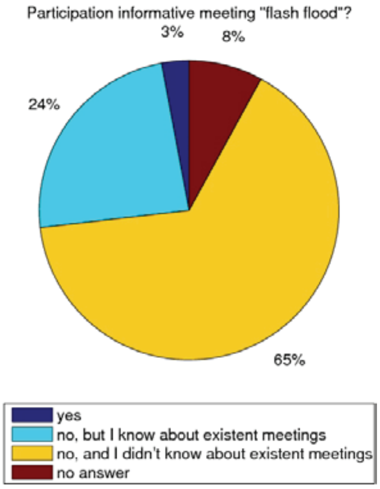


*Fig. 13. Inform. meetings*

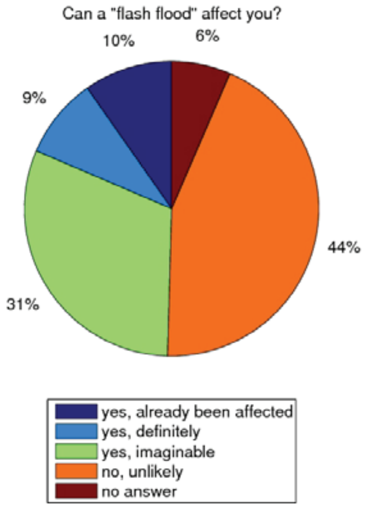


*Fig. 14. Might be FF affected*

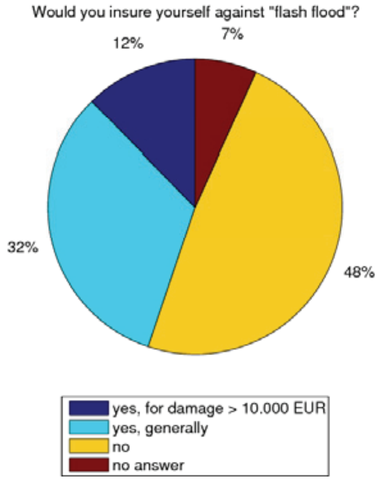


*Fig. 15. Insurance*

## 6. CONCLUSIONS

In summary, the survey reveals that flash flood awareness is lacking in Germany. There is no knowledge about informative meetings and available information materials. On basis of desired informative meetings, information prevention measures must be communicated to the population. Past events show that more than 50 % have already been affected or at least knowing affected people. Before considering technical measures for protection and prevention of damages due to flash floods, this public awareness needs to be properly raised in order to ensure an efficient flood management strategy. Public information initiatives calling for optional closing of natural hazard insurances, as recently carried out by the Bavarian State Chancellery, are demanded for broader mainstreaming of knowledge and expertise in other federal states as well as on the European framework level to help efficiently reducing disaster risks stemming from flash floods in the future.

### *References*

[1] <www.floodsite.net>

[2] <www.urbanesturzfluten.de>

[3] DELRIEU, G. – JATHO, N. – GÖRNER, C. – BERNHOFER, C., 2007. Observation of storm rainfall for flash-flood forecasting – Volume 2 – Satellite structured algorithm system (SAS), FLOODsite, T15-07-08.

[4] DELRIEU, G. – BERNE, A. – BOUDEVILLAIN, B. – BORGA, M. – CHAPON, B. – KIRSTETTER, P.-E., NICOL, J. – NORBIATO, D. – UIJLENHOET, R., 2008. Observation of storm rainfall for Flash-flood forecasting – Volume 1 – Radar structured algorithm system (SAS), FLOODsite, T15-08-02.

[5] BORGA, M. – GAUME, E. – MARTINA, M. – THIELEN, J., 2008. Realtime Guidance for Flash Flood Risk Management, FLOODsite, T16-08-02.

[6] BORGA, M. (2006). Spatial rainfall distribution and hydrological controls of flash flooding, FLOODsite, M1.2.

[7] GAUME, E., 2006. Post Flash-flood investigations – Methodology Note, FLOODsite, T23-06-02.

[8] MIGLIETTA, M. M. – REGANO, A., 2008. An observational and numerical study of a flash-flood event over south-eastern Italy, National Hazards and Earth System Sciences, 8, 1417-1430.

[9] KRON, W. (2009), Überschwemmungsüberraschung: Sturzfluten und Überschwemmungen fernab von Gewässern, Wasserwirtschaft (6), Vieweg + Teubner Verlag, pp. 15-20.

[10] MUNICH RE (2010), Flash Floods: A much underestimated risk, In: Topics 1/2010, pp. 21-25 (>http://www.munichre.com/publications/302-06322_en.pdf>).

[11] URBAS (2009), Vorhersage und Management von Sturzfluten in urbanen Gebieten, Final Report, (<http://www.urbanesturzfluten.de/schlussbericht/schlussbericht/download>)

[12] <www.unwetterzentrale.de>

[13] <www.hydro.uni-wuppertal.de>

[14] <www.dkkv.org>

# HYDROLOGICAL FORECASTING AND WARNING IN CASE OF FLASH FLOOD

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## ABSTRACT

Rainstorms causing flash floods in Central Europe are often of relatively small spatial extent and duration. Therefore the central warning system may fail to deliver the warning on site in time. This contribution set a legal frame of flood warning service in the Czech Republic - local flood authorities are responsible for information provision and flood managing at local scale according to Water Act in the Czech Republic. They can declare the “flood stage” based on water level in stream, its forecast or even based on precipitation (including its forecast). Flood forecasting service provided by Czech Hydrometeorological Institute is introduced. We also explain some experience from 2009 flash floods that may lead to enhancement of the early warning system on national level as well as at affected site. For that purpose a theoretical ways of development and operating flash flood early warning system are outlined for the condition of the Czech Republic.

## 1. INTRODUCTION

Rainstorms causing flash floods in Central Europe are often of relatively small spatial extent and duration. From the meteorological point of view the flash flood could develop virtually anywhere in the area of the Czech Republic, as we are not able to attribute significantly differing probabilities of its occurrence to different regions in the Czech Republic. On the other hand from hydrological perspective more vulnerable area can be identified based on characteristics of slopes, river network, soil and land cover. However, because of geographical conditions of the Czech Republic, majority of the area could theoretically be affected by flash floods.

To decrease a risk of flash floods different measures and instruments can be implemented at different scales and levels. Those include scale landscape management, flood management plans and technical measures at a local scale and flood warning service at regional or national scale. This paper presents state of the art of the hydrological forecasting and warning system operated by the Czech Hydrometeorological Institute in the perspective of its performance in case of flash floods. We also present the current legal framework of the flood service in the light of experience from 2009 flash floods and proposals for its enhancement.

## 2. LEGAL FRAMEWORK OF THE FLOOD SERVICE IN THE CZECH REPUBLIC

A Water Act (No. 254/2001) is the basic legal document driving the flood protection in the Czech Republic. It, together with other connected documents, recognizes three flood levels and defines responsible flood authorities on different administrative levels (municipal – district – regional – national). Flood authorities may, according to Water Act, declare flood levels according to risk of flood. It is mostly done based on defined water level threshold (fig. 1) in selected gauging profiles, however there is a possibility of flood level declaration based on forecasted water level, measured precipitation and newly also based on forecasted precipitation. In addition “Flood Watch” the lowest flood level is automatically set up if CHMI’s warning is issued for particular area. Unfortunately precipitation based flood levels (2nd and 3rd flood level) are not commonly used in real flood protection. The reason is lack of experience in setting those thresholds and thus missing definition in flood protection plans.

However we see this to be a potential significant enhancement of flood protection service if precipitation would be used as a determinant of flood protection action in case of flash floods. To achieve that a guidance on precipitation threshold setting and implementing to local flood risk management plans has to be develop. In the case of setting the thresholds we see great opportunity to use Flash Flood Guidance system (FFG-CZ) which is tested currently at CHMI forecasting office (for more information see a contribution of Šercl in this proceeding). The proper use of thresholds should be framed in new Guidance of Ministry of Environment on flood warning service, which is to be issued during 2011 together with more detailed description given in some "handbook".

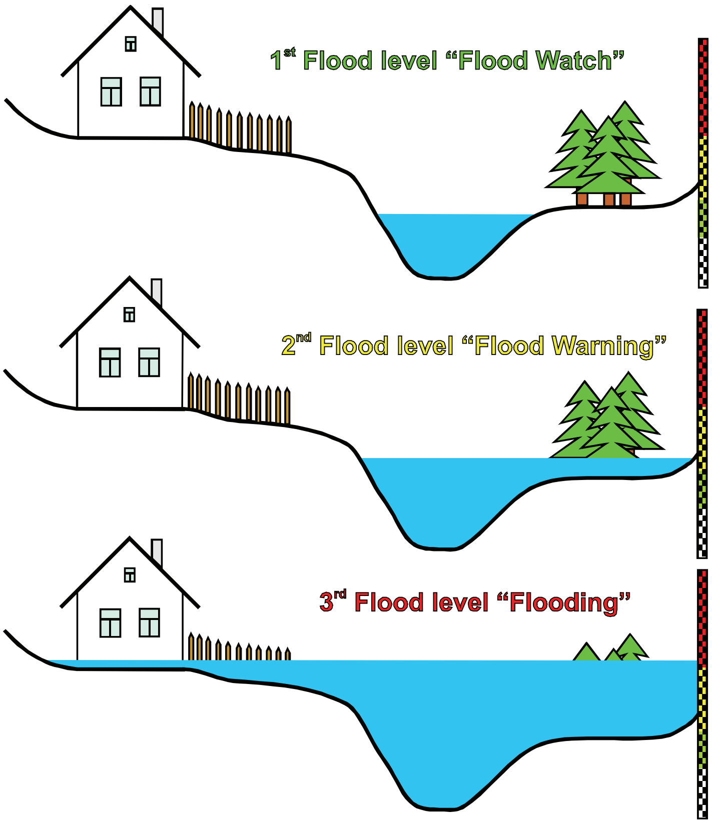


*Figure 1. Three flood levels in the Czech Republic.*

## 3. WARNING AND FORECASTING SERVICE OF CHMI

The Czech Hydrometeorological Institute (CHMI) in coordination with river authorities is responsible for flood forecasting and warning service. CHMI operates Central Forecasting Office and six Regional Forecasting Offices and in cooperation with Army Weather Service issue warning for dangerous hydrometeorological phenomena including heavy persistent precipitation, rain storms and floods.

### 3.1 Warnings

Warnings are issued from Central Forecasting Office. "Prediction" warnings are issued 1 to 2 days before the event, while "occurrence" warnings are issued if some dangerous phenomena are detected. "Occurrence" warnings include some very short term prediction of development of the phenomena.

"Prediction" warnings are based on the numerical weather forecast models and forecaster expertise. Multiple models are used to evaluate the hazard of dangerous phenomena and its intensity. Warnings are issued for particular regions (but districts endangered may be also specified) in three levels of risk: low – high – extreme based on expected event intensity (precipitation amount) or expected level of risk (flood level). Warnings are shared via Meteoalarm web page within the European community.

"Occurrence" warnings are targeted, if possible, to particular districts at risk.

An experience from 2009 flash floods [1] proved that "prediction" warnings are general ones issued for the whole country or several regions without significant differentiation of the level of risk. The reason is the inability of meteorological models (NWP) to simulate severe convection in sufficient detail in localization and sufficient accuracy. Significant enhancement in this field cannot be expected in near future. However the scientific limitation of prediction is mostly not accepted by the users, who complain on receiving too vague information not targeted to their locality. In their words: “I do not care for thunderstorms possibility in South Moravia Region, I care for thunderstorm in my village” or “Do not send me warning if then no thunderstorm occurs at my place”.

Another experience show that “occurrence” warnings must be (1) as localized as possible, (2) it has to used “unscientific” and “non-professional” language and (3) it must give outlook on future development.

Ad 1) Localization must be done at least at district level, but preferably even more local.

Ad 2) If localizing the event, it is preferable to use reference to towns and villages instead of geographical names of mountains units etc. In addition if direction reference is used (further proceeding of thunderstorm) again the town’s names are to be preferred. People are often not able to interpret correctly the information using points of compass. However we feel that this might differ among countries as the usual reference to direction is not common around the world.

Ad 3) When the event is detected at national scale, it usually already cause the damage at place, therefore the main benefit of warning could be not the information on occurrence but on future development in space and time as well as in the meaning of physical response (e.g. if rainfall is detected, an information on expected streams response is expected).

## 3.2 Distribution system

Warnings are disseminated via Integrated Rescue System distribution links (fig. 2), those are operated by Fire rescue Operation Centers on national and regional level. According to legislation warnings are distributed to regional and district Flood Authorities who are responsible for further distribution to municipal level. However in majority of the region fire rescue center distributes warning directly to municipal Flood Authorities. The confirmation of warning delivery is demanded from all recipients. However experience of 2009 flash floods showed that in case of severe thunderstorms the electricity supply often fails as well as cell phone network is out of operation due to lightning activity. Therefore in critical situation the delivery may fail.

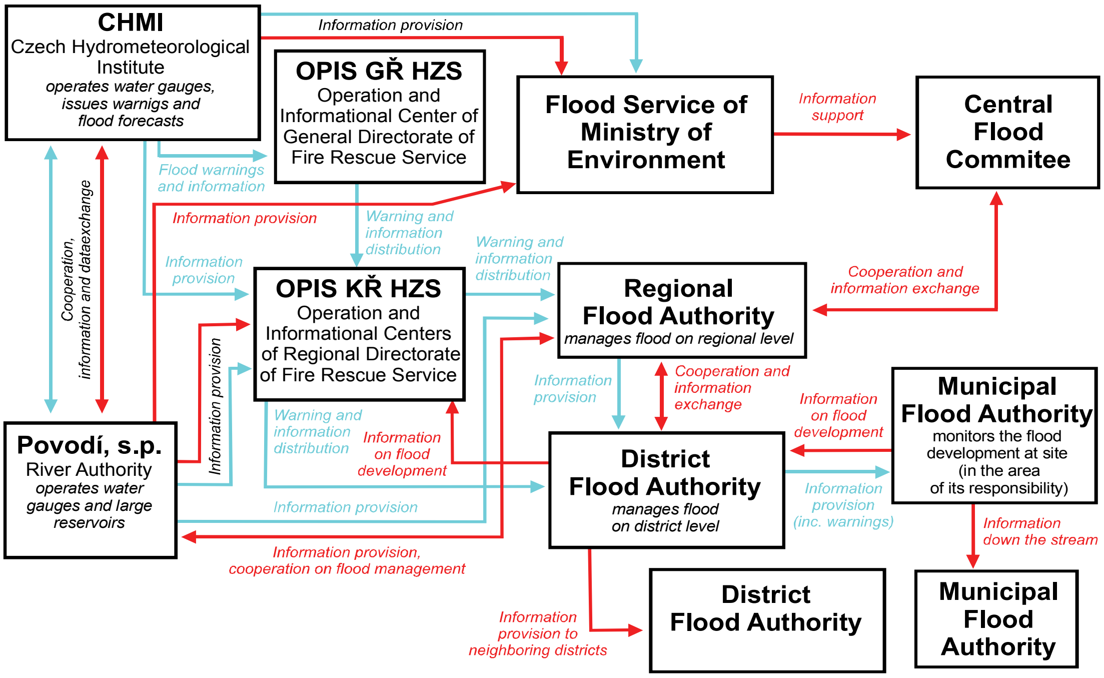


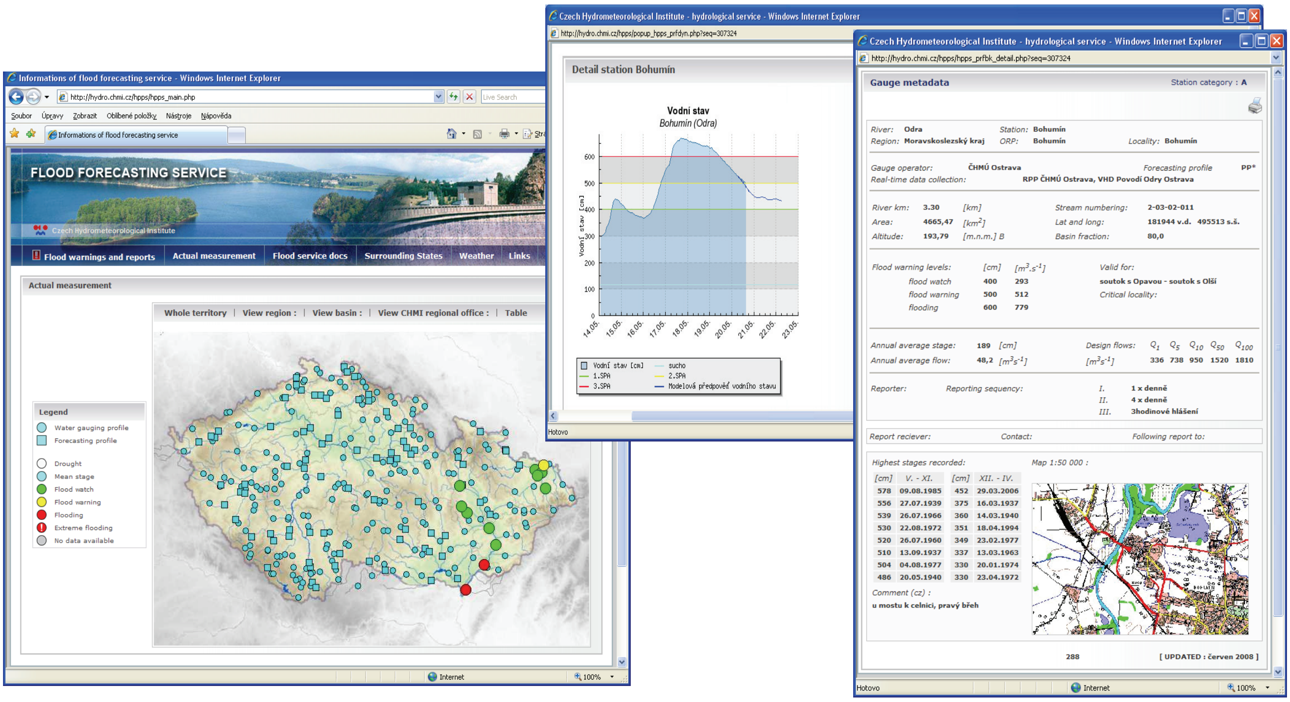
*Figure 2. Distribution system of CHMI's warnings.*

### 3.3 Other information

Warnings initialize the activity of Flood Authorities, further during the flood hydrological information reports are used to provide Flood Authorities with information on flood development and forecast. In addition, observed hydrological data, precipitation and hydrological forecasts are presented at special web page operated by CHMI. Web page also presents information on gauging profiles and flood protection guidelines (fig. 3).

Backup of information for the unlikely case of web page failure is done by simple web presentation at web pages of external provider. Those backup pages are password protected (it was provided to all Flood authorities) to ensure limited number of users during floods.

An important service is automatic SMS warning. CHMI water gauges send SMS if a given threshold of observed water stage is exceeded. The list of recipients of warning SMS (up to 15 individuals) includes CHMI staff (field hydrologist, forecasting office), River Authority, Municipal Authorities and Fire Rescue center. CHMI gauges thus serves as a part of local warning system (fig. 4).



*River:* **Odra** *Station:* **Bohumín**
*Region:* **Moravskoslezský kraj** *ORP:* **Bohumín** *Locality:* **Bohumín**

*Gauge operator:* **ČHMÚ Ostrava** *Forecasting profile* **PP***
*Real-time data collection:* **RPP ČHMÚ Ostrava, VHD Povodí Odry Ostrava**

*River km:* **3.30** *[km]* *Stream numbering:* **2-03-02-011**
*Area:* **4665,47** *[km$^2$]* *Lat and long:* **181944 v.d. 495513 s.š.**
*Altitude:* **193,79** *[m.n.m.] B* *Basin fraction:* **80,0**

| *Flood warning levels:* | *[cm]* | *[m$^3$.s$^{-1}$]* |
|---|---|---|
| *flood watch* | **400** | **293** |
| *flood warning* | **500** | **512** |
| *flooding* | **600** | **779** |

*Valid for:* **soutok s Opavou - soutok s Olší**
*Critical locality:*

*Annual average stage:* **189** *[cm]*
*Annual average flow:* **48,2** *[m$^3$s$^{-1}$]*

| *Design flows:* | $Q_1$ | $Q_5$ | $Q_{10}$ | $Q_{50}$ | $Q_{100}$ |
|---|---|---|---|---|---|
| *[m$^3$s$^{-1}$]* | **336** | **738** | **950** | **1520** | **1810** |

*Reporter:* *Reporting sequency:*
*I.* **1 x denně**
*II.* **4 x denně**
*III.* **3hodinové hlášení**

*Report reciever:* *Contact:* *Following report to:*

*Highest stages recorded:*

| *[cm]* | *V. - XI.* | *[cm]* | *XII. - IV.* |
|---|---|---|---|
| 578 | 09.08.1985 | 452 | 29.03.2006 |
| 556 | 27.07.1939 | 375 | 16.03.1937 |
| 539 | 26.07.1966 | 360 | 14.03.1940 |
| 530 | 22.08.1972 | 351 | 18.04.1994 |
| 520 | 26.07.1960 | 349 | 23.02.1977 |
| 510 | 13.09.1937 | 337 | 13.03.1963 |
| 504 | 04.08.1977 | 330 | 20.01.1974 |
| 486 | 20.05.1940 | 330 | 23.04.1972 |

*Comment (cz) :*
**u mostu k celnici, pravý břeh**

**288** **[ UPDATED : červen 2008 ]**

*Figure 3. Web page providing hydrological information on observed water stages, discharges and hydrological forecasts, as well as on gauging profiles metadata.*

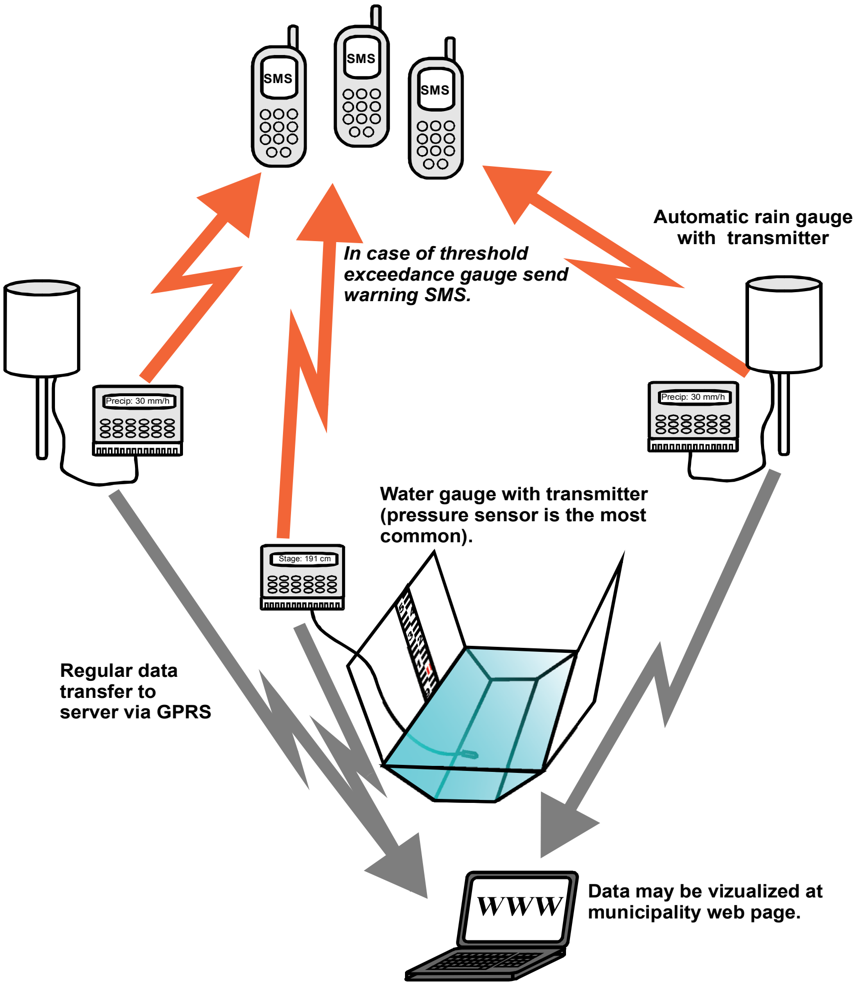


*Figure 4. A scheme of simple local warning system.*

### 3.4 Hydrological forecasting system of CHMI

CHMI developed hydrological forecasting system in the Czech Republic after 1997 disastrous flood. Its aim is to forecast river floods. The majority of important streams were covered in 2001. Since then the regular day to day forecasts are issued including major flood events of 2002 and 2006 (f.e. [2]).

AquaLog forecasting system [3] was developed and implemented for Elbe river basin. Hydrog system is operated in Odra and Morava Rivers basins. AquaLog procedures and environment was inspired by NWSRFS of National Weather Service of the United States as it uses some identical procedures and routines (SAC-SMA, SNOW17). On the other hand specific local needs are addressed during the continuous development of the system. Hydrog system is a Czech model based on St.Venans equations.

The main aim is to forecast floods even at smaller streams in headwaters, as a settlement structure of the Czech Republic demands for it. That determines the characteristics of the forecasting systems:

- the need for rainfall runoff (and snow melting processes) modeling including
- the use of quantitative precipitation forecast (QPF) as an input to achieve
- 48 hours lead-time forecast in 1h time step resolution.
- Computation units are of typical size of 5 to 10 km$^2$, while typical basin of forecasting profile is of size of <100 km$^2$ (in mountains) to 500 km$^2$.

Systems are operated by hydrologists (forecaster) in an interactive way to ensure a quality check of the outputs.

Described system setup is obviously not targeted to flash flood forecasting, that was proved in evaluation of 2009 flash floods (fig. 5) as well as in the long term evaluation of the model outputs (fig. 6).

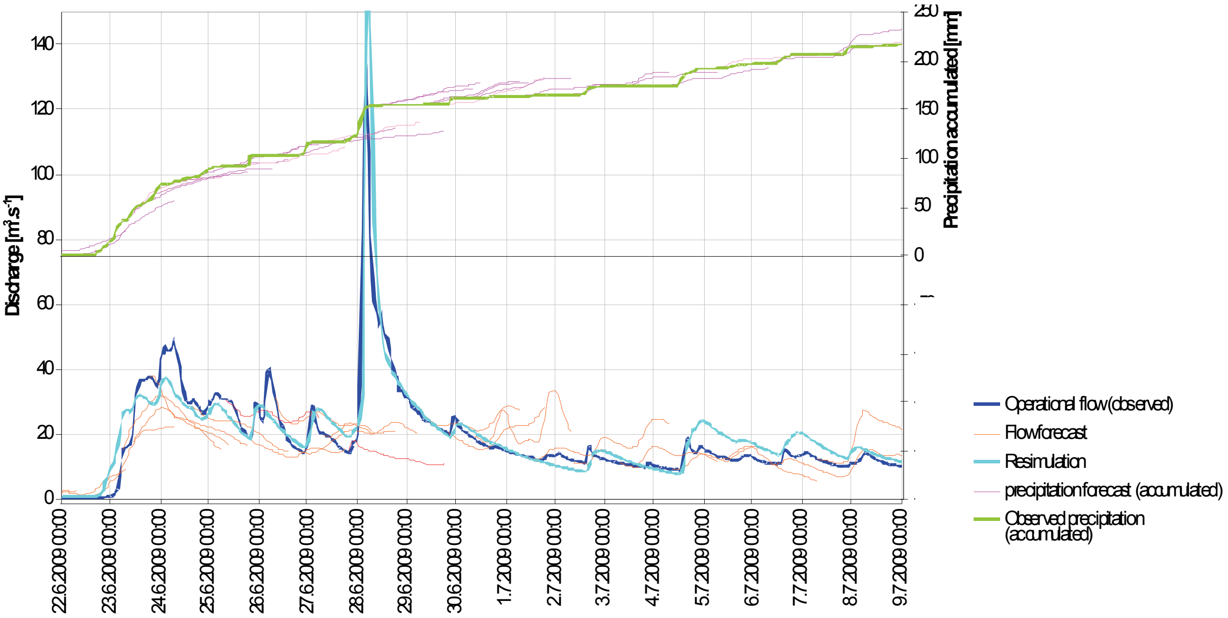


*Figure 5. Real-time meteorological (accumulated precipitation) and hydrological forecasts of June – July floods of Blanice River at Podedvory including flash flood of June 28th. Resimulation proves the reasonable performance of hydrological model itself even for flash flood, but real time outputs heavily depends on QPF accuracy.*

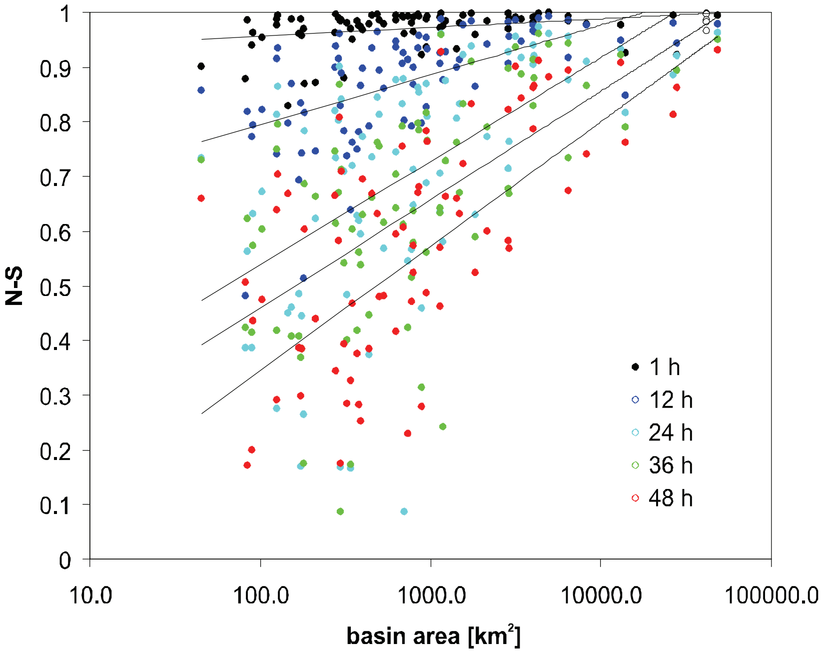


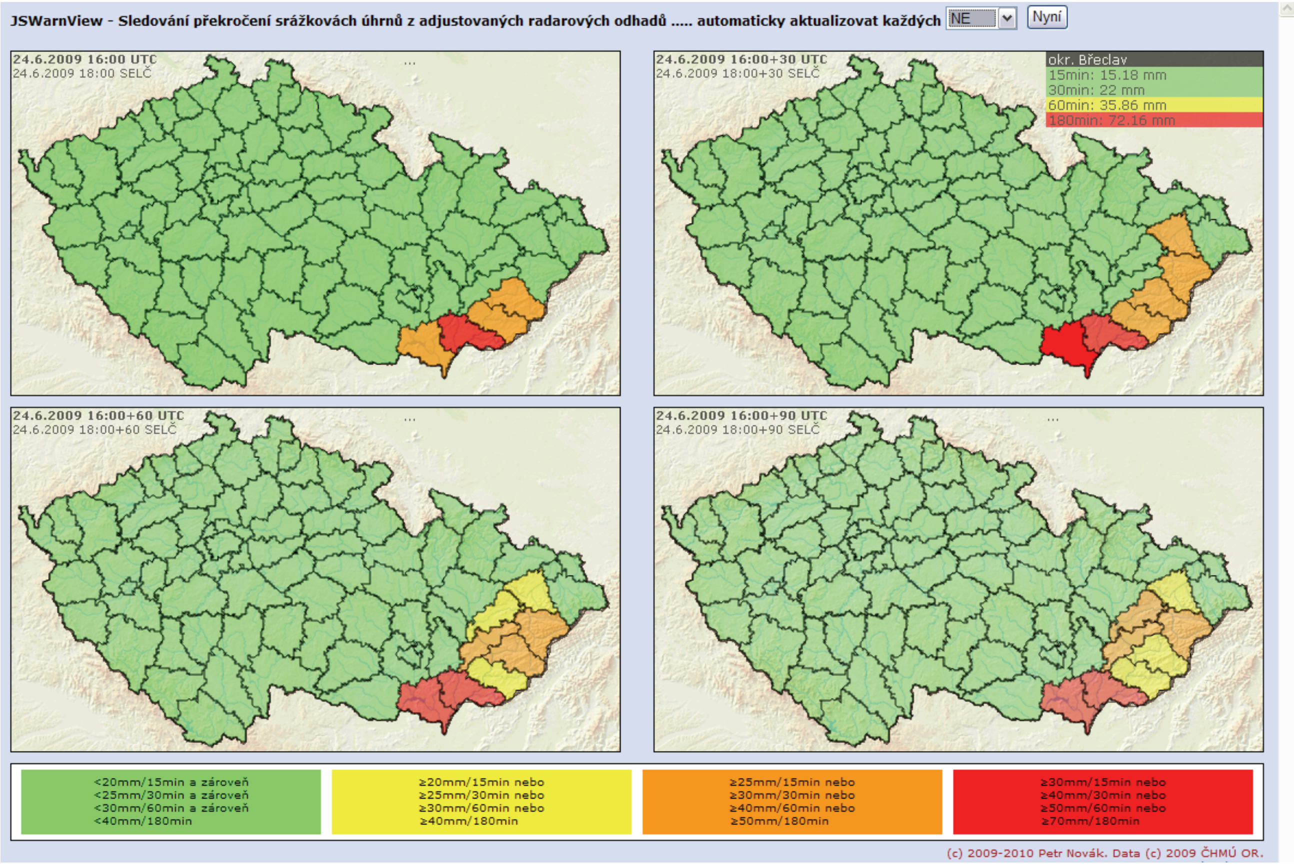
*Figure 6. Forecast users are interested in final output without separating uncertainties of separate steps of described process. Therefore an evaluation of final operational forecasts was done for profiles within Elbe river basin and period 2002 to 2008. Effects of uncertainties of observation, data processing and especially meteorological forecasts were not accounted separately. Nash-Sutcliffe was computed separately for each time step (1 to 48 h) of forecasting period to identify its change with the lead time. Evaluation found significant differences of model forecast skill between forecasting profiles, particularly less skill was evaluated at small headwater basins and longer lead times due to higher impact of QPF uncertainty.*

## 4. A WAY FORWARD?

Flash floods as fast developing phenomena do not provide enough time for precise modeling. We estimate a delay of 30 at 60 minutes in processing the data trough current hydrological models used at CHMI and disseminating the information to the affected locality (at that time flash flood is about to peak there). Study of Šálek et al. [4] proved that even radar based nowcasting use in hydrological model provides only 10 to 30 minutes of lead time for delivering the information to place. That suggests using more uncertain but "fast" indicative methods in assessing the real time flash flood risk.

Among them FFG-CZ at the fist place as a "preparation" tool before precipitation occurs to identify "dangerous precipitation threshold" that could than be easily compared to measured reality. Another lead time can be gained by using nowcasting instead of only observation (although the uncertainties of outputs increase).

Experience from 2009 flash flood showed that meteorologists need more frequent information on rain gauge measured precipitation to support radar information for issuing the warning. Hourly precipitation sum from rain gauge was not sufficient. Therefore the frequency of data transmission and summing was increased to 10 minutes. In addition radar-rainfall combination was implemented in moving 10 minute time step. Another simple tool was made to evaluate maximum radar rainfall estimates (including nowcasting up to 90 minutes) on district level (warning are defined on the scale of districts). WarnView (fig. 7) uses defined precipitation thresholds for different temporal aggregations (15-, 30-, 60-, 180-minutes). The future plan is to implement variable thresholds (in time and space) based on Flash Flood Guidance evaluation of flash flood risk.



**JSWarnView** - Sledování překročení srážkovách úhrnů z adjustovaných radarových odhadů ..... automaticky aktualizovat každých NE

okr. Břeclav
15min: 15.18 mm
30min: 22 mm
60min: 35.86 mm
180min: 72.16 mm

<20mm/15min a zároveň
<25mm/30min a zároveň
<30mm/60min a zároveň
<40mm/180min

≥20mm/15min nebo
≥25mm/30min nebo
≥30mm/60min nebo
≥40mm/180min

≥25mm/15min nebo
≥30mm/30min nebo
≥40mm/60min nebo
≥50mm/180min

≥30mm/15min nebo
≥40mm/30min nebo
≥50mm/60min nebo
≥70mm/180min

(c) 2009-2010 Petr Novák. Data (c) 2009 ČHMÚ OR.

*Figure 7. Warnview – a tool for real time evaluation of maximum radar estimates at district level for observation and three nowcasting lead times – case of June 24th 2009.*

However the most we can gain at local scale if information on measured precipitation does not need to be processed in central databases but serves as information for flood protection action directly at place. That is possible if local warning system (LWS) is at place. There is a financial support from European funds to implement LWS's in the Czech Republic until 2013.

### 4.1 Increase of preparation and risk perception

Flood protection is often described as a chain of actions starting from meteorological and hydrological forecast through dissemination of information, flood committees decision making to general public making useful individual actions. This description fits well the reality as all effort might be lost in one step (weak link).

It doesn't matter what forecasting method and tools do we (hydrometeorological community) use (a probabilistic, a simple indicative or a expert judgment). What does matter is, if our information is understood by users and if they benefit from it. Therefore we have to concentrate more on the end user. There are some questions we have to ask ourselves:

- Do we provide to the user what they want and need?
- Do users understand the warning and information?
- Whose view has to change to overcome troubles and misunderstandings?

In addition there are many aspects remaining unsolved. Next list does not aspire to be exhaustive, nor do we aspire to provide answers. Our aim is to raise it for everybody involved in flash flood protection to consider it in his work and life.

- Concept of risk perception is often misunderstood; unfortunately people usually do not evaluate risk mathematically. There is a great gap between "risk awareness" and "risk perception". People are often aware of risk but do not "live with it". It is quite common that people do not understand that risk cannot be eliminated by physical measures nor can't be solved at national level by some institution.
- The reason for incorrect risk perception is closely connected to mismatch between flood occurrence probability (frequency) and lifetime (or time of living at one location).
- Communication is the only tool for increase risk awareness and perception. However the question of the best communication form and strategy remains unanswered. It is sure that different groups of end users (e.g. decision maker, householders) need different way of communicating different information. Towards the general public we have to avoid to be too complex (pictures and signs might be of better use). However people have to learn to live with risk generally in the same way as they learn to drive in driving school; but they also have to practice driving/living the risk to keep they knowledge and skills.
- The great challenge in communication is to explain the uncertainty (probabilistic nature) of hazard, risk as well as warning (to avoid a crying wolf effect in case of "false warnings"). Should we communicate the uncertainty at all if users do not understand it correctly? (An example of misunderstanding the probabilistic nature of warning is even the term "false warning". Warning cannot be false itself it reflect a risk of event not the real occurrence. Even if the event did not occur it didn't mean there was not a risk of it.).

The general and key thing is "How to get and keep people involved?"

## 5. CONCLUSIONS

We have introduced the current state of the art of the real time flood forecasting in the Czech Republic, experience and progress made after 2009 flash floods. However the main aspects of the efficient flash flood forecasting and warning are the cooperation and communication with end user. Unfortunately, lots remained undone in this field. However we can at least proceed by asking the right questions how to produce products (warnings) of the best use by end users and how to keep them involved in the flood protection chain trough their education, awareness, risk perception and efficient actions during the flash flood events.

***References:***

[1] MINISTRY OF THE ENVIRONMENT, 2009: Evaluation of floods in June and July 2009 in the Czech Republic. <http://voda.chmi.cz/ps09/index.html>

[2] HLADNÝ, J. - KRÁTKÁ, M. - KAŠPÁREK, L. (eds.) 2004: August 2002 catastrophic flood in the Czech Republic, Ministry of Environment of the Czech Republic, p. 44

[3] DAŇHELKA, J., 2007: Operational Hydrology: Hydrological Models and Forecast Uncertainty, CHMI, p. 104 (in Czech)

[4] ŠÁLEK, M. - BŘEZKOVÁ, L. - NOVÁK, P., 2006: The use of radar in hydrological modeling in the Czech Republic – case studies of flash floods. Nat. Hazards Earth Syst. Sci., 6, 229–236, 2006

# STATE OF ART WITH FLASH FLOOD EARLY WARNING AND MANAGEMENT CAPACITIES IN FRANCE

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## ABSTRACT

Recent extreme flash floods events in France with catastrophic consequences have demonstrated that the existing early warning systems have reached their limits for small scale rapidly developing rain patterns. They have also demonstrated that spatial planning related regulations aimed at reducing disasters are sometimes not enforced with sufficient care by the stakeholders.

The present paper summarizes the status of the French early warning system for hydrometeorological Hazards, highlighting its strengths and limits with respect to flash floods. It exposes the plans adopted following the events of 2010 (Xynthia storm and floods in the Var département), plans covering development of new tools and reinforcement of the regulations.

It is based on the presentations made during the FFEW workshop by Mrs Caroline Wittwer (SCHAPI), Joël Crémoux (Météo-France), Jean-Baptiste Migraine (AFPCN) and Alix Roumagnac (Predict Services).

## 1. INTRODUCTION

This paper provides an overview of flash flood early warning capacities and related risk reduction measures in France, as of June 2011. It is built upon contributions by the French Association for Disaster Risk Reduction (AFPCN), the French meteorological service (Météo-France), the French hydrological service (SCHAPI), and a private company providing preparedness and early warning services to local communities (Predict-Services).

The French early warning system related to hydrometeorological hazards is called “the Vigilance system”. Its principles result from the return of experience from floods in south of France and from the storms Lothar and Martin that occurred in late 1999. It was established by the French meteorological service, Météo-France, and the directorate for civil security (DSC) of the Ministry of Interior.

Initially related to meteorological events like storms and heavy precipitation (Meteorological Vigilance), the system has been gradually expanded to taking into account the risk of heat wave (since 2004), floods (since 2008) and will include the marine submersion by the end of 2011.

The “Vigilance system” relies on a close collaboration between the Operators, mainly Meteo-France and the Flood forecast services, within a regulatory framework established with the Ministries respectively in charge of the Interior, Environment and Health.

Various laws and regulations help to strengthen the Vigilance system, including: (i) the Law of 30 July 2003 on prevention of natural and technological disasters and reconstruction, that resulted in better information and accountability of citizens in disaster risk reduction and strengthening of protective measures, (ii) the Law of 13 August 2004 for civil protection modernization that clarified the roles and responsibilities of different stakeholders in the context of crisis management, including those of citizens, (iii) finally, the Organic Law of 1st August 2001 that allowed a sharing of budgetary resources between the stakeholders, thus strengthening the collaboration across departments and specialized agencies for Vigilance and early warning systems.

## 2. HISTORICAL FLASH FLOOD EVENTS

Statistics on natural disasters in France show that more than 90% of events leading to damages and casualties (and therefore to reparations) are linked to flash floods resulting from heavy and localised precipitations events, mainly in the southern part of France, around the Mediterranean Basin. Most of them have a very limited impact, but a few are still in the memories, due to important human and economic consequences, and it is useful to record them here, as they have contributed to define the present early warning system in France.

High intensity rainfall events regularly affect the Cevennes (Cevennes episodes) as well as other parts of Southern France (Mediterranean episodes). Cevennes episodes usually occur in early autumn when the sea is warm enough, in the south-east of the Massif des Cevennes, pré-Alpes and Corbières. Similar phenomena also occur on catchments with high relief located between Catalonia and the Italian Piedmont.

On 29 September 1900, Valleraugue, a small village situated at the foot of the Cevennes' mountain Aigoual, recorded 950 mm of rainfall in 10 hours.

1000 mm of rainfall was recorded in Roussillon on 17 October 1940, and 2000 mm in 5 days. Floods devastated both Spanish and French sides (300 deaths in Catalonia, 50 in France).

In Nimes on 3 October 1988, 400 mm of rain fell in six hours. 14 million of cubic meters passed through the urban part of Nimes, with flows over 2 m in height on some paved roads. 11 people were killed in the flooding. The damage amounted 610 million Euros, affected 45,000 people, and damaged 2,000 houses and 6,000 vehicles, 15 km of roads, 41 schools...

In Vaison-la-Romaine on 22 September 1992, 300 mm of rainfall fell, 150 mm in less than 2 hours, turning the Ouvèze river into a murderous and destructive torrent (41 dead and 320 houses damaged).

On 12 November 1999, almost 650 mm of rainfall were recorded in 36 hours on the Aude at Lezignan-Corbieres. In addition, the intrusion of a marine storm severely disrupted the natural flow of rivers to the sea. 26 people were killed during the night between 12 and 13 November 1999. The damages reached over 533 million Euros.

On 8 and 9 September 2002, the department of Gard and its immediate surroundings were badly affected by heavy rains. Exceptional values of precipitation were recorded: 687 mm in Anduze and even 713 mm in Cardet (south of Alès) in twenty-four hours (about one year of average precipitation). This event caused 24 deaths, mainly following the breaking of a dike in Aramon, as well as an estimated 1.2 billion Euros damages.

The Cevennes episode in early December 2003 was remarkable for its scope and virulence: from the Aude up to the north of the Massif Central and to the Southern Alps. The Rhone River spilled over a considerable number of towns and plains of the Gard departement and the city of Arles, after the collapse of several dikes. 16 million m3 invaded much of the city of Arles and the Rhone achieved a record runoff of 12 777 $m^3/s$ (compared to 1800 $m^3/s$ in normal times). The Vidourle coastal river between the Gard and Herault, flooded for the third time in two years in the city of Sommieres. With 6 meters above its usual course, the Lez reached the height of Lattes and Montpellier's levees protecting tens of thousands of inhabitants. Further west, the rivers Herault, Aude and Orb also flooded some towns and villages.

The return of experience from these event led to a new organisation of the flood forecast services (2003) and to the implementation of the “flood vigilance system” (2004).

More recently, some flash flood events leading to damages, deaths or casualties have marked the opinion. Amongst them; we note the flood of the river Nivelle in the Pays Basque (may 2007), the flooding of Sainte Maxime Town on the Mediterranean Coast (September 2009), and the large flooding of the Draguignan area, in the same region (June 2010), the latter being the most catastrophic, leading to 25 death, more than 260 000 people impacted an more than one billion euros of damages [1].
The returns of experience from these events draw attention on the limits of the territorial planning regulations in vulnerable areas and of the vigilance system when very local phenomena impact rapid response river basins. Some actions have been taken and the last one was the adoption, in January 2011, of a “National Plan for flash submersion” covering both the effect of flash floods and marine submersion.

## 3. THE “VIGILANCE SYSTEM”

### 3.1. Current status

The principle behind the French vigilance system is to disseminate forecast information on the possible occurrence of dangerous phenomena, on a given area, within the next twelve hours and simultaneously to the authorities in charge of crisis management and to the population. The objective is to raise awareness within populations on potential danger in the next hours and to enable the authorities to activate safeguard and rescue plans, if needed. When established in 2001, this approach was really innovative from the previous situation, where the population and the authorities did not get the same type of information.

Today, the vigilance system [2] covers the following hydrometeorological phenomena: wind, rain and floods, thunderstorms, snow and glazed frost, avalanches, cold waves and heat waves [3]. It involves two production chains working together, both operated by Meteo-France (for the meteorological phenomena) and by the Flood forecast services of the Ministry of Environment for the hydrological events. Four level of vigilance have been defined:

- **Green**: nothing to mention;
- **Yellow**: if your activity is conditioned by meteorological or hydrological conditions, keep being informed on the evolution;
- **Orange:** any activity may be impacted by the meteorological or hydrological condition, keep being informed of the evolutions and consider the behaviour advices given on the maps. The chart is relayed through the media to the general public. Authorities are prepared to activate plans in a pre-alert mode.
- **Red:** very dangerous events are expected, stop any activity if possible and wait for authorities’ advices. Alert are disseminated by Authorities through all available means, as part of the activation of rescue plans.

Two vigilance charts are daily published twice a day and, at 6h and 16h local time, with possible updates from the orange level, one for the meteorological events at the département scale [4], one for the flood events at the river basin scale [5], but totally interrelated. These charts may be updated more frequently from the “orange” vigilance level. They are permanently available on the operator’s web sites, which are interrelated.

The Vigilance system is constantly improved by a feedback mechanism involving all stakeholders, which mandatorily takes place after each phase of red alert. The "return on experience" exercises allow continuous improvement on prevention and emergency preparedness legislation and practices. For example, the combined experiences following the 1999 storms and 2002 floods were critical in the development of the current legislation and vigilance system, and allowed to review some building standards and conditions of exploitation in exposed areas.

Quarterly meetings are held, with representatives of Ministries of Interior, Ecology, Transportation and Health, to assess and improve operational capabilities as well as coordination and management from end to end. In addition, an annual assessment document provides statistical data about warning activation and related damages.

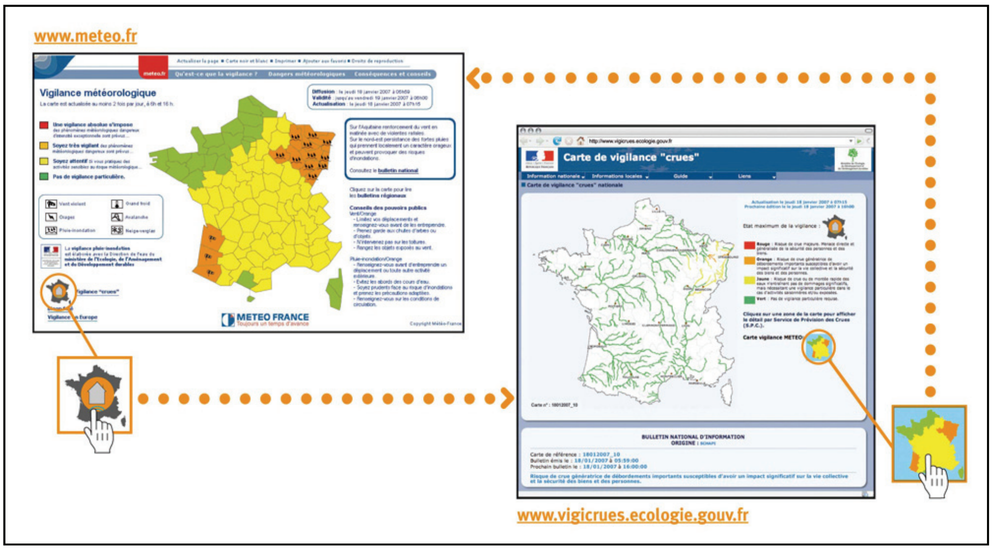

*Figure 1 : Links between the meteorological an floods vigilance maps (Météo-France and SCHAPI)*

## 3.2. Principles and limits

Without entering into detail, it is useful to know that, in case of a crisis related to a natural hazard (but not only), the French civil security system identifies two key authorities for the safeguard and rescue on impacted territories. They are the Prefect of the departement and the Mayor of the city, becoming Directors of rescue operations on their respective responsibilities areas, (according to the historical French administrative organisation) giving to both a responsibility related to civil security and public order.

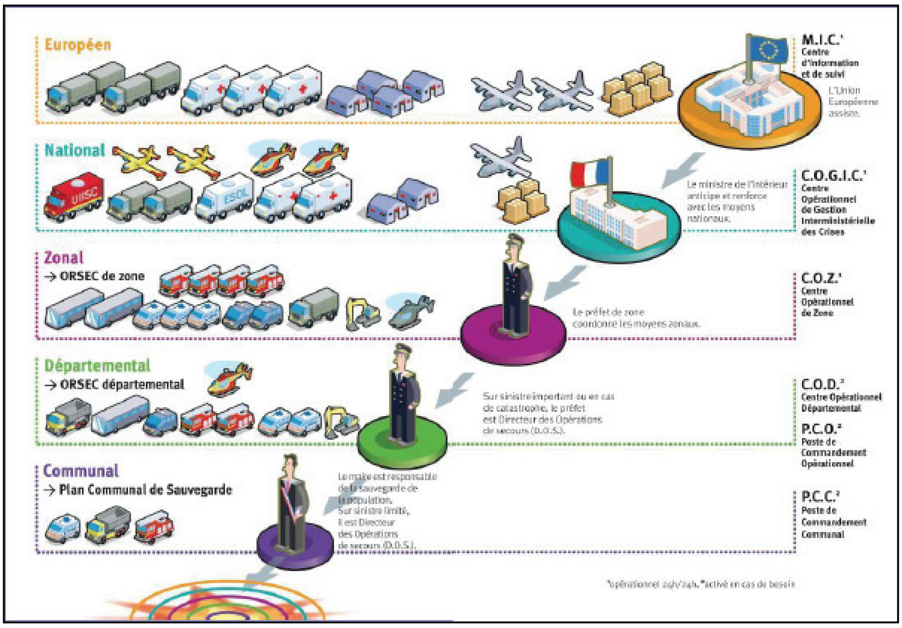

***Figure 2**: the French organization for crisis management. The key actors for purpose are the "Départemental" and the "municipal" (urban districts) ones.  Levels above intervene when the crisis requires mobilizations at larger scale (Source : DSC)*

In case of a potential crisis, the Prefect has the responsibility to alert not only the different actors in charge of crisis management; mainly the rescue services (fire brigades, health services, etc) but also the Mayors of cities and villages. Different levels of alert lead to the activation of dedicated plans by the Prefect on the department and by the Mayor on his territory. In this system, it is the Mayor who shall finally alert the citizen, within the framework of a pre-existing municipal rescue plan he has the responsibility to activate if required by the situation.

Physical protection is necessary but inevitably limited. Emergency preparedness and response are under the responsibility of the mayor for municipality limited events, with assistance from the State (and European Union) for events of greater scope.

The French legislation calls for the development of local safeguard plans in municipalities at risk. These plans should allow advanced identification of the flood zones and prescription of evacuations as necessary based upon local rainfall, upstream runoff and prior soil saturation conditions. However, development and constant testing of these plans are not a common practice yet. In 2010, only 22% of municipalities identified "at risk" have such a preparedness plan, most of them are targeting risks related to wild land fires.

This structure explains why the chosen forecast area for the vigilance system is the département. The main innovation lies in the existence of two channels of information towards the citizen. The first one is general information published daily and aimed at raising awareness on potential dangers and on the ways to respond to it. The second one, in case of a crisis, conveys the alerts to the citizen from the Prefect through the Mayor, as these authorities are entitled to do so. In this scheme it is expected that the citizen, aware of the potential dangers may react properly to protect his life and goods and respond adequately to the received alert.

Experience of vigilance since 2001 shows a very positive impact of the management for most of the hydro meteorological events having occurred, but also shows limits for what concerns rapidly developing phenomena at a smaller scale than the département, mainly for heavy rains that are followed by flash floods. They highlight the need to complement the existing system by an additional step linking more directly the forecasters to the local communities through the Mayors. This aspect is the subject of the following sections.

### 3.3. Vigilance as an element of the disaster risk prevention policy [6]

The French national policy for disaster risk reduction relies on seven items : i) the knowledge of hazards and assets ; ii) monitoring, forecast, vigilance and alert on hazards ; iii) education and capacity building ; iv) urban an territorial planning through regulations ant risk prevention plans ; v) vulnerability reduction ; vi) protection of expose assets; vii) preparation to crisis.

What has been explained above shows that the vigilance system is an element of the DRR system closely linked to the crisis management practices, but not only. It is also (and will be further in the future) related to risk prevention plans. This aspect is to be linked to the possibility of safeguarding people in case of a catastrophic event through local communities safeguard plans (whose efficiency requires a performing forecast, vigilance and alert system). We will see that it is still questionable in the present situation, especially in the case of flash floods, but plans have been established to secure this approach in the perspective of the implementation of the European Flood Directive, which requires the inclusion of an early warning system in any inundations risk management plan on a vulnerable territory.

## 4. OBSERVING AND FORECASTING OF FLASH FLOOD HAZARD

### 4.1. The flood forecasting system [7]

The production of information on floods supposes an operational precipitation forecast system coupled to an operational river runoff forecast system. If the meteorological system dates from many decades, the current hydrological system organisation has been established only in 2003, as a consequence of disaster risk reduction in the law.

This system is operated under the responsibility of the Directorate for disaster risk reduction of the Ministry of ecology. Each of the 22 flood forecasting services (Service de prevision des crues – SPC) has the responsibility to gather information and produce forecast on a given river basin. A Central Service for Hydrometeorology and Flood Forecasting Support (Service central d'hydrometéorologie et de soutien à la prevision des inondations – SCHAPI) supports the work of the SPC and contributes to the development of tools and practices. All SPC except one depend on Regional Directorates of the Ministry of Ecology, the last being hosted by the south-eastern Regional Office of Météo-France.

The length of rivers monitored by this systems represents only 20 000 km of the 120 000 km of rivers above one meter width, but it concerns about 6 300 cities gathering approximately 90% of the population concerned by floods. These rivers are covered by 1 500 automatic real time water level station, also operated by the Regional directorates of the Ministry for Ecology.

This system works in close collaboration with the precipitation forecast service of Meteo-France, especially for what concerns the vigilance system. Daily links are established between the SHAPI and the central forecast office of Météo-France as well as between the SPC and the regional offices of Météo-France.

Each SPC operates according to a regulation on flood information (Règlement d'information sur les crues – RIC) précising the establishing procedures for forecast and vigilance information on well identified river sections (there are 240 recorded on the vigilance maps).

### 4.2. Current capacities for rainfall forecasting [8]

Rainfall forecasting is a product of meteorological forecast. This is done by Meteo-France, by relying on a complex observing system and on rapidly developing forecast tools.

The core of the observation system is a network of 24 rain radars (Aramis network) producing images and data to detect, follow and forecast precipitation patterns. This network is funded by the Ministry of Ecology for the benefit of the flood forecasting system. Its ground truth is given by more than 2 000 real time rain gauges mainly operated by Meteo-France and the Ministry for ecology.

Using these data, Météo-France is able to predict the risk of extreme rainfall on a large area, but not to predict in advance exactly where this phenomenon will be triggered. The short range forecasts historically based on extrapolation from radar images, now relies on simulation by Mesoscale models like AROME (2,5 km mesh) enabling to forecast precipitation patterns 36h in advance and has demonstrated some success in some rain events in the Cevenol area.

But the latest catastrophic events, in 2009 and 2010 showed that the overall system is limited for phenomena at a scale smaller than the département where any weather pattern requires to some extent an individual follow-up.

### 4.3. Complementary systems at local level

The more recent events (2007, 2009, 2010) have demonstrated that even under a yellow vigilance level, some dangerous phenomena can grow and lead to a catastrophe. This means that additional monitoring and forecast systems shall be operated downstream of the national forecast and vigilance system described above.

This aspect is accounted in the RIC related to SPC, expecting that local initiatives by communities enable to implement observation and forecast on small basins not monitored by the national system but where inundation risk is identified, especially with flash floods.

Today, only a few initiatives of this type have been taken by local communities, especially in the south of France, in the Gard area, where flash floods are common. Development of such systems relying on good runoff models is the key question to be solved at the present time. Most of the time, operations of such systems involve dedicated entities funded by local communities.
For example the cities of Nîmes and Marseille have established their own flood forecast services to manage their water discharge systems in case of floods and to help operating safeguard plans as required. But most of the interested municipalities rely on private operators, like PREDICT Services, which is active in the south of France, in the Cevennes area and in Provence, where most of flash floods occur.
These operators provide to local communities a package of services including the elaboration of the safeguard plans, the definition of the observation and forecast tools and a support to decision in case of a potential event (from the yellow vigilance level). Success encountered in such an approach demonstrates that both safeguard plans and early warning systems shall be developed together for a better efficiency.

## 5. FUTURE DEVELOPMENTS

### 5.1. Extension of the Vigilance system [9]

Major events are analysed through return on experience exercises involving various institutions. For smaller events, the practice is still to conduct one feedback per actor and no overall synthesis. The idea of locally-conducted feedbacks has been put forward without finding to date a systematic implementation. Conducting return on experience exercise can be difficult as it may be concomitant with research in criminal responsibility. However, this function of catharsis, memory and synthesis is essential.

The platforms of the European Network of National Platforms (ENNP) is working in partnership with the European Commission towards a joint analysis of a certain number of return on experience exercises to share lessons learned from recent disasters.

Progresses in flash flood forecast can be achieved through the introduction of an additional level, at the scale of small basins, in the existing vigilance system. We just have seen that such level may be activated through a sound dialogue between local communities and some new operators. But this is not sufficient. Such a new level of forecast requires information and tools, the operation of which is generally far beyond the capacities of the local communities and operators.

This is the reason why, after the Xynthia storm (February 2010) and the floods in the Var region (June 2010), the French government adopted the plan related to rapid submersions already mentioned. It includes, amongst others:

- The implementation by end 2011 by Météo-France and the SPCs of a new warning service related to the intensity of the precipitation at a smaller scale than the département, as a complement of the vigilance system towards communities located in vulnerable basins. This service will mostly rely on an automated information chain;

- The renewal and extension of the rain radar network, especially in regions where flash flood mostly occur;
- The consolidation and extension of the number of river basins monitored by the flood forecast systems;

Along with these technical developments, the plan also includes a support to the local communities eager to develop a local early warning system, aspect requiring to asses the social and economic acceptance of such systems accounting the consequences of flooding, including the loss of lives. The development of warning messages targeted to the public at risk would also require collaboration with local historians and geographers, bearers of the local memory and conscious about their natural territory.

### 5.2. Urban and land-use planning; adaptation of building codes

During the flash flood event in the Var in June 2010, half of the victims were trapped in their homes; among them, over 80% were in inappropriate housing considering the exposed area (e.g. ground floor houses or apartments, dilapidated homes, windows sealed with electric shutters).

A critical analysis of the highly abundant French regulation about disaster risk reduction would be needed. Practices by some elected officials, responsible for local planning, seem to be the cause of many conflicts. A general doctrine for the consideration of dike failure risk and land-use planning behind the dikes has been recommended in 2010, in line with the European flood directive.

Disasters are causing controversy over certain planning practices (responsibility of local communities) and lack of protective measures (responsibility of the State). Responsibility for bad practices is often widely shared. Land planning regulations always have an impact on land's value. Authorities must fight denials and specious arguments at all times, and develop a sharp awareness of disaster risks.

### 5.3. Public awareness & education campaigns

The population, living in an area likely to be affected by a flash flood or just spending its holidays there, must acquire preventive protective attitudes as well as some preparedness, to anticipate and not being surprised. Information materials are now mandatorily provided by industry managers, State and local authorities, in order to inform the public.

### 5.4. Insurance

Frequent natural hazards cause moderate damage and are sometimes beneficial to the natural environment. In France, related damages are insured, under the supervision of the State. Insurance for damages related to natural hazards is compulsory and proportional (12%) to the all-damage premium. It allows for extended geographical pooling. However, premiums are not exposed to the most inaccessible while encouraging mitigation). French public policy has become too attached to this area with additional error to qualify for natural disaster incidents requiring the participation of the regime. It seems that attitudes are changing, recent statements confirm this.

## 6. CONCLUSIONS

Recent flash flood events in France show that local communities at-risk often have a poor understanding of extreme events. The gap between management practices for frequent events and catastrophic events is increasing dangerously, due to a misunderstanding of what is an extreme flash event and to the inadequacy of early warning tools in such case.

Although the French early warning system (Vigilance system) appears as comprehensive, relying on competent and technically developed operators, it is reaching some limits when considering hazards occurring at a time and spatial scale smaller than the ones used for its design and for phenomena not yet accounted. Methods and tools exist or are ready being developed to fill these gaps, but the real challenge is to achieve these developments by associating the local communities and the operators. This is the only way to ensure that local communities' safeguard requirements will be met and that early warning will be consistently a key element in the disaster risk reduction regulations.

This is the objective of the plans recently adopted in France, coherently with the content of the European Flood Directive. This is also a topic of exchange experience with the European partners, mainly through structures like the European network of national ISDR platforms.

***References:***

[1] Detailed in the presentation by Alexis Roumagnac during the FFEW workshop.

[2] Detailed by Joel Crémoux (Météo-France) and Caroline Wittwer (SCHAPI) during the FFEW workshop.

[3] Activities led on the basis of organization texts dating from 2004 (floods) and 2007 (meteorology). Marine submersion will be introduced at the end of 2011.

[4] Available on <www.meteo.fr>.

[5] Available on <www.vigicrues.ecologie.gouv.fr>.

[6] The Marine submersion (Xynthia storm, 2010) is not considered here.

[7] Detailed in the presentation by Mrs Caroline Wittwer during the FFEW workshop.

[8] Detailed in the presentation by Mr Joel Cremoux during the FFEW workshop.

[9] Detailed in the presentation by Mr Alexis Roumagnac, during the FFEW workshop.

# FLASH FLOODS - ARE WE ABLE TO FACE SUCH A KIND OF DISASTERS?

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## ABSTRACT

Flash Floods (FFs) – very destructive and dangerous type of floods stroke the Czech Republic in summer 2009. These FFs were triggered by extreme cloudbursts and storms in a large part of the country. These disastrous flash floods revealed some problems and weaknesses in warning and emergency system as well in general preparedness for such quick events. Flash floods are entirely different from river flooding and warning and response as well as preparedness for FFs should be adjusted accordingly to decrease losses of lives and property.

2009 Flash Floods have shown that only a complex and integral emergency system can be efficient. Such a system begins with more precise forecasting and warning, dissemination of warnings to various levels of the state emergency system. The main problems in warning part are uncertainties in prediction of time and place of a strike by FF. Also very high intensity of rainfall and strokes in the late afternoon or at night should be taken into account.

Possibilities of improvement of all parts of warning and emergency system in the Czech Republic especially non-structural measures are reviewed. They include improvement in observation, monitoring, detection and forecast conditions, generation and dissemination of more precise warning products, removing of some shortfalls in dissemination process, better cooperation of national hydrometeorological service with partners in emergency system like Fire and Rescue Service and with responsible regional and community bodies. Very important is also training and education of both active parts of the state emergency system and the public. Finally, coordinating and inspiring role of national disaster reduction platform as well as cooperation among these platforms within European Network of National platforms have been stressed. Therefore, gathering experience people in FFs from more countries has always been very helpful and this workshop about Flash Floods can contribute to the reduction of damages caused by flash floods.

## 1. INTRODUCTION

Flash Floods (FFs) are the most dangerous floods. The growing number of such events causing not only losses of property but very often also losses of lives have been occurring more and more frequently in many countries and including the countries in Europe. The Czech Republic was hit by a series of FFs during June and July 2009 appearing at different locations during the period of two weeks (see Fig.1). Individual FFs of that period originated from one prevailing synoptic situation. The 2009 FFs caused the loss of 15 lives and high damage of property [1]. WMO country level survey confirmed that from 139 countries participating in the survey 105 indicated that FFs were among the top two most important hazards and require special attention [2]. Possibility of using Flash Flood Guidance system seems to be promising [3].

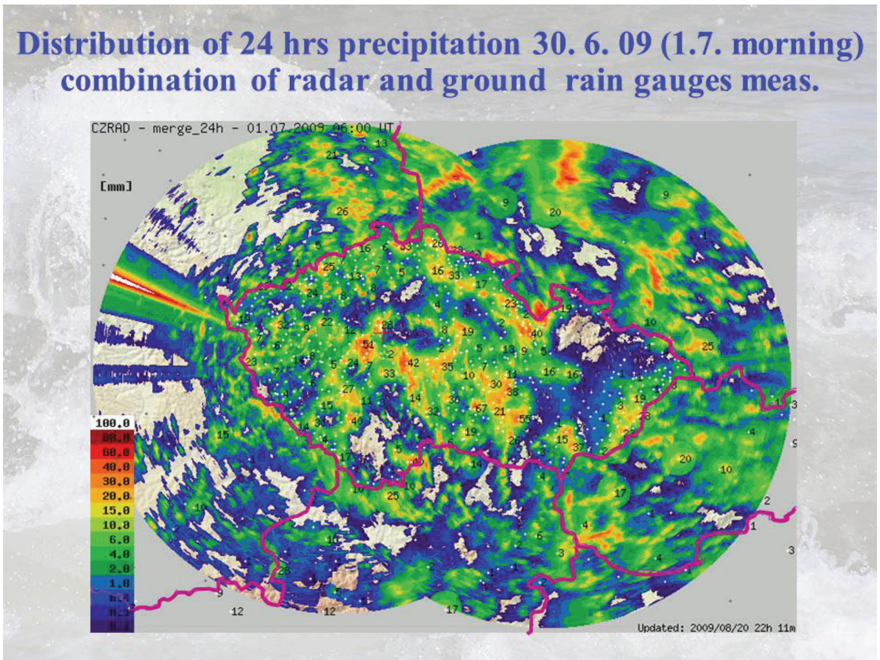
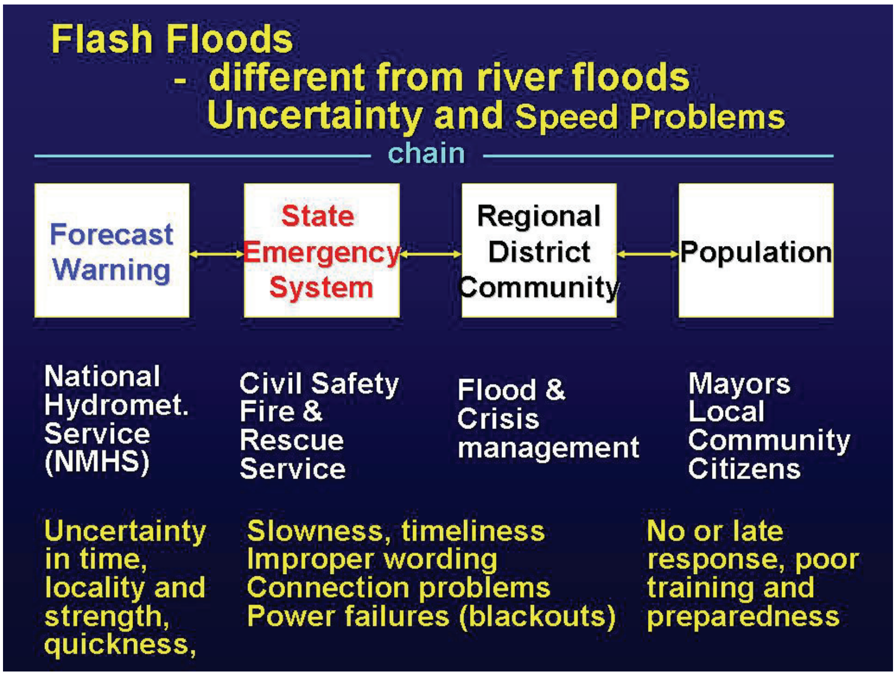


*Fig. 1. Radar image of series of Flash Floods in 2009 year in the Czech Republic*

Czech Hydrometeorological Institute (CHMI) together with the Czech National Committee for disaster Reduction (Czech National Platform) developed an intensive effort to find out drawbacks in existing Early Warning (EW) system used during the 2009 FFs and to learn from this evaluation. The main aim was devoted towards a proposal of necessary improvements in the whole "chain" of disaster reduction specifically for FFs. It starts from early warning followed by an adequately quicker dissemination of warnings helping to quick response. It is clear that a stronger involvement of EW within the state emergency system as well as better preparedness of all parts of the emergency system and especially the public is indispensable. Several workshops and meetings among participants from all parts of the EW chain - Hydrometeorological service, Fire and Rescue Service (fulfilling the role of civil defense in the Czech Republic), regional and local administration and people living in communities hit by FFs have shown several significant features of disaster reduction process for FFs as well as a potential for improvements.

## 2. SPECIFIC FEATURES OF FLASH FLOODS

The main difficulty is connected with high speed of FFs and also with uncertainty of forecasting locality, time and strength of these dangerous floods. Even the use of recently developed technologies does not lead do enough precise forecast and warning of "very local" events like flash floods. Modern technologies like continuous monitoring and nowcasting by the use of meteorological radars and limited area models could be used for such local events only in a limited scale. It is characteristic for FFs that forecasting and warning is strongly dependent on meteorological parameters of convective weather especially in the case of precipitation forecasts – a role of hydrological parameters (situation in river channels) is mostly less important than the amount and intensity of precipitation itself. The specific features mentioned cause great problems. Moreover, widely used and well-developed river flood warning systems in the Czech Republic have shown to be inefficient and almost unusable for the case of FFs. (see Fig. 2).



Flash Floods
- different from river floods
Uncertainty and Speed Problems

chain

Forecast Warning ↔ State Emergency System ↔ Regional District Community ↔ Population

National Hydromet. Service (NMHS)

Civil Safety Fire & Rescue Service

Flood & Crisis management

Mayors Local Community Citizens

Uncertainty in time, locality and strength, quickness,

Slowness, timeliness
Improper wording
Connection problems
Power failures (blackouts)

No or late response, poor training and preparedness

*Fig. 2: Problems of Early Warning for Flash Floods*

Difficulties are also connected with a lack of in-situ data from small regions. Very local character of FFs and conditions in areas hit by storms like heavy intensive rain, lack of electricity, mostly darkness, often destroyed infrastructure e.g. flooded roads, have caused significant problems with dissemination of warnings and response. Experience from the 2009 FFs showed frequently occurring failure of GSM warnings dissemination, problems with the use of sirens and very often slower reaction and lower preparedness of people at community levels. It is quite clear that education and training of both crisis management and people especially at local scale is one of urgent parts of an overall preparedness for FFs.

## 3. POTENTIAL FOR IMPROVEMENTS OF THE MAIN PARTS OF THE EW CHAIN

Experience and evaluation of 2009 FFs revealed several possibilities of improvement of EW and response:
**Forecasting and warning service** – the main problem is an uncertainty both of locality and time of storm causing FF. In 2009 flash floods two levels of warnings specified only for relatively large regions could be issued. Then, local crisis management as well as the public was not able respond adequately. Moreover, the reaction started usually with some delay**. By means of evaluation of performance of the NMHS (CHMI) several proposals for improvement of FF forecasts and warnings have been proposed [4]:**

- To provide forecasts and warnings for smaller areas – districts instead of regions. Warnings for regions (too coarse) proved to be insufficient for reaction and response by people.
- To increase a frequency of calculation of cumulative radar precipitation from 60 min to 10 min and improve nowcasting
- To strengthen warning service for FFs for regions and develop and apply Flash Flood Guidance [5,6] for the whole country (within a year)
- To improve clarity and precision of wording of FFs warnings
- To increase a throughput at flood web pages by an enhancement of telecommunication lines
- To improve dissemination of warnings to district and community levels (jointly with Fire & Rescue Service)
- To optimize the way of information flow on the Internet , GSM and in media
- To implement possible improvements from the project „Evaluation of 2009 Flash Floods in the CR“

- To supply experts for assistance in building new local FFs warning systems
- To help in education and training of emergency bodies and the public (especially children)
- To participate in adjustment of methodology of activities and preparedness for Flash Floods showing main differences from the preparedness for “classical” (river) floods - (together with the ministry of environment).

However, it has also been necessary to improve other parts of the overall emergency system chain:

- **NMHS together with Fire & Rescue Service** (Civil Safety in the Czech Republic):
  - Will jointly improve a system of dissemination of FFs warnings as well as training and education of mayors and the public adjusted especially for FFs. It would be necessary to concentrate on improvement of functionality of GSM networks and sirens during FFs.

- **NMHS will cooperate with the ministry of environment on:**
  - Adjustment of methodology for existing emergency for river floods to much quicker FFs. It is clear that FFs need simpler and faster warning procedures and response and the whole emergency system should be adjusted to these special features of FFs. Appropriate education and training for special FFs methodology should be developed.
  - Preparation of FFs risk mapping for the whole country.
  - Support (also financially) building of local FFs warning systems and also a development of Flash Flood Guidance system

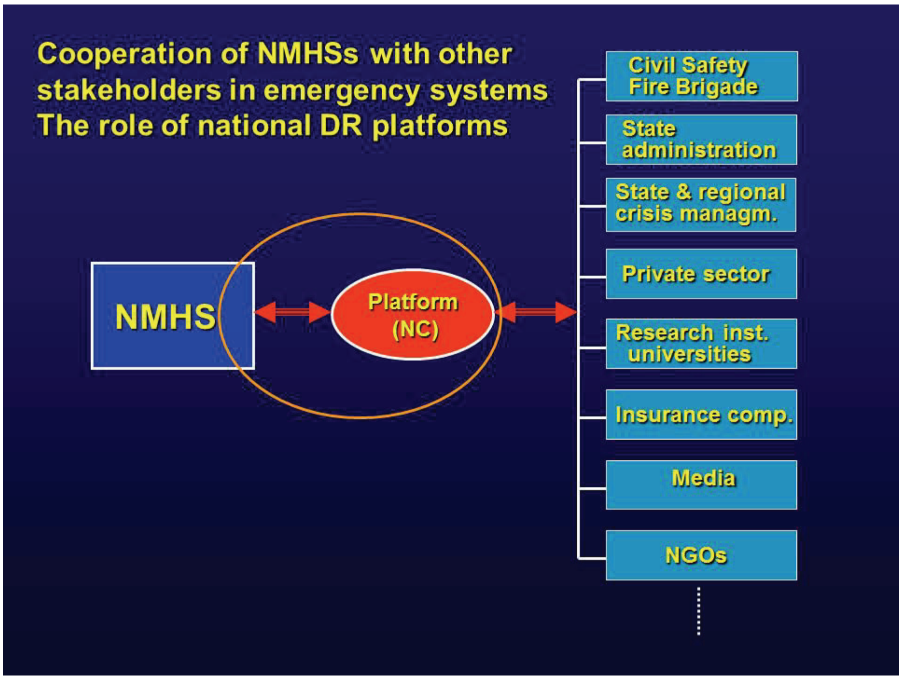
- **Mayors, crisis management structures in districts and communities will:**
  - Improve preparedness for a fast response to FF warnings, insurance, family plans, public education and training, function of sirens, local radio, etc. for FFs even in the conditions of a power failure (blackout)
  - Establish **flood guards** able to observe critical places for FFs after obtaining watch (warning) from NMHS and to alert the mayor in the case of FFs danger for start of response like evacuation, etc.
  - **Parliament, government will cooperate on p**reparation of a novel of crisis law package for better and up-to-date crisis management and response especially to fast events like FFs.

## 4. IMPROVEMENTS REACHED AFTER ONE YEAR

Some of the improvements suggested above have been realized during about one year after the June 2009 flash floods. Some of the proposed measures need a longer time period for their realization. Especially improvements in forecasting and warnings service, provided by the Czech Hydrometeorological Institute, like increased frequency of radar precipitation data transmission and summing, improvement in nowcasting and greater care devoted to wording of warnings and closer cooperation on this issues with the Fire and Rescue Service have progressed relatively quickly (see the papers by Daňhelka [5] and Šálek et al. [7]). Also work on preparation of the flash flood guidance (FFG) system has significantly moved ahead. FFG is a diagnostic tool for Flash Flood Alerts and Warnings and indicates amount of rainfall required to cause a flash flood in small flash flood prone basins (see Šercl [6]).

Březková et al. [8] studied the possibilities of early warning with the help of new 5-minute updated precipitation estimates and nowcasts. Sandev [9] with coworkers significantly have improved the System of Integrated Warning Service (SIWS) in Czech Hydrometeorological Institute and made connection and cooperation with Fire and Rescue Service and other parts of the state emergency system closer and more efficient. On the other hand, some other measures proposed like building of local warning systems with the help of funding from the ministry of environment, the proposal of the adjustment of the existing official methodology for river flood emergency to much quicker FFs, etc., have not been finished yet.

However, the most difficult appears improvement of collaboration between different parts of emergency EW system like establishing of more robust and faster dissemination of warnings even under severe conditions met at places hit by FFs. Some problems appeared in connections with failures of electricity, lowered GSM signals still need more time to be properly solved. Because of higher level of uncertainty of the FFs forecasts and warnings and also the higher speed of FFs close cooperation and coordination of activities among the main part of the EW chain have become more critical than in more common river floods or other natural disasters caused by severe weather. National disaster risk reduction platforms (or national committees) have been successfully helping in filling the above mentioned problems of different parts of EW chain. Moreover, the members of platforms can create personal relations and discuss common problems less officially than through other official channels. Therefore, the platforms create efficient field and the mean how to reach better cooperation and mutual understanding between responsible people from different bodies and institutions involved in disaster risk reduction (see Fig. 3). This feature is especially important in the case of quick and dangerous flash floods.



Cooperation of NMHSs with other stakeholders in emergency systems
The role of national DR platforms

NMHS

Platform (NC)

Civil Safety
Fire Brigade

State administration

State & regional crisis managm.

Private sector

Research inst. universities

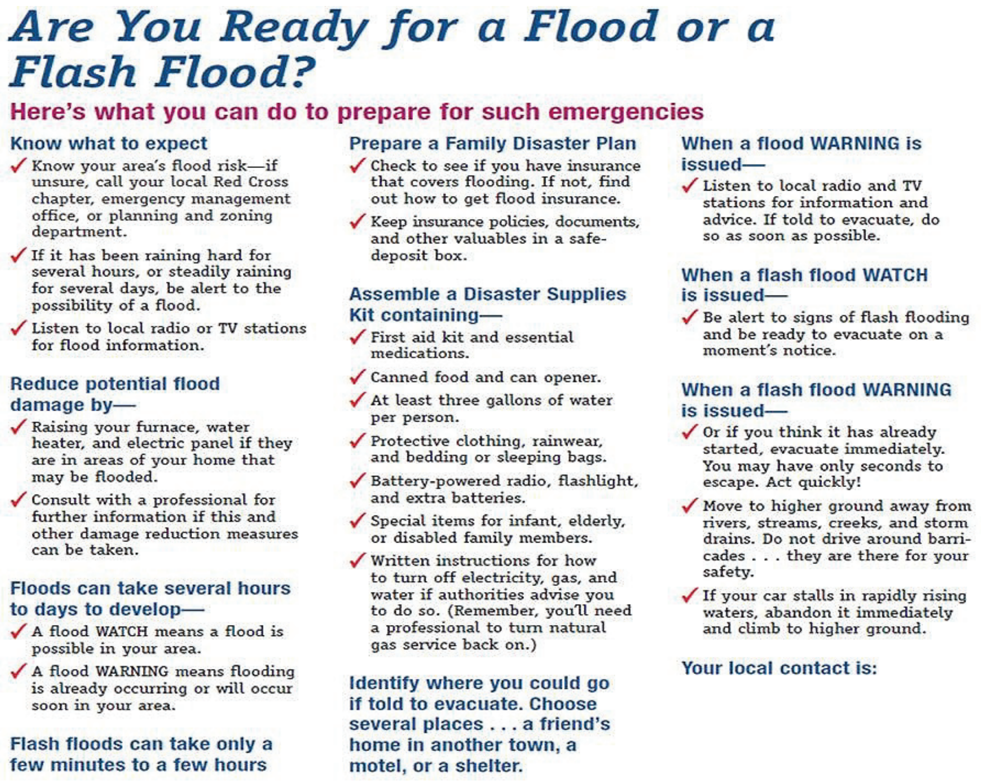
Insurance comp.

Media

NGOs

*Fig. 3: The role of national platforms in improvement of coordination and cooperation between different parts of an emergency system chain*

Even more difficult and urgent appears the need for training towards better preparedness of the public. The difficulty has been connected with a rather low frequency of dangerous and fast events like flash floods at the territory of the Czech Republic or Central Europe. Therefore, it is more difficult to train and prepare emergency system and especially the public for efficient facing flash floods than, for instance, in the United States. Higher occurrence of fast disasters like flash floods but also tornadoes in USA helps for better perception and awareness of the public. People there are prepared for a possibility of forthcoming disaster and ready to obey well-prepared instructions (see Fig. 4). It is not so easy to reach such a level of preparedness in Central Europe. It is quite clear and urgent to develop programs and conditions for improvement of preparedness and lowering vulnerability at European level and the help from disaster risk reduction platforms can play important role in this process.



# Are You Ready for a Flood or a Flash Flood?

## Here's what you can do to prepare for such emergencies

**Know what to expect**

- ✓ Know your area's flood risk—if unsure, call your local Red Cross chapter, emergency management office, or planning and zoning department.
- ✓ If it has been raining hard for several hours, or steadily raining for several days, be alert to the possibility of a flood.
- ✓ Listen to local radio or TV stations for flood information.

**Reduce potential flood damage by—**

- ✓ Raising your furnace, water heater, and electric panel if they are in areas of your home that may be flooded.
- ✓ Consult with a professional for further information if this and other damage reduction measures can be taken.

**Floods can take several hours to days to develop—**

- ✓ A flood WATCH means a flood is possible in your area.
- ✓ A flood WARNING means flooding is already occurring or will occur soon in your area.

**Flash floods can take only a few minutes to a few hours**

**Prepare a Family Disaster Plan**

- ✓ Check to see if you have insurance that covers flooding. If not, find out how to get flood insurance.
- ✓ Keep insurance policies, documents, and other valuables in a safe-deposit box.

**Assemble a Disaster Supplies Kit containing—**

- ✓ First aid kit and essential medications.
- ✓ Canned food and can opener.
- ✓ At least three gallons of water per person.
- ✓ Protective clothing, rainwear, and bedding or sleeping bags.
- ✓ Battery-powered radio, flashlight, and extra batteries.
- ✓ Special items for infant, elderly, or disabled family members.
- ✓ Written instructions for how to turn off electricity, gas, and water if authorities advise you to do so. (Remember, you'll need a professional to turn natural gas service back on.)

**Identify where you could go if told to evacuate. Choose several places . . . a friend's home in another town, a motel, or a shelter.**

**When a flood WARNING is issued—**

- ✓ Listen to local radio and TV stations for information and advice. If told to evacuate, do so as soon as possible.

**When a flash flood WATCH is issued—**

- ✓ Be alert to signs of flash flooding and be ready to evacuate on a moment's notice.

**When a flash flood WARNING is issued—**

- ✓ Or if you think it has already started, evacuate immediately. You may have only seconds to escape. Act quickly!
- ✓ Move to higher ground away from rivers, streams, creeks, and storm drains. Do not drive around barricades . . . they are there for your safety.
- ✓ If your car stalls in rapidly rising waters, abandon it immediately and climb to higher ground.

**Your local contact is:**

*Fig.4: Leaflet with instructions for preparedness for floods or flash floods issued by Federal Emergency Management Agency (FEMA), American Red Cross and National Weather Service (NWS) [10].*

## 5. CONCLUSIONS

Flash floods (FFs) can cause rather large losses of lives and property and finding a more efficient manner of diminishing of the high impact of these disasters is a key problem in the Czech Republic but also in other countries in Europe. Several important aspects and possibilities of improvement of the whole chain of early warning system for FFS have been discussed and some of them have already been applied. Uncertainty of warnings, high speed of FFs, difficulty in dissemination of warnings and also education and training of emergency specialists and the public cause many difficulties. Therefore, it is necessary to increase cooperation and coordination of all activities in this field. National disaster risk reduction platforms and their close cooperation within the European Network of National Platforms (ENNP) can be very helpful in the process of reduction of impact of such dangerous natural disasters.

### *References*

[1] DAŇHELKA, J., KUBÁT, J., 2009. Flash floods in the Czech Republic in June and July 2009. Prague: Ministry of Environment and the Czech Hydrometeorological Institute, 72p.

[2] WMO country-level survey on flood preparedness, 2008. Geneva, WMO.

[3] GRABS, W.E., 2010. Establishment of flash flood guidance systems – approach and implementation. Intern. Disaster and Risk Conf. IDRC, May 30 - June 3, Davos.

[4] OBRUSNÍK, I., 2009. Possibilities of improvement of flash flood protection in the Czech Republic. Presentation at the Czech Parliament, Prague.

[5] DAŇHELKA, J., 2010. Hydrological forecasting and warning in case of flash flood. CHMI, Prague, presented at this Workshop.

[6] ŠERCL, P., 2010. The robust method for an estimate of runoff caused by torrential rainfall and a proposal of a warning system. CHMI, Prague, presented at this Workshop,

[7 ŠÁLEK, M., NOVÁK, P., 2010. The use of weather radar for precipitation estimation and nowcasting at the Czech Hydrometeorological Institute (CHMI). CHMI, Prague, presented at this Workshop,

[8] BŔEZKOVÁ, L., ŠÁLEK, M., NOVÁK, P., 2010. Limits of flash flood forecasting in the conditions of the Czech Republic. CHMI, Prague, presented at this Workshop.

[9] SANDEV, M., 2010. System of Integrated Warning Service (SIWS) in Czech Hydrometeorological Institute (CHMI). CHMI, Prague, presented at this Workshop.

[10] Are you ready for a flood or a flash flood?, 2008. Leaflet prepared jointly by American Red Cross, National Weather Service and Federal Emergency Management Agency.

# THE USE OF WEATHER RADAR FOR PRECIPITATION ESTIMATION AND NOWCASTING AT THE CZECH HYDROMETEOROLOGICAL INSTITUTE (CHMI)

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## ABSTRACT

Forecasting of flash floods is highly dependent on quality of input information about fallen and expected precipitation for several future hours. To obtain high quality precipitation data, it is very useful to combine ordinary rain gage measurements and NWP precipitation forecasts with remote sensing measurements (especially weather radars) and extrapolative nowcasting techniques.

The advantage of weather radars is the surveillance of precipitation over hundreds of thousands square kilometers in (almost) real time, but the physical nature of the radar measurement leads to serious problems with the absolute accuracy of the precipitation estimate. These problems have led to development of several different correction algorithms that often rely on the surface measurements of the precipitation by rain gauges. One of the correction algorithms has been put into operation in 2003 as one of the outcomes of the CHMI-NWS cooperation activity. The system utilized mean-field-bias correction of original radar estimate and for the combined field a modified algorithm of Double Optimum Estimation originally developed by D.-J. Seo was used. In 2008-2009 a new original algorithm of the estimation was developed, which computes the locally variable bias field that is being used for quick correction of radar estimate and nowcasting. The combined estimate that is being computed only for 1-hour and longer time accumulation employs the concept of regression kriging. The resulting precipitation fields, i.e. locally adjusted radar estimates, combined estimates along with gauge-only fields are a part of national flood warning system which is being upgraded after severe flash floods that hit the Czech Republic in June and July 2009.

Radar echo extrapolation technique, based on well-known COTREC method, has been developed at the CHMI. It has been routinely used for qualitative precipitation and severe weather nowcasting since 2003. After extensive evaluation, COTREC quantitative precipitation forecasts (QPF) up to 3h have been routinely used as an operational input into hydrological model HYDROG since spring 2007. Comparison of COTREC QPF with NWP model ALADIN QPF shows better performance of COTREC for lead time 0-1h and 1-2h and similar results for 2-3h. COTREC QPFs for 2-3h have problems mainly in border areas. COTREC method uses two consecutive maximum reflectivity composites of Czech Weather Radar Network (CZRAD) for calculation motion vector fields and adjusted CAPPI 2km reflectivity composite for calculation QPFs. Limited domain of motion vector calculation and precipitation underestimation of CAPPI 2km in farther distance from radar cause obviously deteriorated performance of COTREC QPFs in border areas. To overcome these problems new extrapolation method was developed in the CHMI and is under extensive testing now. New method use NWP model ALADIN to enlarge domain of motion vector calculation and to improve motion vectors in areas without radar echoes. As a reflectivity field to be extrapolated Extended CZRAD composite that includes Czech and some other surrounding radars is also tested.

## 1. INTRODUCTION

Forecasting of flash floods is highly dependent on quality of input information about fallen and expected precipitation for several hours ahead. To obtain high quality precipitation data, it is very useful to combine ordinary raingauge measurements and NWP precipitation forecasts with remote sensing measurements (especially weather radars) and extrapolative nowcasting techniques.

The advantage of weather radars is the surveillance of precipitation over hundreds of thousands square kilometers in (almost) real time, but the physical nature of the radar measurement leads to serious problems with the absolute accuracy of the particular precipitation estimates. These problems have led to development of several different correction algorithms that often rely on the surface measurements of the precipitation by rain gauges. One of the correction algorithms has been put into operation in 2003 as one of the outcomes of the CHMI-NWS cooperation activity and in 2008-2009 was replaced by new algorithm. The resulting precipitation fields are a part of national flood warning system which has been upgraded after severe flash floods that hit the Czech Republic in June and July 2009. The estimated precipitation quantities are then complemented by radar-based nowcasting.

## 2. QUANTITATIVE PRECIPITATION ESTIMATION USING RADAR AND RAINGAUGES

Combined radar-raingauge precipitation estimate has been computed at the Czech Hydrometeorological Institute (CHMI) since 2003. The system utilized mean-field-bias correction of original radar estimate and a modified algorithm of Double Optimum Estimation originally developed by D.-J. Seo [1, 7, 6] was used for the combined field. In 2008-2009 a new original algorithm of the estimation was developed, which computes the locally variable bias field that is being used for quick correction of radar estimate, also for short time intervals lasting less than one hour. The combined estimate that is being computed only for 1-hour and longer time accumulation employs the concept of regression kriging. The system also allows comparison of performance of both the radar and the raingauges and provides a lot of diagnostic information, e.g. histograms of variables, correlation coefficients of radar and rain gauge measurement, semivariograms, maps of the bias, list of suspicious gauge measurement etc. The resulting precipitation fields, i.e. locally adjusted radar estimates, combined estimates along with gauge-only fields are a part of national flood warning system which is being upgraded after severe flash floods that hit the Czech Republic in June and July 2009.

### 2.1 Algorithm of the precipitation estimate

More detailed description of the precipitation estimate algorithm that had been utilized at CHMI until 2009 is available in [8] or [4]. In 2009 several changes has been made that reflected need for precipitation estimate that could be used for better flash flood warnings.

#### 2.1.1 Original radar-based precipitation estimates

The radar estimate is being computed from single polarization C-band radars Brdy and Skalky that cover the area of the Czech Republic and surroundings and perform volume scan every 5 minutes. The radar reflectivity Z is being obtained from pseudoCAPPI 2 km and converted to precipitation intensities by the formula $Z = 200R^{1.6}$ . The precipitation intensities are then integrated according to predefined time intervals. Until 2009 we had used operationally only 1-hour and longer accumulations but in 2009 a new algorithm has been developed that utilize also 15-minute accumulations updated every 5 minutes. The horizontal resolution of the radar estimates and the following estimates is 1 km.

#### 2.1.2 Adjustment of the precipitation estimate

The precipitation estimate is being adjusted by the array of adjustment coefficient (bias) the area of which corresponds with the radar domain. The bias field is being obtained by interpolation of the bias that is calculated from the ratio of collocated radar estimate and available gauge measurement. The corresponding values use the most recent hourly (or longer if needed) accumulation when (or until) it reaches at least predefined threshold, currently two millimeters. The array of adjustment coefficients are updated every hour but it changes only after some “new” precipitation is recorded. The algorithm uses only the pairs when the radar measures reliably (at least 90% of the time and when quality indicator is good). The algorithm of the interpolation of the coefficient is universal kriging.

If the further described algorithm of regression kriging is taken into account, the adjustment does not seem to be necessary. The advantage of such algorithm is very quick and prompt calculation of the radar-based estimate especially when only fraction of rain gauge measurements is available.

### 2.1.3 Rain-gauge only precipitation estimate

Besides radar-based (or radar-influenced) estimates the system computes also gauge-only areal estimate in the same area and the same spatial resolution of 1 km$^2$. The algorithm used is universal kriging. The variogram that is being operationally used is linear without nugget effect. This is not optimal but this type of variogram ensures computational stability, especially in cases of few gauge values. When the number of available gauge measurements is less than 5 then the Inverse Distant Weighting (IDW) method is applied instead of kriging.

### 2.1.4 Combination of the radar estimate and rain gauge measurement

Further step of precipitation estimate algorithm is combination of adjusted radar estimate with available rain gauge measurements. While until 2008-2009 we had used the simplified algorithm of Double Optimum Estimation developed by D.-J. Seo [1, 7], since 2009 the main algorithm is Regression Kriging (RK), mathematically equivalent with Kriging with External Drift (KED - [2, 3]), has been utilized. The combination is being computed only for 1-hour or longer time intervals because of the computational demand. The example of the original radar estimate, adjusted radar estimate, gauge-only field and RK-based combination is in Fig. 1.

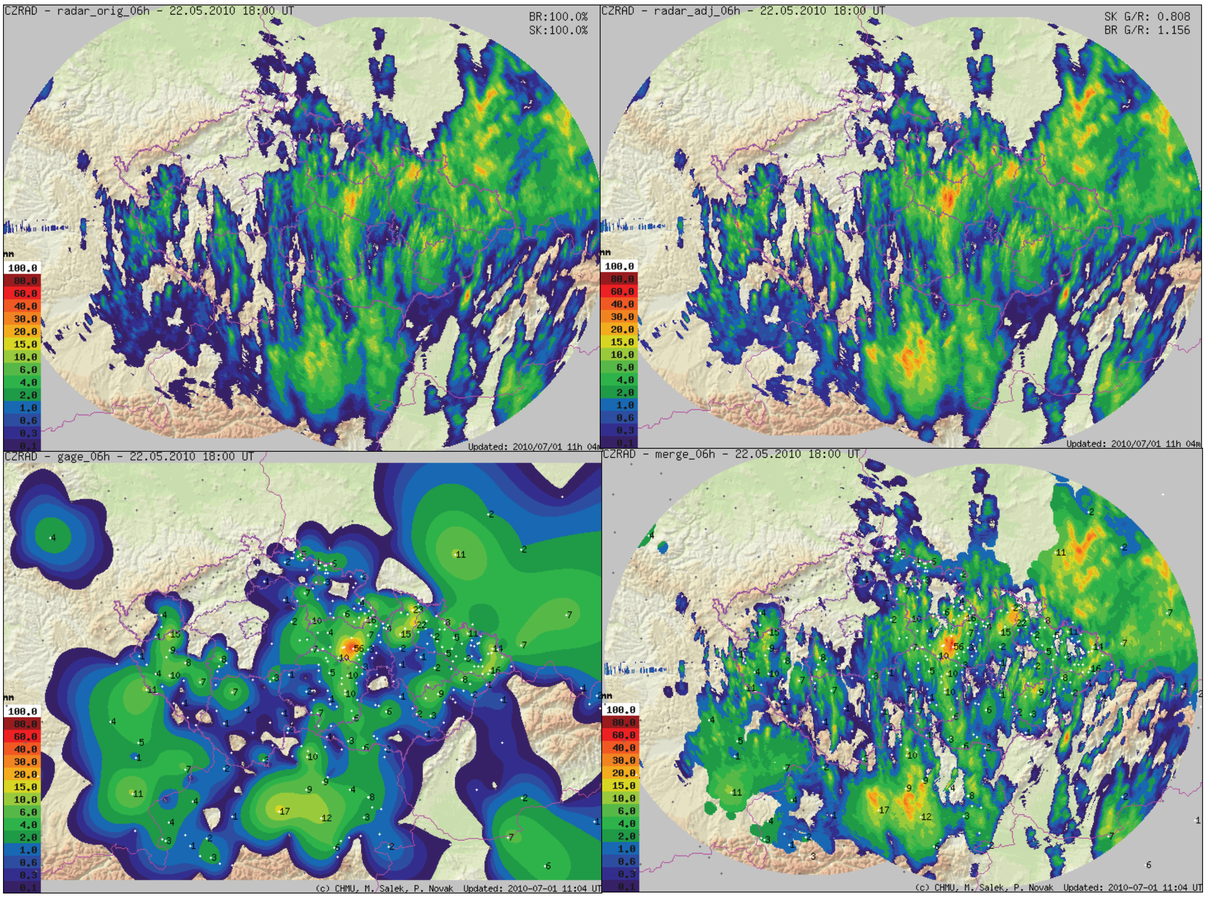


*Fig. 1. Original radar estimate (top left), the radar estimate adjusted by locally variable adjustment coefficient (top right), rain gauge-only estimate computed by universal kriging (bottom left) and combined radar-rain gauge field (bottom right) obtained by algorithm of regression kriging. The estimates are overlaid by the state boundaries and the boundaries of administrative regions. The estimate is 6-hour accumulation on May 22, 2010, 18 UTC.*

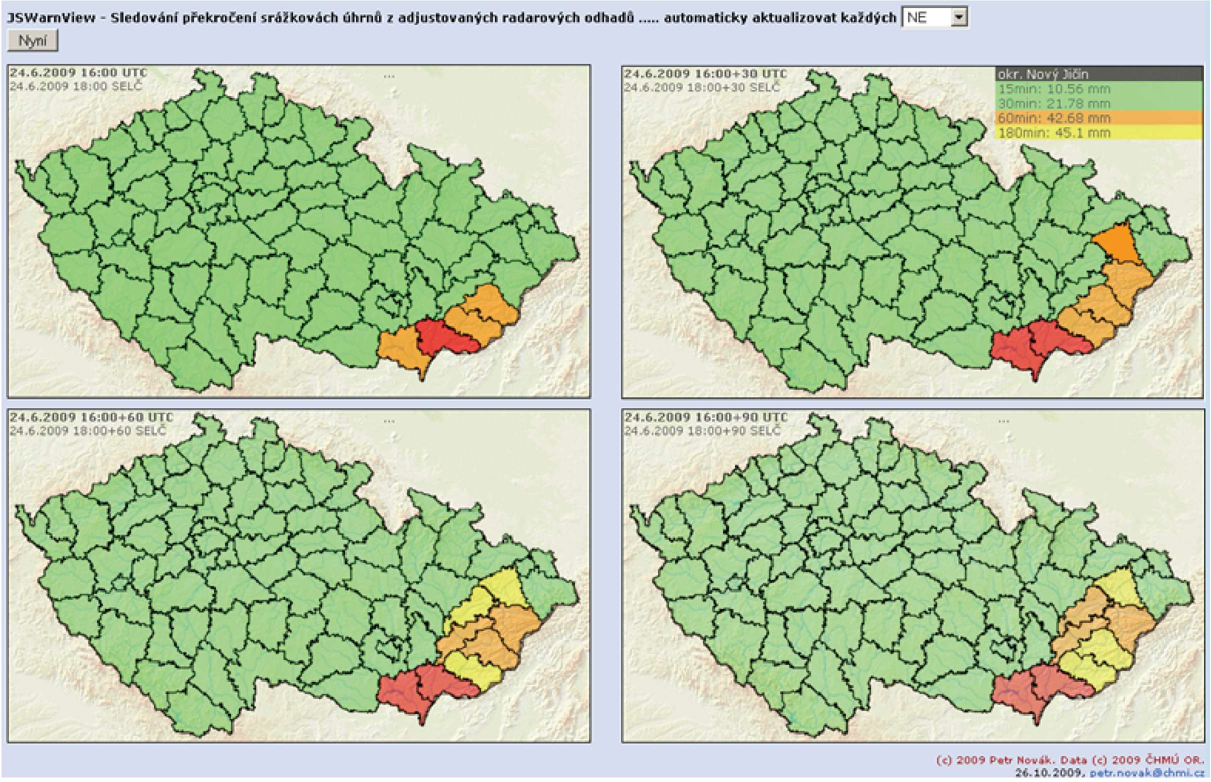
## 3. RADAR-BASED PRECIPITATION NOWCASTING

Radar echo extrapolation technique, based on well-known COTREC method, was developed in the CHMI [5]. It has been routinely used for qualitative precipitation and severe weather nowcasting since 2003. After extensive evaluation, COTREC quantitative precipitation forecasts (QPF) up to 3h have been routinely used as an operational input into hydrological model HYDROG since spring 2007. Comparison of COTREC QPF with NWP model ALADIN QPF showed better performance of COTREC for lead time 0-1h and 1-2h and similar results for 2-3h. COTREC QPFs for 2-3h have problems mainly in border areas. COTREC method uses two consecutive maximum reflectivity composites of Czech Weather Radar Network (CZRAD) for calculation motion vector fields and adjusted CAPPI 2km reflectivity composite for calculation QPFs. Limited domain of motion vector calculation and precipitation underestimation of CAPPI 2km in farther distances from radar cause obviously weaker performance of COTREC QPFs in border areas. To overcome these problems new extrapolation method was developed in the CHMI and is under extensive testing now. New method use NWP model ALADIN to enlarge domain of motion vector calculation and to improve motion vectors in areas without radar echoes. As a reflectivity field to be extrapolated Extended CZRAD composite, that includes Czech and foreign radars, is also tested.

## 4. OUTPUTS

For the best operational estimate of the current and upcoming development of rainfall, the short range quantitative precipitation forecasting (or quantitative precipitation nowcasting – QPN) has to be added to the QPE. The resulting field of currently measured and “nowcast(ed)” precipitation can be compared to the predefined limits indicating possible threat of (flash) floods. These limits can be fixed, or, more optimally, should be derived according to the real situation taking into account antecedent precipitation and geographical conditions including the vegetation cover etc. Such scheme is currently being tested at the CHMI.

An example of that output in graphical form is at *Fig. 2*. The estimated (measured) precipitation is complemented by the QPN for the next 3 hours (and for shorter intervals of 15, 30 and 60 minutes) and the algorithm delineates potentially endangered districts according to the predefined precipitation limits.



JSWarnView - Sledování překročení srážkovách úhrnů z adjustovaných radarových odhadů ..... automaticky aktualizovat každých NE

okr. Nový Jičín
15min: 10.56 mm
30min: 21.78 mm
60min: 42.68 mm
180min: 45.1 mm

(c) 2009 Petr Novák. Data (c) 2009 ČHMÚ OR.
26.10.2009, petr.novak@chmi.cz

*Fig. 2. JSWarnView - delineation of districts where the estimated (fallen) and nowcast precipitation exceeded predefined threshold for any of the 15, 30, 60, 180 minute accumulation. The potential threat is indicated by particular color (yellow: low risk, orange: high risk, red: extreme risk).*

***References:***

[1] FULTON, R. – BREIDENBACH, J. – SEO, D.-J. – MILLER, D. – O'BANNON, T.: The WSR-88D rainfall algorithm. *Weather and Forecasting*, ročník 13, 1998: s. 377–395.

[2] HENGL, T. – GEUVELINK, G. – STEIN, A.: Comparison of kriging with external drift and regression kriging. Technical report, ITC, 2003.

[3] HENGL, T. – HEUVELINK, G. – ROSSITER, D.: About regression-kriging: From equations to case studies. *Computers & Geosciences*, ročník 33, č. 10, October 2007: s. 1301–1315, ISSN 00983004, doi: 10.1016/j.cageo.2007.05.001. http://dx.doi.org/10.1016/j.cageo.2007.05.001

[4] ŠÁLEK, M. – NOVÁK, P.: Experience gained by five years of the utilization of the radar-based quantitative precipitation estimation at the Czech Hydrometeorological Institute. In *Fifth European Conference on Radar in Meteorology (ERAD 2008)*, Helsinki: Finish Meteorological Institute, 2008.

[5] NOVÁK, P. – BREZKOVÁ, L. – FROLK, P.: Quantitative precipitation forecast using radar echo extrapolation. *Átmospheric Research*, ročník 93, č. 1-3, 2009: s. 328–334.

[6] SEO, D.-J.: Real-time estimation of rainfall fields using radar rainfall and rain gage data. *Journal of Hydrology*, ročník 208, č. 1-2, 1998: s. 37 – 52, ISSN 0022-1694

[7] SEO, D.-J.: Real-time estimation of rainfall fields using rain gage data under fractional coverage conditions. *Journal of Hydrology*, ročník 208, č. 1-2, 1998: s. 25 – 36, ISSN 0022-1694,

[8] ŠÁLEK, M. – NOVÁK, P. – SEO, D.-J.: Operational application of combined radar and raingauges precipitation estimation at the CHMI. In *Third European Conference on Radar in Meteorology (ERAD), ERAD Publication Series*, ročník 2, September 2004, s. 16–20.

# SYSTEM OF INTEGRATED WARNING SERVICE (SIWS) IN CZECH HYDROMETEOROLOGICAL INSTITUTE (CHMI)

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## ABSTRACT

CHMI's warning service is a component of Integrated Rescue System of Czech Republic which supplies issuing of warning information for the territory of Czech Republic from both meteorological and hydrological risks point of view. Its main purpose is to inform and warn authorities, media, people and other users of hydrometeorological data about probability of dangerous weather and to protect human lives and property. Currently, emphasis is placed on warnings related to extreme weather, especially to events with rapid progression, as flash flood is. It is therefore necessary to develop tools for early detection of these phenomena, mainly in areas of nowcasting and streamline and speed up information on an imminent threat.

This service is carrying out by meteorological and hydrological forecasting sections (Central and Regional Forecasting Offices) of CHMI in co-operation with Military Weather Service of Army of Czech Republic using concept of System of Integrated Warning Service. Basic component of SIWS is warning information. Outputs from SIWS are available in both ASCI and XML formats immediately after their issuing. Special text information is sending to Integrated Rescue Service, Military Weather Service, local authorities, catchment organizations, media … Warning is given to Web site of CHMI in graphical and tabular format. Notifying message for many users is prepared and distributed automatically by email when warning information is issued. SMS information is also prepared for some users. In 2007 CHMI has become a participant in EMMA project (Meteoalarm) of visualization of warning information on web pages. It is also important to educate authorities, media and other users for better understanding of warning information.

## 1. INTRODUCTION

Czech Hydrometeorological Institute (CHMI), besides other meteorological, hydrological and air quality control tasks are authorized for dispensation warning service for meteorological and hydrological events for the territory of Czech Republic. This service is carrying out primarily by the System of Integrated Warning Service, which was putted into operation in February 2000. After experience from the following years, especially after big floods in 2002, the system was widely innovated (using Davidson et al., 2005) and with a new shape rerun in January 2006. After the innovation this system very significantly contributes to reduce impacts of dangerous meteorological and hydrological phenomena.

SIWS was developed at CHMI in collaboration with Military Weather Service of Czech Republic. It means that it is a common service of both institutes. This co-operation increases quality of warning information, it obviates double counting or/and substantial differences in warning information of both institutions.

In addition to SIWS, CHMI purvey forecasts of dangerous events to other special users as road maintenance authorities or media. Unlike of that forecasts, the SIWS unambiguously defines rules and criterions for issuing of warning information for meteorological and hydrological events and becomes a basis of CHMI warning system.

## 2. ISSUING AND DISTRIBUTION OF WARNING INFORMATION

Forecasting and warning service of CHMI is provided by Central and six Regional Forecasting Offices. Each of them has meteorological and hydrological division cooperating closely together. Warning information of SIWS are issued only by Central Forecasting Office after regular, or if it is necessary, after irregular conferences on Central Forecasting Office, between Central and Regional Forecasting Offices as well as with Military Weather service. In case of flood occurrence a conference leads hydrologist on duty.

The basic item of SIWS is a senior forecaster on Central Forecasting Office who is responsible for assembling and timely issuing of this information. Outputs are available in ASCI and XML format. Distribution of information is automated. All users can obtain information immediately after its issuing by GTS, mail, fax or SMS. Warning information is also present on special CHMI web page shown in Fig.1. Flood Forecasting Service of CHMI has own web page presented in Fig. 2.

ČHMÚ: SYSTÉM INTEGROVANÉ VÝSTRAŽNÉ SLUŽBY (SIVS)

vysoký stupeň nebezpečí

Je předpovídán nebo pozorován nebezpečný hydrologický a/nebo meteorologický jev. Je nezbytná bdělost a potřeba sledování hydrometeorologické situace.

SIVS je společně poskytovaná výstražná služba ČHMÚ a Odboru HMZ VGHMÚř (meteorologická služba armády ČR) pro území ČR v oblasti meteorologie a hydrologie. Smyslem těchto stránek je umožnit rychlý přístup k výstrahám, ale i k dalším informacím. Vaše připomínky uvítáme zde.

neděle 05.11.2006 23.24

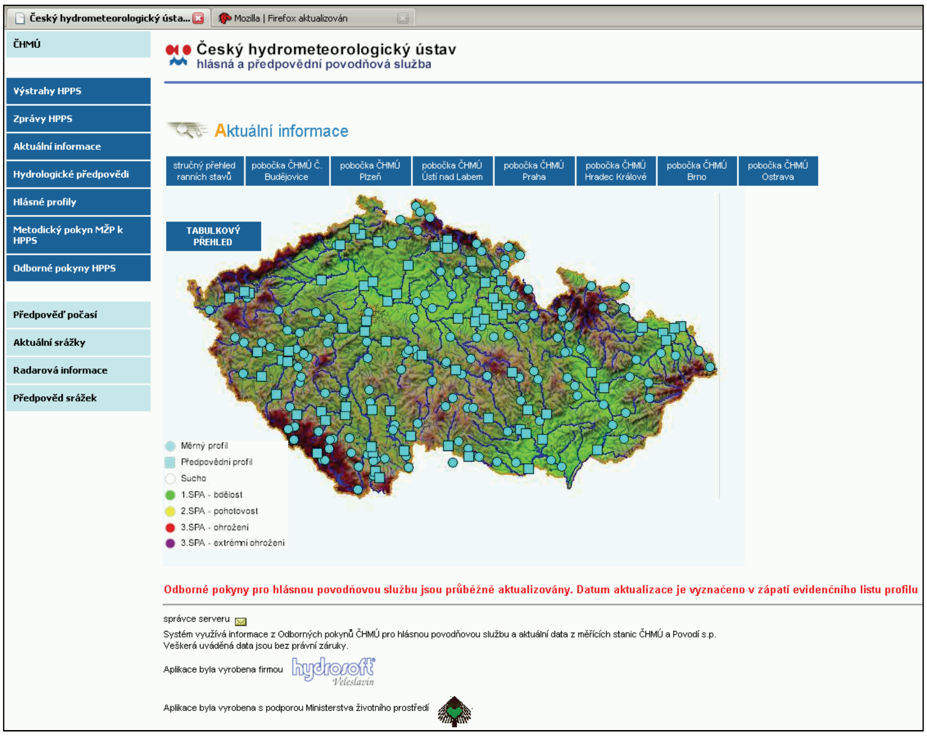
**PŘEDPOVÉDNÍ VÝSTRAŽNÁ INFORMACE ČHMÚ a ODBORU HMZ VGHMÚř**

Kolem hluboké tlakové níže nad Baltem k nám v čerstvém severozápadním proudění proniká vlhký oceánský vzduch od severozápadu.

Severozápadní vítr bude mít večer a během noci průměrnou rychlost 8 až 12 m/s, v nárazech a na horách 20 až 25 m/s, na hřebenech hor 25 až 30 m/s. Do 18.h pokračovala v západních Krkonoších srážková činnost intezivněji než se předpokládalo, později se poněkud utlumila. Maximální srážkové úhrny představují v této oblasti od 8 do 18 h. cca 30-70 mm. Zatím nejvyšší úhrn je zaznamenán ve stanici Kořenov 66 mm (8-17 h.) Hladiny Smědé, Jizery a Kamenice jsou nyní na úrovni 1. až 2. SPA, na horních tocích na úrovni 3. SPA (Bílý Potok, Jablonec n. J.). Smědá-B.Potok byla pravděpodobně dosažena kulminace v 19. h., na Jizeře se blíží kulminace na horním toku. Hladiny ( bez dosažení SPA) stoupají aktuálně v povodí Orlice. Předpokládáme, že intenzita srážek v Krkonoších pravděpodobně dále zeslábne, v průběhu noci může ještě spadnout 10-15 mm. Je proto velmi pravděpodobné, že se bude vzestup hladiny v Jablonci n. J. a Bílém Potoce i nadále tlumit, může však dojít ke kratšímu oživení vzestupů (kolísání). Kulminace bude zřejmě na základě zmíněného vývoje srážek dosažena na horních tocích před půlnocí, v nižších partiích Krkonoš a na Frýdlantsku v průběhu noci. Dolní a střední tok Jizery bude pravděpodobně kulminovat na úrovni 1.SPA během zítřka. Potenciálně

| region | platnost jevu |
|---|---|
| (A) Praha | |
| (S) Středočeský kraj | Povodňová bdělost<br>05.11. 22.30 až 06.11. 20.00 |
| (L) Liberecký kraj | Povodňová pohotovost<br>05.11. 22.30 až 06.11. 20.00 |
| (C) Jihočeský kraj | |
| (P) Plzeňský kraj | |
| (K) Karlovarský kraj | |
| (U) Ústecký kraj | |
| (H) Královéhradecký kraj | Povodňová bdělost<br>05.11. 22.30 až 06.11. 20.00 |
| (E) Pardubický kraj | Povodňová bdělost<br>05.11. 22.30 až 06.11. 20.00 |
| (J) Kraj Vysočina | |
| (B) Jihomoravský kraj | |
| (Z) Zlínský kraj | |
| (M) Olomoucký kraj | Povodňová bdělost<br>05.11. 22.30 až 06.11. 20.00 |
| (T) Moravskoslezský kraj | Povodňová bdělost<br>05.11. 22.30 až 06.11. 20.00 |

*Figure 1. The main web page of Czech Hydrometeorological Institute for visualization of warning information on territory of Czech Republic (<http://pocasi.chmi.cz>)*



Odborné pokyny pro hlásnou povodňovou službu jsou průběžně aktualizovány. Datum aktualizace je vyznačeno v zápatí evidenčního listu profilu

Systém využívá informace z Odborných pokynů ČHMÚ pro hlásnou povodňovou službu a aktuální data z měřících stanic ČHMÚ a Povodí s.p.
Veškerá uváděná data jsou bez právní záruky.

Aplikace byla vyrobena firmou hydrosoft Veleslavín

Aplikace byla vyrobena s podporou Ministerstva životního prostředí

*Figure 2. The main web page of Hydrological Monitoring and Floods Forecasting Service of CHMI for visualization warning flood information on territory of Czech Republic (<http://hydro.chmi.cz/hpps>)*

In September 2007 Czech Republic has become a co-operative member of the EUMETNET (Network of European Meteorological Services) project METEOALARM. A base of the project is internet web page (<http://www.meteoalarm.eu/>) giving quick overview of warnings on dangerous phenomena in Europe. The page is intended primarily for the public. On the map of Europe are colourfully marked states or regions for which are issued warning information. In 2009 probably will be involved into the project also floods warning information.

In domain of Integrated Rescue System of Czech Republic a main recipient of warning information is Central Fire Rescue Office which distributes it onwards to Regional Fire Rescue Offices. In case of flood information the main recipients are also National Flood Authorities and catchments organizations.

Basic distribution system of IWSS warning information is presented in Fig. 3.

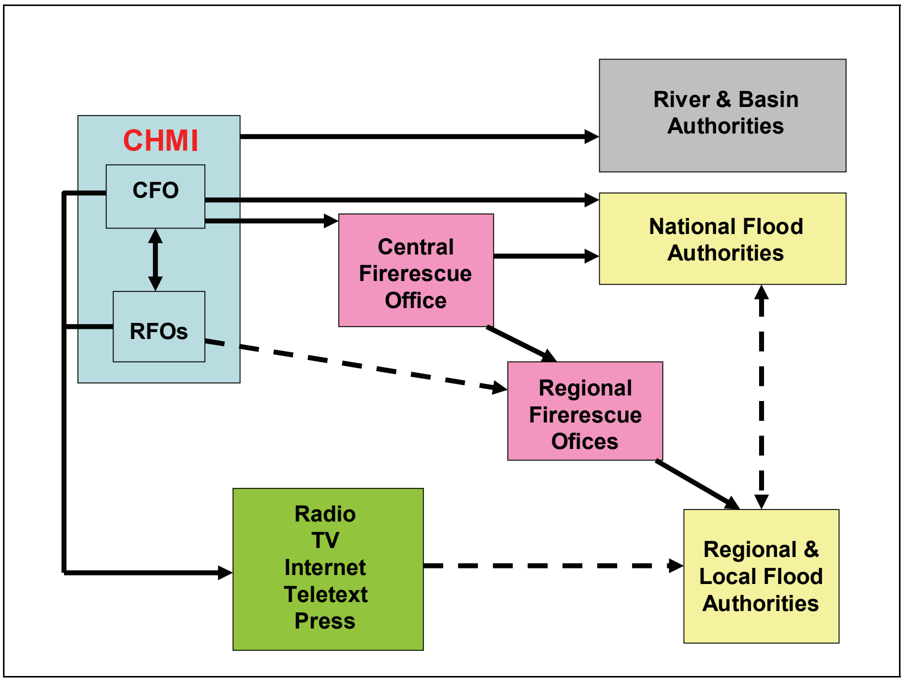


*Figure 3. Distribution of hydrometeorological warning information in Czech Republic*

## 3. CONCEPT OF SIWS

Warning information of SIWS is issued for 26 dangerous hydrometeorological parameters and phenomena divided into 7 categories (Tab. 1).

*Table 1. Categories of dangerous hydrometeorological parameters and phenomena using in CHMI warning system*

| |
|---|
| I. Temperature and humidity conditions |
| II. Wind |
| III. Snowfall and snow phenomena linked with increased of wind speed |
| IV. Freezing phenomena |
| V. Thunderstorms with accompanying phenomena |
| VI. Rainfall |
| VII. Flood phenomena |

Warning information are issued for phenomena, which could lead to very different consequences and damages, in extremely cases with catastrophic effects. Therefore each phenomenon is assigned to one of 3 levels of danger (Tab. 2). In agreement with international projects of visualization danger weather on web pages (Davidson et al., 2003), each level has its own color. Area for which warning information is issued is region with app. 5000 km2. In Czech Republic there are 14 administrative districts. These colours at the first sight enable to recognize threat region and a danger of degree. If for one region is forecasted two or more dangerous phenomena with different level of danger, region is colored in color corresponding with the highest one.

*Table 2. Levels of danger in the SIWS*

| **Level of risk** | **Class of risk** | | |
|---|---|---|---|
| None | | **N** | green |
| Low | | **L** | yellow |
| High | | **H** | orange |
| Extreme | | **E** | red |

CHMI issues two types of warning information: forecasting warning information issued for all hydrometeorological phenomena and information about occurrence of extreme events.

Forecasting warning information is issued, if any of extreme weather phenomenon of SIWS is forecasted or it has just occurred and it is supposed its further duration. Warning information defines the beginning and the end of validity and obviously is issued with 12 to 48 hours ahead; in case of rapidly develop phenomena like thunderstorms even earlier. At any time one forecasting warning information can be in validity. Issuing of a new one automatically cancels the previous one.

Information for occurrence of extreme events is issued in a case of occurrence (measured, observed or objectively detected) of danger event with extreme level of risk and rapid progression like snow storm, severe thunderstorms with very dangerous accompanying phenomena, extreme precipitation or flood danger (reaching the third flood stage). It is issued to notify occurrence of extreme dangerous event or to describe its development up to three hours ahead. In this case can be in validity more than one information.

If warning information contains any of hydrological phenomena (see Tab. 2, category V. to VII.), parallel warning information from Hydrological Monitoring and Flood Forecasting Service of CHMI is issued. During flood events this service prepares special informative bulletins with the main aim to provide deeper description of hydrological evolution and forecasts. They can also inform about ice jams on rivers, snow reserve or drought etc.

***References:***

[1] <www.meteoalarm.eu>

# THE ROBUST METHOD FOR AN ESTIMATE OF RUNOFF CAUSED BY TORRENTIAL RAINFALL AND A PROPOSAL OF A WARNING SYSTEM

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## ABSTRACT

Forecasting of torrential rainfall and flash floods remains one of the most challenging tasks for hydrometeorological services. Beside the accuracy it has fulfil aspect of timely issue as well. Flash floods occurrence is determined by many factors. The most important are precipitation intensity, temporal and spatial distribution of rainfall but infiltration and retention properties of soil, land cover, land use and terrain must be also considered.

A functional system for a forecast of runoff caused by torrential rainfall and issuing of warning messages should:

a) Work with catchments of area close to horizontal size of convectional storm.
b) Include determination of actual state of potential retention capacity of landscape (e. g. saturation by antecedent precipitation).
c) Use actual precipitation data in very short time step.
d) Implement simple rainfall-runoff model for direct runoff estimation in the catchment.
e) Set a threshold value of runoff or discharge or some multi-criteria index, to define a potential risk of flash flood occurrence in some particular region.

Within the research project SP/1c4/16/07 „Implementation of new techniques and stream flow forecasting tools“ (guaranteed by Czech Ministry of Environment) a forecasting system for estimation of runoff caused by torrential rainfall is being developed.

System has been developed in common GIS platform (ArcView GIS 3.x from ESRI) using basic available functions for pre-processing and post-processing of input and output data to and from rainfall-runoff model and a complex tailor made extension that includes the procedures of rainfall-runoff model.

15 minutes radar rainfall estimates serve as meteorological input. The system is prepared also for COTREC based nowcasting data input. System operates in the scale of small catchments, which areas are typically of size about 5 km$^2$.

Estimation of direct runoff is based on CN method. CN value automatic update based on antecedent precipitation and actual evapotranspiration (rainfall-evapotranspiration-runoff balance) is used to estimate possible runoff from storm.

Transformation of direct runoff to catchment response is realized by Clark’s unit hydrograph. Rainfall-runoff model parameters were estimated from empirical equations based on selected physio-geographical characteristics of catchments.

Outputs of the system include daily indicative map of precipitation intensity that could cause the direct runoff. However the key output is an estimate of hydrograph for all selected catchment outlets (in cms) including comprehensive information about areal precipitation and runoff amounts (in mm) and time occurrence of peak discharge for each (selected) catchment.

The flash flood risk estimation is based on exceeding 3 defined thresholds defined as ratios between the estimated peak flow and theoretical 100-year flood on particular basin.

The procedure is being tested in central forecasting office of Czech Hydrometeorological Institute. It proved the underestimation of rainfall by raw radar data and thus the need for real time adjustment of radar estimates based on rain gauge data.

## 1. INTRODUCTION

Forecasting of torrential rainfall and flash floods remains one of the most challenging tasks for hydrometeorological services. Beside the accuracy it has fulfil aspect of timely issue as well. Flash floods occurrence is determined by many factors. The most important are precipitation intensity, however temporal and spatial distribution of rainfall but infiltration and retention properties of soil, land cover, land use and terrain must be also considered.

A functional system for a forecast of runoff caused by torrential rainfall and issuing of warning messages should:

a) Work with catchments of area close to horizontal size of convectional storm.

b) Include determination of actual state of potential retention capacity of landscape (e.g. saturation by antecedent precipitation).

c) Use actual precipitation data in very short time step.

d) Implement simple rainfall-runoff model for direct runoff estimation in the catchment.

e) Set a threshold value of runoff or discharge or some multi-criteria index, to define a potential risk of flash flood occurrence in some particular region.

Within the research project SP/1c4/16/07 „Implementation of new techniques and stream flow forecasting tools“ (guaranteed by Czech Ministry of Environment) a forecasting system for estimation of runoff caused by torrential rainfall is being developed (FFG–CZ).

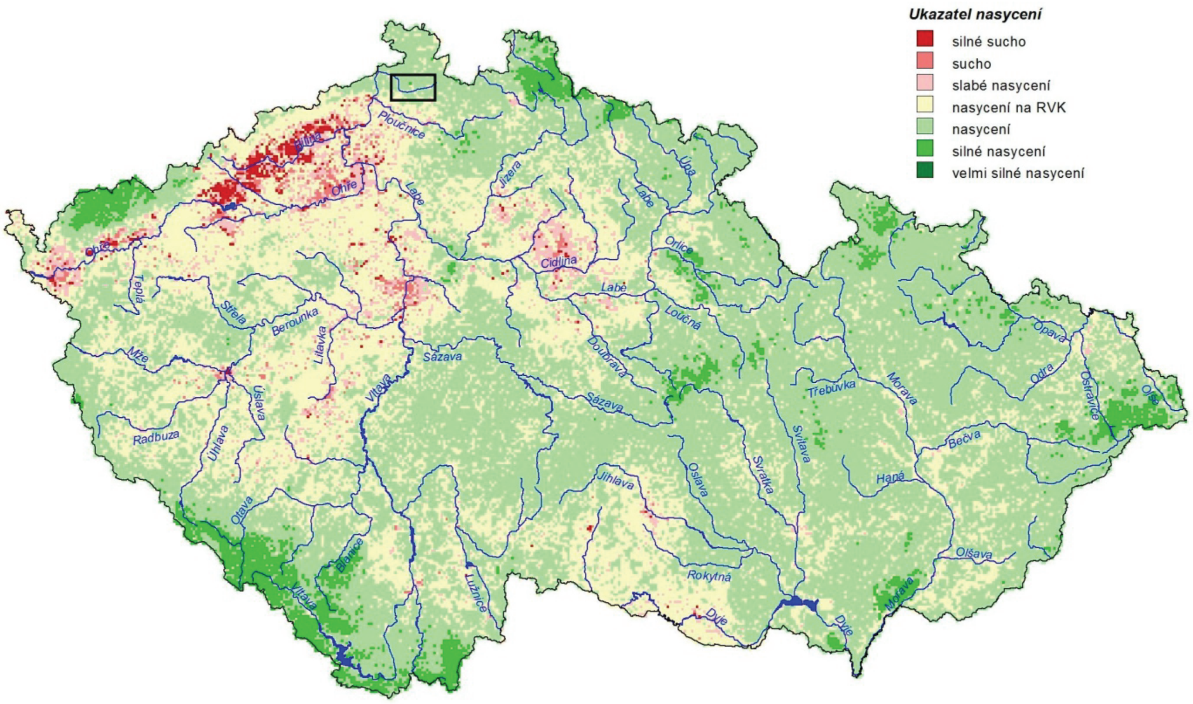
## 2. SHORT DESCRIPTION OF PROCEDURES

System has been developed in common GIS platform (ArcView GIS 3.x from ESRI) using basic available functions for pre-processing and post-processing of input and output data to and from rainfall-runoff model and a complex tailor made extension that includes the procedures of rainfall-runoff model.

### 2.1 Procedures with the daily time step

#### 2.1.1 Actual saturation estimate

Actual saturation of soil as daily CN updated values is the main output of this procedure. Daily precipitation and actual evapotranspiration data serve as input into procedure computing simple hydrological balance including gridded precipitation, estimated runoff, evapotranspiration and estimated subsurface runoff. Values of gridded direct runoff are derived from CN method. Actual saturation is depicted in the form of saturation index, which values are in the direct relationship to threshold values of CN for dry and wet state [1]. Example from 9th June of 2010 is shown on Fig. 1, where a black rectangle drawn in the map represents a region hit by flash flood this day.



(c) ČHMÚ

*Fig. 1. Gridded saturation index from 06/09/2010 as a result of simple hydrological balance and CN daily updating procedure (red – drought, green – wet).*

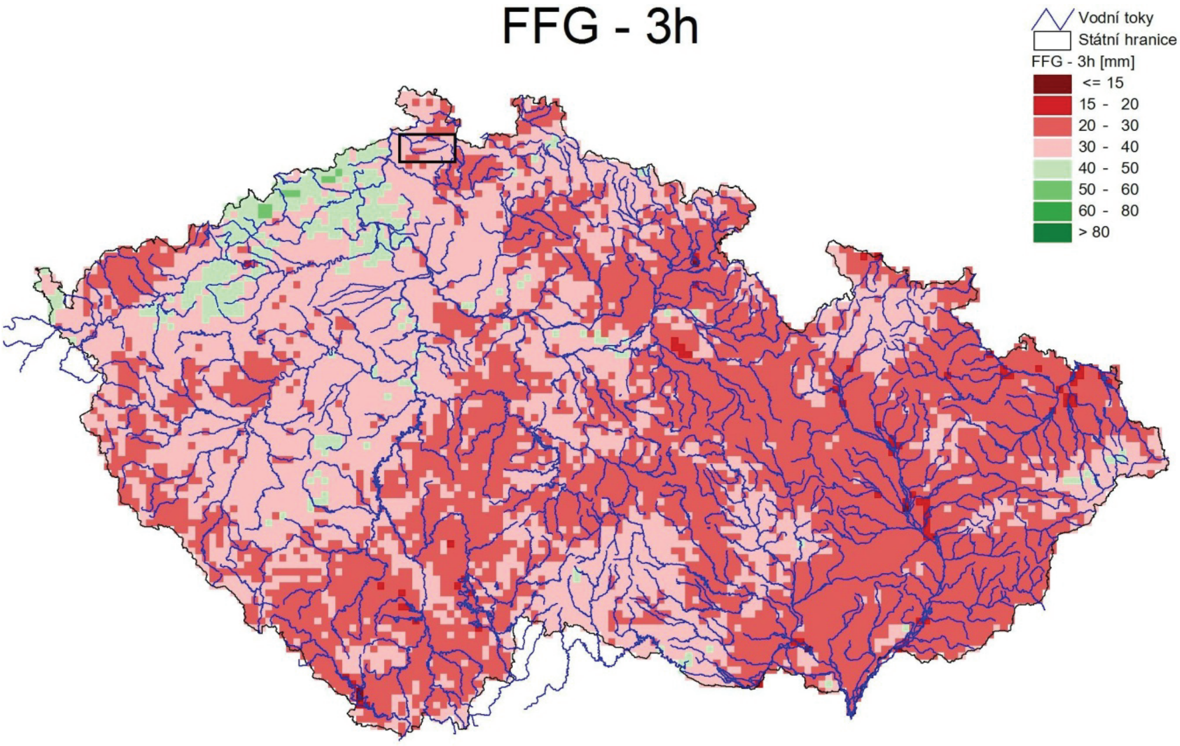


*Fig. 2. Potential risk precipitation of 3 hours duration for 06/09/2010*

### 2.1.2 Potential risk precipitation

Potential risk precipitation values for particular duration intervals are daily computed by National Weather Service for individual counties [2]. These values are known as Flash Flood Guidance (FFG) and represent the average number of inches of rainfall for given durations required to produce flash flooding in the indicated county [3]. These estimates are based on current soil moisture conditions.

The Czech methodology for derivation of FFG values has been slightly inspired by US approach [2], but instead of county as base unit it uses “hypothetical” catchments as grids of unit area 9 km$^2$ with derived physio-geographical characteristics. Current soil moisture conditions are represented by actual CN values (described in 2.1.1 chapter). For derivation of risk precipitation amounts the SCS unit hydrograph method is used. Volumes of hydrographs and peak flows are “known” (threshold ratio of 100year specific runoff) and corresponding precipitation amounts for particular duration are searched. Fig. 2 represents a map with 3-hour risk precipitation for the date 06/09/2010.

Both procedures mentioned above can be automatically launched in given time on the forecasting office. Presentation of main outputs (saturation index, potential risk precipitation) to public will be accomplished by map server technology.

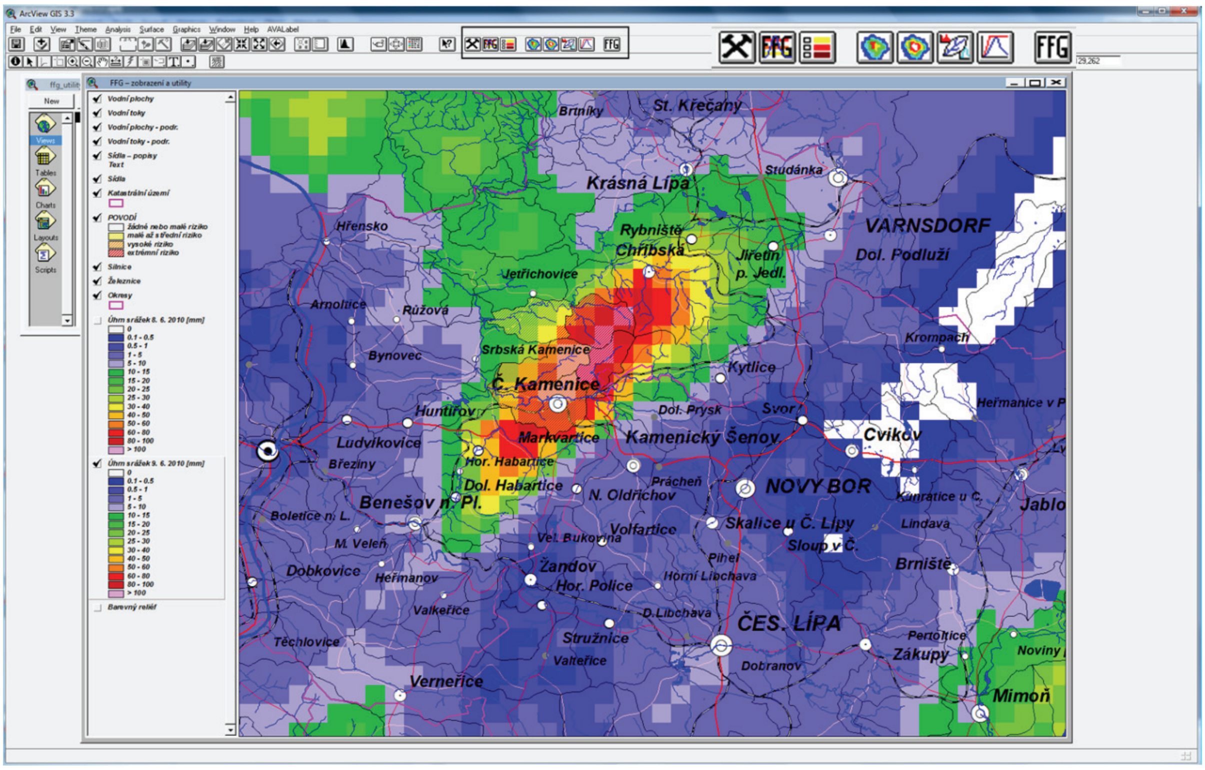


*Fig. 3. FFG–CZ application interactive environment with flash flood caused precipitation field displayed*

## 2.2 Procedures with a shorter time step

The second purpose of FFG–CZ system is to predict potential risk of flash flood occurrence in real time. For this case the 15 minutes adjusted radar rainfall estimates serve as meteorological input. The system is prepared also for COTREC based nowcasting data input. System operates in the scale of small catchments, which areas are typically of size about 5 km$^2$.

Estimation of direct runoff is based on CN method. Updated CN values based on antecedent precipitation and actual evapotranspiration (rainfall-evapotranspiration-runoff balance, see chapter 2.1.1) is used to estimate possible runoff from storm.

Transformation of direct runoff to catchment response is realized by SCS or Clark's unit hydrograph and Muskingum method is used for hydrograph routing. Rainfall-runoff model parameters were estimated from empirical equations based on selected physio-geographical characteristics of catchments.

The key output is an estimate of hydrograph for all selected catchment outlets (in cm) including comprehensive information about areal precipitation and runoff amounts (in mm) and time occurrence of peak discharge for each (selected) catchment.

Risk estimation is based on exceeding 3 defined thresholds (yellow, orange, red) defined as ratios between the estimated peak flow and theoretical 100-year flood on particular basin.

The example of adjusted radar precipitation field for storm and flash flood really occurred 06/09/2010 in northern part of Bohemia (Kamenice river catchment) is depicted on Fig. 3. The results of forecast issued in 16:45 UTC are displayed on Fig. 4.

The procedure described above can be launched manually through GIS interactive environment (Fig. 3) or automatically in predefined time intervals.

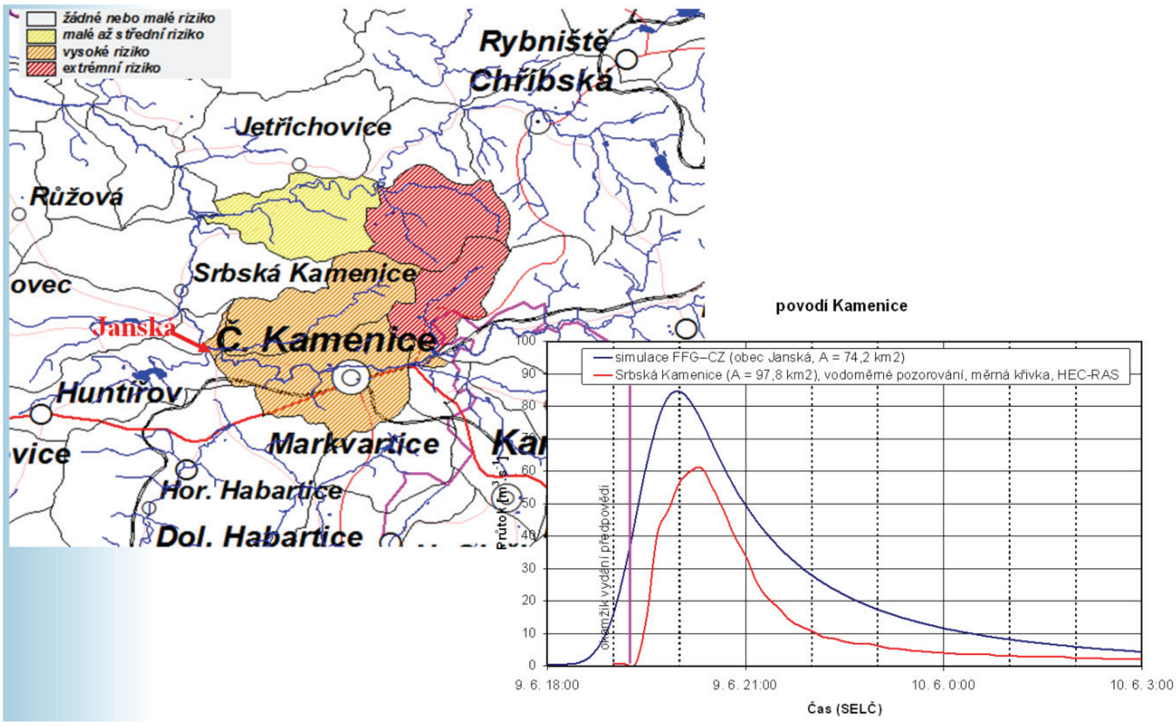


*Fig. 4. The forecast of risk-level flash flood occurrence in particular catchments hit by torrential rainfall 06/09/2010*

## 3. CONCLUSIONS

The FFG–CZ system has been developed primarily for prediction of potential flash flood risk occurrence. It is based on daily updated soil moisture conditions and radar precipitation field received online. The system was intensively tested during the summer period 2010.

The system has proved as useful tool for hydrological forecasters both for evaluation of soil moisture conditions and prediction of flash flood risk-level.

The incorporation of FFG–CZ procedures into warning system and presentation of main outputs to public are things remaining to solve in the year 2011.

***References:***

[1] US Army Corps of Engineers, 1994. Flood-Runoff Analysis. Engineer manual EM 1110-2-1417. Washington, DC 20314-1000.

[2] SWEENEY L. T., 1992. Modernized Areal Flash Flood Guidance, NOAA Technical Memorandum NWS HYDRO 44.

[3] National Weather Service – Flash Flood Guidance, <http://www.srh.noaa.gov/rfcshare/ffg.php>.

# MAXIMUM POSSIBLE RAIN RATES

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## ABSTRACT

Heavy precipitation occurs on a variety of time and space scales. In mid-latitude conditions there are two mechanisms causing heavy precipitation. In the low pressure frontal systems the characteristic scales are about one day covering an area of 10 to 100 thousand km$^2$. In convective conditions the scale characteristically is smaller, about 10 to 100 km$^2$, with duration of one hour. This results in distinctly different water volumes to be expected from these two types of weather event): about 1 km$^3$ of water from a frontal system, and about 0.001 km$^3$ from a convective system. In European continental conditions so called „meso-scale convective systems, MSCs“ do occur, bringing amounts of rain in between the two types mentioned before.

To estimate the maximum amount of precipitation from either process requires the knowledge of all the parameters responsible to contribute to its formation. There are several approaches on how to quantify a probable maximum precipitation event. The most widely used one is described by WMO as „... the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-time climatic trends.“ (WMO, 1986).

Heavy precipitation events are known to occur in virtually all parts of the world. Such events are notorious for their subsequent flood events. Disaster mitigation and disaster preparedness need quantitative estimates of maximum precipitation in any given area. This then allows to shape measures, protecting lives and values from any possible adverse effects of such precipitation events. In most cases a cost-benefit analysis will lead to the conclusion, not to consider PMP in real measures. However, even then PMP-estimates give a valuable orientation, if not for the public, so for the specialists in the field and the responsible authorities. Such information goes beyond simple learning from past events, and has the character of a projection analogue to long-term climate projections. It is noteworthy, that the deduction from past events has several limitations, mainly because in the limited observational period relevant combinations of rare parameters might not have occurred at all.

This means, that methods are needed allowing to estimate the probable maximum precipitation. Such estimates have to be based on the information on all relevant parameters under the assumption that these should be invariant in a certain time climate interval. There are, as already mentioned, several methods available on how to calculate the probable maximum precipitation. The simplest approach is river catchment oriented and combines the maximum observed precipitation amount in a sufficiently long time interval with the maximum probable water vapour content of the atmosphere. Usually these two quantities do not occur simultaneously. The key information on the water vapour content is derived from the surface dew points, wherefrom it is extrapolated to the top of the troposphere. The maximization of the precipitation is achieved by extrapolating the water vapour content to an occurrence level of 1/100 years. This vertically integrated water vapour content is then compared to the values as observed in the maximum the precipitation event. Between these two water vapour contents a difference results, so that an adjustment factor can be found, allowing estimating the precipitation, then called PMP. In general, precipitation formation in an arbitrary atmospheric layer depends on two quantities, the vertical velocity and the difference of the specific humidity between the bottom and the top of the layer. Interestingly enough, a simple sensitivity study shows, that the amount of liquid water formed (precipitation, if all of it falls out of the layer) depends linearly on the vertical velocity. However, a doubling of the specific humidity at the bottom of the layer, potentially the result of a temperature increase of about 10K, results in an increase of only about 25 % of the liquid water formation. This shows that a more careful consideration on vertical velocity should be part of PMP-estimates.

Therefore, it is necessary to include both key factors into the calculations of PMP. Any estimates of vertical velocity require a more complex physical description of the precipitation process. This is available with any state-of-the-art numerical weather prediction model. To estimate PMP, it is necessary to find idealized – PMP producing – initial conditions. Vertical velocity is best approached via the whole three-dimensional wind field, thus relying on the horizontal wind speed as base information. The maximum temperature and the dew point temperature can be taken from climatological estimates and from available climate forecasts. Model runs resulted in several sets of data, giving estimates of PMP in frontal systems and for orographic conditions. To access the convective case, an additional physical model was applied, based on some available 3D-distributions of water vapour and vertical velocity, resulting in the maximum rain rates for the given initial conditions. Orographic enhancement of precipitation is estimated with either method. The maximum values for convective conditions in central European conditions result in a precipitation rate of about 7 mm/minute, with the maximum duration not very well definable, but definitively being longer than 6 hours.

### 1. INTRODUCTION

Torrential rain means a rain rate of 1 mm per minute or more. If such a rainfall lasts for more than a few minutes, in many locations surface water runoff forms a so called flash flood connected with a rapid rise of the water level, and damage caused by the power of rushing waters rather than by sheer inundation. There are some peculiar features to such an event. They occur in a limited area, mostly limited to some km$^2$ or some tens of km². The warning time is short, mostly much less than one hour, and adverse effects per area may be very high. On the other hand such events are rare, because they combine the occurrence of a small scale weather event and a small scale sensitive area, mostly urban. However, in case of an occurrence the adverse effects are high, and the actual warning in the vast majority of the cases was insufficient. This latter aspect often results in the perception of failure of the forecasting and/or warning system.

Physically, the energy intensity of these events is of astounding size, because the energy turnover in W/m² may exceed 100 times the solar constant. This means that the water vapor supply needs horizontal advection, in other words a larger scale organization of the event. However, the total amount of rain water produced in one single event is small, usually not exceeding 1/1000th when compared to the mid-latitude standard large scale weather events. Consequently, these events only very rarely hit disaster prone areas, like urban areas, and therefore it is difficult to build up local experience among the potentially affected people.

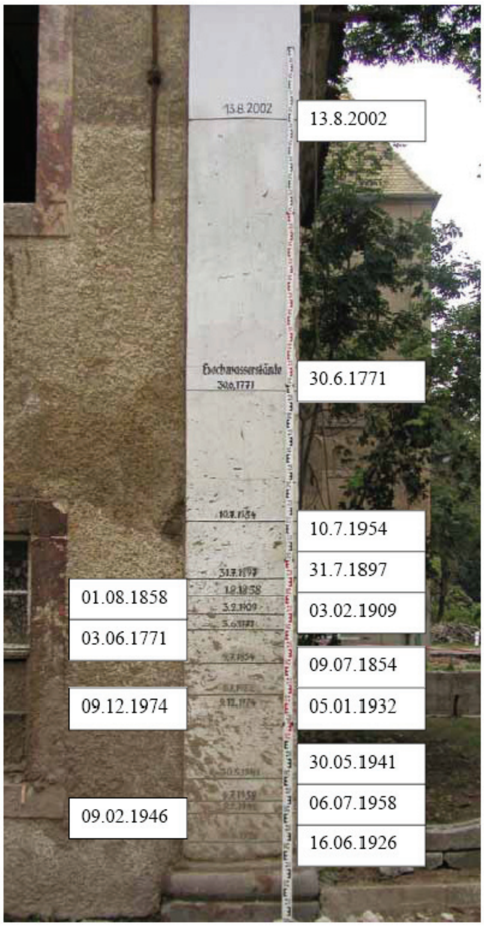

*Fig. 1. Historical flood marks on a building in the city of Grimma (Germany) taken after the severe flash flood of August 2002 (Photo: Andreas Schumann, 2003).*

These intensive rainfall events in combination with the local river catchment's orography may lead to flash floods. For the past one hundred years there is a wealth of knowledge available on the properties and the frequencies of occurrence of convective rains. Flash flood records even cover longer periods of time. Closer inspection of the latter ones reveals an interesting aspect. The maximum flood level on record in many cases is by far bigger than the second biggest event on record. Moreover, often the increment between the events seems to increase with size in a non-linear way.

A sufficiently long time series secured, the contrary, a sort of approximation to a “saturation” value should result. This may be interpreted in two ways. For once it may mean that the time series are too short, at second it hints the contribution of many different processes, only a few of them being combined in most of the observed events. There are no secret unknowns involved, nevertheless a systematic sensitivity analysis on the contributions of all relevant parameters and processes is not yet available, and why this should lead to the observed ranking of the extreme river gauge values. An example for a suite of flood levels is presented in figure 1 for the river gauge levels of the river Mulde in Grimma. The biggest event on record was the recent event of August 2002. There are other records which show the same structure, with the biggest event occurring at any other time of the record, not at the end like in the case of the Mulde.

Disaster reduction needs long term preparedness and the design of protection measures, including the finding of threshold values below which adverse effects are prevented. This means the definition of design criteria for the protection measures and the infrastructure of a location and/or region. In the case of flood design, thresholds usually use the flood event size with a return period of one event per 100 years. The decision to apply this threshold value is the result of a societal consensus. However, it is not trivial to find the magnitude of the 100-year-event. These values rely on observed data alone. Considering the above structure of the maximum flood levels, there might be some problems with the analysis of the observations. They might not belong to the same statistical population, thus limiting applicability and quality of results of statistical algorithms. In general all values of 100-year-events show a band width. Finally, around the calculated value – often of a not very well defined range – it is allowed to call every value “the” 100-year-value. In practice, experience allows to shun this more theoretical difficulty.

There is an additional disquieting aspect in this with respect to the design of disaster protection. The amount of adverse effects increases with the size of the flood level of the flash flood. The functionality of this increase shows a rather wide range in the literature, increasing with the 3rd to the 6th power of the size of the triggering event. Figure 2 shows the tornado fatalities. Only 1% of all tornadoes in the United States of America was of the size F4 or even more violent. These few events were however responsible for about 2/3 of the fatalities caused by these events, while about ¾ of the total number of tornadoes, being of categories F0 and F1, caused about 1/20th of all victims. Thus, the problem is in the uncertainty of the size of the design threshold values. Any small change of the realized design threshold either gives rise to enormous potential damage or enormous cost for disaster prevention measures. Practical decisions on disaster reduction are often enough influenced by the sheer rareness of such events and the uncertainties involved.

The second component important in the reduction of adverse effects of flash floods is timely warnings. In the case of torrential rains the convective atmospheric processes responsible for the formation of such rains limit the forecast time interval to usually about ¼ of an hour to not more than about 2 hours. For disaster reduction management this is a rather short time, because the information chain mostly does not allow to take a precise warning to the appropriate addresses, comprising disaster reaction forces as well as the affected people. Local rain and water level observations may be of very little use, because it may mean that such an observation just confirms that a disastrous event occurs.

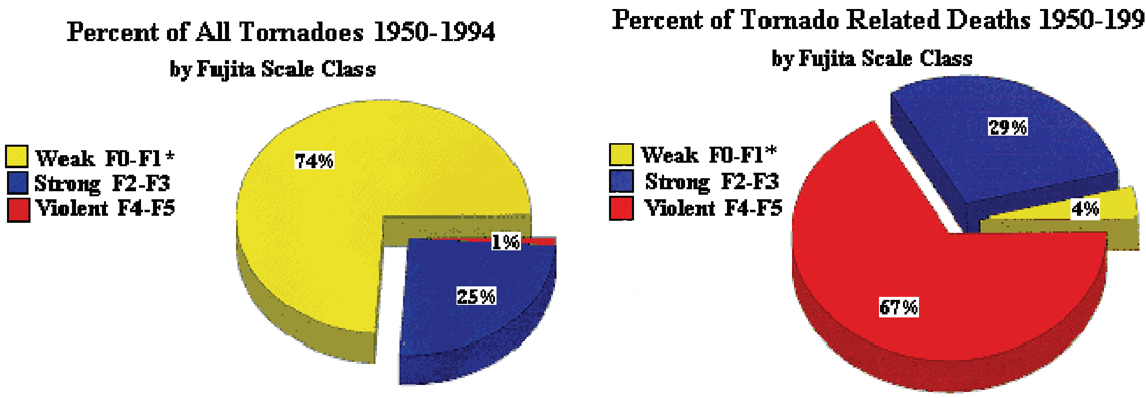

*Fig. 2. Nonlinear relationship between the size of the triggering event and the observed deaths (The Tornado Project, 1999).*

The rain rate in a convective rain event is highly time dependent. This is due to the structure of the cellular cloud causing the rains. The actual rain rate is strongly coupled to the cell size, intensity of the atmospheric processes and the direction and speed of the propagation of the convective cell. This can lead to quite different time series of the observed rain rates and the overall rain sum even for neighbored places.

The mentioned uncertainties of the 100-year-events and the small spatial extension of such events call for a method allowing the estimation of the physical limits of maximum rain rates. In the past, several approaches were being applied to obtain such estimates. The motivation often was fostered by the lack of observational data, and the need to design a protective system. The estimates usually were called “Probable Maximum Precipitation” (WMO, 1986) estimates. These were estimates of probabilities, relying on frequency analysis of rain and dew point temperatures in catchment areas. However, when data are rather sparse the uncertainties of the statistical values increase and there is a need to find the physical limits of the maximum rain rates for any given location. This means to use a comprehensive physical simulation model of the atmosphere as available in the weather forecast models. The task is then to find the maximum values of the parameters determining the rain rates. Such results can be used in estimates of long term maximum rain rates being the basis for long term disaster reduction measures.

## 2. MAXIMUM PRECIPITATION MODEL

We have used a diagnostic maximum precipitation model to tackle the physical upper limit of convective precipitation (Zimmer, 2008). It was derived from the orographic maximum precipitation model described by Tetzlaff and Raabe (1999) which makes use of the principle of forced upslope ascent providing the necessary lifting of moist air masses. The model is driven by idealized or observed vertical profiles of temperature, humidity and winds.

The orographic model is able to predict the orographic fraction of total precipitation in cases of nearly saturated and near-neutrally stratified air flow regimes (without convection). In these cases, the air will flow over the barrier without significant blocking of air upstream of the mountains (see Miglietta and Rotunno, 2005 for example). The surface-induced orographic ascent $w_{oro}$ is then calculated as

$$w_{oro} = U\, dH/ds,$$

where U is the effective wind component perpendicular to the terrain slope dH/ds. The main remaining variable to be parameterized in the model is the vertical decay w*(z) of the orographic lifting $w_{oro}$ to obtain the required profile of lifting w(z) varying with height:

$$w(z) = w_{oro}\, w^*(z).$$

For near-neutral atmospheric stability, the decay is relatively weak. For simplicity, we can assume that $w^*(z)$ follows an exponential function with scale heights of 5-10 km.

The orographic model has been applied for several heavy precipitation events in the Erzgebirge Mountains (East Germany). The extreme rain event of 12-13 August 2002, which led to widespread and damaging flooding in the Elbe river catchment, could be well reproduced with the diagnostic model. For the steepest slopes in the eastern part of the mountain range the model yielded orographic rain rates of up to 9 mm/h (Zimmer et al. 2006), matching the observations at the station Zinnwald-Georgenfeld during the evening and night hours of August 12/13. However, localized flash flooding occurred early in the event and was attributed to embedded convection, which contributed another 10-15 mm/h adding to the background rain rate caused by frontal and orographic lifting.

If the wind profile (direction and speed) is maximized and a saturated background flow of neutral stability is fed into the model, flash floods might well be triggered by orographic rain alone. For the mentioned setup, the diagnostic model produces rain rates up to 20 mm/h near Zinnwald.

The convective precipitation model makes use of a different source for lifting. It converts convective available potential energy (CAPE) – resulting from the warmer in-cloud temperatures in an unstable atmospheric environment – into kinetic energy which is feeding the updraft's vertical velocity w. The theoretical upper limit of w at the top of the cloud is:

$$w_{max} = \mathrm{sqrt}(\ 2\ \mathrm{CAPE}\ ).$$

In reality, the effective potential energy which can be converted into updraft speed is lower. The two main diminishing effects, the weight of precipitation particles and the entrainment of mass from outside the cloud, are considered in the diagnostic model. Both act to reduce the vertical velocity whose only source is buoyancy due to the density difference $\rho'$ between cloud and environment. Neglecting perturbation pressure gradient and Coriolis forces, the model equation for vertical velocity can be expressed as:

$$dw/dt = -g\, \rho'/\rho - g\, q_L - \alpha\, w^2,$$

where $q_L$ is the condensed water vapor (cloud and precipitation particles) and $\alpha$ is the entrainment parameter after Holton (1972).

The entrainment of environmental air slows down the updraft because some kinetic energy is needed to accelerate the initially resting air outside of the cloud. Furthermore, this air is usually unsaturated, hence the buoyancy of the saturated updraft air is reduced due to evaporative cooling and precipitation formation is delayed until saturation is reached again during the continued ascent. However, the effect of subsaturated entrainment is not considered in the maximum precipitation model.

Precipitation particles are created within the saturated updraft air due to release of surplus water vapor when air is cooled below its dewpoint temperature. The particles (cloud droplets, ice crystals, rain, snow and later graupel/hail in intense storms) initially are quasi-suspended in the updraft, until they reach a certain size and mass that accelerates them towards the ground, hence contributing to deceleration of the updraft. In the case of a tilted cloud in an environment of vertical wind shear, a fraction of the generated precipitation will not fall through the updraft. Thus, vertical wind shear can significantly reduce the negative effect of ”water loading”.

The wind speed profile is also important for the propagation of convection. Individual cells typically move with the mean wind vector, averaged over the cloud's vertical extent. Conglomerated cells (multicells) and convective systems (MCSs) are additionally influenced by the inflow of warm unstable air at lower levels. They usually show a propagation component directed against the inflowing air (Corfidi, 2003). Orography may further modify the propagation, leading to quasi-stationary regeneration of convection in rare cases.

For the presented maximization process, we assume a moderately tilted convective cloud due to weak/moderate wind shear. This ensures that a considerable fraction of precipitation does not fall back into the updraft. The cell movement is assumed to be marginal at $U_{cell}$=2 m/s, allowing point rainfall for almost one hour. The terminal fall velocity of the particles is considered as well.

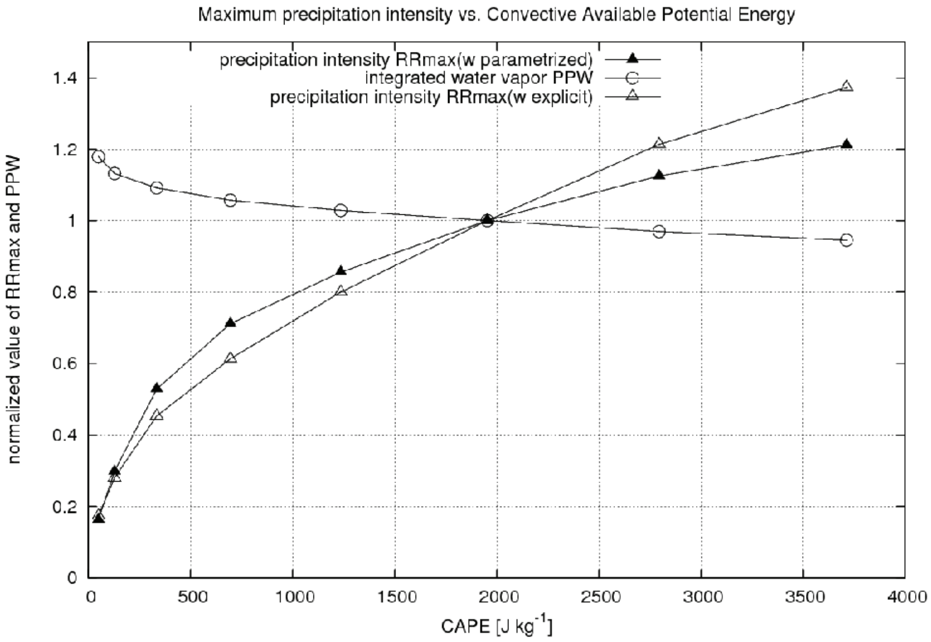

*Fig. 3. Precipitation intensity for different atmospheric profiles with varied* CAPE*. The results are shown for explicitly computed and parametrized vertical velocity* w *(open and filled triangles, respectively). The precipitation intensity is normalized to a* CAPE *value near 2000 J/kg. The total water vapor content* PPW *of the profile is drawn for orientation purposes, since* PPW *actually decreases with* CAPE*, due to cooler mid- and upper-level temperatures.*

The convective available potential energy (CAPE) has been varied via changed mid- and upper-level lapse rates. Since the buoyancy force represented by CAPE is the only source for lifting in the convective model, it becomes clear that CAPE strongly influences the rain rate as well. The relationship is shown in figure 3. The rain rate increases proportional to the square root of CAPE, but modified by the entrainment, water loading and fall velocity terms. CAPE can either be raised by cooling the air aloft or by warming and/or moistening the inflowing air near the surface. If maximum convective precipitation is expected to increase in a warming climate, then this would require stronger low-level warming compared to middle and upper levels.

Another aspect regarding the maximization of convective processes is their life cycle. As air rushes upwards through the updraft, a compensating downward motion is required to maintain balanced mass fluxes (see e.g. Fritsch, 1975). The downdraft of rain/graupel/hail contributes a portion to that flux, but the sinking of environmental air outside of the cloud plays the major role here. This dry downdraft can vary in its areal extent depending on the degree of cell organization, among other factors. As a consequence, CAPE decreases with time since this compensating dry-adiabatic subsidence gradually warms the air aloft. This may lead to a rapid decline of upward motion and rain rate if the subsidence takes place in a small area around the cell. The sensitivity of the ratio *a* between updraft and subsidence area is shown in figure 4. Thus, more widespread subsidence prolongs the potential lifetime of the cell.

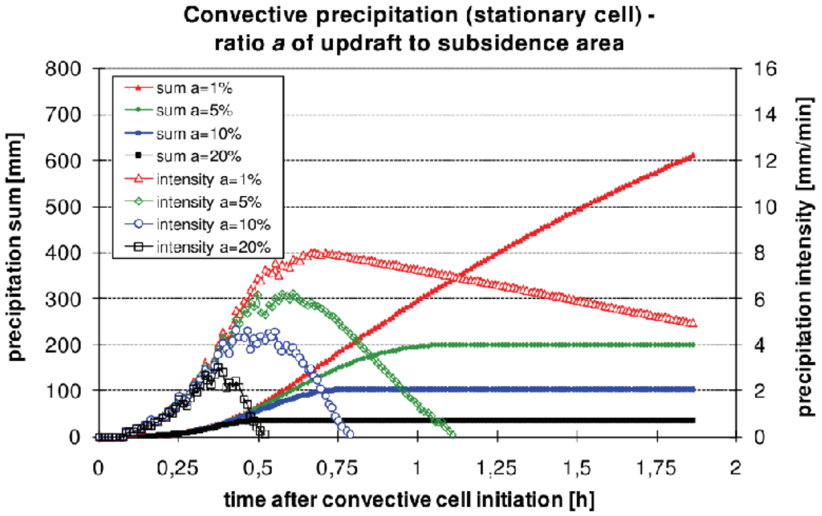

*Fig.4. Sensitivity study of convective precipitation produced by an idealised stationary cell, depending on the ratio of updraft to subsidence area. Open symbols describe the temporal evolution of precipitation intensity for differently sized subsidence areas, filled symbols represent accumulated amounts over time. Higher values of imply larger relative updraft areas and smaller relative subsidence regions (from Zimmer, 2008).*

The model design requires the input of a suitable, maximized combination of water vapor and wind profiles, in the way that the convective cell “produces” strong updrafts while moving very slowly in the horizontal plane to ensure rainfall duration at one place. Reasonable combinations were obtained from the sensitivity study. The size of the storm as well as the size ratio between updraft and lateral sinking zone are the only critical degrees of freedom which have to be given (e.g. from past experience or theoretical considerations).

In order to prove the ability of the model to provide a good estimate of maximum convective rain rates for a given atmospheric situation, we applied it for the extreme rain event in Berlin-Tegel on 25 August 2006. 108 mm of rain and hail fell within just one hour, with the peak intensity reaching 3 mm/min. The responsible broken convective line moved northward across the area, but was continuously building new cells in the vicinity of the station of Tegel. Given the moderate CAPE of around 800 J/kg (Zimmer, 2008) the diagnostic model produces maximum rain rates of 3.5 mm/min, accumulating to 149 mm in 70 minutes. This is only 27 mm above the observed amount in the same time frame (see figure 5). This result suggests that the principle of the maximum precipitation model provides reasonable intensity estimates if the cell movement is correctly estimated as well.

The maximum values for CAPE, low-level moisture and temperature were obtained from a series of 30-year radiosonde sounding data at Lindenberg and Dresden (East Germany). Only very few soundings exhibited the combination of strong instability (1500-2500 J/kg Mixed Layer CAPE) and weak winds. For values of CAPE=2500 J/kg and a cell movement of 2 m/s the maximum rain rate amounts to about **7 mm/min** and the rain accumulates to slightly over **200 mm in one hour at one point**. This is thought of as the *probable maximum convective precipitation rate* produced by a single cell under the past 30 years' climate conditions in East Germany. However, the combination of even higher instability values and quasi-stationary cells with large-scale compensating subsidence cannot be excluded ultimately. This would result in slightly amplified rain rates – the *maximum possible rain rate* will therefore depend on the selection of those parameters.

It has to be noted that the modeled rain rates are the result of balanced up- and downdrafts within and around the cloud. Under certain conditions a greater amount of precipitation particles may be suspended in the updraft and be suddenly released in a tremendous downburst of this body of saturated air. In the so-called wet microbursts, the additional downward velocity originates from density differences between the cool rain and the comparatively warmer environmental air. The downdraft speed adds to the terminal fall velocity of the drops. Therefore, the precipitation rate can be more than twice as high as the balanced, “production” rain rate because the convective cloud is kind of depleted within minutes. The extreme rainstorm of Füssen (German Alps) on 25 May 1920 which reportedly dropped 126 mm in 8 min (~16 mm/min) has likely been such an event.

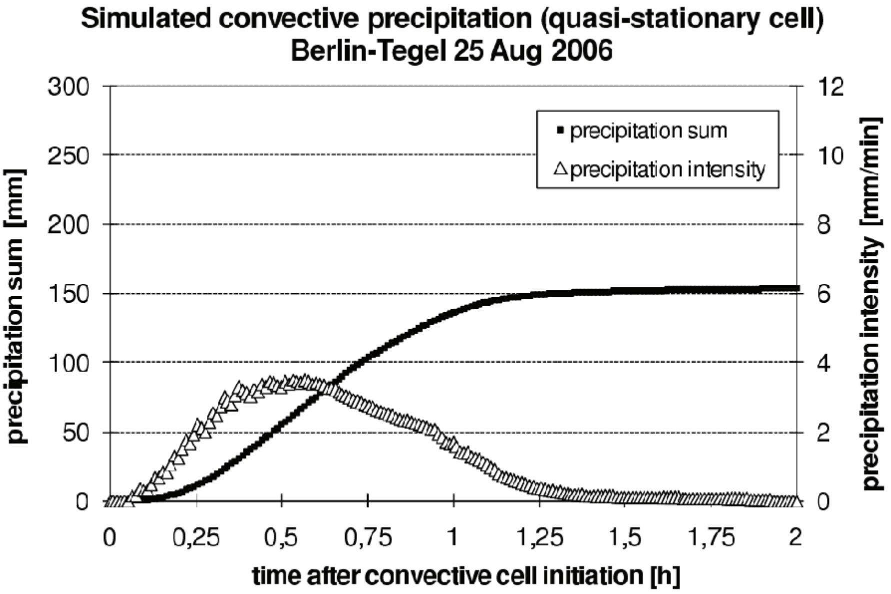

*Fig. 5. Temporal evolution of the heavy precipitation convective storm simulated with the idealised one-dimensional model, illustrated by convective rainfall intensity (open symbols) and accumulation (filled). Stationarity has been assumed to meet the quasi-stationary character of the observed storm (from Zimmer, 2008).*

The presented convective precipitation model is designed for estimating the upper limit of convective rain rates under given atmospheric conditions. Hence it can neither forecast the occurrence of convection nor can it be used to model the spatial distribution of more or less randomly organized cells (clusters). Moreover, the omission of certain terms which can further reduce the rain rates (perturbation pressure force, entrainment of unsaturated air, particle evaporation outside of the updraft) limits its application to extreme convective conditions. Nevertheless, since it uses radiosonde soundings which are statistically more robust than point precipitation observations, the model is expected to provide reasonable estimates of maximum convective rainfall, especially in data-sparse regions.

The better use of weather forecasts for warnings on flash floods needs a detailed information of the potential development of a flash flood based on rain rates as they are possibly produced in convective storms. To find the flash flood level, a numerical simulation of the flood level following rains is required. The goal is to better prepare for and to better make use of rain forecasts, both for the long term prepared and for the use of reaction forces.

## ***References***

[1] CORFIDI, S.F., 2003. Cold pools and MCS propagation: Forecasting the motion of downwind-developing MCSs. Weather and Forecasting Vol. 18, 997-1017.

[2] FRITSCH, J.M., 1975. Cumulus dynamics: Local compensating subsidence and its implications for cumulus parameterization. Pure and Applied Geophysics, Vol. 113, No. 1, 851-867.

[3] HOLTON, J.R., 1972. An introduction to dynamic meteorology. Academic Press, 319 pages.

[4] MIGLIETTA, M. M. – ROTUNNO, R., 2005. Numerical simulations of nearly moist neutral flow past a two-dimensional ridge. Journal of the Atmospheric Sciences, 62, 1410-1427.

[5] SCHUMANN, A., 2003. Hochwasserstatistische Einordnung des Hochwasserereignisses vom August 2002. Report to the Saxonian Ministry for the Environment and Geology, unpublished.

[6] TETZLAFF, G. – RAABE, A., 1999. Räumliche und zeitliche Verteilung maximaler Niederschläge. Extreme Naturereignisse und Wasserwirtschaft - Niederschlag und Abfluss, Internationales Symposium, Bayrisches Landesamt für Wirtschaft, Informationsheft, 5, 57-64.
[7] THE TORNADO PROJECT, 1999. The Fujita Scale. <www.tornadoproject.com/fscale>
[8] WORLD METEOROLOGICAL ORGANIZATION, 1986. Manual for Estimation of Probable Maximum Precipitation, 2nd edition, Operational Hydrology Report No. 1, WMO - No. 332, Geneva, 190 pages.
[9] ZIMMER, J. – RAABE, A. – TETZLAFF, G., 2006. Quantification of topographic effects on predicted precipitation in the Erzgebirge. Wiss. Mitteil. Inst. f. Meteorol. Univ. Leipzig, Bd. 37, 125-136.
[10] ZIMMER, J., 2008. Estimation of maximum convective precipitation: an idealised model approach. Wiss. Mitteil. Inst. f. Meteorol. Univ. Leipzig, Bd. 42, 33-41.

# Conclusions from the Workshop

The workshop gathered experts from four European countries (France, Germany, Poland and the Czech Republic) – the members of the European Network of National Platforms (ENNP) and a representative of the National Weather Service from the United States. The participants covered the whole chain of Early Warning (EW) from National Meteorological and Hydrological Services (NMHSs), civil defense, other parts of crisis management and the representatives of local administration. The workshop confirmed the usefulness of mutual cooperation and exchange of views from different countries for finding potential improvement of EW for Flash Floods (FFs). The participants stressed that flash floods belong to the most dangerous weather related disasters with high losses of property and lives. FFs differ from usual fluvial floods and need to develop specific approach to EW and preparedness: Discussion during the workshop lead to formulation of several joint views and conclusions

1) A FF develops from rain to full flood event within a time span ranging from about one hour to about one day. The total area covered usually does not exceed an area of about 100 km2. Current numerical forecasting tools do not bring optimum results in the time/space range of FFs. It is therefore necessary to improve FFs forecast and warning by diminishing overall uncertainty of forecasting locality, time and magnitude of dangerous flash floods and with their very fast development and their small spatial extension. NMHSs as the first segment of the whole EW chain should develop better, more accurate and faster forecasts and warnings by using best available tools comprising modern observation networks, radars, and nowcasting approaches linked to the modern numerical forecasting systems.
2) Forecasting and warning for FFs is strongly dependent on meteorological parameters of convective weather especially when forecasting heavy convective rains. This is different from forecasting river floods caused by spatially extended precipitation the consecutive floods evolving over a time span of several days. The forecasts and warnings for the inundation type of floods often can rely on hydrological observations alone.
3) Warnings need to be tailored ensuring they will be easily understood by the end users. The end user needs specific understanding of the warning, so he is capable to scale the warning (more standard frequent type of event, or an event of unprecedented size). Furthermore, the end user needs to be prepared to react accordingly, thus avoiding/reducing adverse effects. The dissemination of FF-warnings to the end users including local authorities and general public needs to utilize fast communication links like direct lines, internet, mobile phones with SMSs, etc. Also electronic media like radio and TV should be used whenever possible. Tight cooperation between of NMHSs with civil safety and other responsible bodies should be established and maintained to ensure fast dissemination of warnings. It is necessary to establish a cross-check mechanism to make sure the warnings were delivered to specified users (authorities responsible for flood protection at local and regional scale).
4) Dissemination of warnings should preferably use the means not vulnerable towards outage of electricity appearing very often during FFs caused by storms. Very simple means not requiring electricity should be prepared for a back-up.
5) There does exist a great gap between “risk awareness“ and “risk perception“. People are often aware of risk but do not “live with it”. Communication/instruction/education is the tool for increasing risk awareness and perception. It was identified that different groups of end users (e.g. decision makers, householders) need different way of communication/instruction/education and demand for different warnings and information.
6) Very important is to continuously build and maintain a flood awareness and education program, which will treat FFs as a special, fast, localized and very dangerous kind of floods. It is the key to the success of any warning and response system. Local officials and the general public need to be informed about the causes of flash floods, their risks, the warning system and emergency safety measures they need to be ready to take. In addition they have to understand the uncertain nature of

the forecasts and warnings and take into account in their decision making. Local warning plans need to be reviewed and practiced on a regular basis. It is possible to calculate a FF-potential for each region separately and make this the basis for the information/instruction/education of the people/authorities in potentially affected regions.

7) Flash Flood Guidance system for prediction of potential flash flood risk occurrence on the basis of the computed FF-potential is one way of facing to a danger of FFs. Physically it needs local information such as daily updated soil moisture conditions and radar precipitation field received online. Such systems should be developed and applied for areas prone to FFs.
8) Participants agreed with strengthening activities towards stronger involvement of planning, building codes and other measures in general flood and disaster protection. Individual flood plans could be very helpful. They should be based on the FF-potential-information. Organization and periodical repetition of practical trainings for endangered communities should preferably be established. Schools and media should be involved in this process.
9) The workshop stressed an important role of national disaster reduction platforms which can stimulate and maintain cooperation and coordination of activities of the main parts of warning and response systems and generally, the disaster reduction process in their respective countries.
10) International exchange of knowledge about early warning for FFs has proved to be very beneficial and helpful and should be maintained. The FFs workshop in Prague has been a very good example of such international cooperation among national platforms, NMHSs and other parts of disaster reduction chains from participating countries and such a process should continue in future.

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