Regional Rainfall

FACULTY OF CIVIL ENGINEERING
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Regional Rainfall

REGIONAL EXPERT MEETING ON RAINFALL MEASUREMENT DATA PROCESSING AND ANALYSIS

IRTCUD UNESCO

Ministy of Agriculture,
Forestry and Water management,
Water Directorate

Regional Expert Meeting

REGIONAL COOPERATION ON RAINFALL MEASUREMENT, DATA PROCESSING AND ANALYSIS

1-2 December 2005
Belgrade, Serbia and Montenegro

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Organized by:

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REPUBLIC OF SERBIA
Ministry of Agriculture,
Forestry and Water
Management,
Water Directorate

Foreword

The idea of organizing a workshop related to precipitation measurement and analysis in the region of the southeast Europe was suggested at several instances in a series of the International Workshops on Precipitation in Urban Areas, taking place in Pontresina and St. Moritz, Switzerland, since 1990. The IWA/IAHR Working Group on Urban Rainfall (GUR) encouraged and supported the initiative of the Faculty of Civil Engineering in Belgrade to organize a workshop with an aim to gather professionals from meteorological and hydrologic sectors, representatives of relevant institutions and researchers from the region. The following countries were invited: Slovenia, Croatia, Bosnia and Herzegovina, Albania, Serbia and Montenegro, Macedonia, Greece, Bulgaria, Turkey and Romania. As a result, the Regional Rainfall Workshop was held at the Faculty of Civil Engineering on 1-2 December 2005.

The need for regional cooperation in this field is obvious. Most countries in the region, and especially ex-Yugoslav republics, still have very similar methodologies for measurements and data processing, influenced by inherited services and experience. Some of the ex-Yugoslav republics also have significant gaps in measurements and processing in the period of 1990's and regional cooperation can improve filling of these gaps. Also, cooperation between the countries of the region has already been established through numerous regional projects related to water resources that are either in the implementation or planning phase (such as the projects related to the river Danube and the river Sava watersheds).

The importance of precipitation data is unquestionable from many points of view. Climatologic aspects influence country's economy in the fields of agriculture, energy, flood management, large infrastructures, tourism, etc. Precipitation data is therefore an inevitable part of any climatologic analysis. Stormwater management in urban environments is nowadays of highest significance for local communities to be able to control storm runoff, flooding damages, urban pollution and waterborne diseases. Therefore, improvement of precipitation measurement and analysis, in a direction that would take into account needs imposed by modelling of various hydrologic processes and different water uses, is strongly needed in the region.

This workshop was conceived to bring together experts from developed countries to present up-to-date methodologies and professionals from the region seeking for modern tools and new technologies in order to provide significant benefits for operational hydrology and real time control of infrastructure systems. The organizers would therefore like to express their gratitude to international experts Dr Boris Sevruk of Switzerland, Dr Thomas Einfalt of Germany and Prof. Maria Manuela Portela of Portugal for their valuable contributions and enthusiastic support.

The organizers are grateful to all participants from the region, and particularly to those professionals who prepared presentations on national experiences in this field and all who took part in fruitful discussions. Conclusions of the workshop are drafted in the following chapter. The ultimate conclusion is that there is a strong need for communicating and exchanging data and results among the countries of the region. An interest was also expressed to initiate joint projects in this field.

The last but not the least, Faculty of Civil Engineering is grateful to the Directorate of Water from the Ministry of Agriculture, Forestry and Water Management of Serbia for financial support of the Regional Rainfall Workshop.

Belgrade, December 2005

For the Organizing Committee
Jovan Despotović and Jasna Plavšić

Contents

Conclusions of the Regional Rainfall Workshop
Belgrade, 1-2 December 2005

After two days of fruitful discussions at the Regional Rainfall Workshop, certain ***common comments*** were emphasized, as follows:

- A wide variety of the levels of precipitation measurement, processing and application of data is noted in countries of the South-East European region.
- Reliable and accurate long-term measurement of precipitation are important, since measurements cannot be replaced;
- It is very important to control measurements, to process data, to analyze results of precipitation measurements concerning different climatic aspects and numerous natural, industrial, environmental and economic domains;
- A significant interest has been shown during the Workshop for the exchange of information on rainfall measurements and processing, and particularly for improving the use of precipitation data for hydrologic and hydraulic modeling;
- Presentations given have shown promising directions of improvement of the precipitation measurements, processing data and above all application of the results.
- Very important is active participation of hydrometeorological services from all countries presented;
- There is a strong need for more examples of using rainfall data in hydrologic models in order to evaluate availability and quality, i.e. reliability and accuracy of data;
- A need for other type of data (other than rainfall) for assessing climate and other aspects.
- Radar provides very useful information additional to traditional raingauge measurements, in particular on the spatial structure of rainfall.

Among the participants of the Regional Rainfall Workshop and within the presentations, the ***following issues*** were noticed:

- Different levels of processing, analysis and application of precipitation measurement data.
- Usefulness of exchanging experience presented at the Workshop.
- Significant differences in assessment of optimal number of raingauges and measurement networks.
- Presentations have shown that both raingauge density and measurement reliability and accuracy have to be increased along with the improvement of application of observed data.
- The following common analysis could be performed at the regional level:
  - high-intensity short-duration rainfall,
  - extreme recorded historical events and floods in the region,
  - main characteristics of precipitation, such as: statistics, quantiles, periodicity, trends etc.
- Precipitation measurement and analysis is the most important among all climatic aspects and in this regard a comprehensive regional analysis should be promising,

since climatic conditions are the most important ones for sustainable development of the region.

- Precipitation should be considered taking water resources into account, including both extremely large precipitation causing floods and lack of precipitation in dry periods causing droughts.
- Different experience gained trough different measurements should be exchanged in regard to solve numerous specific problems.

The following ***conclusions*** can be drawn:

- There is a strong need for intensifying exchange of information and education in the field of rainfall data processing and implementation, taking into account assessment of water resources, including both their use and control of floods and droughts in the region.
- All the countries from the region should be included in the discussion, exchange of information and subsequent steps of precipitation analysis.
- In each of the countries a commission should be established that will participate in future preparation of the project for the region.
- It is useful to investigate into new technologies if new material needs to be installed.
- The requirements of rainfall information should be based on an application oriented point of view and include multi sensor / multi source information.
- The existing networks in the region (radar and raingauges) should be analysed for their availabilities for concrete applications (e.g. flood forecasting, climate analysis, design of retention basins);
- Further communication in regard to make use of national research and professional projects as a basis for common project is encouraged.
- It is proposed to initiate cooperation on precipitation analysis in a region of approximately 500 km width around the 200E longitude as the axis of the South-East European region.
- It is desirable to have communication as frequent as possible, including meeting at various events. One such opportunity is the International Workshop on Urban Rainfall to be held in St. Moritz, 7-10 December 2006.

Belgrade, January 2006

Jovan Despotović

List of contributions

PLUVIOMETRIC NETWORK IN ALBANIA – PROCEDURE OF MEASUREMENTS AND ELABORATION METHODS
Bojko Themelko, Vangjel Mustaqi, Hydrometeorological Institute of Albania

CURRENT LEVEL OF RAINFALL NETWORK OF TURKEY
Ibrahim Gurer, F. Ebru Yildiz, Gazi University, Faculty of Engineering and Architecture
Hamza Ozguler, Turkish State Hydraulics Works, Department of Investigation and Planning

SYSTEMATIC ERROR OF PRECIPITATION MEASUREMENT
Selected annotated bibliography of the author

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Abstract: Since two and half centuries there are hundreds of publications on the systematic errors of precipitation measurement. Comprehensive summary reports including these published by the author of the presented paper and two annotated bibliographies by Kurtika and Rodda exist. (See Sevruk, 1981 for complete references). Instead of writing a new report, which would necessarily mean to repeat a lot of what was already published, it was decided to present here a kind of selected annotated and illustrated bibliography of publications of the author and his co-authors. The references of other authors are cited in the author's references as mentioned in this paper. The purpose is to introduce in abbreviated form the subject and it last development as it is reflected in the author's publications and to allow for a simple search of subjects through the author's list of publications.

Introduction

A serious drawback of point precipitation measurement using common can-type gauges elevated above ground is that it is subject to the systematic errors. It is difficult to measure precipitation without introducing these systematic errors or biases. The quality of any measurement will depend on the type of gauge used and the details of the installation as well as the characteristics of the gauge site including exposure and the prevailing weather. The systematic errors are mostly due to deformation of the wind field above the orifice of elevated precipitation gauge, wetting of inner walls of gauge container and collector, evaporation losses of accumulated water in the container, splash-out and splash-in, blowing snow, etc. Because these measurement errors are systematic, precipitation gauges frequently show different precipitation figures at the same site. This is the case, when the gauges are of different construction or the same construction but from different manufacturers, or are installed at different heights at the same site near to each other, or under different gauge site exposure. With the exception of measurements of blowing and drifting snow they show less precipitation than the "true" precipitation falling on the ground. This, of course, has consequences for a computation of water balance and climatological and meteorological studies.

Generally, the old literature up to 1950 focused on the methods of precipitation measurement with the purpose to develop the best possible precipitation gauge including the optimal material, shape and installation. It was shown than an ideal common gauge is difficult to find. Since 1950 the focus changed rather to the development of correction procedures of systematic error of precipitation measurement, which can be applied to precipitation measurements of any kind of a gauge. Such correction procedures were based on empirical methods using the World Meteorological Organization, WMO, reference standards, such as the pit gauge for rain and the double fence shield for snow, and additional laboratory experiments (**Fig.1**). In this context three international intercomparison measurements (Sevruk and Hamon, 1984; Goodison et al., 1998), three special workshops were organized by the WMO (Sevruk, 1985; 1989; 1993) and a summary report on corrections was published by the WMO (Sevruk 1981). The fourth WMO intercomparison measurements of recording precipitation gauges, including tipping-bucket gauges and the modern electronic weighing gauges is going on and will be finished in 2006 (Lanza et al., 2005). Moreover national intercomparison measurements were carried-out in different countries and correction procedures developed (Sevruk, 1982). They are different for rain and snow, for different type of precipitation gauge and various time intervals according to the availability of necessary input data. Recently the empirical methods were substituted by numerical simulation.

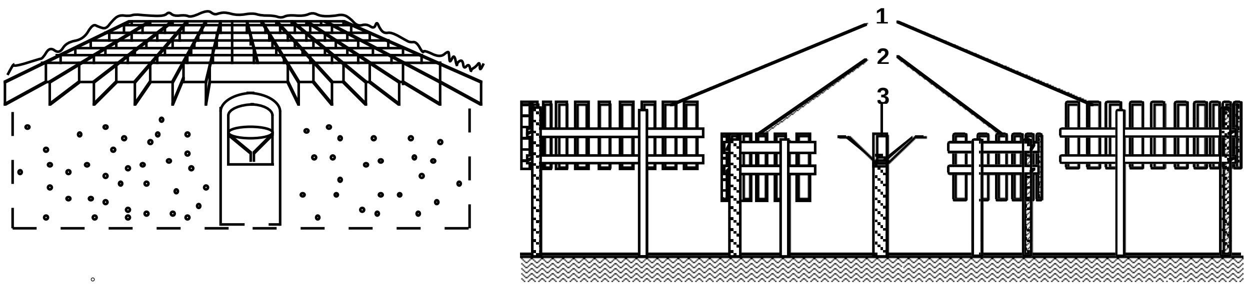

Figure 1: WMO reference standards for liquid and solid precipitation measurement. From the left: the pit gauge with anti-splash grid and the double-fence consisting of 1: the outer fence of 12 m diameter and 3.5 m height, 2: the inner fence of 4 m diameter and 3 m height and 3: the Russian Tretyakov gauge with windshield. According to Sevruk (2004).

References

Goodison B. E., P.Y.T. Louie and **D. Yang**: WMO solid precipitation measurement intercomparison, WMO/TD-No. 872, 88pp+212pp Annex, World Meteorol. Org., Geneva, 1998.

Lanza, L., M. Leroy, J. van der Meulen and **M. Ondras**: The WMO laboratory intercomparison of rainfall intensity gauges. Instruments and observing methods, Rep. 82, WMO/TD No. 82, 8 p., (CD).World Meteorol. Org., WMO Geneva 2005.

Sevruk, B. See Selected references below.

General and summary reports

In the following publications problems of point precipitation measurement using common type of gauges are discussed and global aspects of precipitation measurement specified. They content relevant references in different languages including Russian, and mostly a short chronology, the phenomenology and methodology of the problem. It is explained (i) why the point measurements are subject to systematic errors, (ii) why it is necessary to evaluate precipitation gauge performance, (iii) what procedures can be used to achieve this goal and (iv) what consequences does it have for climatological, meteorological and hydrological studies (Sevruk1981; 1986; 1987; 1993; 2004; 2005). In this respect the spatial and temporal inhomogeneity and water balance computations are mentioned (Sevruk, 1994).

Types of standard daily gauges and recording gauges as used in different countries are presented and illustrated (Sevruk and Klemm, 1989a,b; Sevruk 1989a,b; Sevruk, 2002; 2004). The standard precipitation measurement techniques and reference instruments such as the pit gauge for rain and the double-fence gauge (Waldai) for snow are presented and their physical background discussed (Sevruk, 1993; 2004; 2005). Systematic errors of precipitation measurement and their corrections as based on field experiments are dealt with in general manner. These errors depend on the particular instrument and observational method used (Sevruk, 1971: 1989b; 2004), the climate conditions and the gauge site exposure. Since different observational methods are used in different countries and the gauge site exposure in a network varies from exposed to protected, it causes the precipitation data to be spatially inhomogeneous and non-compatible. Temporal inhomogeneity also can exist owing to changes in observational methods and exposure degrees of a particular gauge site during the observational period. The adjustment for this kind of inhomogeneity using statistical methods does not eliminate the systematic error. Both kinds of inhomogeneities can be eliminated only using the correction procedures (Sevruk, 1994).

The results of international intercomparison measurements using reference instruments are analyzed. A short recent overview is presented in Sevruk (2005). Most complete and a very detailed information of all problems including the history, the assessment of areal precipitation in the mountains can be find in the text book of the author in German (Sevruk, 2004). It contains also an extensive Appendix with Tables and a Chapter with lessons for students. It summarises the results of author's 40-year activities in the field as the university lecturer, scientist and expert on mountainous hydrology, member of international bodies, organizer of relevant workshops and the 25-year -long period as the WMO rapporteur on the subject. In this period the most noticeable progress in problem solutions took place. It started in the 1960s in the former Soviet Union by distinguish scientists as Strutzer, Bogdanova, Golubev, Netchajev etc. (Sevruk, 1981; 1982) and continues presently by the WMO laboratory and field intercomparisons (Lanza et al. 2005, see above).

NOTE: Bold print reference indicates more relevant papers on the subject from different authors in the volume. * indicates review of literature and + indicates both original work and review of literature as well.

Sevruk, B.: Comments on "Seasonal Variation in Rain Catch" By J. L. McGuinness and G. W. Vaughan. Water Resources Res., 7 (3), 741-743, 1971.

Results of intercomparison measurements at the Baye de Montreux basin in Switzerland showed differences in measurements using different types of gauge. The mean monthly differences of a 10-year period indicate seasonal pattern. The Swiss storage gauge measurements were greater than that of the standard Hellmann gauge in the winter season, due to the wind shield and considerably smaller in the summer due to evaporation. In June-July the deficit was up to 10 %. The pit gauge showed greatest amounts of precipitation out of all other gauges in the summer.

+Sevruk, B.: Methodical investigation of systematic error of Hellmann rain gauges in the summer season in Switzerland (in German). Trans. Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, Swiss Federal Institude on Technology, ETH Zürich, Mitt. No. 52, 297 pp., 1981, Zürich. (http://e-collection.ethbib.ethz.ch/cgibin/show.pl?type=diss&nr=6798).

A review of methods and history of correction of wind-induced and wetting losses and their application to corrections of mean monthly precipitation amounts from 70 selected Swiss climatic stations in the summer season from April to September.

*Sevruk, B.: Methods of correction for systematic error in point precipitation measurement for operational use. World Meteorol. Org., WMO, Operational Hydrol. Rep.,, 21, WMO-No. 589, 91 p. Geneva 1982.

A summary report and a short chronology with tables and figures of methods and results of correction procedures of wind-induced error, wetting and evaporation losses as developed in many countries, particularly in the former Soviet Union, which was the leader in research at that time.

Sevruk, B.: Point precipitation measurements: why are they not corrected? In: J.C. Rodda and N.C. Matalas (Eds.) Proc. Water for the Future: Hydrology in Perspective. Internat. Assoc. Hydrol. Scie., IAHS, Publ., No. 164, 477-486, 1987.

Numerous papers suggest corrections of systematic errors of precipitation measurements. Reasons why the corrections are needed but are still not operationally used are analysed. The future prospects are discussed.

Sevruk, B.: Precipitation Measurement**. Proc. International Workshop on Precipitation Measurement, St. Moritz, Switzerland,** 3.-7. December, 1989. Institute of Geography, Swiss Federal Institute of Technology, ETH Zurich, 589 pp., 1989 (Editor). (See: **WMO/TD-No. 328, 1989a**).
A total of 85 conference reports and posters from 120 participants from all aver the world, amounting to 590 pages are reproduced. They include problems of point precipitation measurement accuracy, corrections and standardisation of global precipitation measurements, the topics of spatial distribution and areal assessment of precipitation as well as applied fields such as radar, satellite, urban precipitation, the optimisation and design of networks, snow cover and climatic change.

Sevruk, B.: Reliability of precipitation measurement. In: B. Sevruk (Ed.) **Precipitation Measurement. Proc. International Workshop on Precipitation Measurement, St. Moritz, Switzerland,** 3.-7. December, 1989. Institute of Geography, Swiss Federal Institute of Technology, ETH Zurich, 13-19, 1989. (See: **WMO/TD-No. 328, 1989b**).
This study summarizes the practical aspects of results of research, particularly of conventional methods of assessment of areal precipitation and the systematic error of point precipitation measurement. It attempts to explain the basic concepts in a more general way using examples and illustrations.

Sevruk, B. and S. Klemm: Catalogue of national standard precipitation gauges. Instruments and Observing Methods Rep., No. 39, 52 p. World Meteorological Organization WMO, Geneva. 1989a.
In addition to Sevruk and Klemm (1989b, see below) it includes also a description of systematic error sources of precipitation measurement and lists the countries where changes of measurement techniques were made in the last 30 years.

Sevruk B. and S. Klemm: Types of standard precipitation gauges. In: B. Sevruk (ed.): **Precipitation measurement. Proc. Internat. Workshop on Precipitation Measurement. St. Moritz, WMO/TD-No. 328, 227-232, Geneva 1989b.**
The report describes 54 types of national standard precipitation gauges as used at present by national Meteorological Services of 136 countries, covering an area of 90 % of the global mainland and islands. It contains each gauge type name and country of origin, its picture, elevation height, orifice area, depth of collector, height of gauge, material and countries where it is used.

Sevruk, B.: Checking precipitation gauge performance. In: S. Couling (Editor). Measurement of airborne pollutants. p. 89-107, Butterworth Heinemann, Oxford, 1993.
The necessity to evaluate precipitation gauge performance and the procedures, which can be used to achieve this goal, are discussed. Standard precipitation measurement techniques and reference instruments, such as the pit gauge for rain and the double-fence gauge for snow, are presented and their physical characteristics discussed. Methods to evaluate and correct systematic errors of precipitation measurement are described and examples of their application presented. The results of international intercomparison measurements are analysed and global aspect of precipitation measurement discussed.

Sevruk, B.: Spatial and temporal inhomogeneity of global precipitation data. In: M. Desbois and F. Desalmand (Eds.). Global Precipitation and Climate Change. NATO ASI Series, Vol. I 26, 219-230, Springer Verlag, Berlin 1994.
Inhomogeneities of precipitation time series can be caused in a number of ways by the systematic error of precipitation measurement, in particular the wind-induced error, namely the replacement of instruments and changes in their elevation high and the environmental changes at precipitation gauge site or their surrounding such as grooving woods or cutting off the woods, urbanisation and the mowing of instruments from old to new sites. In this way the exposure of gauge site can also be affected. The spatial and temporal inhomogeneities can be eliminated if the corrections of systematic errors of precipitation measurement are applied.

Sevruk, B.: The WMO questionnaire on recording precipitation gauges: State-of-the-art. Water Sci. Techn., 45(02), 139-145, 2002.

An inquiry by the WMO responded by 118 countries shows that there is a great variety in types of recording precipitation gauges, orifice area sizes, elevation highs, methods of observation, manufacturers, heating, wind shield application and data transmission.

+Sevruk, B.: Precipitation as the water cycle element. Theory and practice of precipitation measurement (in German). 300 p., Zürich-Nitra 2004. (Available from boris.sevruk@env.ethz.ch).

Textbook with theoretical, practical and geographical aspects, many examples and illustrations, appendix and lessons for university students of meteorology, hydrology , climatology and environmental sciences. State-of-the-art, review of literature and of author's contributions as a university teacher and researcher, mountain hydrologist, member of international bodies and organizer of international meetings. In addition to the problems of point precipitation measurement accuracy and corrections, the methods and results of assessment of spatial distribution and areal precipitation in the mountains are dealt with. Mean monthly corrections for 300 Swiss precipitation stations are tabulated and a very detailed review of history is given.

Sevruk B.: Rainfall measurement: Gauges**.** In: M. G. Anderson (ed.). Encyclopedia of Hydrological Siences, Vol. 1, Part 2, Hydrometeorology, Chapter 40 (in press), Wiley&Sons Ltd., 8 p., Chichester, UK. 2005.

A short description of problems of point precipitation measurement accuracy and corrections of systematic errors of precipitation measurement. A review of recent literature with figures and examples.

Wind-induced losses

The wind-induced loss constitutes the greatest systematic error of precipitation measurements and its assessment is a problem of major concern. Field intercomparison measurements using either (i) WMO reference standards (**Fig. 1**) (Sevruk and Hamon, 1984, Sevruk, 1985a) or (ii) secondary references such as the water equivalent of fresh snow (Sevruk, 1983; 1985b; 1987; Sevruk aet al, 1998;Zweifel and Sevruk, 2002) (iii) wind tunnel experiments (Nespor et al., 1994; Sevruk et al. 1989; 1991) and (iv) numerical simulation were applied to evaluate these losses (Nespor and Sevruk, 1999; Sevruk and Nespor, 1998; Sevruk et al., 2000; Chvila et al., 2002). The wind-induced losses increase with wind speed and a fraction of small particles in the total amount of precipitation (i.e. decreasing intensity of precipitation). If the actual intensity of precipitation is considered as a structure parameter, the weather conditions have to be accounted for. Consequently, corrections are based on relationships to wind speed and a parameter of precipitation structure, which is different for rain and snow. Chvila et al. (2005) show such a relationship for convective (cumuliform clouds) and non-convective (stratiform clouds) rains derived by field intercomparison measurements of elevated and pit gauges and **Fig. 2** using a numerical simulation.

Generally, not all variables needed for application of corrections are measured in the common national precipitation networks and have to be derived from the existing data (Sevruk, 1985b). (Better situation exists in the automatic meteorological networks with recording precipitation gauges.) In order to assess the missing variables reduction procedures and classification schemes were developed. These include:

- the wind speed during the precipitation events at the level of the gauge orifice (it is related to the gauge exposure site, Sevruk and Zahlavova, 1994);
- intensity of precipitation or the fraction of small intensity rains in the total amount of precipitation (Sevruk, 1989a,b). The latter depends on weather conditions. For convective rains the fraction is small and for non-convective rains it is great for the same intensity (Chvila et al., 2002; 2005).
- temperature and a fraction of solid precipitation in the total amount of precipitation (Sevruk, 1984).

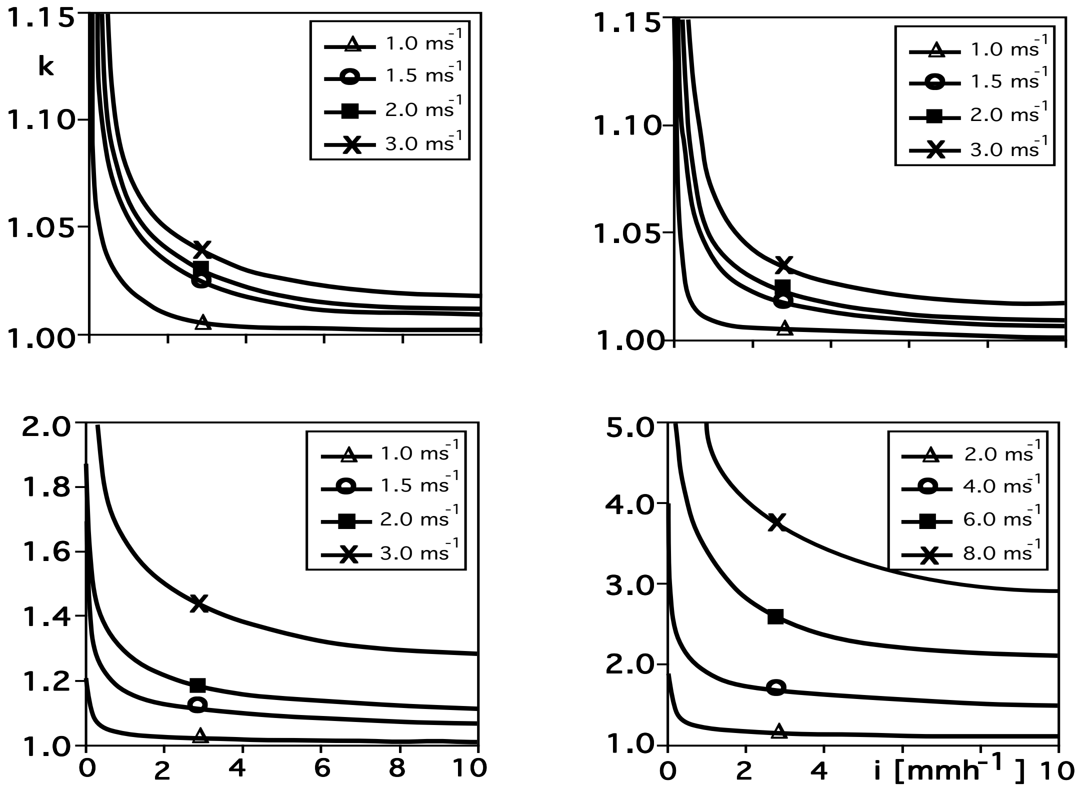

Figure 2: Relationships between the wind-induced losses k, intensity of precipitation i and wind speed derived for a recording precipitation gauge using numerical simulation according to Sevruk (2004). k is ratio of "true" and measured precipitation. Note different scale on top and bottom.
Top from left: convective (thunderstorms) and non-convective (orographic) rains. *Bottom*: snow.

Sevruk, B. and V. Nespor: The effect of dimensions and shape of precipitation gauges on the wind-induced error. In: M. Desbois and F. Desalmand (Eds.). Global Precipitation and Climate Change. NATO ASI Series, Vol. I 26, 231-246, Springer Verlag, Berlin 1994.

The results of various kinds of studies into the physics of precipitation gauges including field intercomparison measurements, wind tunnel experiments and simulation using computational fluid dynamics are reviewed. The focus is on the effects of precipitation gauge construction parameters on the wind-induced error regarding practical applications such as the development of correction procedures or the selection of suitable design criteria for the sensitive parts of precipitation gauges. In this context, the following gauge parameters are to be noted: the proportions and the shape of both gauge body and orifice rim. In addition, the use of wind shielding devices is one of the most critical factors. The ideal precipitation gauge should have a streamlined body in a shape of a flat plate protected by the wind shield. Yet such gauges are not used at all. A common precipitation gauge consists of an upright cylinder having rather poor aerodynamic properties. Therefore, with regard to a considerable systematic error due to wind, the measured precipitation values have to be corrected.

Sevruk, B. and W.R. Hamon: International comparison of national precipitation gauges with a reference pit gauge. Instruments and Observing Methods Rep., No. 17, 135 pp., 1984. World Meteorol. Org., Geneva. (See also below).

The wind-induced losses were estimated for 60 measuring sites situated all around the world. They amount on average to 3 % (up to 20 %), or 4-6 % when the wetting and evaporation losses are accounted for. The original data and pictures of installation at six evaluation stations are presented.

Sevruk, B.: Effect of wind and intensity of rain on the rain catch: International comparison of national precipitation gauges with a reference pit gauge (Evaluation stations). In: B. Sevruk (Ed.) Proc. Workshop on the Correction of Precipitation Measurements. Zürcher Geographische Schriften, ETH Zürich, No. 23, 251-256, 1986. (See: **WMO/TD-No. 104, 1985a**).

The results of the WMO International Intercomparison Measurement of national precipitation gauges with a reference pit gauge showed a non-linear relationship between the increment percentage difference of rain catch per wind speed unit and the fraction of rainfall falling at intensity smaller than 0.03 mm min^{-1}. Such a relationship can be applied to correct the wind-induced losses of precipitation measurement. In addition corrections of wetting and evaporation losses were developed. Four types of precipitation gauges at six sites were investigated: the Australian gauge, the Finish Wild gauge, the German Hellmann gauge and the US Weather Bureau gauge. The pit gauge was similar in design to the English Mk2 (Snowdon) gauge.

Sevruk, B.: Wind-induced measurement error for high-intensity rains. In: B. Sevruk (Editor) **Precipitation Measurement. Proc. International Workshop on Precipitation Measurement, St. Moritz, Switzerland,** 3.-7. December, 1989. Institute of Geography, Swiss Federal Institute of Technology, ETH Zurich, p. 199-204, 1989. (See: **WMO/TD-No. 328, 1989a**).

The wind-induced error of precipitation measurement amounts to 5 % for high intensity rains. The reason is strong wind, which frequently associates such rains. The error increases sharply with decreasing rain intensity, in particular if it remains below a certain threshold value, approximately 2.0-3.5 mm h^{-1}. The threshold value is not a constant and it increases with wind speed. Above a particular threshold value the effect of intensity on the wind-induced error is considerably smaller.

Sevruk, B.: Precipitation correction: Parameter estimation of precipitation structure. TECIMO IV, Instruments and Observing Methods Rep., No. 35, 317-322. World Meteorol. Org., Geneva 1989b.

Different methods of estimation of actual and mean monthly values of parameter of rain structure, which is defined as a fraction of small intensity of rains ($i<0.031$ mm min^{-1}) in the total amount of rain, are compared and a new indirect method is suggested. This method uses an index of monthly values of temperature and precipitation per day and allows for the ssessment of the wind-induced losses at sites where at least wind speed is known.

Sevruk, B and L. Zahlavova. Classification system of precipitation gauge site exposure: Evaluation and application. Internat. J. Climatol., 14(6), 681-689, 1994.

The precipitation gauge site exposure is assessed from the station history records: Four classes and three interim classes ranging from open to protected gauge sites are used. They are characterized by the average vertical angle of obstacles around the gauge, as measured in eight directions of the wind rose. The accuracy of class estimates was checked in the field. The error of estimates for an experienced person is approximately $\pm 1/2$ of the class. Applications of the classification system for the reduction of wind speed to the level of precipitation gauge orifice and the estimation of wind-induced error of precipitation measurement as well as the detection of inhomogeneities of precipitation time-series are discussed.

Snow and heating losses

Sevruk, B.: Correction of measured precipitation in the Alps using the water equivalent of new snow. Nordic Hydrology, 14(2), 49-58, 1983.

The Hellmann heated siphon pluviograph with wind shield shows 56 % less winter precipitation than measured on a snow board at an altitude 2. 540 m a.s.l. For the Swiss heated tipping-bucket gauge and the storage gauge, both also with wind shield, the precipitation was 31 % less. A relationship between the deficit and wind speed was only found for the unheated storage gauge. Such a relationship can be used to correct the wind-induced losses of storage gauges at sites where the wind speed data are available. For the two heated gauges no relationship was found due to heating losses.

Sevruk, B.: Conversion of snowfall depths to water equivalents in the Swiss Alps. In: B. Sevruk (Ed.) Proc. Workshop on the Correction of Precipitation Measurements. Zürcher Geographische Schriften, ETH Zürich, No. 23, 81-88, 1986. (See: **WMO/TD-No. 104, 1985b**).

Daily values of density of snow from 3635 events in the Swiss Alps depend on the local physical and meteorological characteristics, particularly wind speed or site exposure and temperature. The unit value of 0.1 can be used only in open locations. In exposed locations it is considerably more. The ratio of water equivalent of snow as measured using snow samplers and precipitation gauges can be applied to correct the systematic error in the point precipitation measurement. It is related to the wind speed at the level of the gauge orifice.

Sevruk, B.: Assessment of snowfall proportion in monthly precipitation in Switzerland. In: Proc. 18th International Coference for alpine Meteorology, 25-29. Sept. 1984, Opatija, Yugoslavia, Zbornik Meteoroloskih i Hidroloskih Radova, Belgrad, 10, 315-318, 1984.

The mean fraction of snow in the total monthly precipitation in Switzerland is related to temperature and altitude of the site. It is shown that seasonality plays also an important variable. Tables with fraction values depending on such variables and the review of relevant literature are presented.

Sevruk, B.: On difficulties of checking storage gauges in winter. In: Proc. 13th Conference of Carpathian Meteorology. Institut of Meteorology and Hydrology, Bucharest, 169-174, 1987.

Comparisons of monthly precipitation values with water equivalents of snow is a suitable method of checking storage gauges only at protected sites. At exposed sites the snow deposited on the ground is frequently blown off. Accounting for melting snow, the precipitation values at an exposed site, altitude 1436 m a.s.l. , were 13 % lower than water equivalents of snow but as much as 50 % less than precipitation values at the near protected sites. Between protected sites no differences at all emerged.

Sevruk, B.: Comparisons of snowfall measurement techniques. In: B. Sevruk (Editor) Snow cover measurements and areal assessment of precipitation and soil moisture. Operational Hydrology Rep., No. 35, WMO No. 749, Annex II.3, p. 195-200, 1992. World Meteorol. Org., Geneva.

Sevruk, B., M. Paulais and Y.-A. Roulet: Correction of precipitation measurement using fresh snow as reference. Proc. WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, TECO-98. WMO/TD-No. 877, 349-352, 1998, Geneva, Switzerland.

Correction procedures of the wind-induced error of snow measurement using the French precipitation gauges, ASSOCIATION and SPIEA, were derived applying the depth of fresh snow measurements and the density of fresh snow as derived from temperature and wind speed measurements. The wind-induced loss is large. For a wind speed of 2. 0 m/s, it amounts up to 50 % of measured precipitation.

Zweifel, A. and B. Sevruk: Comparative accuracy of solid precipitation measurement using heated recording gauges in the Alps Proc. **WCRP Workshop on Determination of Solid Precipitation in Cold Climate Regions, Fairbanks, Alaska, 2002** (CD Rom edition).

Field experiments to derive a relationship between wind speed and the wind-induced losses of solid precipitation measurements using heated recording tipping-bucket gauge ASTA are subject to different error sources. On average losses amount to 35 % and varies between the six gauge sites from 14 to 58 %. A linear relationship of the error with the mean wind speed during precipitation event was found only for two gauge sites (R^2 = 0.71 and 0.48). In addition to the random errors of fresh snow measurements on the snow board including the site specific conditions, drifting snow etc., the most important seems to be the evaporation losses due to heating the gauge. Using the Swiss heated tipping-bucket gauge ASTA these losses almost equal the wind induced losses if the wind speeds are smaller than 1 ms^{-1}. In the case of wind speeds between 1 and 2 ms^{-1}, the heating losses amount to one-third of wind induced losses. Therefore it is suggested to use non-heated recording precipitation gauges to measure the amount and intensity of snowfalls and to derive corrections procedures of wind induced losses based on wind speed. The electronic weight systems are to be preferred to tipping-bucket gauges.

Corrections

Sevruk, B.: Correction of precipitation measurements: Swiss experience. In: B. Sevruk (Ed.) Proc. Workshop on the Correction of Precipitation Measurements. Zürcher Geographische Schriften, ETH Zürich, No. 23, 187-196, 1986. (See: **WMO/TD-No. 104, 1985c**).

A simple practice-oriented method and results of correction procedures developed for the Swiss conditions as well as regionalized maps of mean monthly corrections are presented. The corrections reveal a distinct seasonal and regional pattern. The range of mean annual corrections varies from 4 % in Tessin to 25 % in the Alps. The respective figures in the winter season (October-March) are from 4 % to 35 % and in the summer seaso (April-September) from 3 to 15 % (see also Sevruk and Kirchhofer, 1992).

Sevruk, B. (ed.): Correction of precipitation measurements. Zürcher Geographische Schriften, ETH Zürich, No. 23, 200 pp., 1986. (**WMO/TD-No. 104, 1985**).

52 meteorologists from 23 countries presented 36 papers and 9 posters on a wide range of topics documenting a considerable progress of research. The topic covered: new precipitation gauges and more accurate measuring techniques; comparison measurements of precipitation gauges of various types and with different location and exposure; national state-of-the-art reports on corrections from Bulgaria, Canada, Czechoslovakia, Denmark, Finland, Germany, Poland, Switzerland and USSR; snowfall corrections and acid rainfall measurements.

Sevruk, B. and W. Kirchhofer,: Mean annual corrections of measured precipitation amounts 1951-1980. In: Hydrological Atlas of Switzerland, Part 2.3, Eidgenössische Drucksachen und Materialzentrale Bern, Switzerland, 1992.

Spatial distribution of mean corrections of wind-induced and wetting losses of precipitation measurement in Switzerland is presented in a map at a scale of 1: 500.000. It is shown that mean corrections can be estimated even for gauge sites with missing input variables, such as wind speed, temperature and the fraction of snow in the total precipitation. These variables can be estimated and corrections computed by analogy and regionalisation procedures. This allows for isolines of corrections to be drawn over a territory of the whole country and to correct mean annual precipitation for the Swiss precipitation map.

Recording gauges

Sevruk, B.: Adjustment of tipping-bucket precipitation gauge measurements. Atmos. Research., 42(1-4), 237-246, 1996.

The tipping-bucket gauge shows 14 % less precipitation than the Hellmann gauge at the Airport of Geneva. The differences depend on wind speed and intensity of precipitation. The prediction model as based on 576 daily values of the period 1980-1985 shows that the relationship is not linear and that the intensity plays a special role. There is a threshold value of intensity as related to the percentage difference of precipitation values for each interval of wind speed. This threshold value increases with increasing wind speed. Below the threshold value a sharp increase in percentage difference exists with decreasing intensity. Relationships of a similar nature have general application for correction of the wind-induced error of precipitation measurement or for adjustment of precipitation values from one gauge type to the other.

Chvila B., B. Sevruk and M. Ondras: The wind-induced loss of thunderstorm measurements. Atmos. Res., 77, 29-38, 2005.

Paired elevated and ground-level recording precipitation gauges of the electronic weighing type with a resolution of 0.01 mm per minute were tested during the three-year field experiments at two sites in Slovakia. The wind-induced loss, defined as the difference between the ground-level and the elevated gauge measurements, is related to the average wind speed and the average intensity of precipitation during a particular time interval. Two intervals of 15- and 60-minute of total number of 1611 and 736 precipitation events, respectively, were used in the analysis. The events are divided according to the type of clouds into two groups. The cumuliform cloud group is representative for heavy (convective) precipitation and the stratiform cloud group for all other types of (non-convective) precipitation. The results show a non-linear dependence of the wind-induced loss on intensity of precipitation and wind speed. The wind-induced losses are smaller for the convective precipitation as compared with the non-convective precipitation. There are also differences between the results for the two time intervals. The smaller interval shows larger wind-induced losses than the greater one. The results agree well with the previous findings of the authors and these obtained by the numerical simulation. Using a threshold value of precipitation intensity $i \leq 8$ mm h^{-1} instead of the cloud genesis to separate the non-convective precipitation from the convective one resulted in different wind-induced losses for the group of so defined "non-convective" precipitation. The wind-induced losses differ by up to ±15 %.

Wind tunnel experiments

Sevruk, B.: Comments on "Numerical models of the raingauge exposure problem, field experiments and an improved collector design" by C. K. Folland (Q. J. R. Meteorol. Soc., 114 (484), 1485-1586, 1988). Q. J. R. Meteorological Society, 116 (491), 239-242, 1990.

Some new wind tunnel data on the airflow over several types of precipitation gauge are presented. The new data are in much better agreement with those of Robinson and Rodda (1969) than with those of Green and Helliwell (1972) supporting Folland's preference for the former data. In addition, the new data provide support for Folland's assumption that the airflow over the 5-inch and Hellmann gauges are similar, though this appears to be more or less accidental.

Nespor, V., B. Sevruk, R. Spiess and J.-A. Hertig: Modelling of wind tunnel measurements of precipitation gauges. Atmosp. Envir., 28(11), 1945-1949, 1994.

Some aspects of wind-flow deformation around precipitation gauges are deals with. A number of wind tunnel measurements are analyzed with the aim of determining a gauge characteristic scale length and a suitable value for the reference velocity for normalizing of vertical velocity profiles, used for intercomparison of different precipitation gauges. For this purpose, the outer diameter of the gauge and the measured velocity value taken from a height of twice the outer diameter and divided by 1.0225 are recommended. The flow around the Mk2 gauge has been numerically simulated and intercomparisons with measurements show promising agreement.

Sevruk, B., J.-A. Hertig and R. Spiess: Wind field deformation above precipitation gauge orifices. In: J. W. Delleur (Editor): Atmospheric deposition. Internat. Assoc. Hydrol. Scie., No. 179, 65-70, 1989.

Seven types of precipitation gauges having various sizes and forms of orifice rim were investigated in a wind tunnel. The wind speed and intensity turbulence profiles above the gauge orifice confirmed that the orifice rim considerably affects the wind field deformation. The gauges with a large orifice rim or a bird protection ring showed the greatest increment of wind speed above the center of the orifice. The smaller the gauge orifice area, the greater was this effect. The intensity of turbulence was greater for gauges with a small orifice rim and a large orifice area.

Sevruk, B., J. A. Hertig and R. Spiess: The effect of a precipitation gauge orifice rim on the wind field deformation as investigated in a wind tunnel. Atm. Envir., Vol. 25 A, No. 7, 1173-1179, 1991.

(See above.)

Numerical simulation

Nespor V. and B. Sevruk: Estimation of wind-induced error of rainfall gauge measurements using a numerical simulation. J. Atmosp. Ocean. Techn., 16(4), 450-464, 1999.

A new method of estimating the wind-induced error of rainfall gauge measurements is presented. The method is based on a three-dimensional numerical simulation of the air-flow around a precipitation gauge and subsequent computation of particle trajectories. Three-dimensional velocity and turbulence flow fields around a gauge are computed for wind speeds ranging between 1 and 12 m/s by employing the k-epsilon turbulence model. Two-dimensional measurements of the flow using a constant temperature anemometer are carried out in a wind tunnel. The measurement results are used to verify numerical flow simulations. Subsequently, the computed flow fields are used for rain drop trajectory simulations, and assessment of wind-induced measurement errors related to a given unique drop diameter and wind speed. These errors are approximated by a gamma-type function and integrated over a gamma drop size distribution. The resulting wind-induced error is presented as a function of the rate of rainfall, wind speed, and drop size distribution parameter. The wind-induced measurement error is evaluated for three operational precipitation gauges. The results show an increase of the error with a decreasing rainfall rate, and increasing wind speed and fraction of smaller drops. The comparison of gauges also reveals differences. The computed wind-induced errors are compared with the errors derived from field rainfall measurements. The compared values show a relatively good agreement. See also :

Nespor, V: Investigation of wind-induced error of precipitation measurements using a three-dimensional numerical simulation. Swiss Federal Institute of Technology, ETH, Geography department, Zurich 1996. 117 pp. (http://e-collection.ethbib.ethz.ch/cgi-bin/show.pl?type=diss&nr=11060).

Sevruk, B. and V. Nespor: Empirical and theoretical assessment of the wind-induced error of rain measurement. Water Scie.Technol., 37(11), 171-178, 1998.

The computational fluid dynamics and the simulation of precipitation trajectories were applied to assess the wind-induced error of precipitation measurements using the Hellmann gauge. The results agree well with the empirical correction formula for the same gauge type derived from field data obtained from intercomparison measurements of paired Hellmann elevated and pit gauges in Les Avants (982 m a. s. l.), Switzerland. This means that correction procedures can be derived for any type of gauge using the theoretical approach instead of the empirical one. The computational and empirical results fit well a model which uses the intensity of rain as independent variable and produces a set of one parameter curves (wind speed) with increasing threshold value of intensity for increasing wind speed. Below the threshold values the wind-induced error increases quickly with decreasing intensity of precipitation, above it the increase is slow.

Sevruk, B., Y.-A. Roulet and V. Nespor: Corrections of the wind induced error of tipping-bucket precipitation gauges in Switzerland using numerical simulation. Instruments and Observing Methods Report, No. 74, WMO/TD No. 1028), 144-147, Geneva 2000.

The wind-induced error of hourly precipitation measurements of 64 gauge sites of the Swiss Automatic Network (ANETZ) from December to February 1996/97 amounted to 18 % of measured precipitation. The corrections vary considerably between gauge sites and regions. The smaller ones occur in the lower parts of Ticino and the larger ones in the Alps.

Chvila, B., M. Ondras and B. Sevruk: The wind-induced loss of precipitation measurement of small time intervals as recorded in the field. Instruments and Observing Methods Rep., No. 75, WMO/TD-No. 1123, Geneva 2002.

The wind-induced loss increases with wind speed and decreasing intensity of rain. The dependence is non-linear. Under a certain threshold value of intensity the increase is great and exponential. Above the threshold value is small and quasi-linear. The threshold value increases with wind speed. Derived empirical dependencies for small time intervals agree well with the results of numerical simulation and can be used to correct the wind-induced loss of recording precipitation gauges.

Wetting and evaporation

Sevruk, B.: Correction for wetting loss of Hellmann precipitation catch. Hydrol. Sci. Bull., 19 (4), 549-559, 1974.

As determined by laboratory and field tests the average wetting per rainfall event for galvanized funnels of Hellmann gauges was 0.15 mm compared to 0.31-0.40 mm for painted and lacquered funnels. The scratching of the inner surface of painted or lacquered gauge funnels causes an increase in wetting. After emptying the container, an average of 0.15 mm of water per event rests in the galvanized container as compared with 0.07 mm in the others containers. The total wetting losses of funnel and container were 2.8 % of rain catch for the galvanized gauge and 3.8 % for the painted and lacquered gauges. The differences in catch between the galvanized and the painted and lacquered gauges were smaller if wetting losses were accounted for. In the basin of Baye de Montreux the wetting losses over a period of ten years from April to September amounted to 3.1 % or 0. 35 mm per daily measurement of rain.

Sevruk, B.: Correction of monthly precipitation for wetting losses. In: Proc. WMO TECIMO/, July 8-12, 1985, Ottawa, Canada. Instruments and Observing Methods Rep., No. 22, 7-11, World Meteorol. Org., Geneva.1985.

The corrections for wetting of Hellmann gauges were computed as a product of the number of precipitation days and the average wetting per day, which was estimated experimentally at 0.30 mm. Based on this assumption the wetting correction in Switzerland varies from 2 to 7 %.

Sevruk, B.: Initial wetting losses incurred by ground level stereo-gauges. Water Resources Res., 9(3), 759-763, 1973.

The wetting of the gauge per event ranged from 0.135 mm for the gauge with a 15^{o}-inclined orifice to 0.205 mm with a 47^{o}-inclined orifice. The mean wetting correction of rain catch for 32 gauges distributed in the basin of Baye de Montreux over a 10-year period for June to September amounted to 0.172 mm per event, or to 2.6 % and varied only slightly in the respective years.

Sevruk, B.: Evaporation losses from containers of Hellmann precipitation gauges. Hydrol. Sci. Bull., 19 (2), 231-236, 1974.

The evaporation losses from the container of an old galvanized Hellmann gauge, 7.1 cm^2 orifice area were five times greater than the losses from the container of a new gauge, 1.8 cm^2 orifice area, of almost the same grey colour. The maximum evaporation from the old gauge amounted to 0.75 mm per day. The same evaporation losses in the Baye Montreux basin in Switzerland over a period of 10 years from April to September amounted to 0.09 mm per day or 0.7 %. There is a relationship between the monthly percentage evaporation losses in the April-September season and the ratio of evaporation time and rainfall duration.

Sevruk, B.: Comparison of evaporation losses from standard precipitation gauges. In: Proc. TECEMO/WMO, September 24-28, 1984, Noordwijkerhout. Instruments and Observing Methods Rep., No. 15, 57-61, World Meteorol. Org., Geneva 1984.

Evaporation losses from the container of standard precipitation gauges are in general small if the container is placed in a protecting can. They are difficult to estimate theoretically because of the complex configuration of the gauge but they can be computed using empirical formulae and graphical functions. A comparison of such indirect approaches for various types of standard precipitation gauges with a practical application in the Swiss national precipitation network is presented.

Sevruk, B.: Evaporation losses from storage gauges. In: Distribution of Precipitation in Mountainous Areas, WMO-Publ. 326(2), 96-102. Geneva 1972.

A review of literature is presented. The evaporation from the Swiss storage gauge can not be prohibited by an oil layer of 2 mm thick. Over a period of 10-years in the summer season this resulted in a loss of 6 %. Only by an oil layer of 5.5 mm no evaporation losses were detected in spite of the fairly warm weather.

Sevruk, B.: The effect of temperature on the precipitation measurement by means of storage gauges (in German). In: Veröffentlichungen der Schweizerischen Meteorologischen Zentralanstalt, Zürich, 30, 22-24, 1973.

The evaporation losses from the Swiss storage gauges and the change of volume of chloride solution in relation to the temperature showed that (i) an oil layer 3.5 mm thick cannot prevent evaporation and that (ii) by the applying the volumetric method of measurement ,the change of the solution level in dry periods can cause a further error of ± 10 %.

Sevruk B. and B. Chvila: Error sources of precipitation measurements using electronic weight systems. Atmos. Res., 77, 39-47, 2005.

Liquid precipitation amounts below 0.05 mm in combination with intervals of measurement greater than 3 minutes and temperature above 15°C can considerably affect the measured precipitation using electronic weighing gauges. This was shown by tests using different weights put in the gauge in different intervals in order to simulate different precipitation amounts and measuring intervals. These results were confirmed by field intercomparison measurements using pit gauges in two locations in Slovakia. In total, 1571 weight tests consisting of combinations of simulated precipitation amounts of 0.025, 0.05, 0.2 mm and measuring intervals of 1, 2, 3, 5 and 10 minutes were carried out. Based on these tests and special software a new gauge was developed. Using this gauge, the above mentioned error sources were minimized. The Slovak Hydrometeorological Institute now uses it at 90 gauge sites. This type of gauge was selected to participate in the current World Meteorological Organization, WMO, Intercomparison measurements of recording precipitation gauges.

Special gauges

Sevruk, B.: Precipitation measurements by means of storage gauges with stereo and horizontal orifices in the Baye de Montreux watershed. In: Distribution of Precipitation in Mountainous Areas, WMO-Publ. 326(2), 86-95, 1972, Geneva.

The measurements over a period of 19 years show that precipitation gauges with orifice parallel with the slope are better suited than horizontal orifices for measurements on steep open slopes exposed to rain-bearing winds. On such slopes such gauges collected twice as much precipitation as the gauges with the horizontal orifice in the basin of the Baye Montreux. In the wooded zones and sheltered locations the increase was small.

Sevruk, B.: Experiences with elevated and ground level stereo and tilted storage gauges in the basin of Baye de Montreux (in German). In: Veröffentlichungen der Schweizerischen Meteorologischen Zentralanstalt, Zürich, 30, 1-21, 1973. (See above).

Regional co-operation on rainfall data measurement, processing and analysis as a basis for water resources assessment and flood management

The Portuguese contribution

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December 1-2, 2005
Belgrade, Serbia and Montenegro

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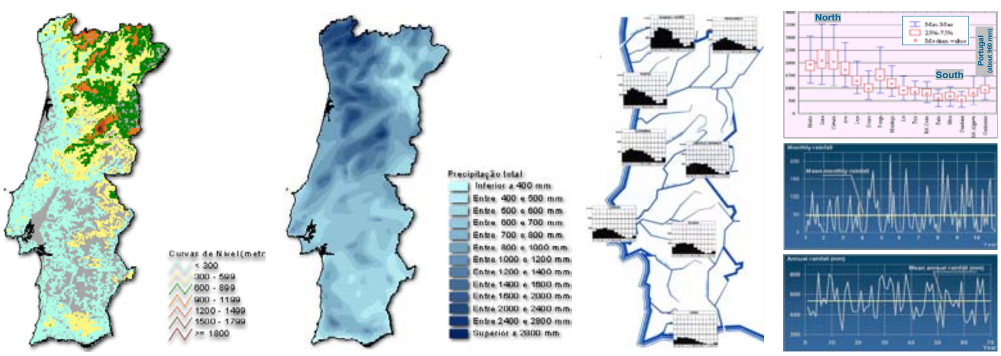
1. Introduction. The rainfall regime in Portugal mainland

Portugal (mainland) is a very small southwestern European country with a shape almost rectangular and with about 89 000 km² (maximum length of ca. 560 km and maximum width of ca. 218 km).

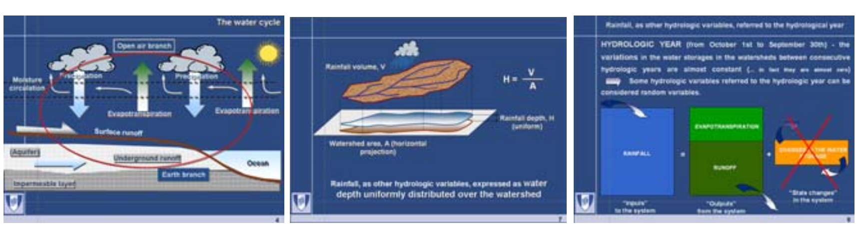
Portugal. General location.

The rainfall is one of the most important components of the water cycle and, for Portugal, far beyond the main factor of the hydrologic characteristics of the country. In fact, due to the shape and relief of the region most of the watersheds have relatively small areas. At the same time, the Portuguese groundwater resources are poor. As result, the response of the watersheds in terms of surface waters follows closely the rainfall regime, that regime being highly irregular either in space or in time.



Correspondence between relief and mean annual rainfall. General characteristics of the rainfall regime.

The mean annual rainfall in some Portuguese Northern regions can reach 2000 mm in average (with extreme annual values of more than 3500 mm) while other regions, located especially in the South, have less than 550 mm per year. The irregular spatial distribution of the rainfall is strictly connected with the landforms: high hills cover the northern third of Portugal, including an extension of the Cantabrian Mountains from Spain. The mainland's highest point is a peak in Serra da Estrela, at 1991m. Further south and west, the land slopes to rolling hills and lowlands, and to a broad coastal plain.



The water cycle. Hydrologic variable expressed as water depths. The hydrologic year.

Please notice that, in Portugal, the hydrologic variables are generally expressed as water depth uniformly distributed over the horizontal projection of the watershed area and that their annual values are referred to the hydrologic year that begins October 1st. The hydrologic year is such that the water storage in a watershed between consecutive hydrologic years is almost constant (... in fact it is almost zero) which allows treating the annual values of the hydrologic variables as random variables, by means of statistical methods.

Along the year the rainfall regime has a very pronounced seasonal behaviour: in average, from 70% to 85% of the annual rainfall occurs during the wet semester (from October to March) and the rest during the dry semester (from April to September). The mean annual rainfall over the country reaches about 960 mm and the corresponding surface runoff about 385 mm.

2. Rain gage networks

2.1 – General features

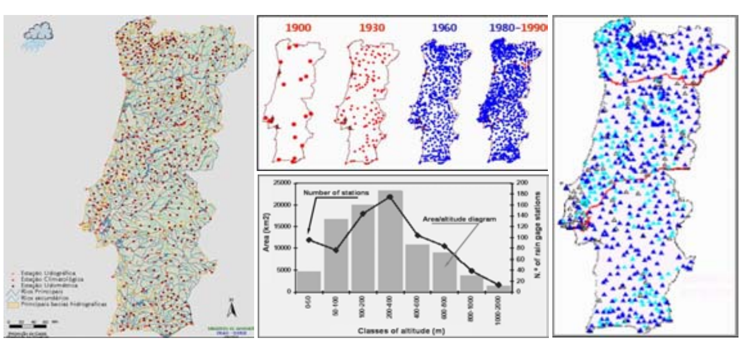
To begin with, it should be stressed that the rainfall data acquisition in Portugal it is strictly carried out by specific public entities (mainly the Portuguese Water Institute and the Portuguese Meteorological Institute) and therefore it is not within the intervention sphere of the University. So, all the aspects presented herein are mentioned in the perspective of an intensive "user" of the hydrologic data, that is to say, in the perspective of an expert who needs to have a consistent idea about the available records (kind, quantity and quality) in order to adjust the hydrologic models to those records.

The present Portuguese meteorological network comprehends two types of stations: those stations where only rainfall data is acquired and those also measuring other climatic variables such as temperature, air humidity, wind velocity, solar radiation, and so on.

The Portuguese network of rain gages was conceived and improved along the years in order:

- To allow the characterization of the spatial and temporal variability of the rainfall, even at the microclimate scale.
- To allow the hydrologic modelling, including the evaluation of the water resources based on hydrologic budgets.
- To check for changes or trends in the samples.
- To access the hydrologic phenomenon, for instances having in view flood vigilance and alert systems or the integrated management of reservoirs.

The rain gage network comprehends more than 870 measuring points, though presently including about 130 non-operational rain gages (deactivated, suspended, extinct …) some of them having however past records and even long samples of past records. From the operational rain gages, a little bit more than 610 belong to the Portuguese Water Institute (*Instituto da Água),* INAG, 100 to the Portuguese Meteorological Institute (*Instituto Meteorológico)*, IM, and the rest to the national energy production entity (Electricity of Portugal). Nowadays, most of the stations from the Water Institute, INAG, and from the Meteorological Institute, IM, have or are about to have automatic data acquisition and storage systems. The rain gage density is, in average, of about one station per 125 km^2, though some parts of the country (mainly in the south) are not as well equipped as others.



Portuguese rain gage network: evolution, distribution by altitude and length of the samples
(after the National Water Plan).

Due to the irregularity of the rainfall regime but also to a strong tradition in the construction of hydraulic systems, the Portuguese administration soon felt the necessity of understanding the behaviour of the hydrologic regime. But to understand it is necessary to measure, and, in fact, the first systematic measurements of the rainfall took place in the 19^{th} century. The first reinforcement of the number of measuring points occurred in the decade of 1930 and the second reinforcement in the decade of 1960, in connection with the development of the country in terms of irrigation projects and of hydropower plants, respectively.

The rain gages were located in order to ensure more measuring points in the most representative areas of the country, thus resulting in a distribution of the number of rain gages by altitude close to the distribution of areas also by altitude, as shown in the slide.

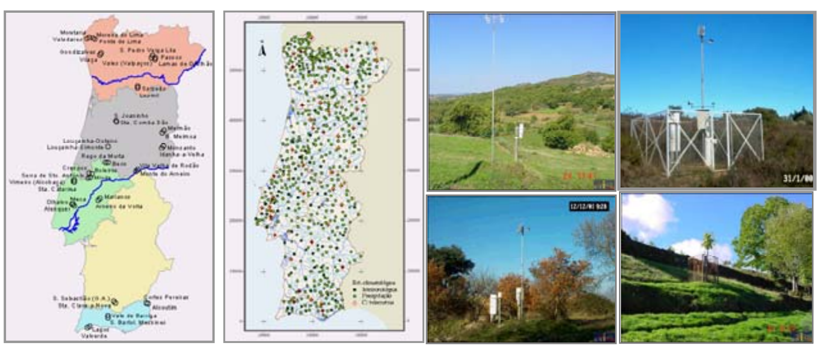
It should be stressed that much more than 50% of the rain gages has more than 30 years of measurements, at least in what concerns the annual rainfalls. Among those stations, quite a considerable number has more than 70 years of records. In the slide some of the traditional rainfall measuring equipment utilized either in Portugal or in other countries is shown.

2.2 – The network of rain gages from the Water Institute. The SNIRH database: overview

Since more or less 2000 the rain gages owned and explored by the Water Institute were re-organized in order to improve the quantity and the quality of the measurements. The re-organization comprehended aspects such as:

- The installation of automatic data acquisition and storage systems and, in those stations belonging to the National Water Resources Vigilance and Alert System (related with flood and drought monitoring), also of telemetry systems.
- Wind velocity and direction data acquisition in order to establish correction factors for the rain measurements.
- De-activation of those rain gage stations with records with poor quality or representing redundant information.
- Implementation of new rain gage stations in those areas with insufficient information, in connection, for instances, with real time forecasting systems or in key-points in terms of water resources management.

The improved rain gage network from the Water Institute and some photos of the rain gage stations are presented in the slides.



Re-organization of the rain gage network owned and explored by the Water Institute. Stations with redundant information, improved network and photos of automatic rain gages
(after SNIRH).

But one of the most relevant characteristics of the rain gage network from the Water Institute, INAG, is that all the measurements are of public domain and can be obtained by Internet through the so called Water Resources Information National Service (*Serviço Nacional de Informação de Recursos Hídricos)*, SNIRH. The records acquired by the Meteorological Institute are not directly accessible.

SNIRH is a public database of the records of the several types of variables (including hydrologic variables) measured in the networks owned and explored by the Water Institute or by its regional agencies. It should be stressed that, besides the rain gage network, the Water Institute is in charge for several other data acquisition networks related with river flow, water quality (surface, underground and coastal waters), springs, piezometry, reservoir levels and sediment production measurements. Some of the stations also provide real-time information. In the slide the main screen of SNIRH is displayed.

The SNIRH database operates in a user-friendly basis. Firstly the operator must choose (by name or interactively, based on a map) the main watershed in which the measuring point is located (in the SNIRH the information was grouped into 16 main watersheds). The networks available in the selected main watershed are next displayed: meteorological, hydrometric, quality, dams and reservoirs, sediment, ground water, and so on. Once a network is identified, a specific station or measuring point needs to be provided to the system (by name or code or interactively, based on a map). The available measurements for that station are next presented, organised in tables that can be directly exported to an Excel file. In what concerns the rainfall, the available data comprehend records of annual, monthly and daily rainfalls, as well as of annual maximum daily rainfalls. This last kind of records relates to the maximum rainfall amount in 24 h in each year (one record per year) and it is crucial for flood analysis.

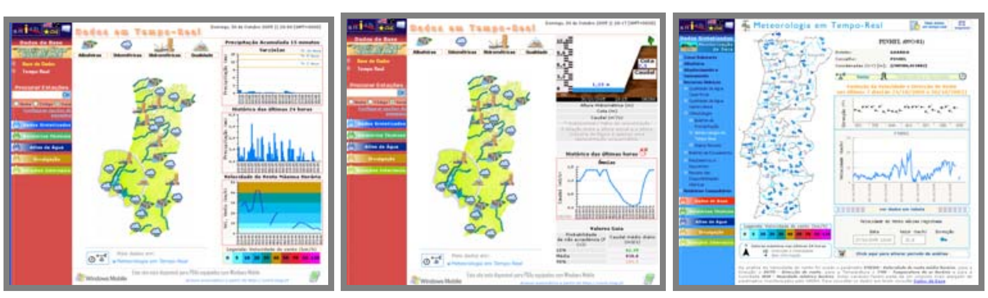
SNIRH database (after SNIRH).

If the rain gage belongs to the automatic network and has more records the systems provides that information. In this case, additional records of hourly precipitation as well as wind parameters are displayed.

Each automatic station comprehends a data storage device and sensors and it is fed by solar energy. Only weekly or monthly maintenance (for cleaning, calibration and data retrieval) is required.

The automatic meteorological network can be chosen ahead (the difference, in terms of records, between a traditional rain gage and an automatic one is that the latter provides more information, related with hourly rainfall values and with wind characteristics, as previously mentioned). In a short time all the rain gages will become automatic as the replacement of the traditional equipment is going on.

But the SNIRH also provides real-time information though, for the time being, only the records from a few stations are of public domain. Those records include measurements of rainfall, river discharge, level, storage and discharge at reservoirs and water quality parameters, as exemplified in the slides.



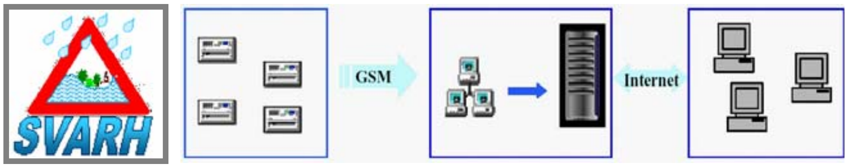
SNIRH database: real-time information. Examples: rain, discharge and wind measurements (after SNIRH).

2.3 – The network of rain gages from the Water Institute. The SVARH system: overview

The Water Institute, INAG, is also in charge by the so-called Water Resources Vigilance and Alert System, the SVARH (*Sistema de Vigilância e Alerta de Recursos Hídricos*). The SVARH is a flood risk management tool restricted to authorise users, namely to those services that are supposed to get involved under flood occurrences, such as the Civil Protection Service and the fire corporations.

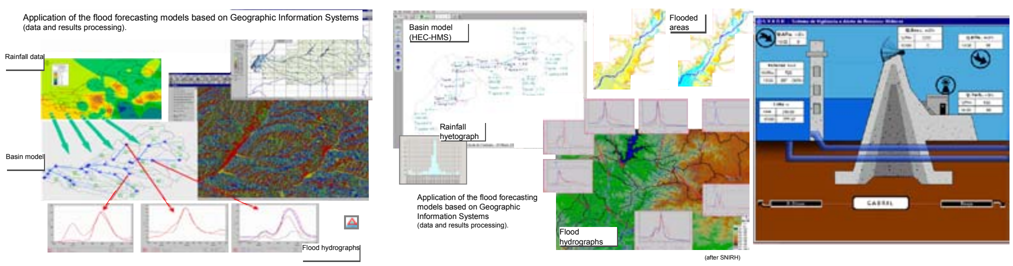
It should be stressed that floods are a pertinent issue that affects a great number of the Portuguese major cities, as shown in the slide.

Conceptually the SVARH is built upon three main components: a data acquisition system, a centralised data processing system and an information/transmission system. The communications among components are performed by GMS and Internet.



The SVARH (Water Resources Vigilance and Alert System) (after SNIRH).

The flood characterization is accomplished by means of hydrologic and hydraulic models based on real-time rainfall data and also on rainfall forecasts from the Meteorological Institute. The hydrologic model provides the flood hydrographs due to rainfall events and also performs the flood wave routing along river reaches or reservoirs, in this last case, in connection with the operation rules of the spillway gates. The hydraulic model provides the water surface profile and the flow characteristics (like velocity or water depth) along the channels. Based on the water surface profile maps of the flooded areas can be produced.



The SVARH system and the *Rios* interface (after SNIRH).

The main hydrologic model of the SVARH system is the HEC-HMS (Hydrologic Modelling System) and the main hydraulic model the HEC-RAS (River Analysis System). Both models were developed by the Hydrologic Engineering Center of the US Army Corps of Engineers and are wide used across the world.

Besides the rainfall data, the HEC-HMS model requires parameters related with the features of the watersheds, the baseflow, the rainfall losses, the type of soil and the antecedent moisture conditions (these last two generally expressed by means of the Curve Number, CN) and with the flow routing technique. One of its main tools is a rainfall-runoff model, generally of the unit-hydrograph type. The HEC-RAS model requires the geometric data for the main channel, for the riverbanks and for other structures that interfere with the flow (like bridges, weirs, lateral ponds, embankments, and so on), the hydraulic parameters related with the friction slopes and with the head losses at contractions and expansions and the boundary conditions. A Geographic Information System, GIS, supports the application of the HEC-HMS and HEC-RAS models.

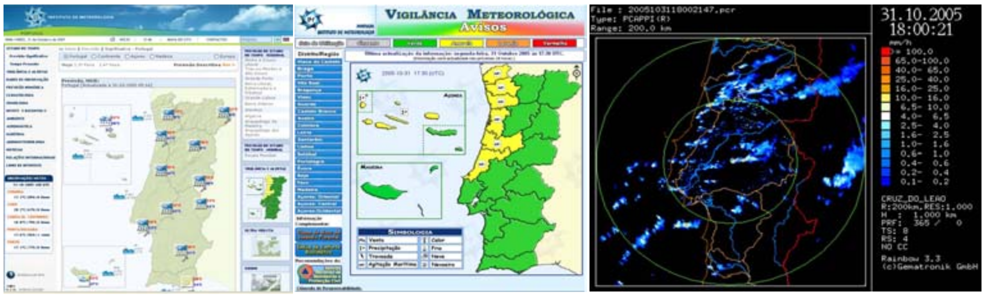
The users communicate with the SVARH through a specific application or interface called *Rios* (Rivers) that organizes and displays the simulated results in easy understandable screens. The information provided involves water level and discharge either along a river or a reservoir, as exemplified in the slides.

2.4 – The network of climatic stations from the Portuguese Meteorological Institute: overview

Along with the networks from the Water Institute, INAG, there is another relevant meteorological network, owned and explored by the Portuguese Meteorological Institute, IM. Besides other competencies the Meteorological Institute is the national authority in the meteorological, climate and geophysics domains. All the official weather forecasts are of its responsibility. The Meteorological Institute is also the entity responsible for producing meteorological alerts, related with extreme occurrences, such as strong winds, heavy rainfalls, thunder storms, extreme high or low temperatures, snow, etc.

As mentioned before, the measurements accomplished by Meteorological Institute are not public though they can be bought or acquired within especial collaboration agreements. Besides its own meteorological stations (in which all the relevant variables related with the climate are measured), the Meteorological Institute, IM, explores to only radar that, for the time being, provides information related with the weather: the Coruche radar.

The Coruche radar is located nearby Lisbon and has a range of 200 km, which covers the south, the central and part of the north regions of Portugal.



The Portuguese Meteorological Institute (after IM).

3. Pre-processing the rainfall data

3.1 – Quality of the rainfall measurements

After the previous short presentation about the availability of rainfall data in Portugal, aspects related with the pre-processing of the measurements, namely with the assessment of the quality of the records and with the evaluation of the missing values and of the areal rainfall will be next referred. In item 4, two hydrologic applications of the rainfall data will be briefly mentioned.

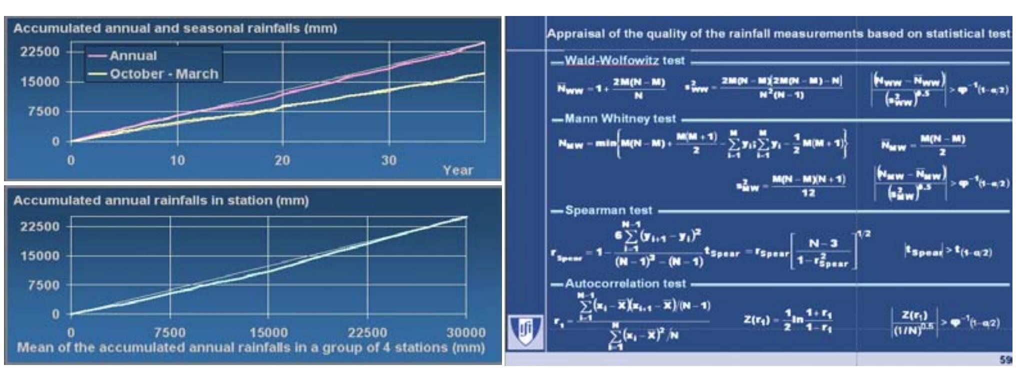
The availability – in quantity and quality - of rainfall data is often a crucial issue for the hydrologic modelling.

However prior to the application of a hydrologic model it is necessary to ensure that the quality of the samples is good enough. There are several procedures to assess the quality of the rainfall data samples, namely in terms of their homogeneity. The non-homogeneities can be caused by occasional changes of exposure or location of the rain gages or changes of the procedure in collecting and processing data. However, persistent changes may also occur due to more intrinsic factors, like the climate change phenomenon.

Two of the simplest ways to check the homogeneity of a rainfall data sample are the single-mass and the double-mass tests. In the former test the accumulated annual or seasonal values of the rainfall are plotted as a function of the time while in the latter test those values are represented as a function either of the accumulated values in a nearby reliable station or of the averages of the accumulated values in a group of nearby reliable stations. If, in any test, the plotted points do not deviate from a straight line the records are considered to be homogenous and, therefore, to have good enough quality. But sometimes the results of those tests are not straightforward, as occasional and brief changes in the slopes may not necessarily denote non-homogeneities.

An alternative way to assess the quality of the samples – and not only in terms of their homogeneity – utilizes the application of statistical tests, such as the Wald-Wolfowitz test (global homogeneity test), the Mann-Whitney test (homogeneity test for the average), the equivalent homogeneity test for the standard deviation, the Spearman test and the autocorrelation test (both tests for randomness), among others.

The presence of persistent trends in the samples is also a non-homogeneity though with a particular meaning as further discussed.



Homogeneity tests: simple and double--mass test and statistical approach.

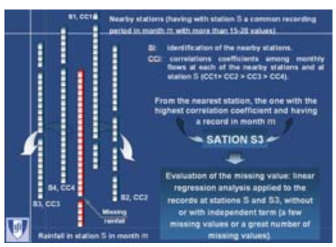
3.2 – Estimation of missing rainfall records

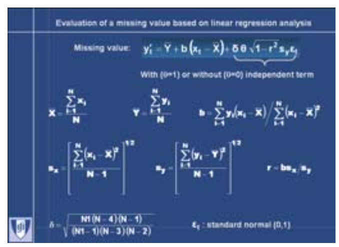
Another important issue in preparing the rainfall data for analysis concerns the missing values. Generally, the missing values are estimated by any kind of interpolation based on the existing records at nearby stations, as proposed by the World Meteorological Organization, WMO. One of the most common procedures assumes that a missing value can be evaluated as a weighted sum of the rainfall measured at three nearby stations. Each weighting factor is given by the ratio between the mean annual rainfall at the station with a missing value and the mean annual rainfall at one of the nearby stations, as shown in the slide.

Recently (around 1998-2001) a procedure based on linear regression analysis was implemented in a GIS environment and extensively applied to almost all the Portuguese rain gage stations in order to fulfil the missing monthly rainfalls.

Let *S* denote a rain gage station with a missing record in month *m*. The procedure identifies the stations nearby station *S* and, for each of these stations, computes the correlation coefficient among the rainfalls records in month *m* at that station and at station *S*. Only the nearby stations having a common recording period with station *S* with more than 15-20 values are considered. The nearby stations are next ordered by decreasing correlation coefficients. The nearby station with the highest correlation coefficient and having the rainfall record in month *m* is then selected. The missing value is finally computed by means of linear regression analysis applied to the rainfall samples in month *m* at this station and at the station with a missing value.

Two alternative ways of performing the regression analysis can be considered: with or without an random term, as shown in the slide. If only a few missing values need to be evaluated the regression analysis should be accomplished without random term. Otherwise, if there are several missing values or if the purpose is to extend the rainfall sample a random term should be considered in order to avoid the decrease of the variability of the fulfilled or extended series.





Evaluation of missing values.

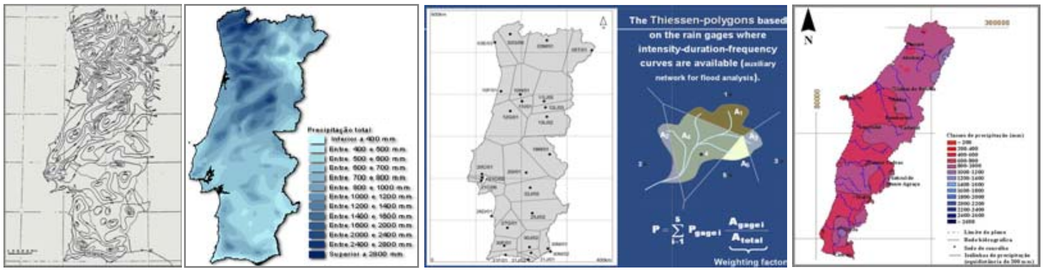
3.3 – Computation of areal average rainfall

The most common methods to compute the areal average rainfall in Portuguese watersheds are the isohyetal method and the polygon method or Thiessen-polygon method.

The isohyetals are contour lines of the rainfall surface obtained by interpolation based on the rainfall records at the rain gages. The first isohyetal map of the mean annual rainfall for Portugal mainland appeared in the decade of 1960 and it is still on use though with a different aspect (slide). In this method the rainfall in a given area is computed taking into account the areas encompassed between consecutive isohyetals. The isohyetal method allows the analyst to adjust manually the contour lines taking into account additional factors that may affect the rainfall pattern, such as the relief, the proximity to the sea or the hillside orientation. Therefore, an isohyetal map also reflects the analyst expertise, which makes the method more accurate. However, in comparison with the polygon method, the isohyetal method is much more laborious as based on a given set of measuring points there is not a unique isohyetal map as the contour lines depend upon the rainfalls measured in those points.

In the Thiessen-polygon method the rainfall in the vicinity of each rain gage station is considered to be equal to the rainfall measured in that station. The area in the vicinity of each station is such that each point of that area is closer to the station than to any another station. In mathematical terms the Thiessen-polygons coincide with the Voronoi polygons. The portion of the watershed area in the vicinity of each station defines the weighting factor for that station. The average areal rainfall is given by the sum of the products of the weight of each station by the rainfall in that station. The Thiessen method is quite expeditious as the polygons defined based on a given set of measuring points are unique, despite the different amounts of rainfall in the presence.

The recent development of Geographic Information Systems, GIS, enabled the drawing of the isohyetals as well as the rainfall areal averaging based on several automatic procedures. Among the simplest averaging methods is the Inverse Distance Weighting Method, IDW, which was extensively applied to the rainfall mapping in Portugal. However, in most applications of GIS, especial attention need to be paid to the automatic methods as sometimes the results from a given mathematical procedure, though being agreeable may not be the more accurate ones. In fact, some interpolation techniques introduce smoothing factors that result in regular and smooth isohyetals or smooth rainfall variations that are no longer in accordance with the real pattern of the rainfall.



Computation of areal average rainfall.

4 – Some applications of the hydrologic models

4.1 – Flood analysis

The flood analysis is one of the most common issues in the hydrologic modelling and it is quite a relevant subject in Portugal as the country is particularly prone to floods, including to flash floods.

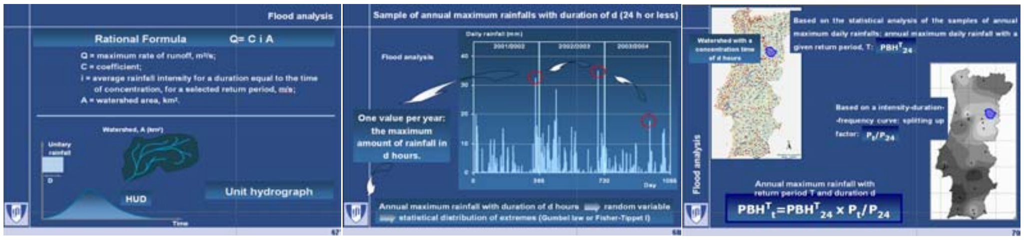
Generally, the flood analysis utilizes two main approaches based on flow data or on rainfall data. Only this last approach will be briefly mentioned herein.

The flood analysis based on rainfall data utilizes a rainfall-runoff model. One of the simplest models is the rational formula, presented in the slide. Another method, not as simple as the previous one, but more accurate, utilizes unit hydrographs either established for the watershed under consideration or of the synthetic type. It should be stressed that while the rational formula assumes a rainfall with uniform intensity and with duration equal to the time of concentration of the watershed, the unit hydrograph technique allows either non-uniform rainfall intensity or duration different from the time of concentration.

Both models require estimates, based on statistical analysis, of intensive short duration rainfalls. For that purpose measurements of annual maximum rainfalls with durations from a few minutes to 24 h also need to be acquired by the rain gage network. A sample of the annual maximum rainfalls with a given duration is composed by one value per year that value being equal to the maximum amount of rainfall with that duration. It is therefore a sample of a random variable that can be analyzed by means of statistical methods, generally based on a statistical distribution of extremes like Gumbel law (Fisher-Tippet type I law).

However, prior to the recent installation of automatic rain gages only a few gages provided rainfall measurements with durations shorter than 24 h while quite a considerable number of rain gages had values of annual maximum daily rainfalls. Due to this fact, several methodologies were developed to evaluate the annual maximum rainfall with a given duration by combining the values of the annual maximum daily rainfalls (provided by most of the rain gages) with the intensity-duration-frequency curves established for the few rain gages having records of short duration rainfalls. An intensity-duration-frequency curve relates the intensity of the rainfall with a given return period with its duration.

In fact, several studies, from 1970 on, showed that the spatial variation of the ratio between two intensive rainfalls with the same return period, one with a duration shorter than 24 h and other with the duration of 24 h, is very regular and smooth, as exemplified in the slide. Therefore the annual maximum rainfall with a given return period and a given duration in a watershed can be computed by splitting up the maximum annual daily rainfall in that watershed. The splitting up factor can be established based on the intensity-duration-frequency curve available for a rain gage as close as possible of the watershed under analysis. According to this methodology, that proved to be accurate enough for Portugal mainland, measurements of the rainfall for durations shorter than 24 h are only required in a few rain gages, provided the records of annual maximum daily rainfalls are available at a great number of rain gages. For instances, in Portugal and for the time being, only 27 rain gages (represented by the dots shown in the right hand figure of the slide) have intensity-duration-frequency curves while a few hundreds have annual maximum daily rainfalls.

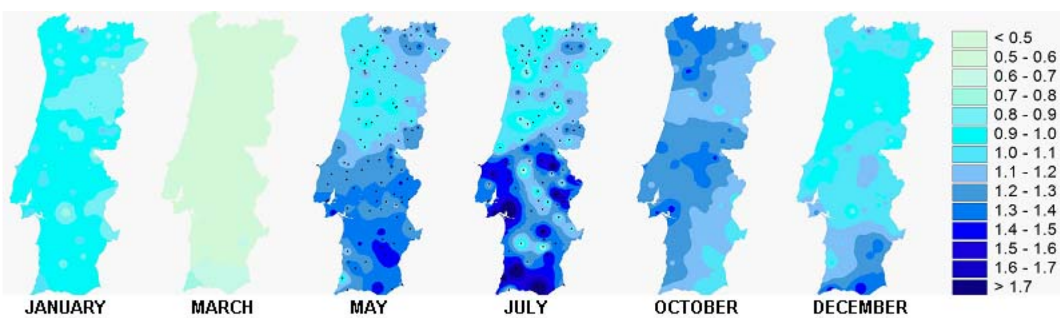


Flood analysis.

4.2 – Trends in the rainfall samples

An important issue that requires availability of rainfall samples is related with the search of trends in the series. As in Portugal there is a considerable number of rainfall samples with more than 70 values and even with more than 100 values, several studies have be accomplished having in view the recognition of trends and their analysis under a climate change scenario.

Trends, due to a natural cause or not, are non-homogeneities and therefore their recognition can be based on the tests applicable to identify other types of non-homogeneities. In some of the studies carried out for Portugal the Student test and the Mann-Whitney test were applied. Those studies proved that many of the rainfall values (especially in the inner and southern regions of Portugal) exhibit decreasing tendencies that, however, may differ along the different months of the year. The more significant decreases occur in March: in fact, in the last decades the rainfall in March is progressively decreasing its values being less than 40% of the values at the beginning of the 20th century. A more irregular distribution of the rainfall along the year is also pointed by some authors as well as an amplifying tendency for the extreme values. This tendency may result in more recurrent floods and droughts. Additional studies are being developed in order to evaluate the effect of the tendencies exhibit by the rainfall series, but also by the runoff series, in the exploitation of the water resources systems, especially of those systems with reservoirs for irrigation purposes.



Trends in the long rainfall samples: dimensionless ratios.

5 – Final remarks

The hydrological modelling is a very pertinent issue as it supports almost all of the studies related with the water resources management and planning and not only in what concerns the mankind needs but special from the point of view of the ecosystem Earth. Water will be the oil of the future.

But to make the "best use" of the water it is necessary to characterize it in terms of quantity and quality and for that it is crucial to measure it, either directly or indirectly. As stated by several authors a model can not describe a phenomenon with accuracy greater than the capacity to measure it. Also a model needs to be verifiable: it is necessary to know whether it is valid or not and its validity limits. For this purpose its results need to be compared with observed values.

In the "water puzzle" the rainfall is perhaps the most important piece as it is the main input of the system. It is also relatively simple and low-cost to measure the rainfall, at least when compared with the measurements of other hydrologic variables, such as river flow discharges.

It may not matter how detailed and complex a hydrologic model can be: without rainfall measurements or, in a broad sense, without the measurements of the pertinent hydrologic variables, its results will be doubtful or even non-supportable expectations.

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New developments in rainfall measurement and forecasting

Thomas Einfalt
einfalt&hydrotec GbR, Luebeck

Overview

- Introduction: who am I?
- What are radar measurements?
- Radar data vs. raingauge data
- Rainfall data quality control
- Rainfall forecasting
- Hydrological applications
  - Do you need radar data?
  - Examples
- Conclusions

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Who am I ?

- Name: Thomas Einfalt
- Working with radar data: since 1983
- Academic education:
  - Mathematician (Hannover University)
  - Ph.D. in Environmental Sc. & Tech. (ENPC, Paris)
- Initiator of GUR (IWA working group on Urban Rainfall), first chairman (1996-2002) and currently its secretary
- Creation of einfalt&hydrotec GbR in 1999
- Work fields: radar, raingauge data, hydrological models
- Hobbies: …

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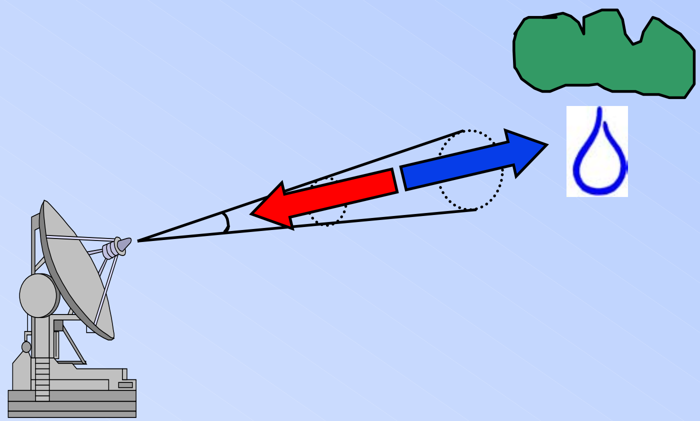
What are radar measurements?

Indirect measurement: reflectivity



What are radar measurements?

Reflectivity factor Z

$$Z = \int n(D) D^6 dD \quad \left[\frac{mm^6}{m^3}\right]$$

1 drop with D = 1 mm => Z = 1

1.000.000 drops with D = 0,1 mm => Z = 1

Rainfall intensity R

$$R = \int n(D) v(D) D^3 dD \quad \left[\frac{mm}{h}\right]$$

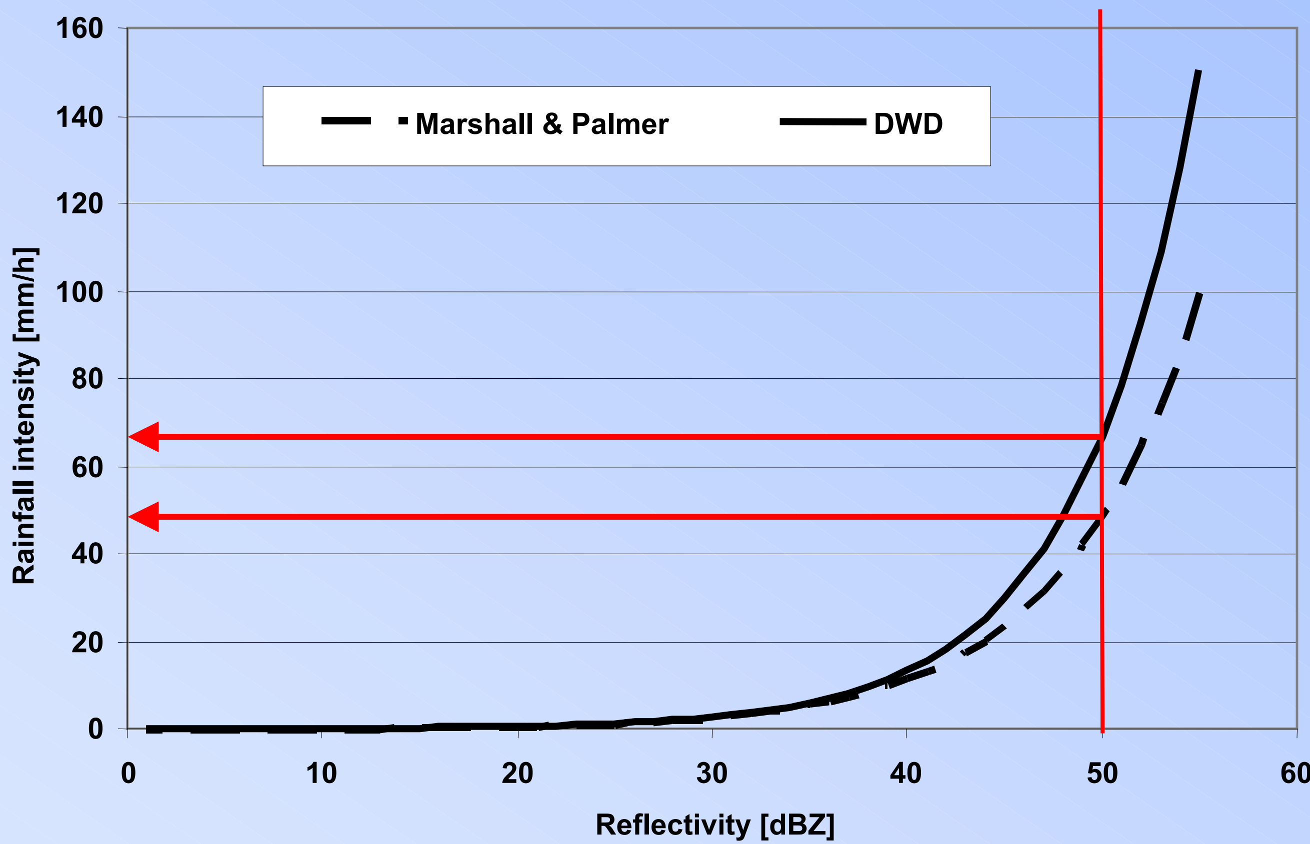
=> no direct relationship between Z and R

What are radar measurements?

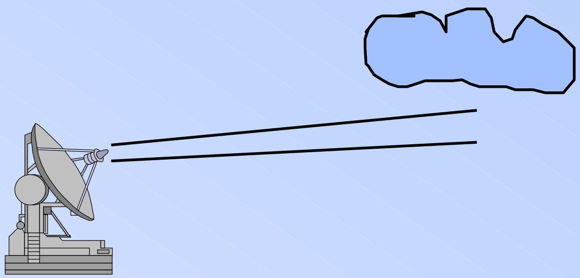
Variables:

Z	reflectivity factor
D	drop diameter
n (D)	number of drops inside a defined diameter (drop size distribution)
R	rainfall intensity
v (D)	fall speed of the drops (terminal speed)

What are radar measurements?



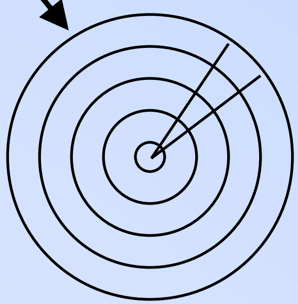
What are radar measurements?



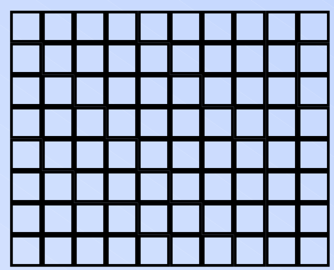
Measurement of rain drops

Reception of the reflection
of the impulse sent out

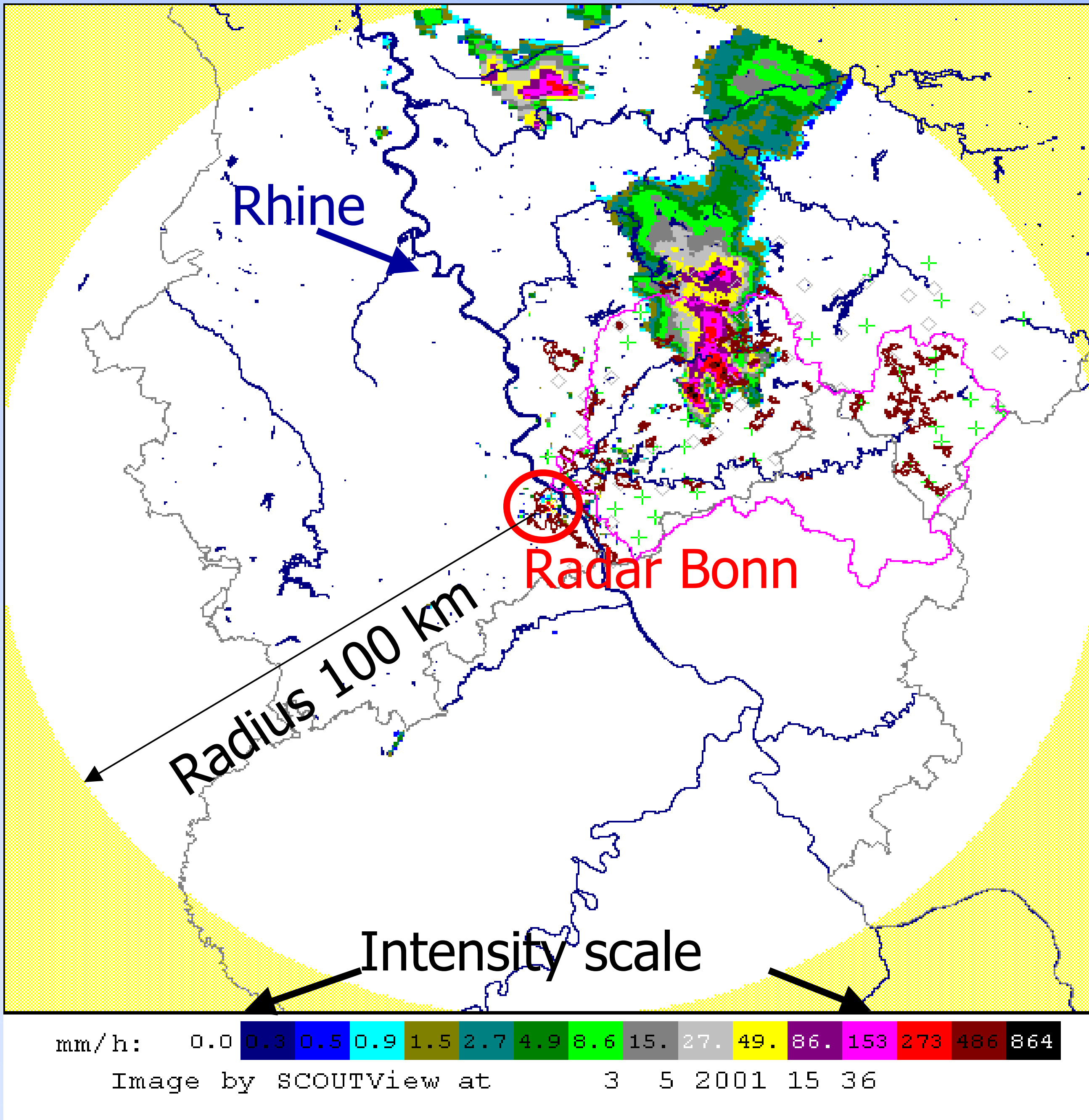
Radar image
in polar coordinates
- continuous values



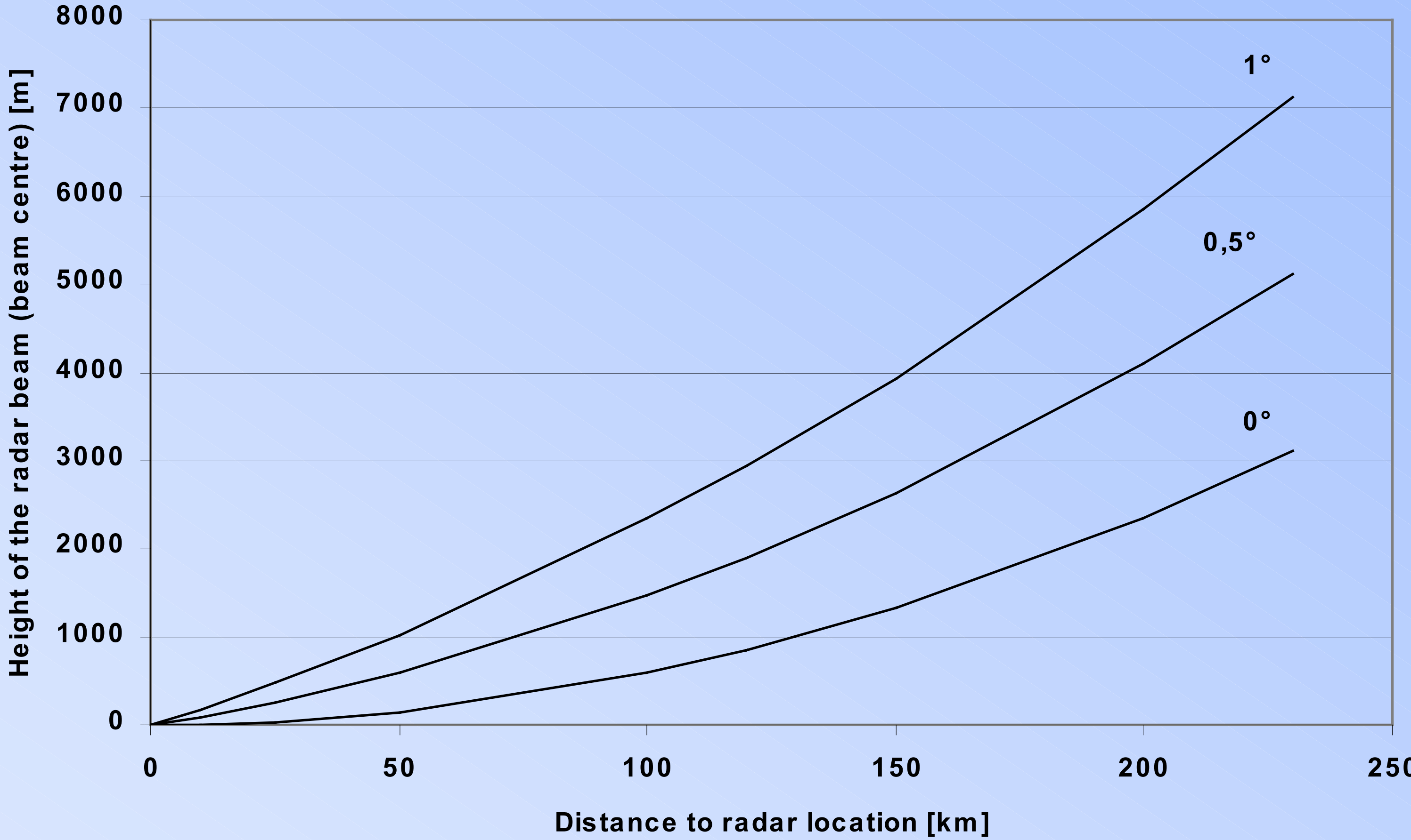
Transformation



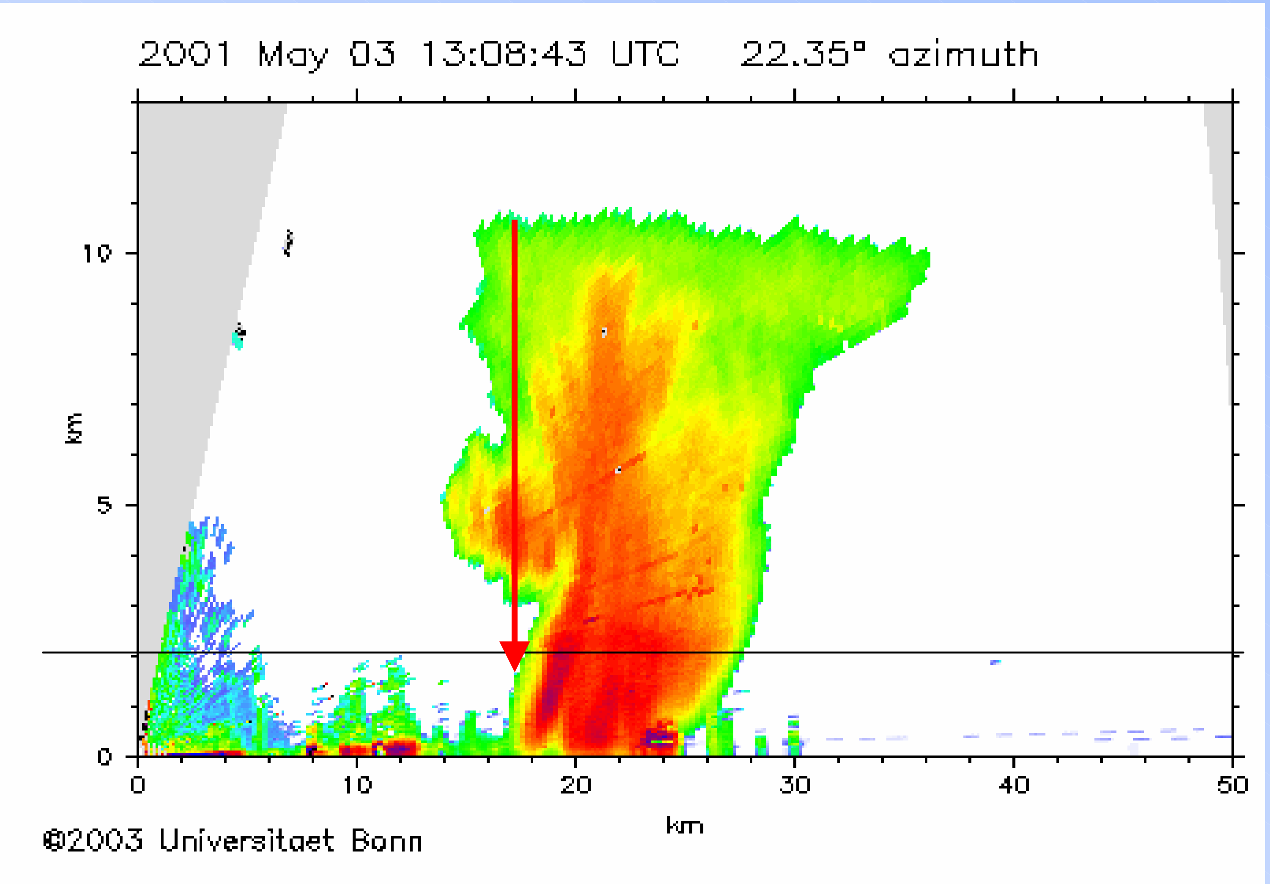
Radar products, e.g.
in cartesian coordinates
- values in 256 classes


Rhine
Radar Bonn
Radius 100 km
Intensity scale
mm/h: 0.0 0.3 0.5 0.9 1.5 2.7 4.9 8.6 15. 27. 49. 86. 153 273 486 864
Image by SCOUTView at 3 5 2001 15 36

What are radar measurements?
Beam elevation scheme



Vertical profile of X-Band Radar Bonn



What are radar measurements?

- High spatial resolution (approx. 1 measurement per km²)
- Temporal resolution usually 5 minutes
- High spatial coverage (up to 40 000 km² per radar site hydrologically usable)
- Forecasting possibilities

- Indirect measurement
- Different error sources than for raingauges
- Additional specific knowledge required for data use

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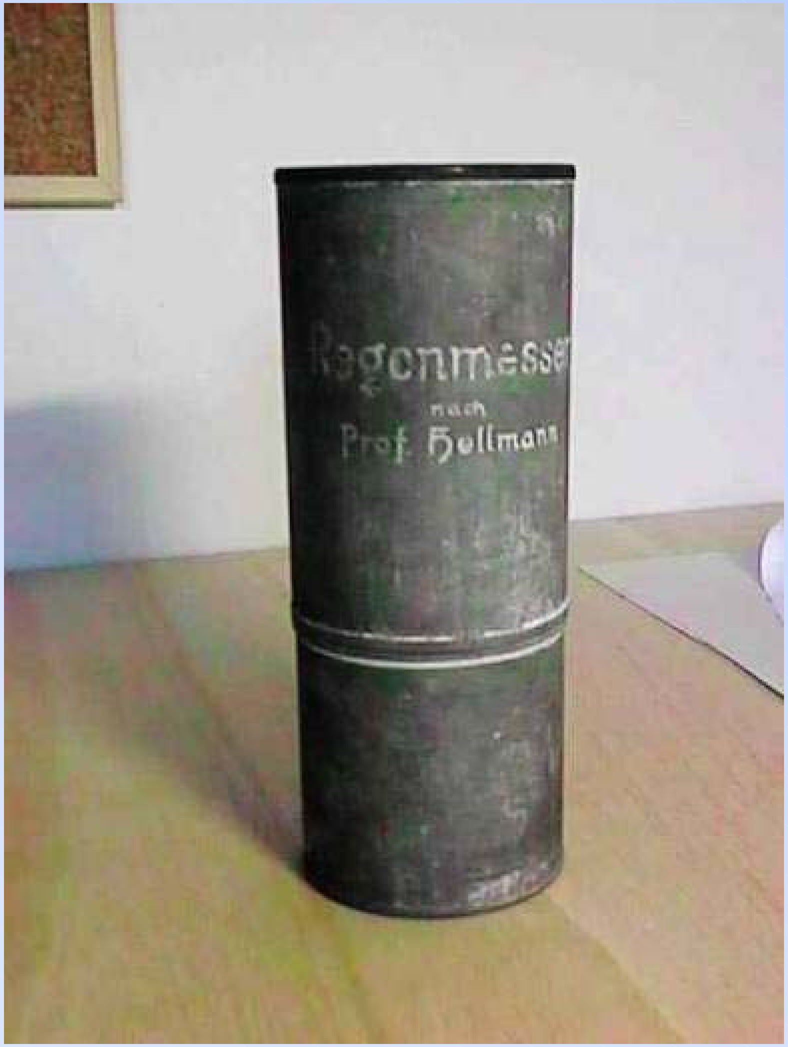
Radar data vs. raingauge data



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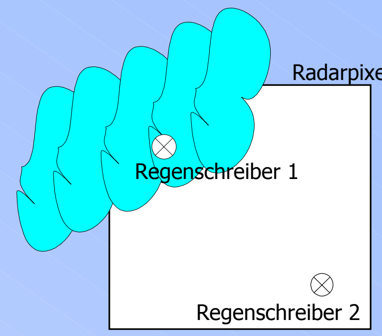
Radar data vs. raingauge data

Radar and Raingauge are measuring differently:

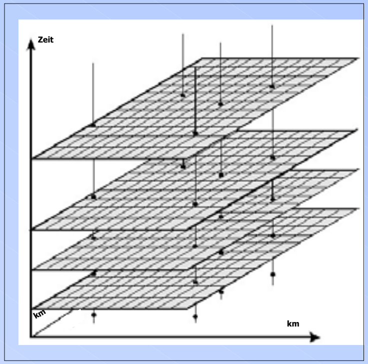
- radar is measuring a volume, raingauges at a point



- radar is measuring up in the air, raingauges on the ground
  - ➔ Causing temporal discrepancies (time of the drops to reach the ground)
  - ➔ Causing spatial differences (drift of the drops when falling)
  - ➔ Causing volumetric differences (evaporation of drops)

- radar is measuring reflectivities, raingauges rainfall volumes

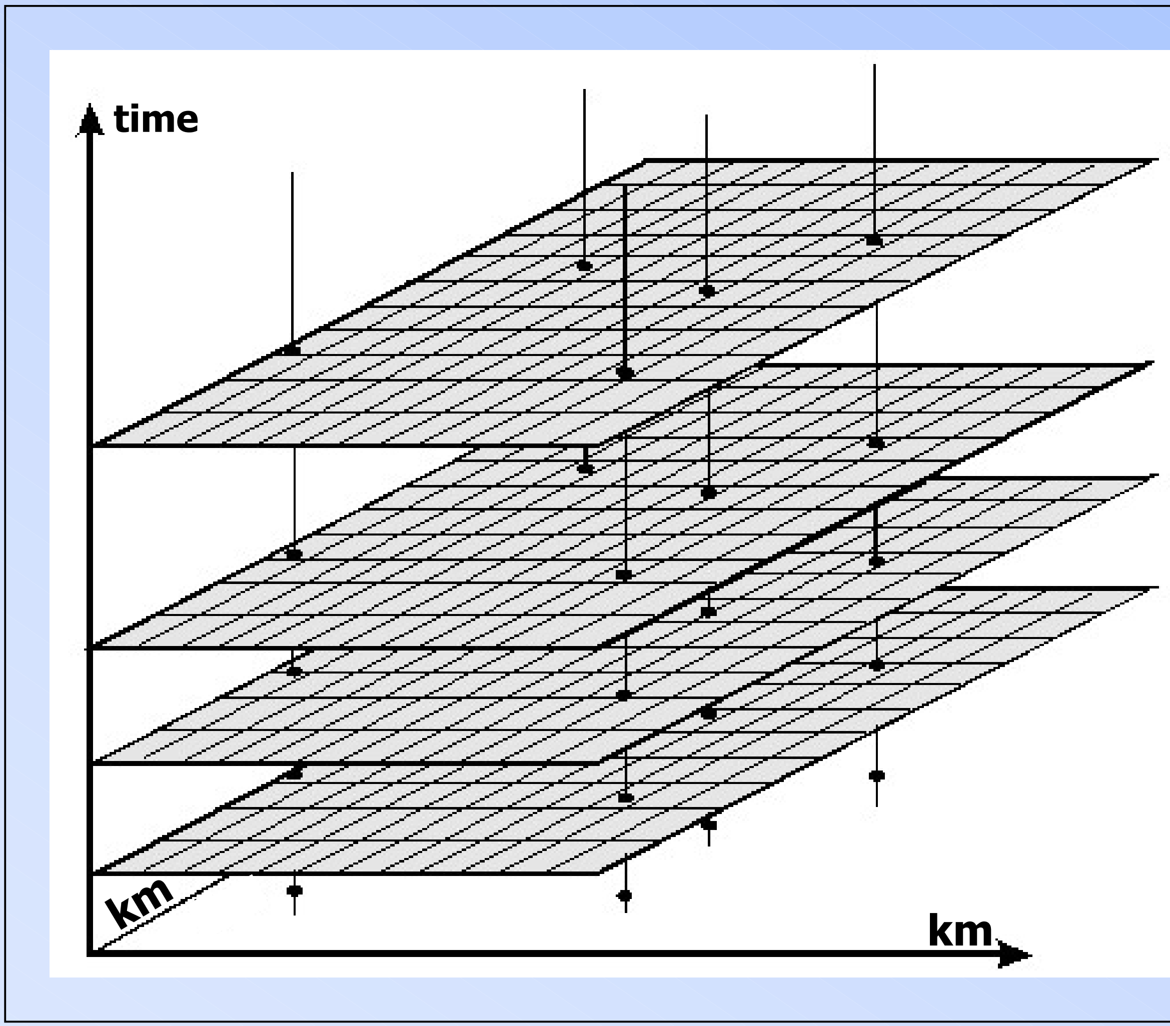
- A radar measurement is an instant in time, a raingauge measurement is continuous

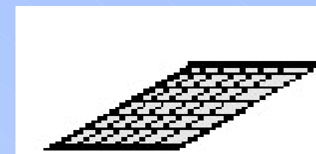


➔ **A comparison of both measurements is required, but you cannot expect the data to be the same !!**

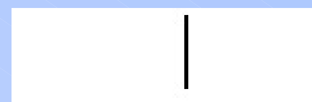
Radar data vs. raingauge data

	Raingauge	**Radar**
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	**continuous (+)**	**at discrete time steps (-)**





Radar
continuous in space
instantaneous



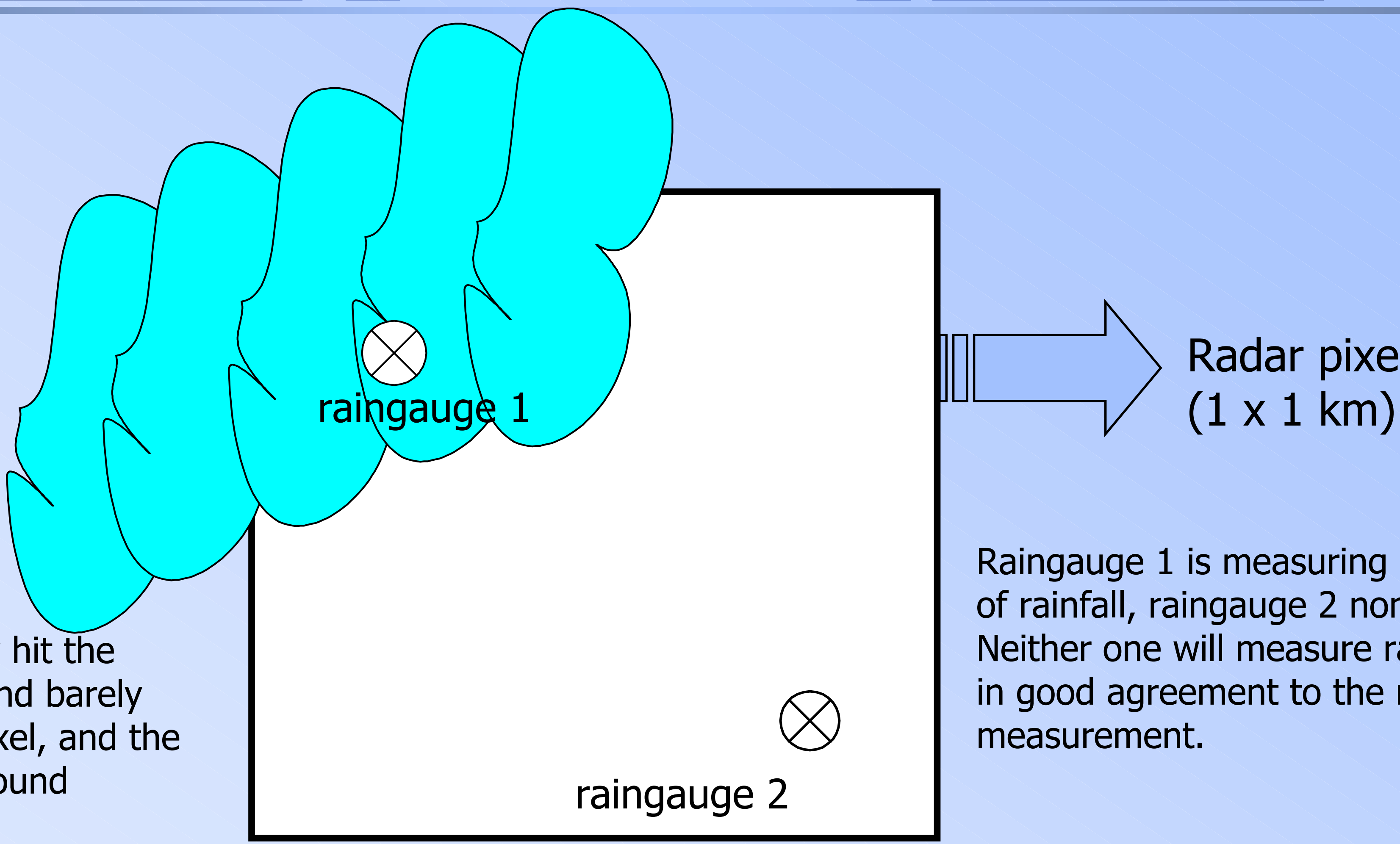
Raingauge
at a point
continuous in time

Common point in time and space for radar and raingauge measurements

Radar data vs. raingauge data

	Raingauge	**Radar**
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	continuous (+)	at discrete time steps (-)
Spatial representation of rainfall	**point (-)**	**area (+)**

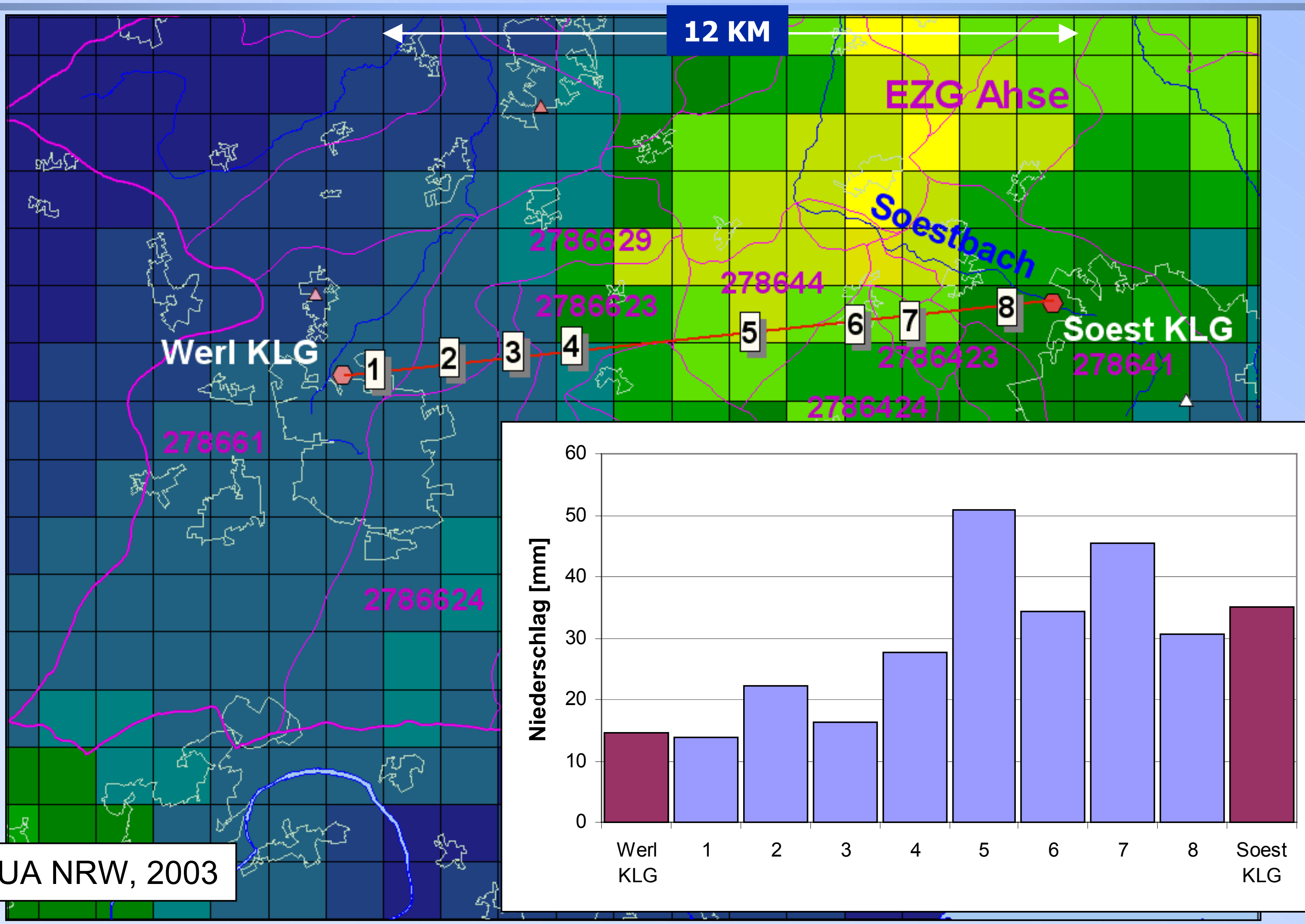
Radar data vs. raingauge data



Rainfall may hit the raingauge and barely the radar pixel, and the other way round

Raingauge 1 is measuring a lot of rainfall, raingauge 2 none. Neither one will measure rainfall in good agreement to the radar measurement.

Radar data vs. raingauge data



Source: LUA NRW, 2003

Radar data vs. raingauge data

	Raingauge	**Radar**
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	continuous (+)	at discrete time steps (-)
Spatial representation of rainfall	point (-)	area (+)
One rainfall value based on	**orifice diameter (200 cm²)**	**volume (size variable)**

Radar data vs. raingauge data

	Raingauge	**Radar**
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	continuous (+)	at discrete time steps (-)
Spatial representation of rainfall	point (-)	area (+)
One rainfall value based on	orifice diameter (200 cm²)	volume (size variable)
Errors of measurement	**diverse error sources**	

Radar data vs. raingauge data

	Raingauge	**Radar**
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	continuous (+)	at discrete time steps (-)
Spatial representation of rainfall	point (-)	area (+)
One rainfall value based on	orifice diameter (200 cm^2)	volume (size variable)
Errors of measurement	diverse error sources	
Data availability	**decentralized (-)**	**central (+)**

Radar data vs. raingauge data

	Raingauge	Radar
Measurement principle	direct (+)	indirect (-)
Temporal feature of measurement	continuous (+)	at discrete time steps (-)
Spatial representation of rainfall	point (-)	area (+)
One rainfall value based on	orifice diameter (200 cm^2)	volume (size variable)
Errors of measurement	diverse error sources	
Data availability	decentralized (-)	central (+)
Rainfall forecast possibilities	**limited (-)**	**available (+)**

Radar data vs. raingauge data
Uncertainties

- Raingauge
  + for a point **uncertainty +/- 5-10 %**
  - for an area **???**

  → Depends on the spatial rainfall distribution
- Radar
  - for a point **uncertainty: factor 1.0 – 5.0**
  + for an area **relative amount +/- 0 - 20%**

  → Depends on rainfall type and dropsize distribution
- Forecasts

  → Radar: depends on rainfall type

  → NWP: depends on scale of rainfall

Radar data vs. raingauge data
Uncertainties

- Concrete basin volume
- Example: basin 10 x 20 x 3 m = 600 m³
  5 cm uncertainty in construction
  → +/- 15 m³ volume

- Flow measurement
- Example: Doppler + level → 15 – 20 %

Overview

- Introduction: who am I?
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- Radar data vs. raingauge data
- Rainfall data quality control
- Rainfall forecasting
- Hydrological applications
  - Do you need radar data?
  - Examples
- Conclusions

Rainfall data quality control

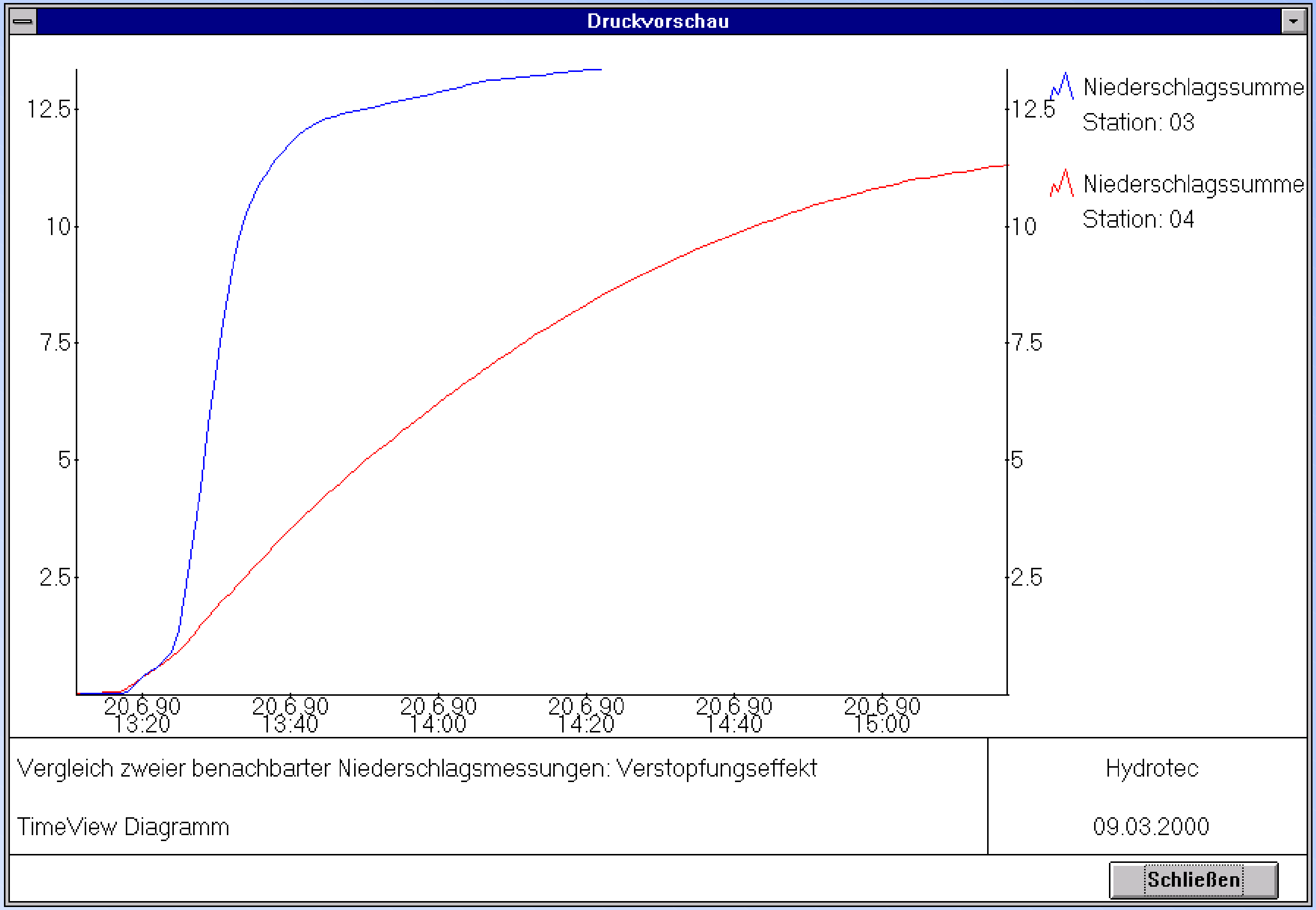
- Data quality check
  - » Use as many independent information sources as possible (e.g. raingauge, radar, satellite)
  - » Use different views (time series, spatial view)
  - » Use simple comparisons / statistics (volume per time interval, spatial variance, etc.)

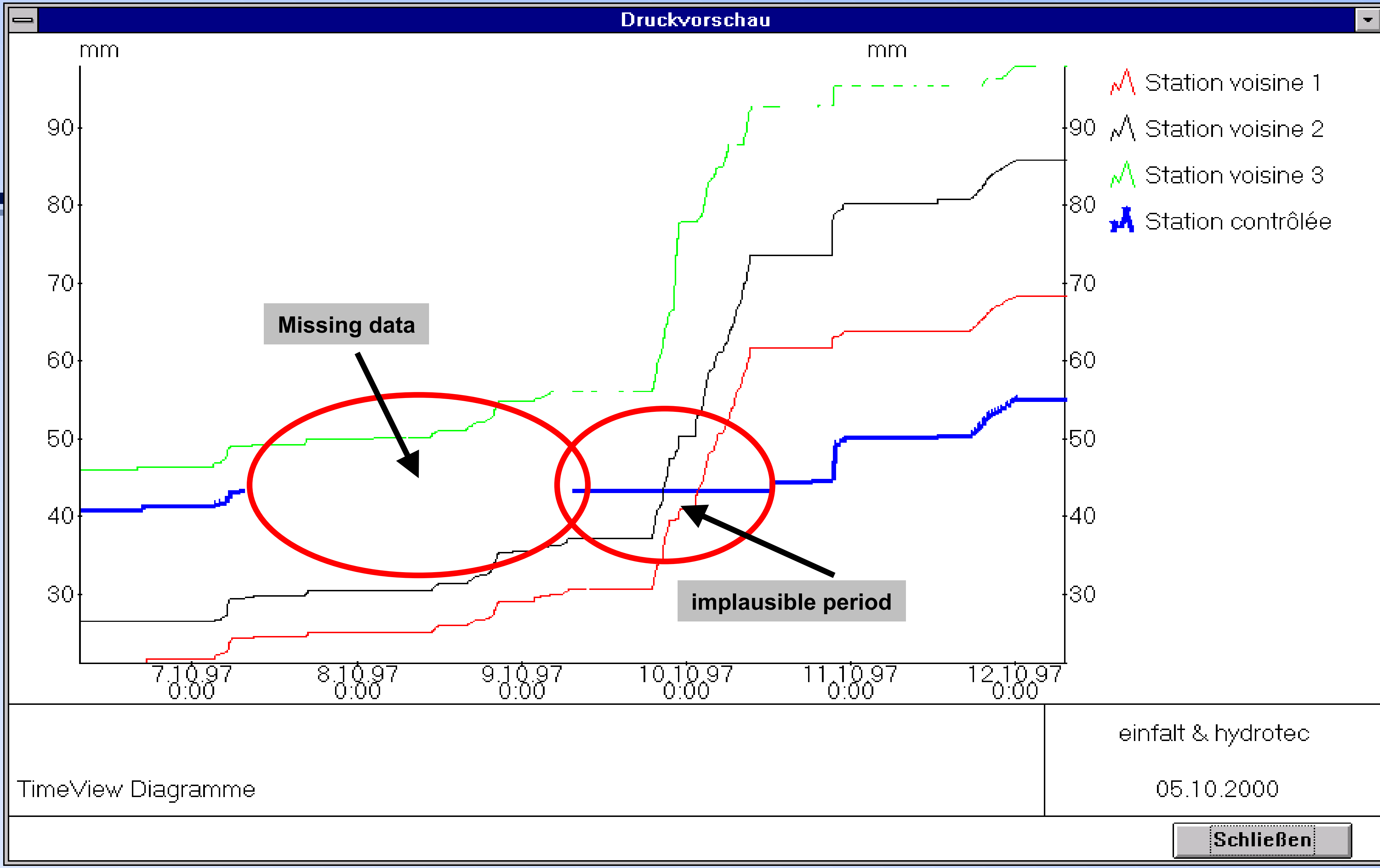
Rainfall data quality control

- Examples
  - » Raingauge data

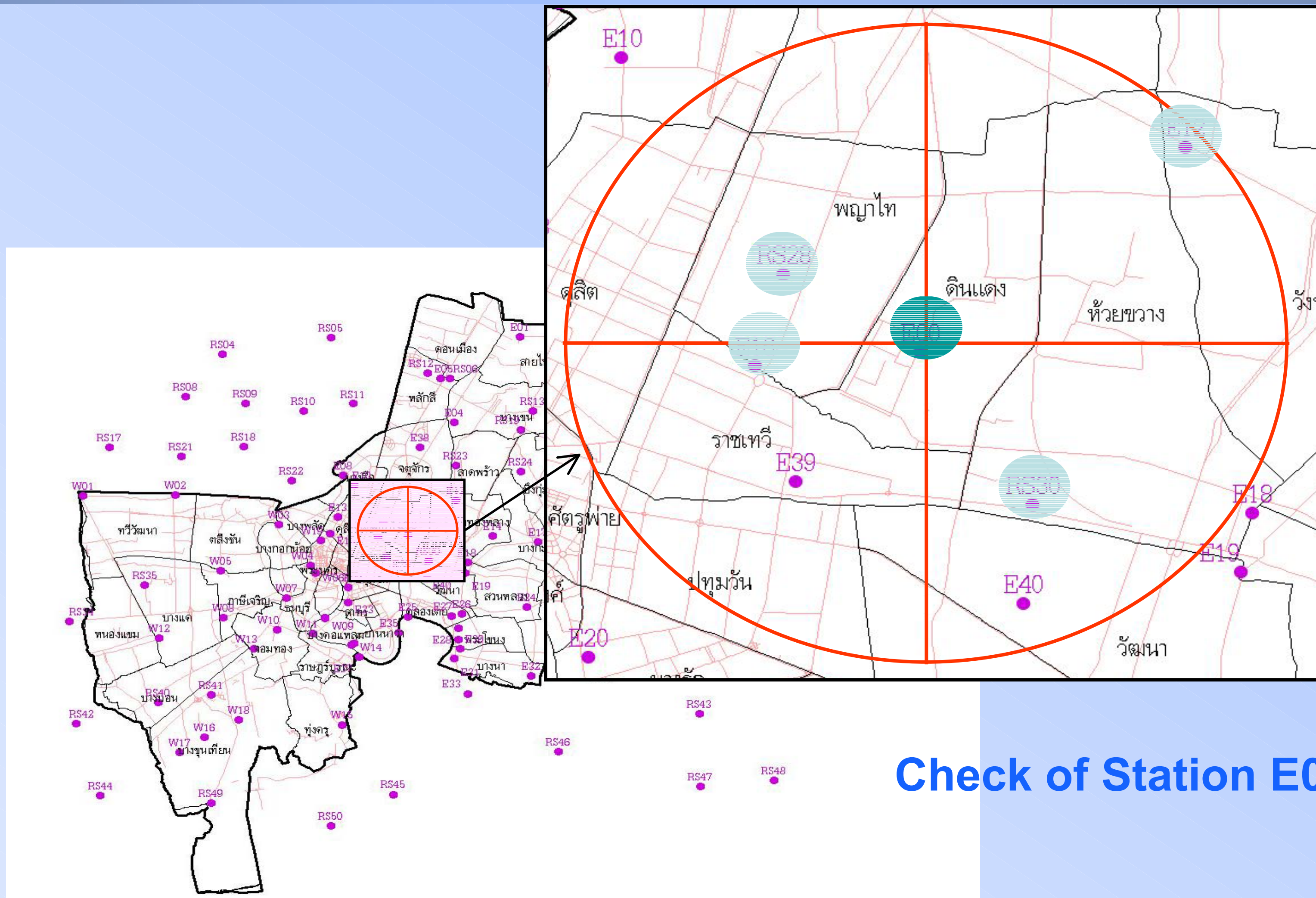
Errors in raingauge measurements
Example

- Plugging
  how to detect?
- - uniform rise of the cumulative rainfall curve,
  - comparison with neighboring stations (figure: red raingauge plugged, blue raingauge ok)




Druckvorschau
mm
mm
90
80
70
60
50
40
30
Station voisine 1
Station voisine 2
Station voisine 3
Station contrôlée
Missing data
implausible period
7.10.97 0:00
8.10.97 0:00
9.10.97 0:00
10.10.97 0:00
11.10.97 0:00
12.10.97 0:00
TimeView Diagramme
einfalt & hydrotec
05.10.2000
Schließen

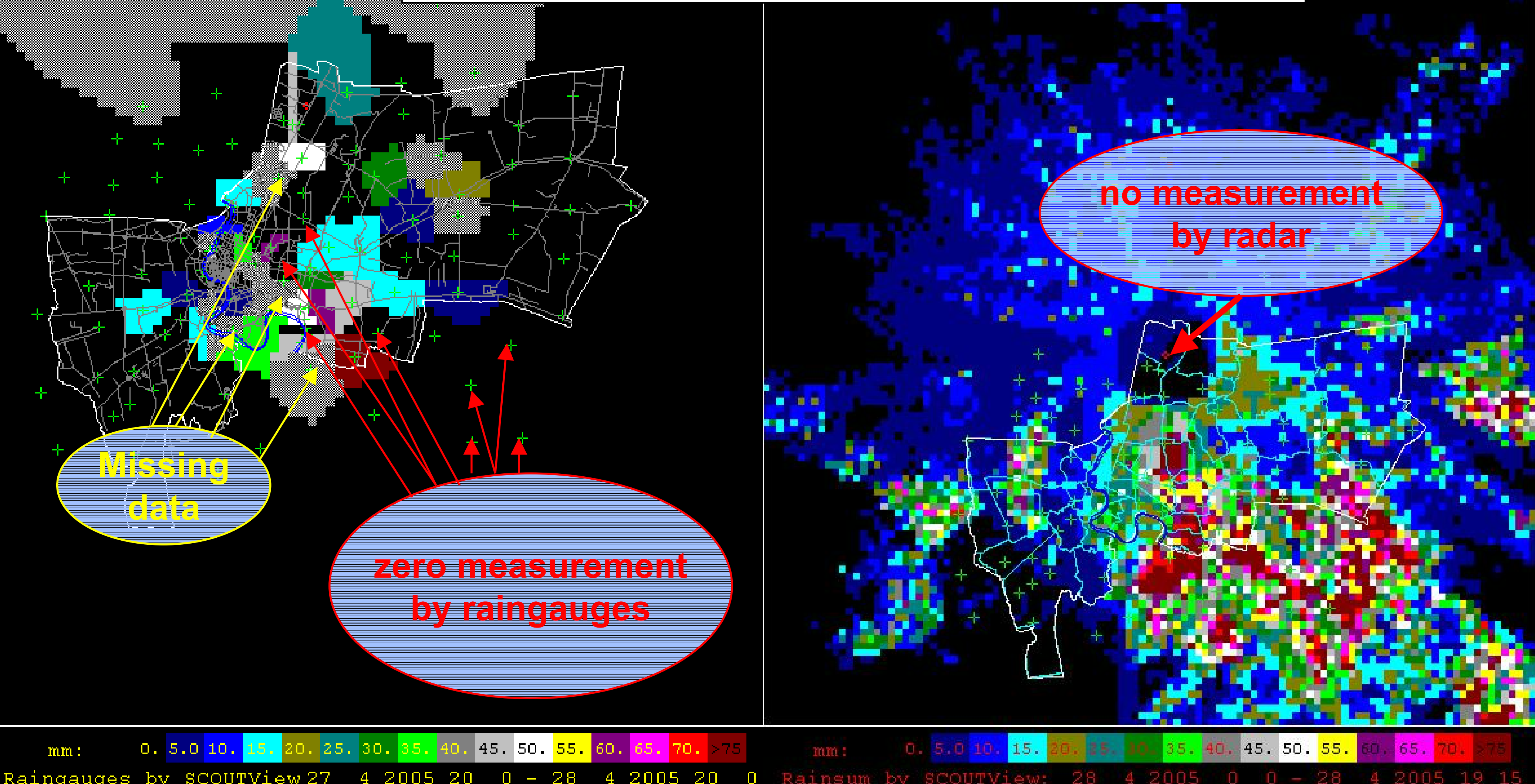
Automatic Raingauge check



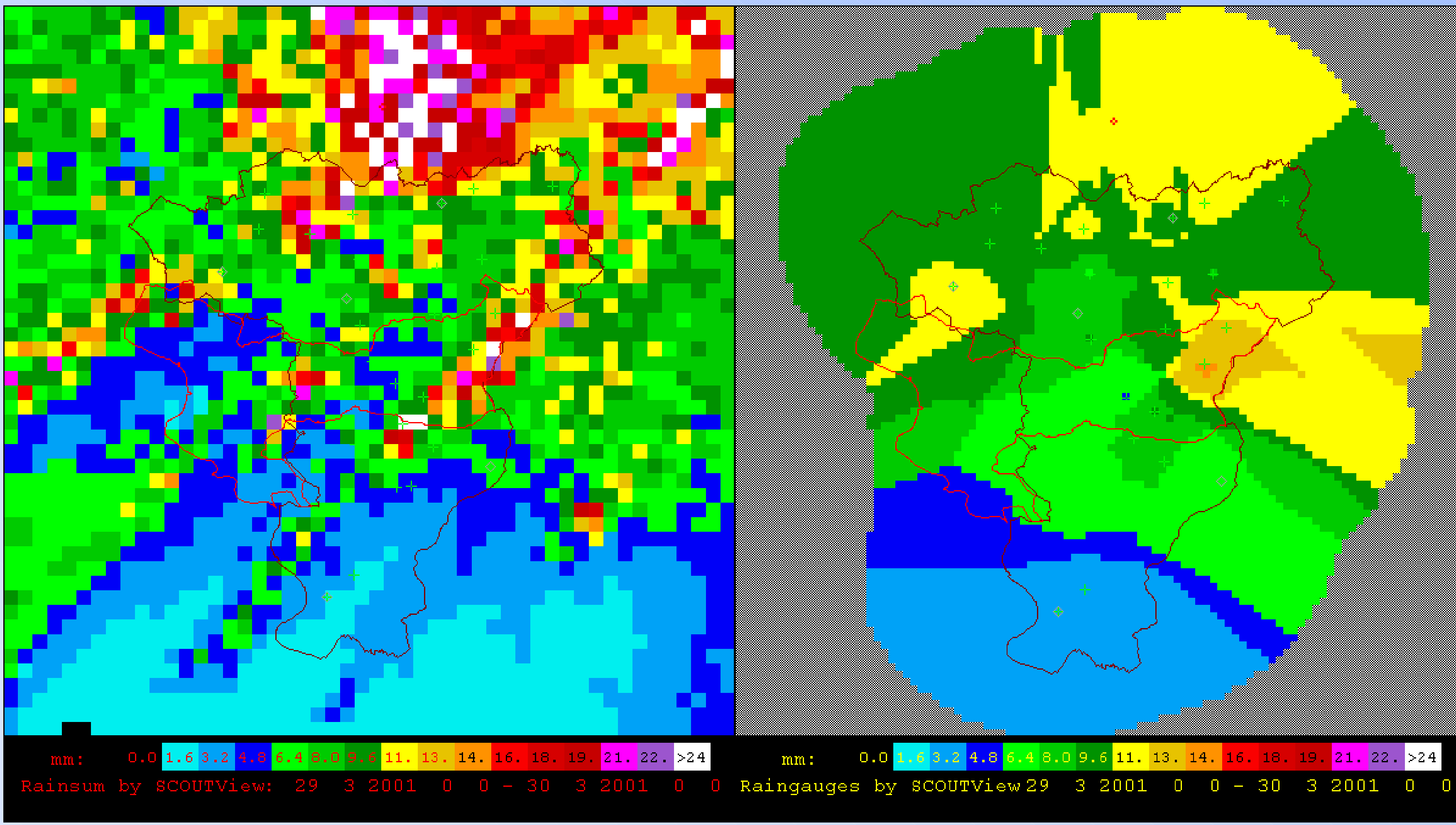
Check of Station E00

Example 28 April 2005

Data source: Bangkok Municipal Administration + Thai Met. Dept., 2005



Comparison radar - raingauge
accumulated images (29th March 2001)



accumulated adjusted radar sum

interpolated raingauge sum

Rainfall data quality control

- Examples
  - » Radar data

COST 717 report on data quality

Weather Radar Data Quality in Europe: Quality Control and Characterization

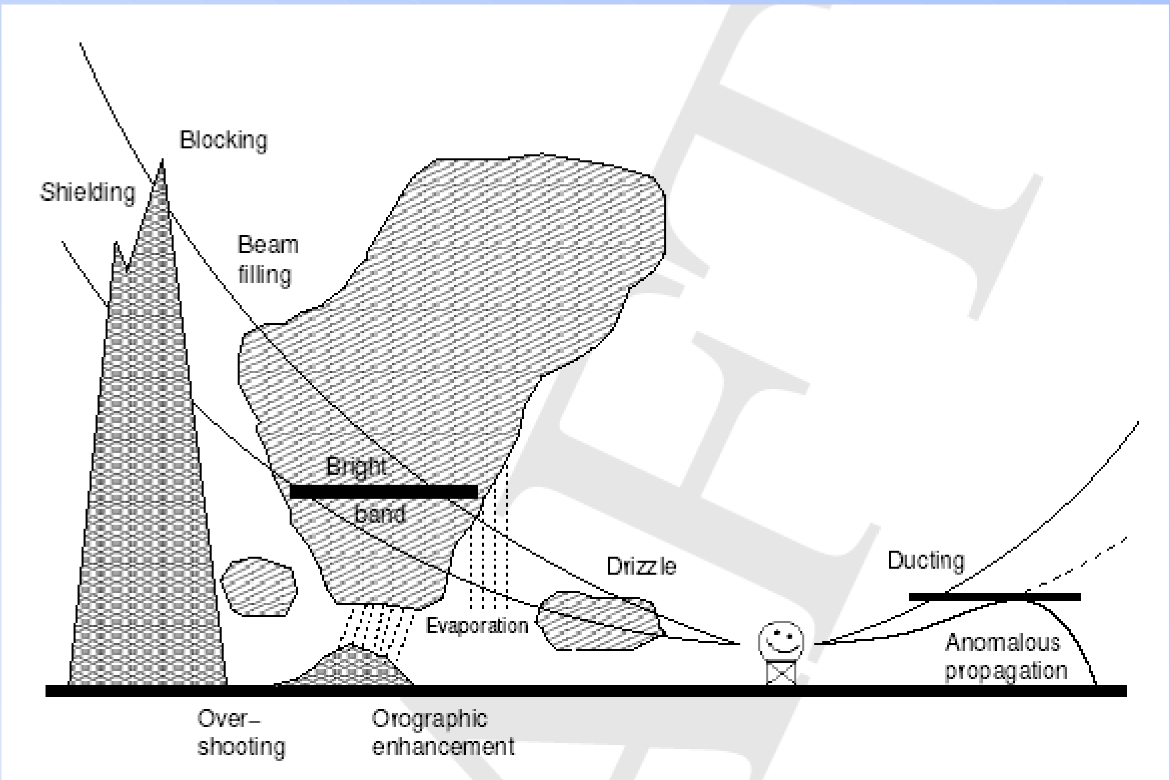
D. Michelson[1] T. Einfalt[2] I. Holleman[3] U. Gjertsen[4] K. Friedrich[5]
G. Haase[1] M. Lindskog[1]
J. Szturc[6]

[1]Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden
[2]einfalt & hydrotec GbR, Lübeck, Germany
[3]Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
[4]met.no, Oslo, Norway
[5]German Aerospace Center (DLR), Oberpfaffenhofen, Germany
[6]Institute of Meteorology and Water Management (IMGW), Katowice, Poland

COST 717 Working Document WDF_02_200204_1

March 28, 2004

Weather Radar Data Quality in Europe: Quality Control and Characterization

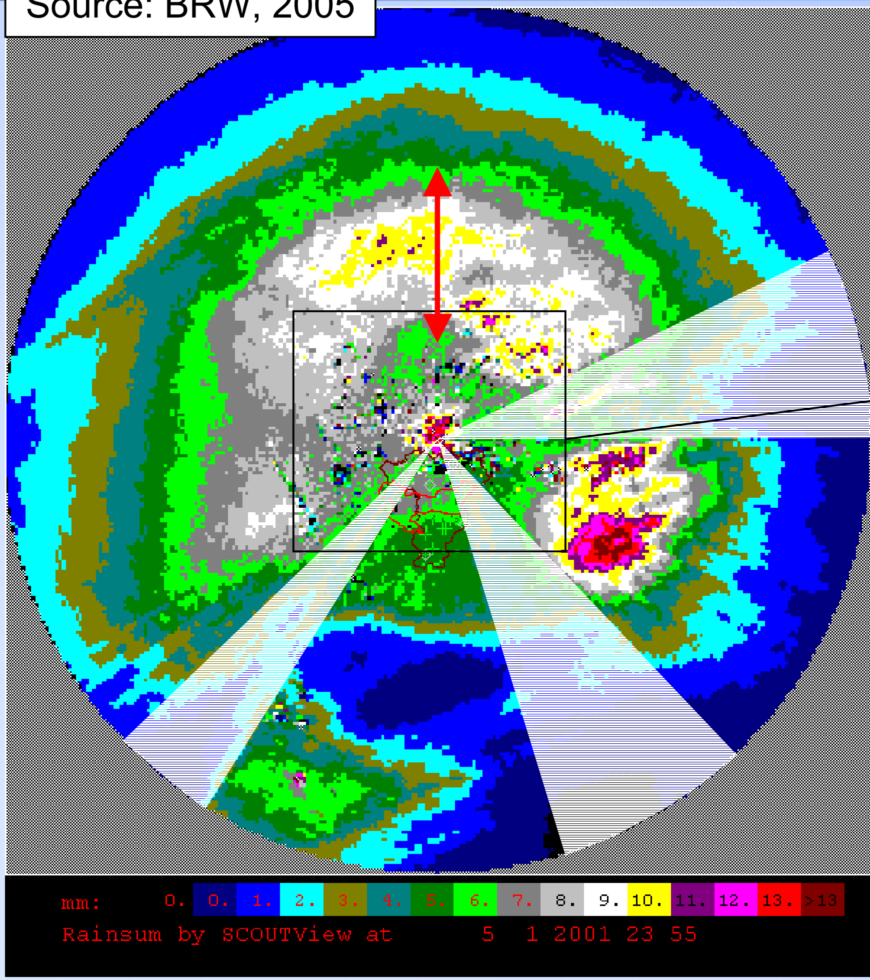


Main problems with radar data quality

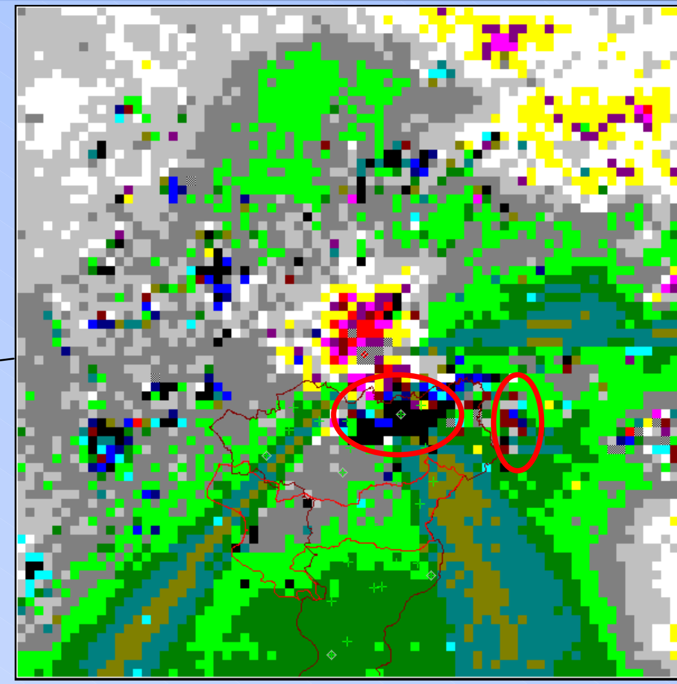
- Data availability
- Data collection interval
- Ground clutter / statistical filters
- Attenuation / effects of hail
- Bright band
- Beam blockage
- Beam overshooting
- Anomalous propagation
- Spurious effects in the data

Rainfall data quality control

Source: BRW, 2005



Bright Band



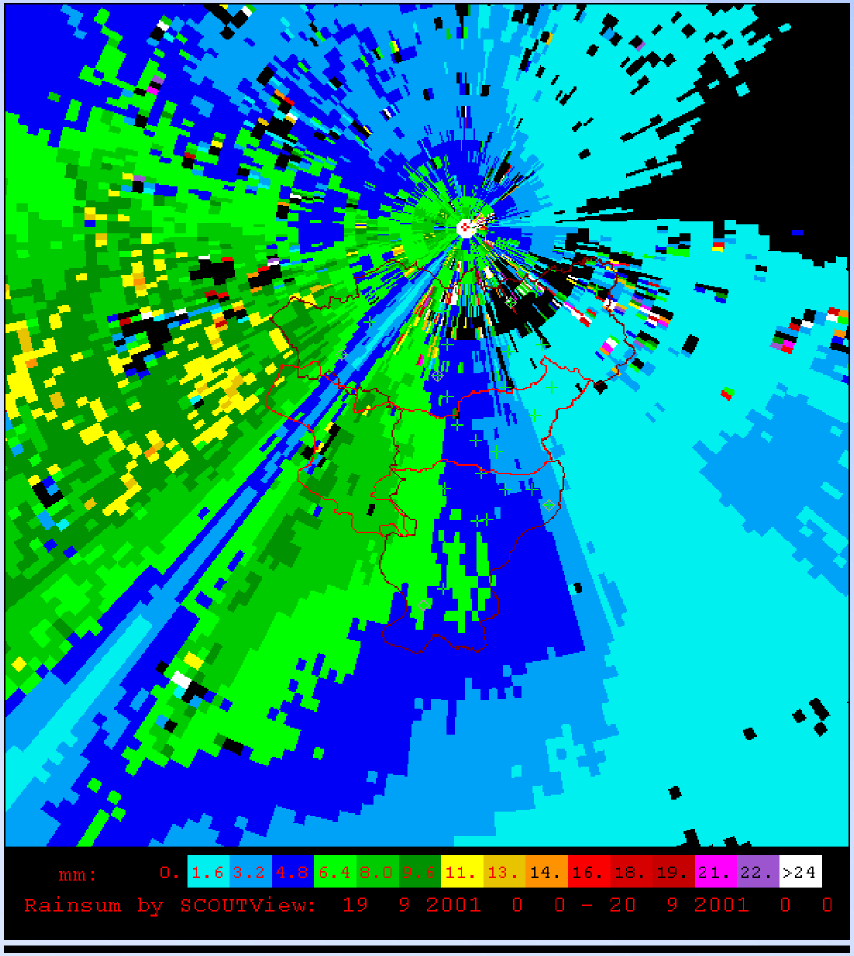
Localised beam error

Ground clutter

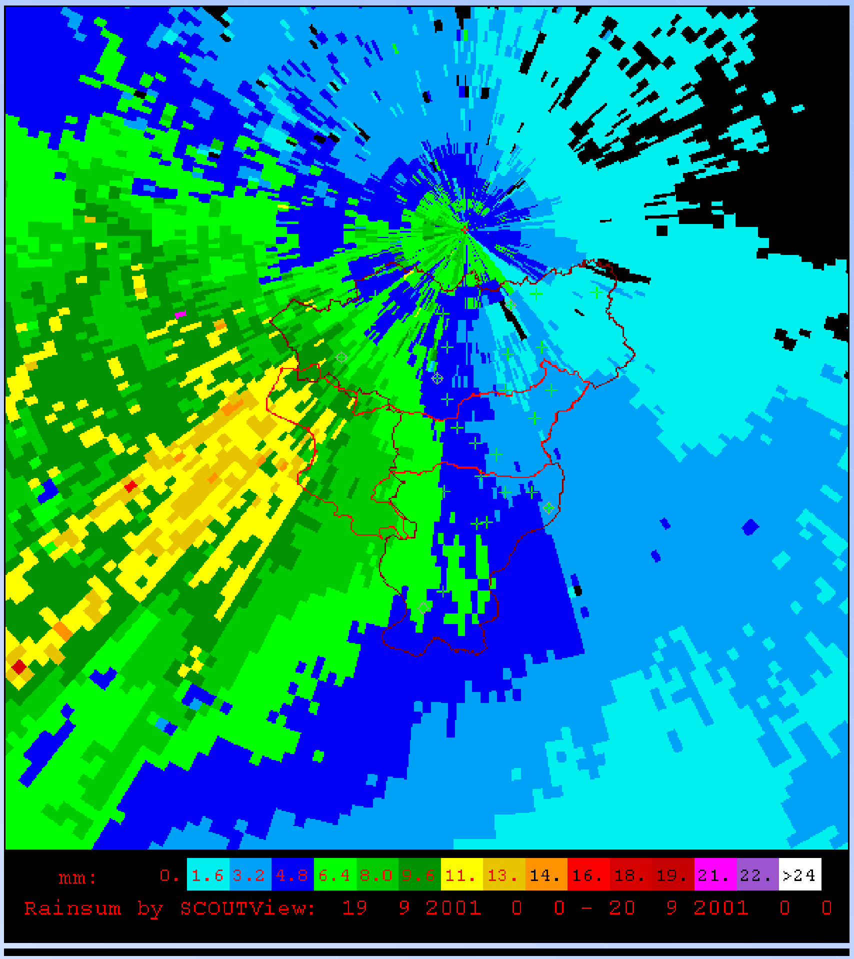
Correction of radar images

- Beam shielding
- Clutter and „negative" clutter

Results of the correction
beam blockage and clutter correction



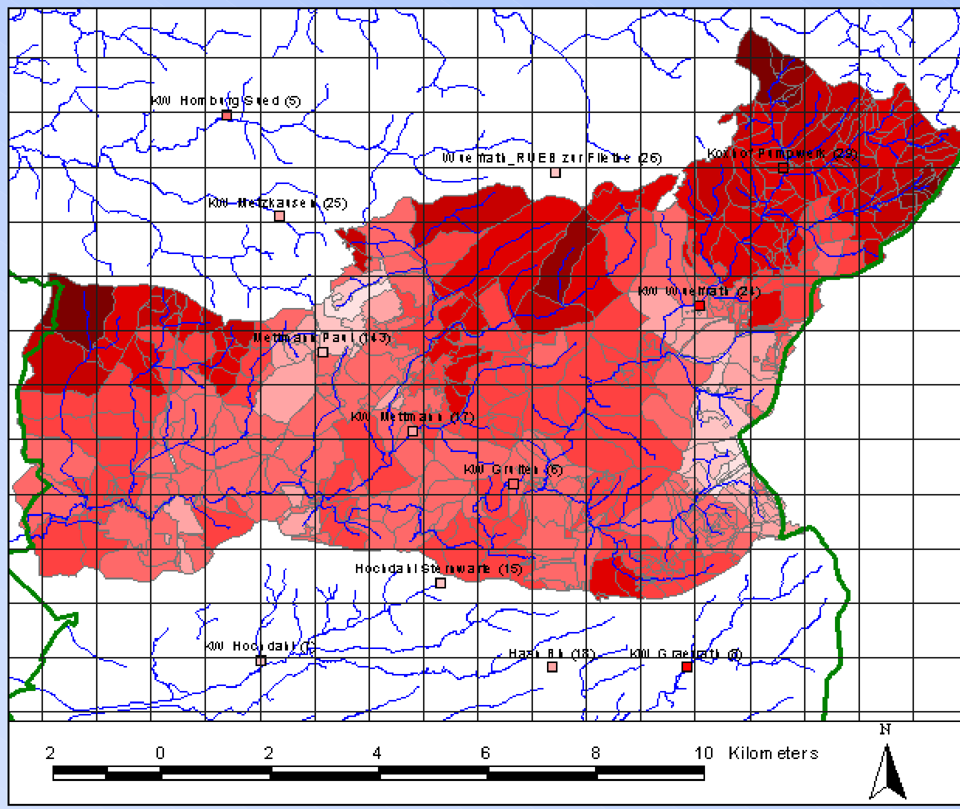
accumulated radar image (original data)



accumulated radar image (corrected data)

Rainfall data quality control
Results

- Preparation of 450 subcatchment time series (river Duessel)
- Adjusted daily accumulated radar images

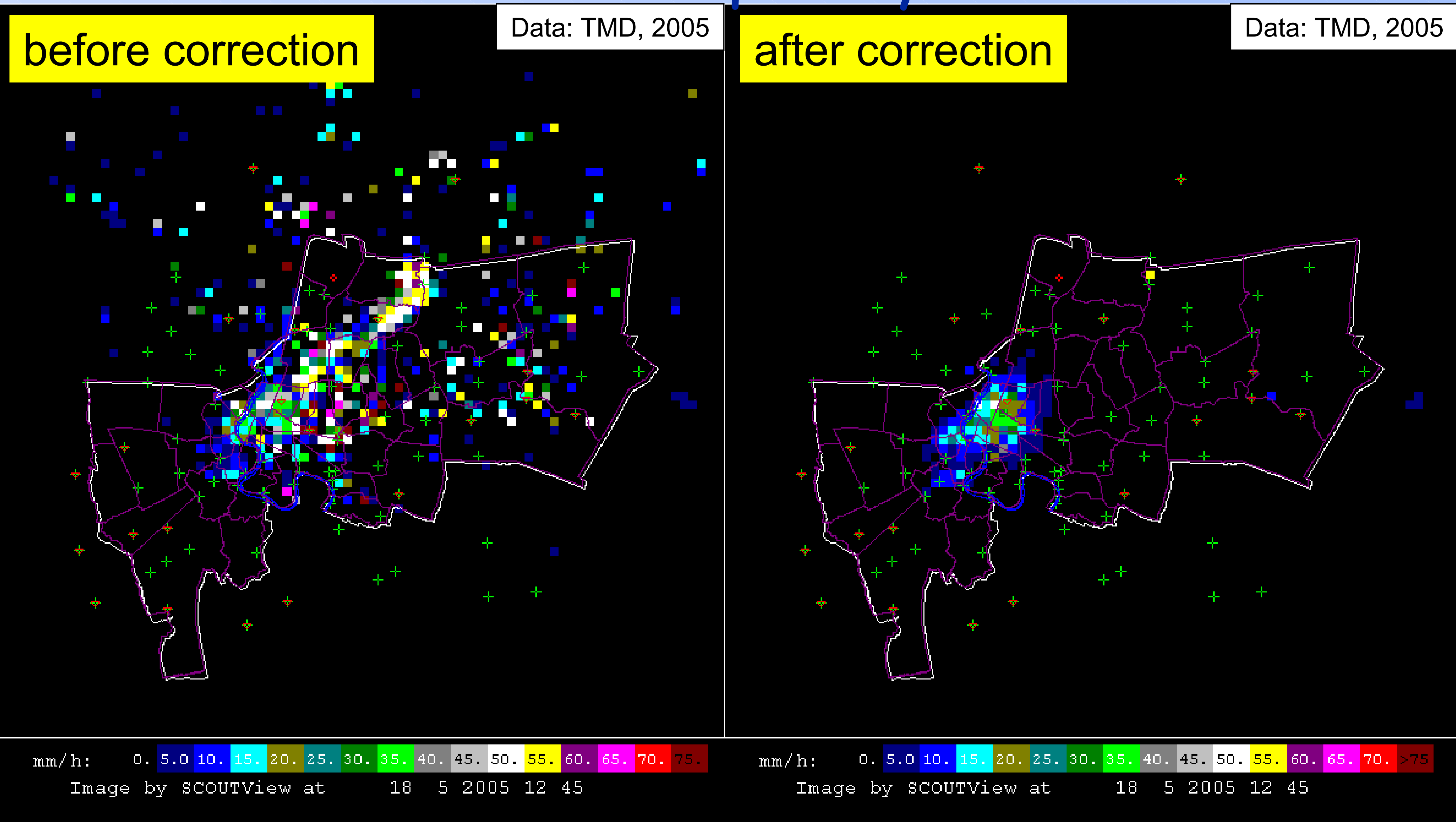


total rainfall sum of the subcatchments

Correction of radar images

- Clutter map

Rainfall data quality control



QC algorithms for radar data

Problem	2D-data	3D-data
Attenuation	"cumulative gate-by-gate algorithm"	"mountain return method"
Ground Clutter & Speckle	"clutter map" "texture-based algorithm" "segment size"	"vertical and horizontal substitution"
Classification convective / stratiform	"3 criteria"	"2 methods"
Vertical profile (VPR)	"climatological or idealised profile"	"MAVPR"
	"maximum method"	"Mesobeta profiles"
Radial anomalies	"radial filter" "beamblock"	"EMITTER"
Anomalous propagation (ANAPROP)	"motion filter"	"tilt-test"

Rainfall data quality control

- Not all uncertainties and errors can be corrected, some can only be detected
- It is difficult to objectively judge if a correction has really improved the data

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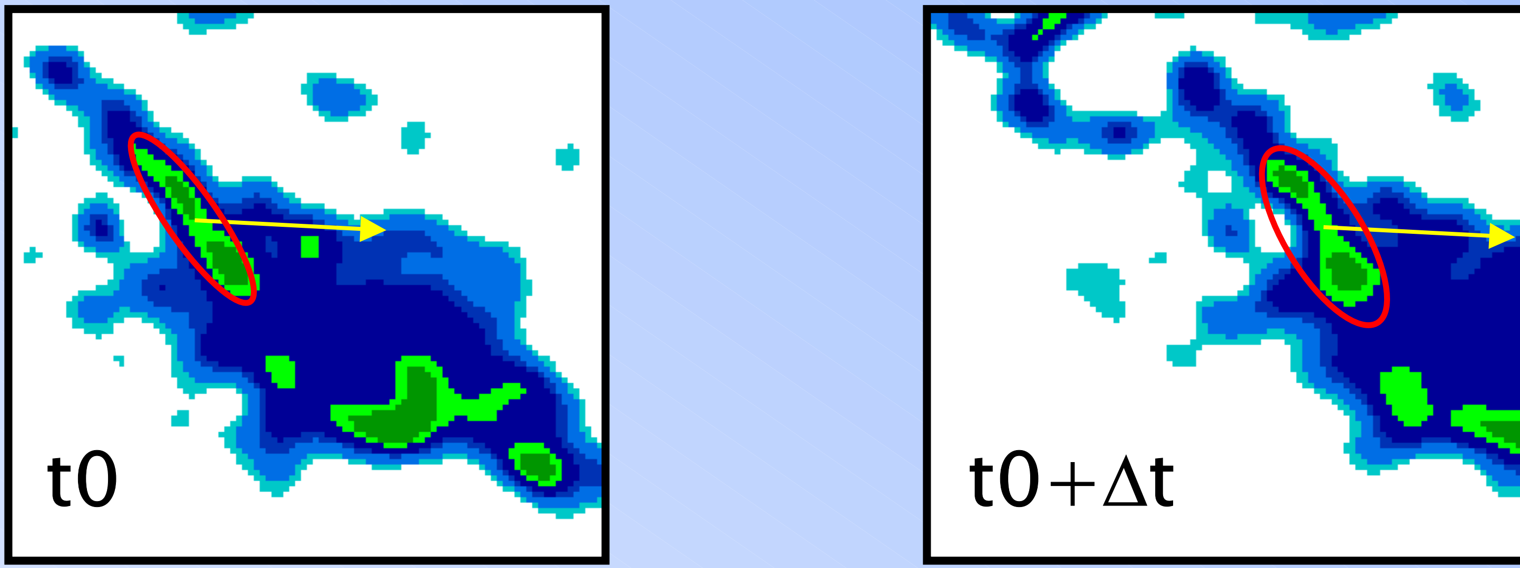
- Conclusions

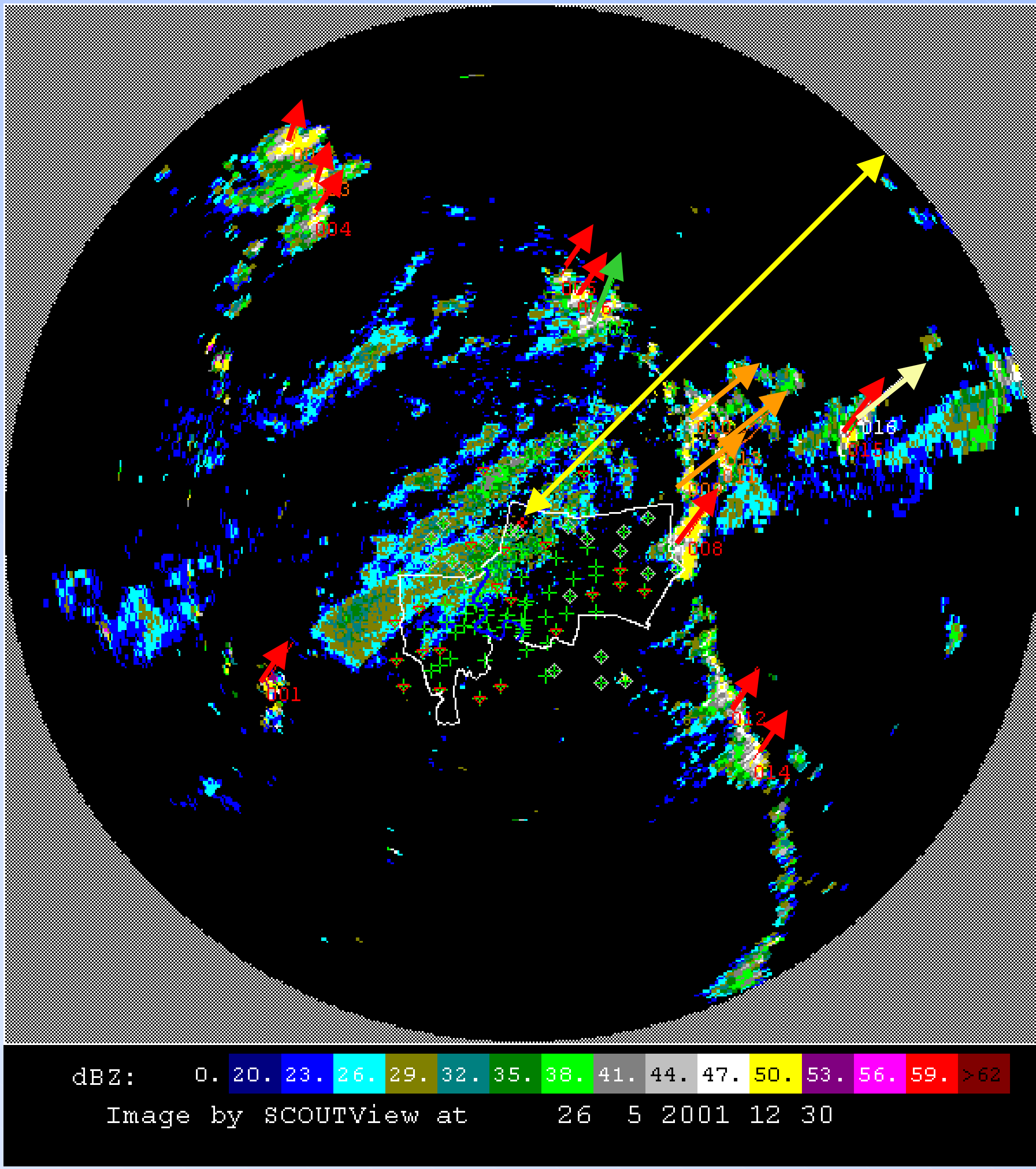
Rainfall forecasting

- Nowcasting
- Important: Never expect a perfect forecast!

SCOUT nowcasting scheme



- identification of rainfields
- characterisation of rainfields
- recognition of rainfields
- analysis of past rainfield dynamics
- extrapolation of dynamics into the future
- assessment of forecast accuracy

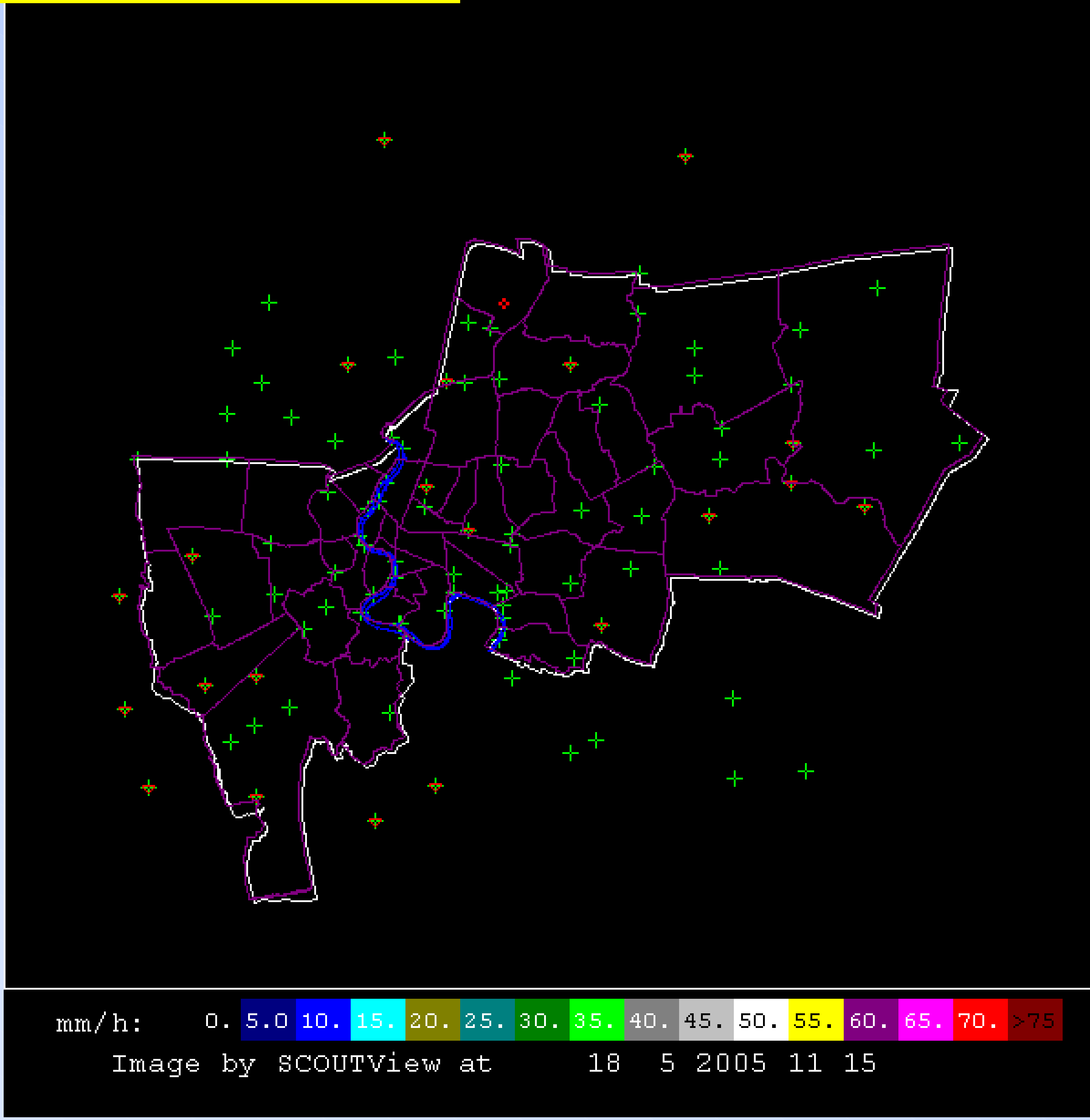

004
001
008
018
012
014
dBZ: 0. 20. 23. 26. 29. 32. 35. 38. 41. 44. 47. 50. 53. 56. 59. >62
Image by SCOUTView at 26 5 2001 12 30

Rainfall forecasting

- Example

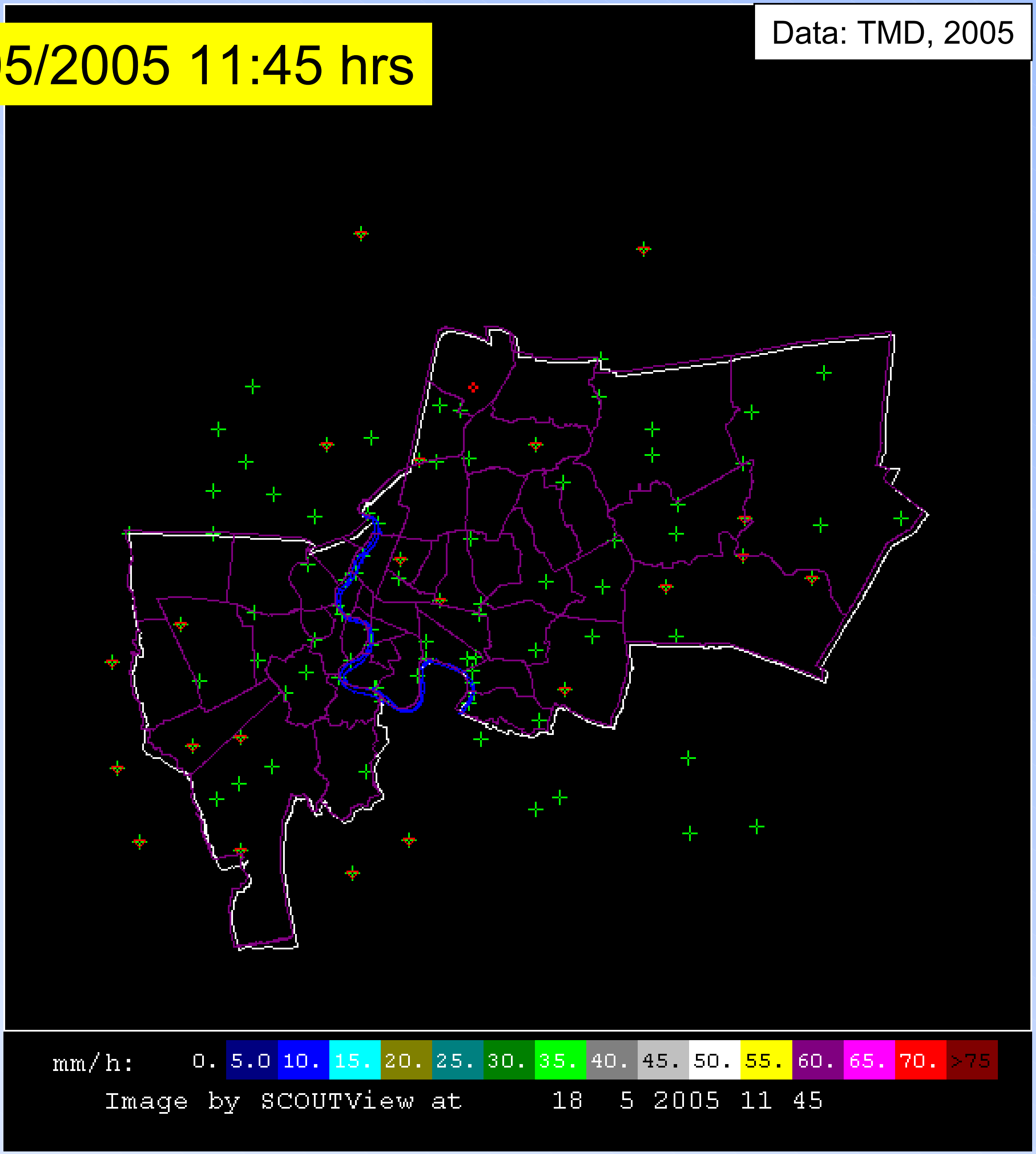
Example 18/05/2005 11:15 hrs

Data: TMD, 2005

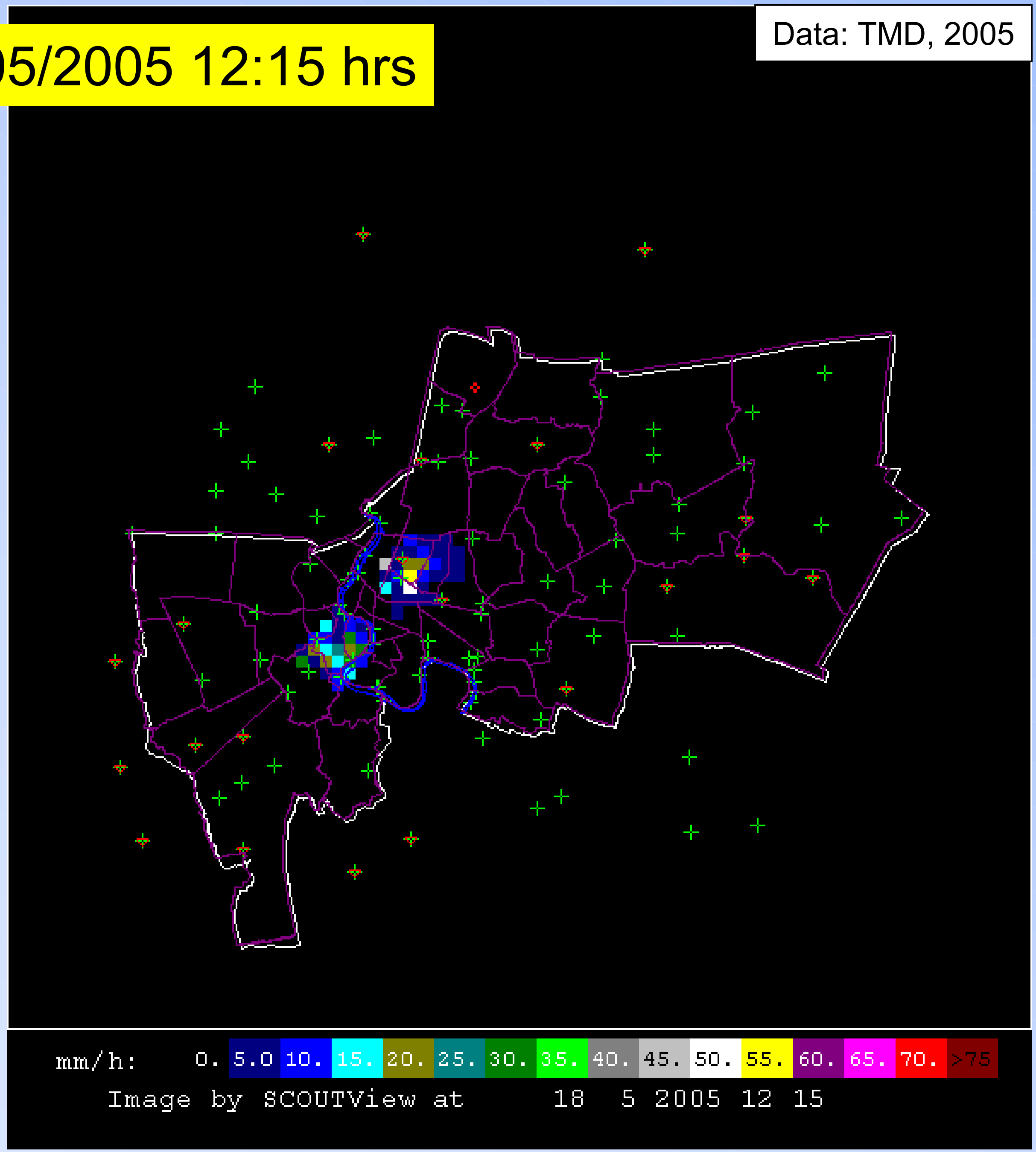


Example 18/05/2005 11:45 hrs

Data: TMD, 2005

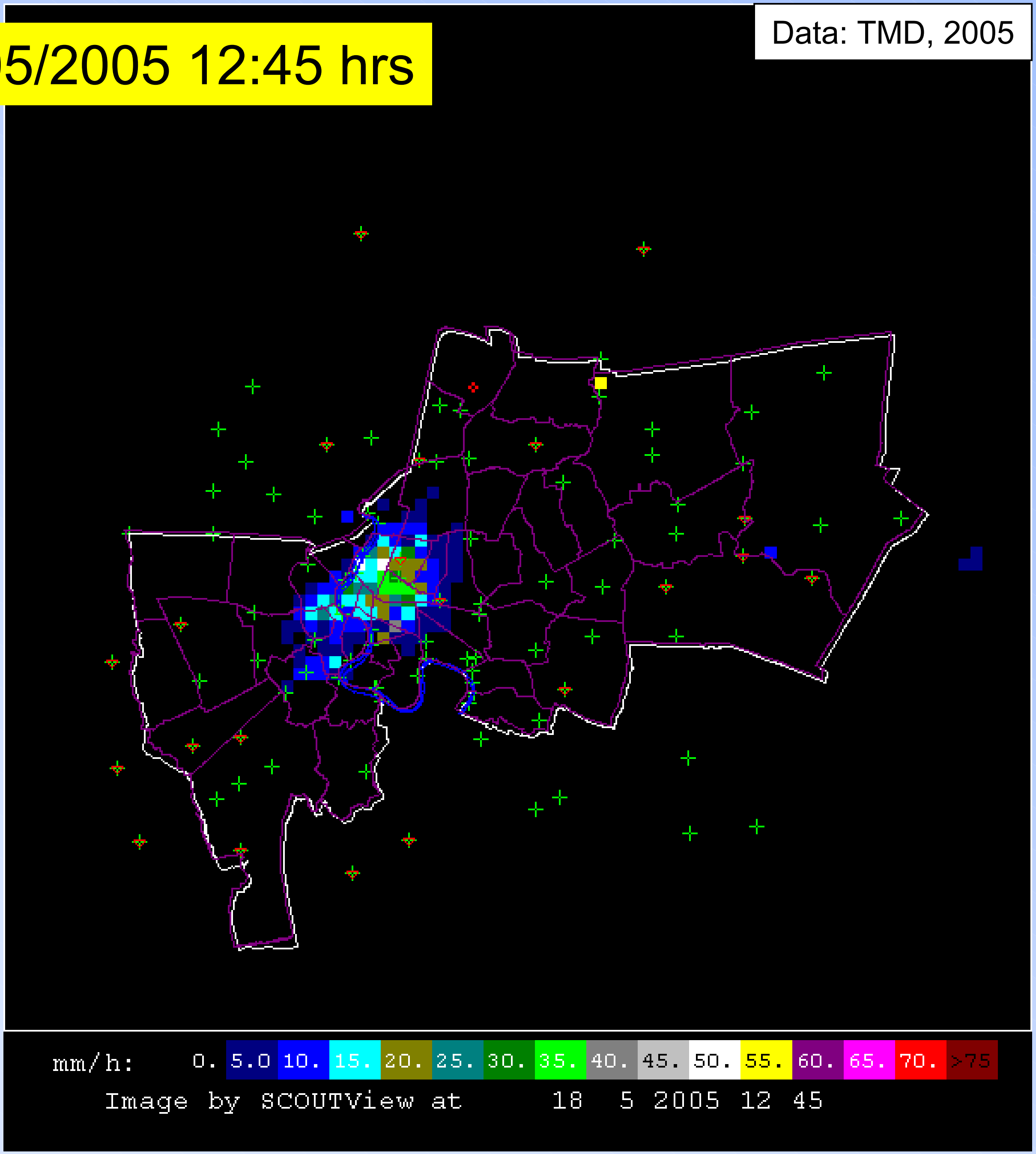


Example 18/05/2005 12:15 hrs



Example 18/05/2005 12:45 hrs

Data: TMD, 2005



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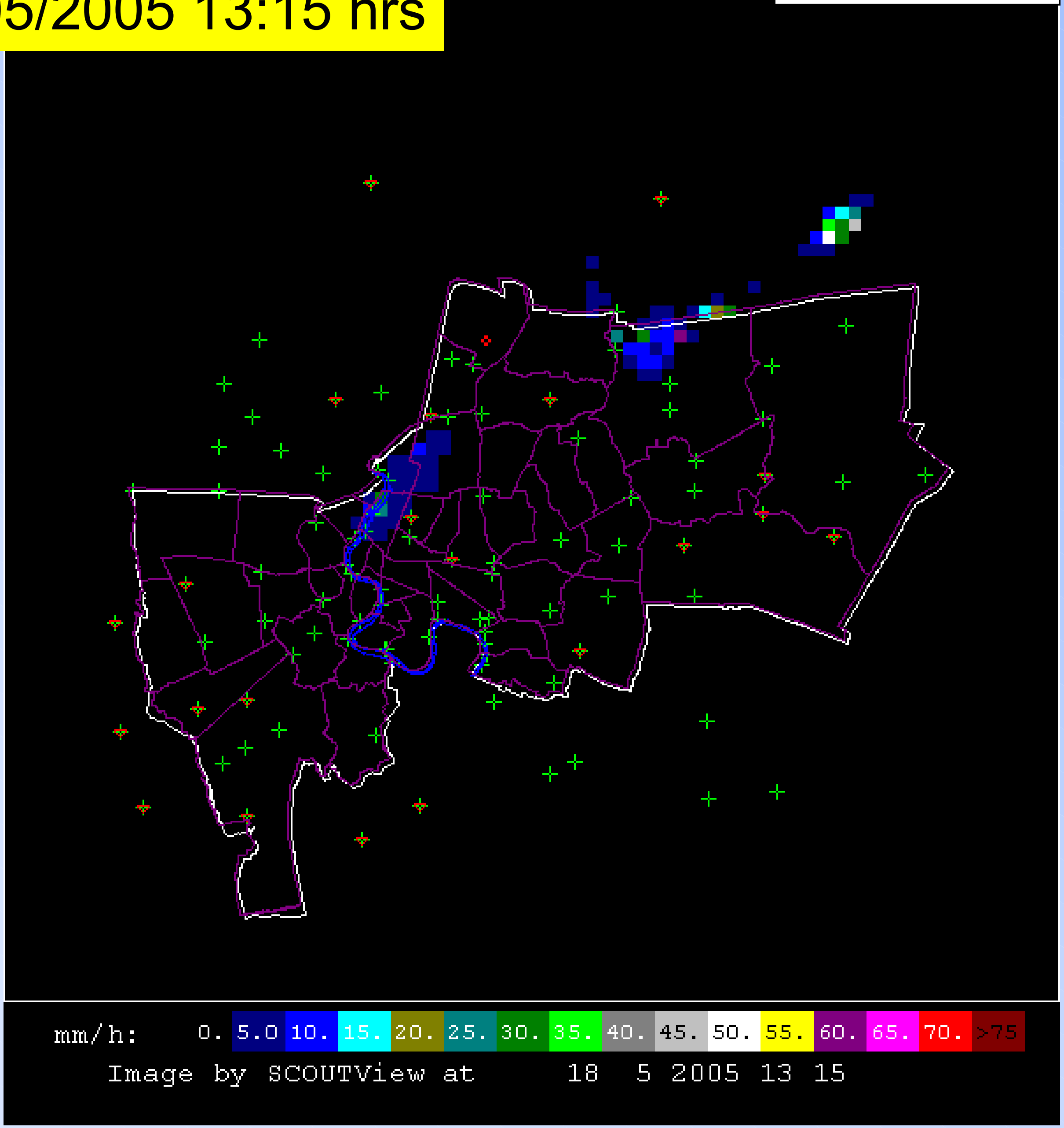

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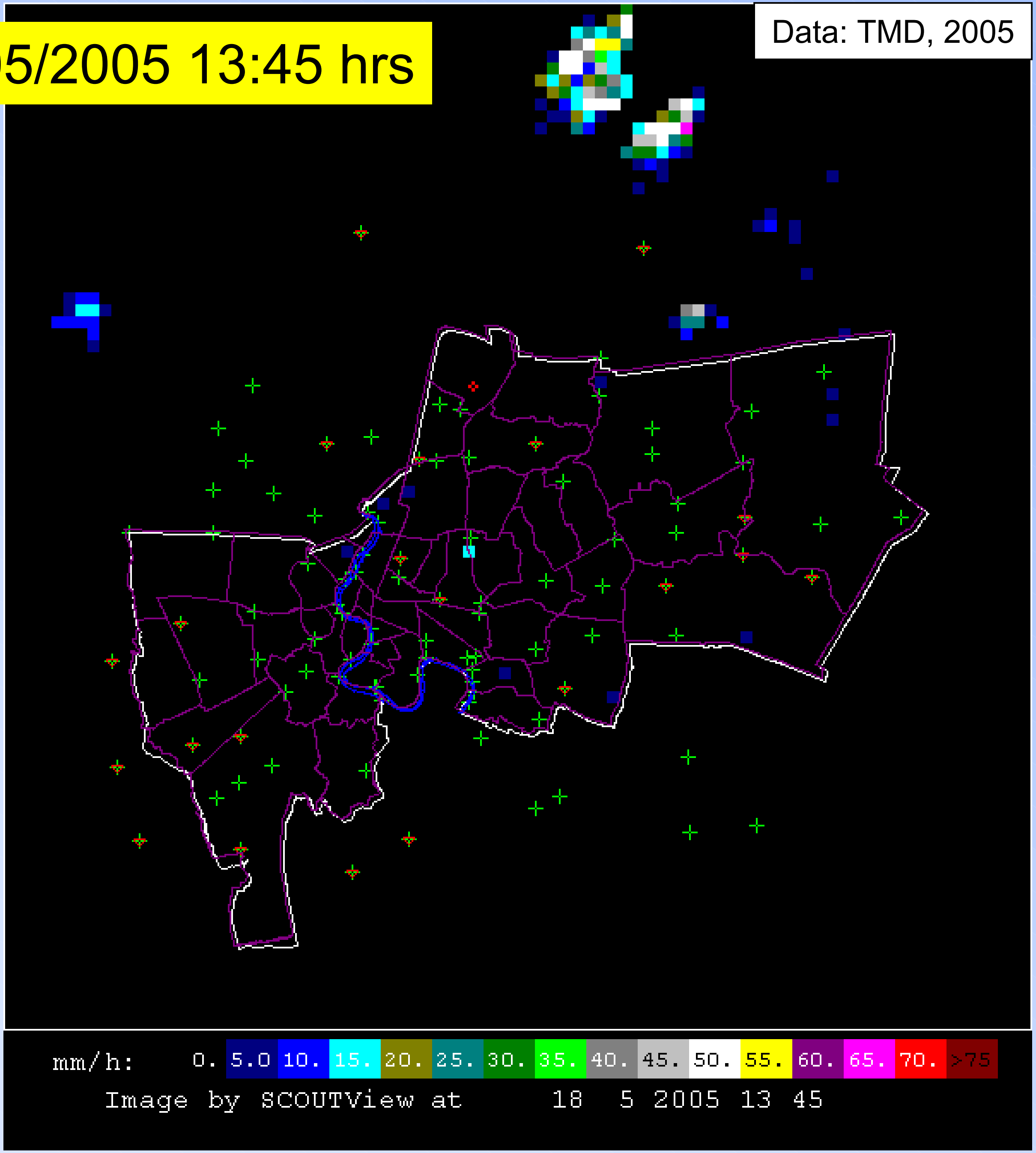


Rainfall forecasting

What can we see?

- Radar alone cannot guess where rainfall is going to create
- Rain cells with a short life time are difficult to forecast, even when they are already existing
- Rain can only be forecasted if detected by radar, rainfields outside the radar range cannot be used

Radar forecasting limits

Radar based forecasts are limited by

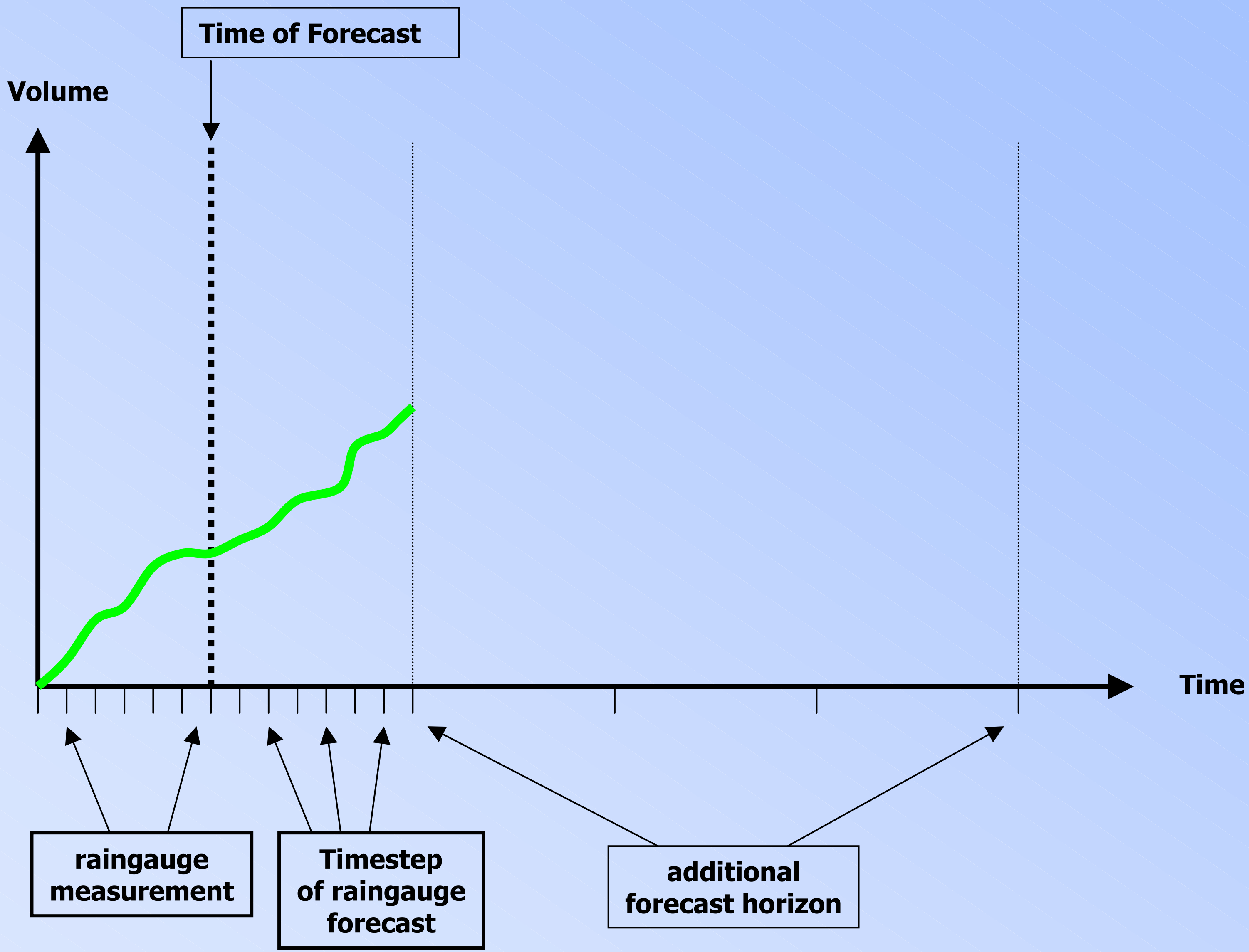
- Life time of rainfall fields
- Radar radius and rainfield speed

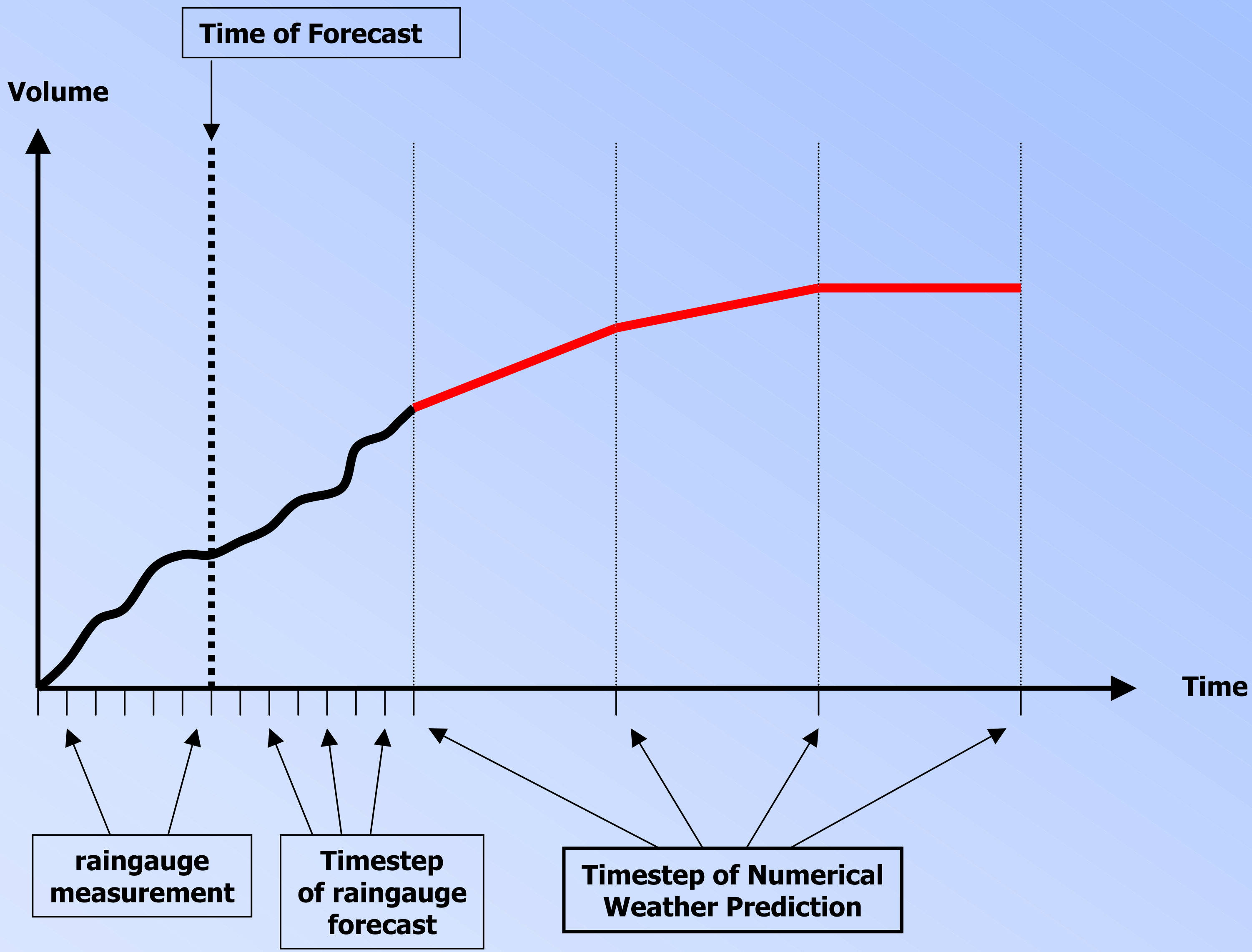
→ Numerical Weather Prediction (NWP)

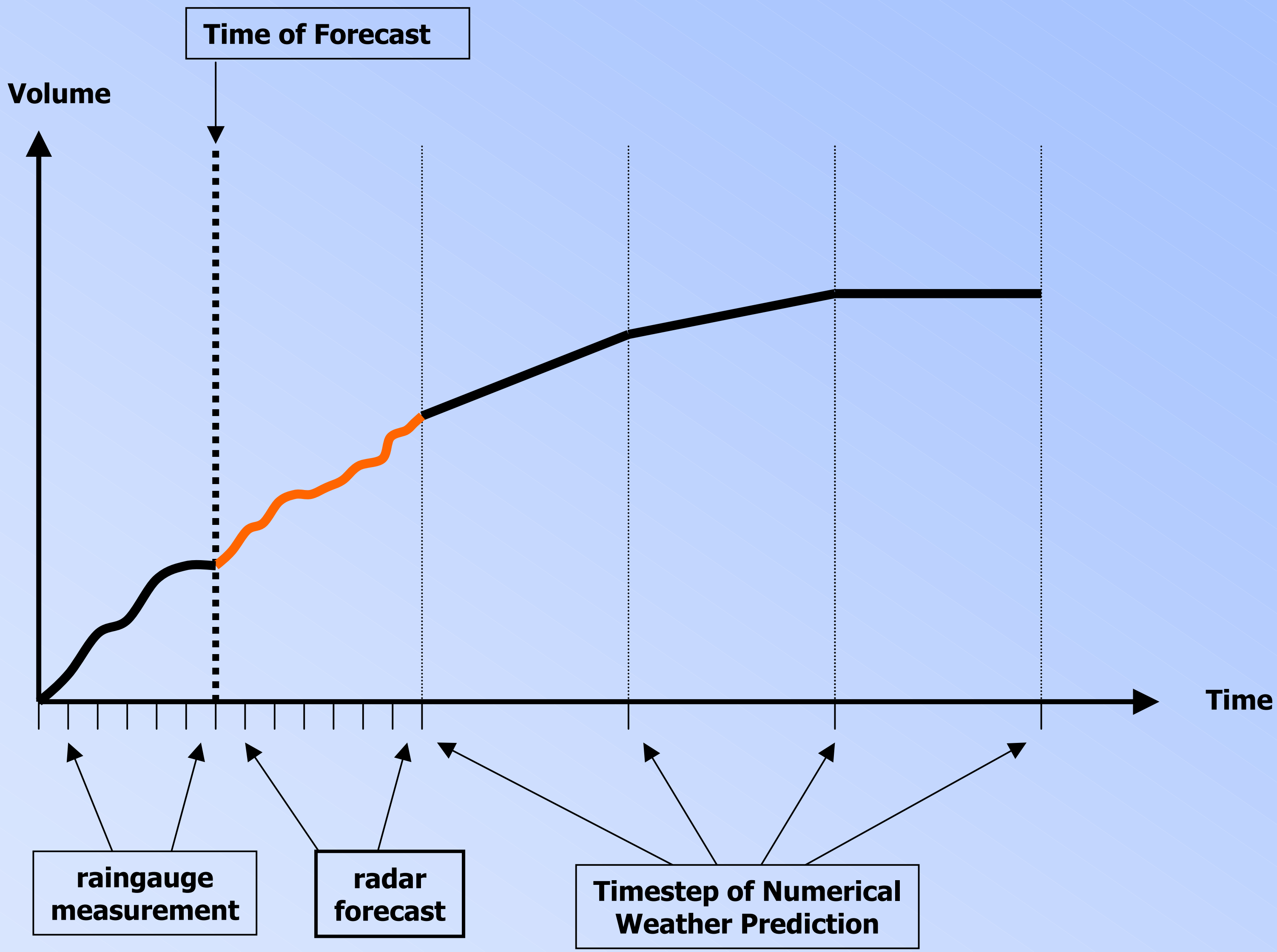
- Inherently knows the cyclone tracks
- Provides rainfall forecast (convective and stratiform part)

Rainfall forecasting

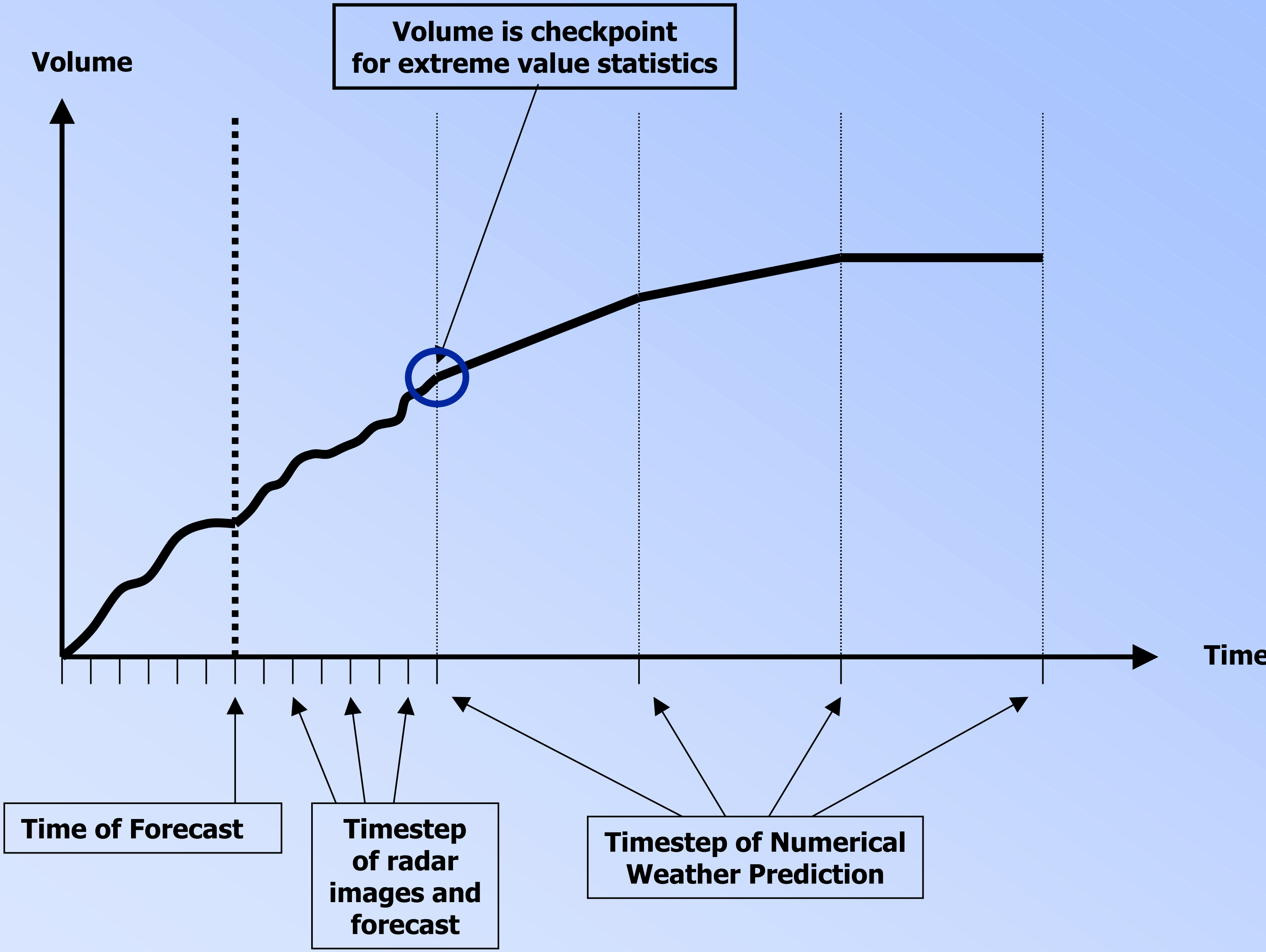
- Combined nowcasting and Numerical Weather Prediction

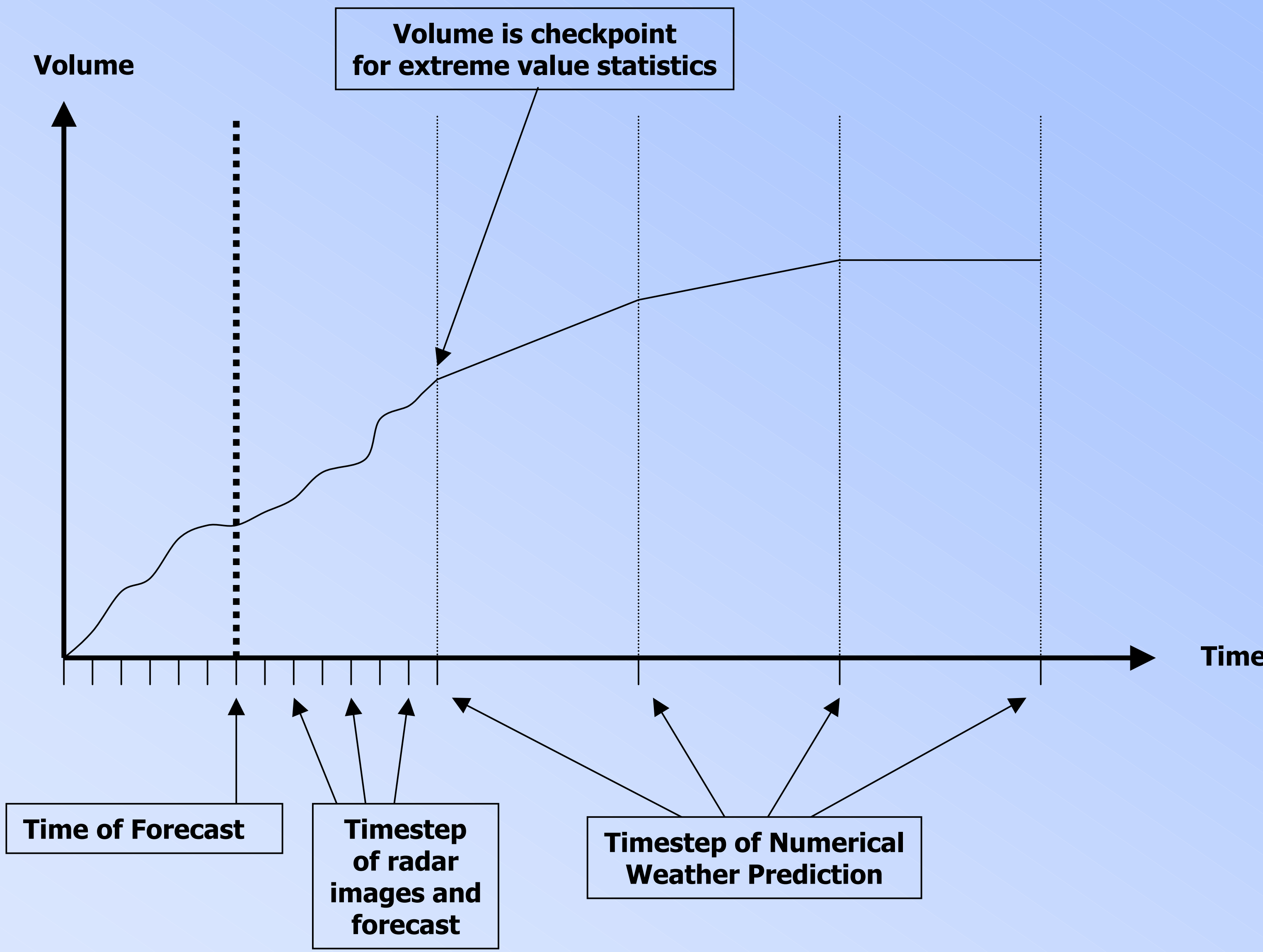

Time of Forecast
Volume
Time
raingauge measurement
Timestep of raingauge forecast
additional forecast horizon


Time of Forecast
Volume
Time
raingauge measurement
Timestep of raingauge forecast
Timestep of Numerical Weather Prediction



Time of Forecast
Volume
Time
raingauge measurement
radar forecast
Timestep of Numerical Weather Prediction


Volume is checkpoint for extreme value statistics
Volume
Time
Time of Forecast
Timestep of radar images and forecast
Timestep of Numerical Weather Prediction



Volume is checkpoint for extreme value statistics
Volume
Time
Time of Forecast
Timestep of radar images and forecast
Timestep of Numerical Weather Prediction

Overview

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  - Do you need radar data?
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Hydrological applications

Radar data – ready to use in hydrology?

In many cases:

- YES !

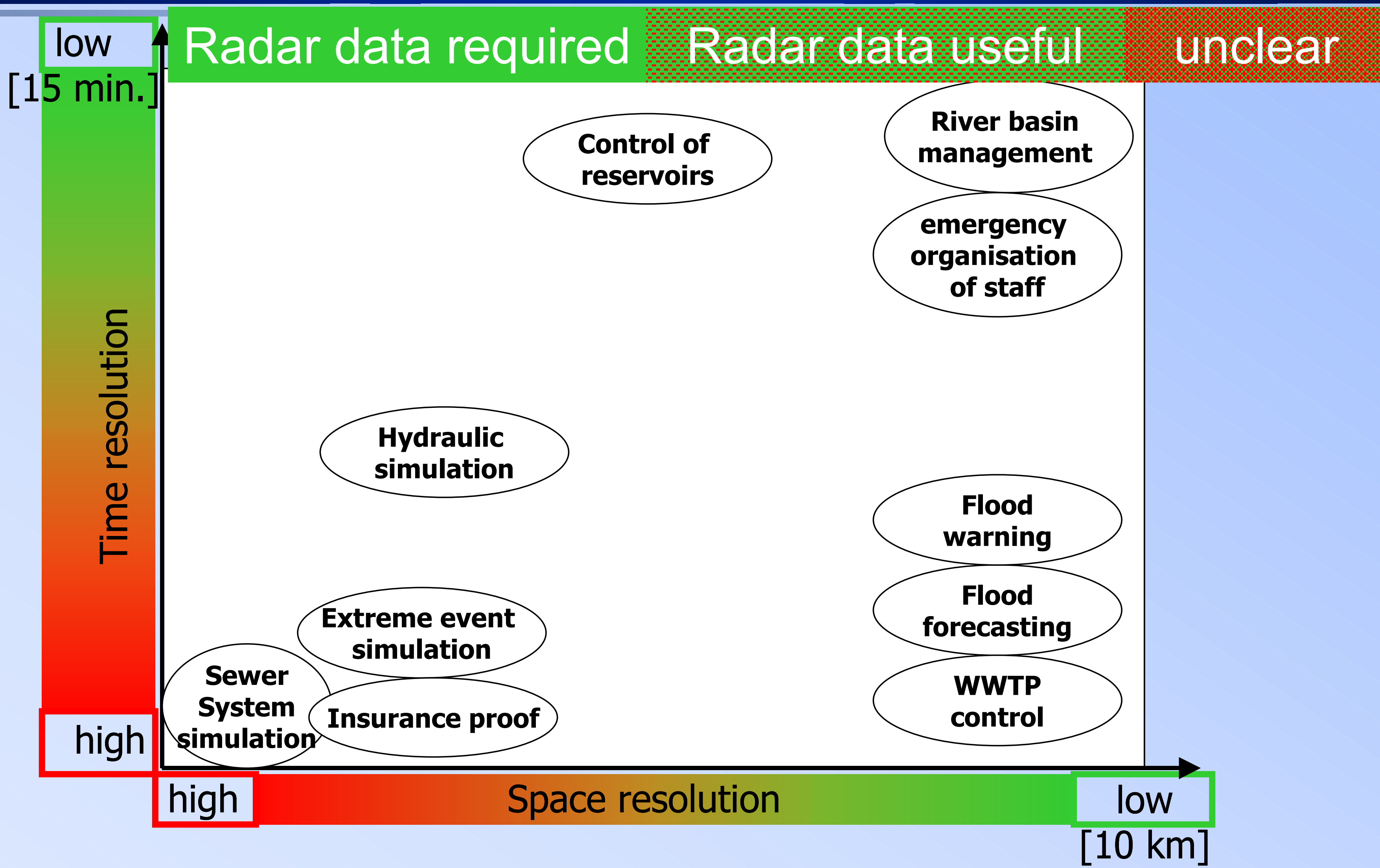
→ BUT: do you really need radar data?

→ When is it advisable to use radar data?

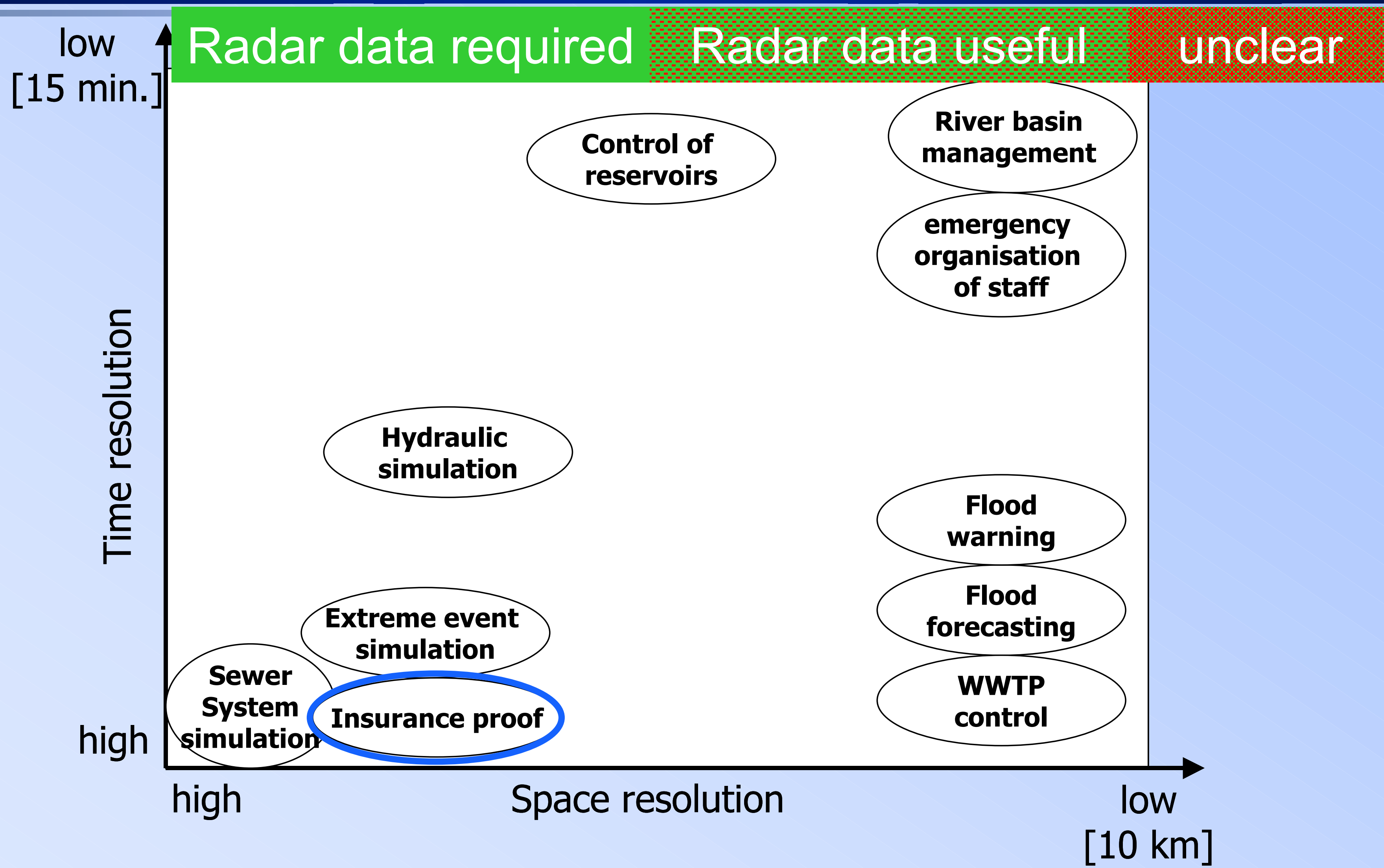
Do you need radar data?

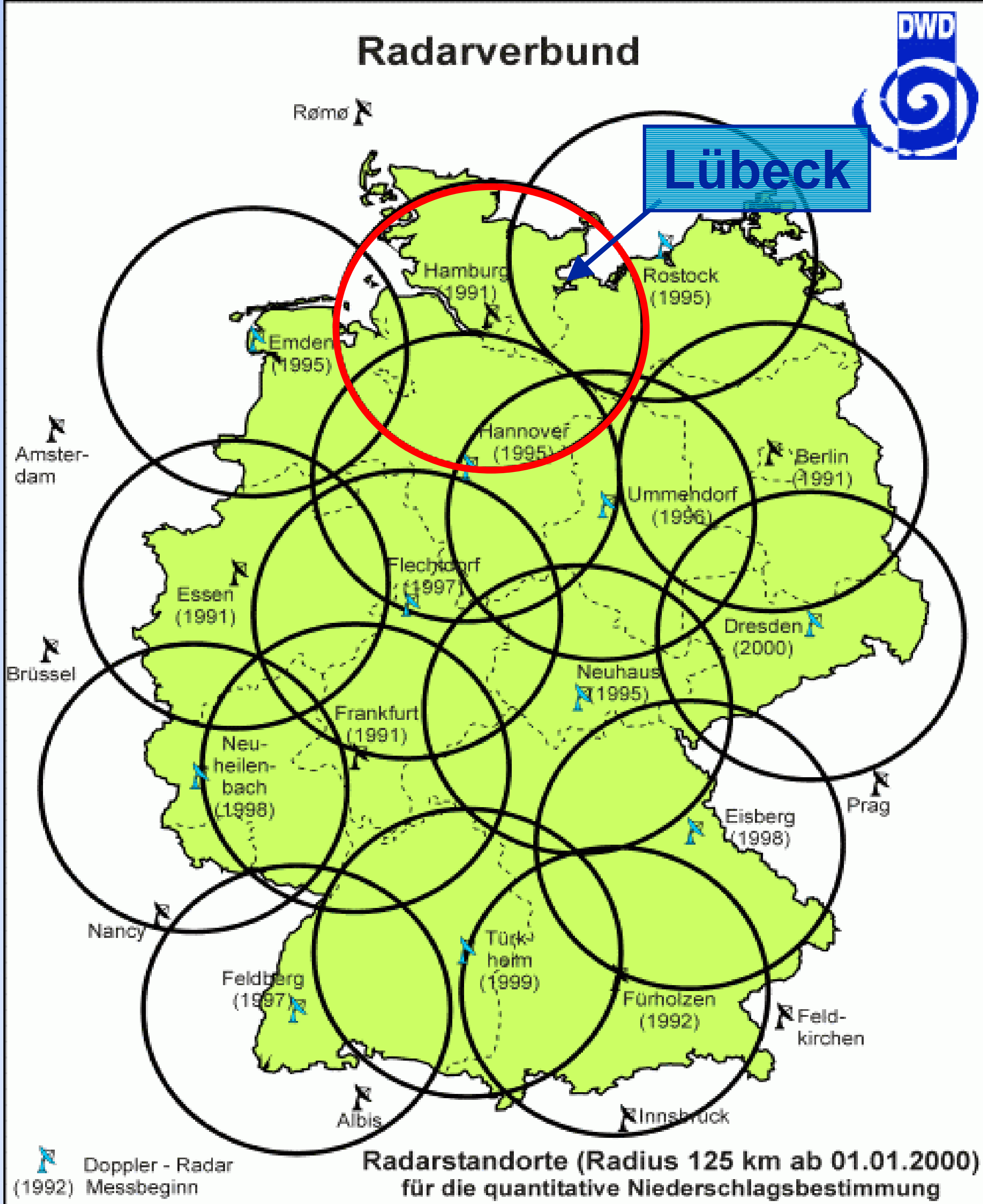
- perhaps:
  - Online
    - Warning
    - Simulation: control of basins, sewers, WWTP
    - Forecast
  - Offline
    - Long-term simulation (spatially detailed model)
    - Event assessment (extreme events / spatially variable events)

Do you need radar data?



Examples


Radar data required
Radar data useful
unclear
low
[15 min.]
Time resolution
high
high
Space resolution
low
[10 km]
Control of reservoirs
River basin management
emergency organisation of staff
Hydraulic simulation
Flood warning
Flood forecasting
Extreme event simulation
Sewer System simulation
Insurance proof
WWTP control

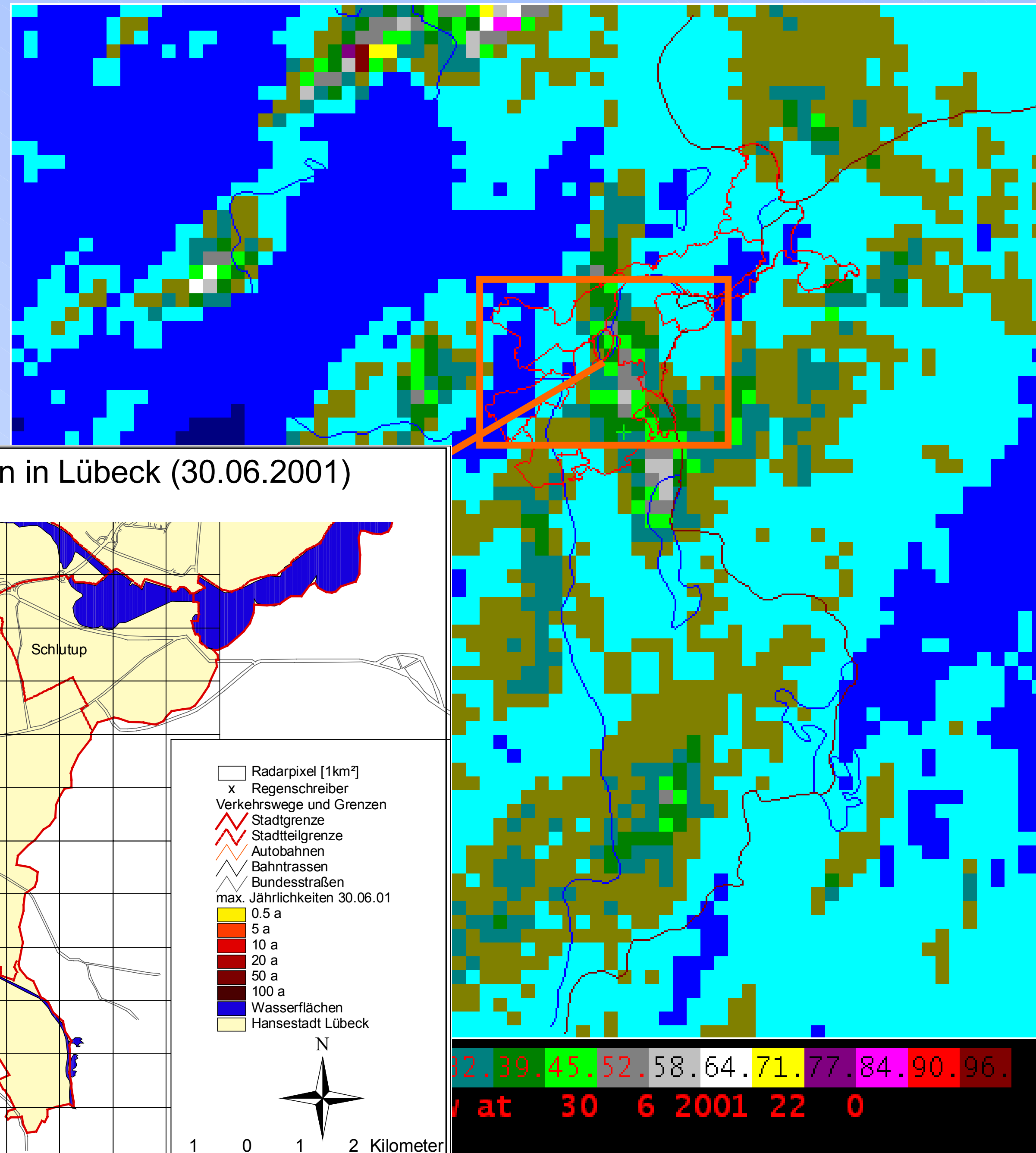

Radarverbund
DWD
Lübeck
Rømø
Hamburg (1991)
Rostock (1995)
Emden (1995)
Amster-dam
Hannover (1995)
Berlin (1991)
Ummendorf (1996)
Flechtdorf (1997)
Essen (1991)
Dresden (2000)
Brüssel
Neuhaus (1995)
Frankfurt (1991)
Neu-heilen-bach (1998)
Eisberg (1998)
Prag
Nancy
Türk-heim (1999)
Feldberg (1997)
Fürholzen (1992)
Feld-kirchen
Albis
Innsbruck
Doppler - Radar
(1992) Messbeginn
Radarstandorte (Radius 125 km ab 01.01.2000)
für die quantitative Niederschlagsbestimmung

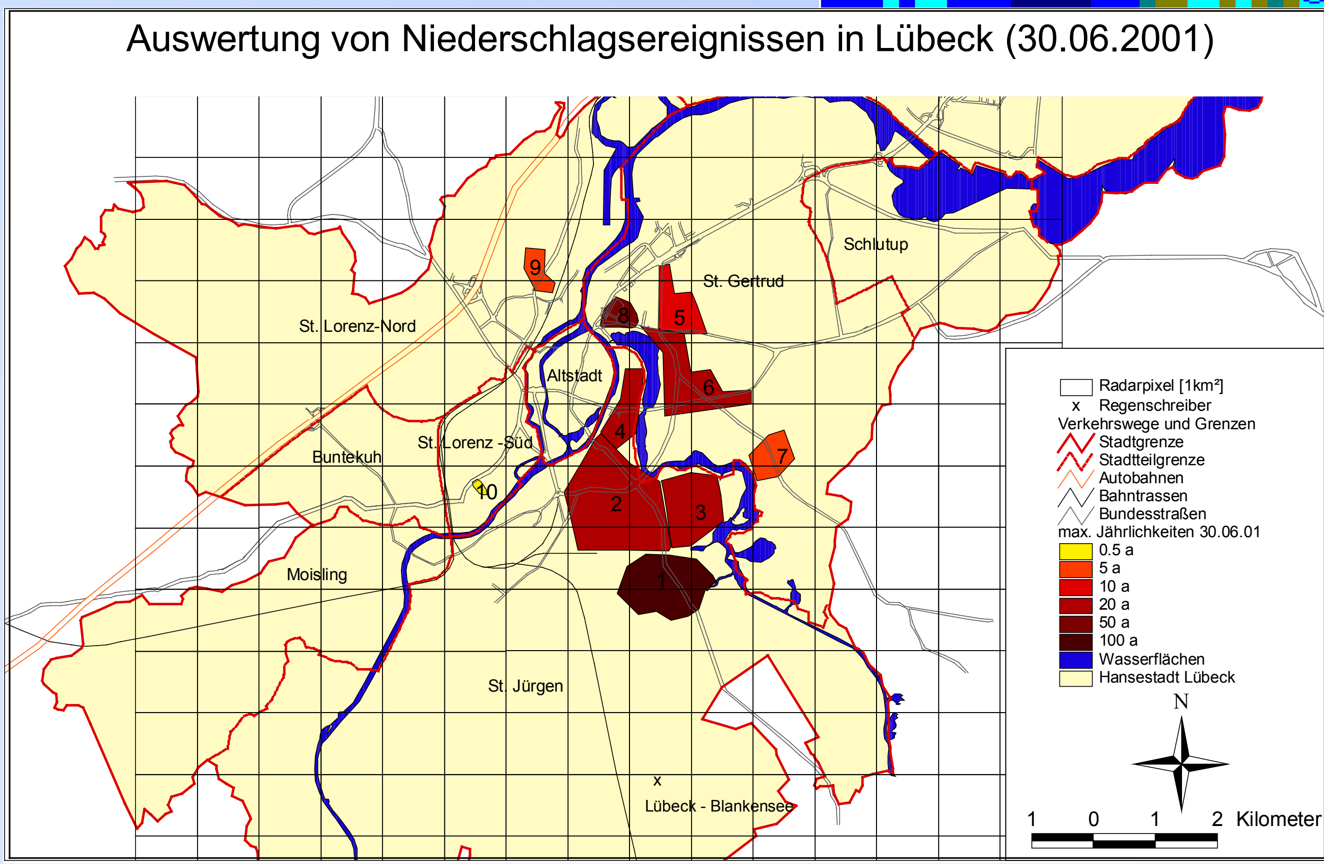
Example: insurance proof

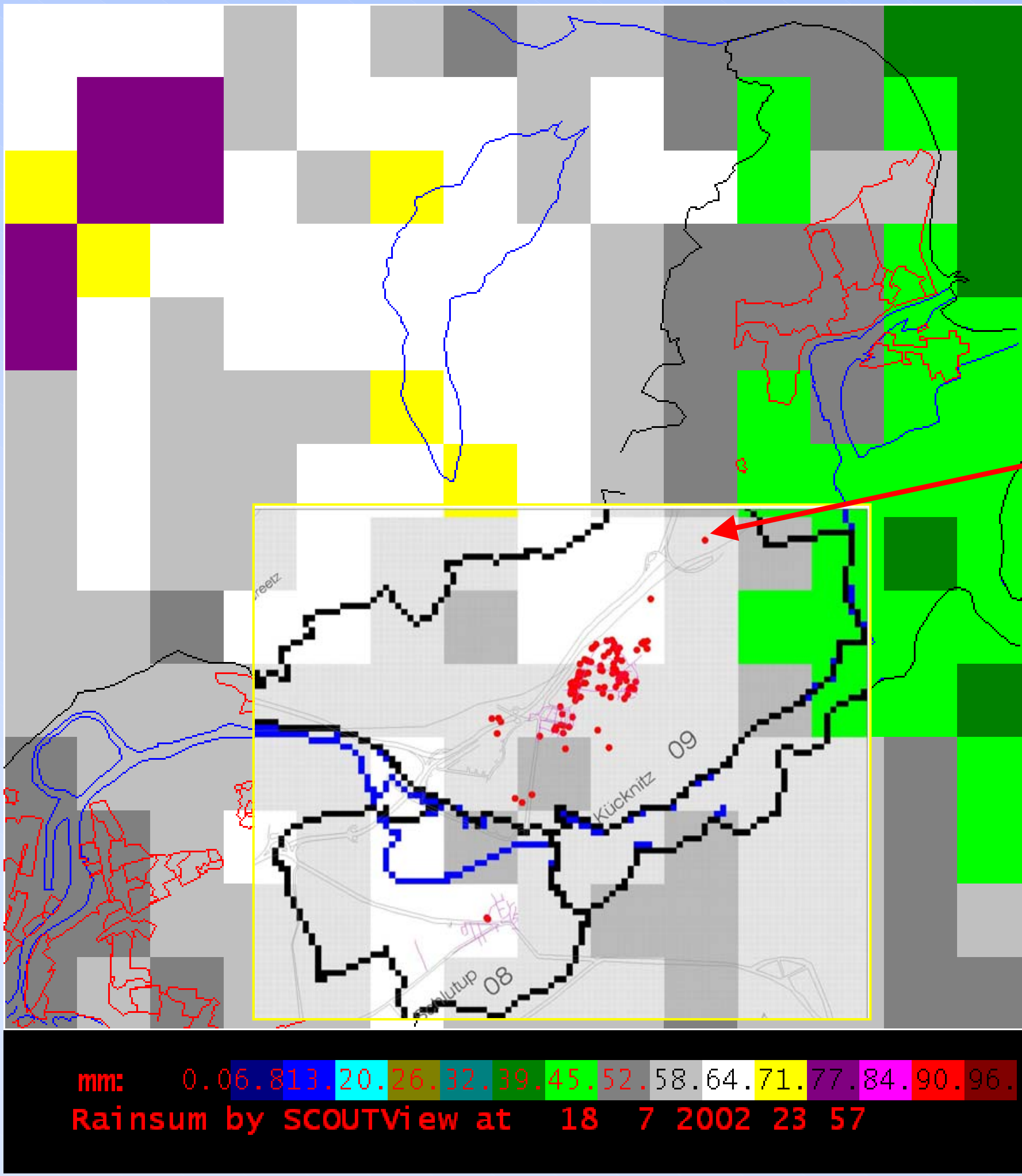
- Offline radar data
- Offline raingauge data
- Extreme value statistics for comparison
- High quality of radar data
- Small scale differences important

Rainfall sums in Lübeck and the vicinity

on 30.06.2001

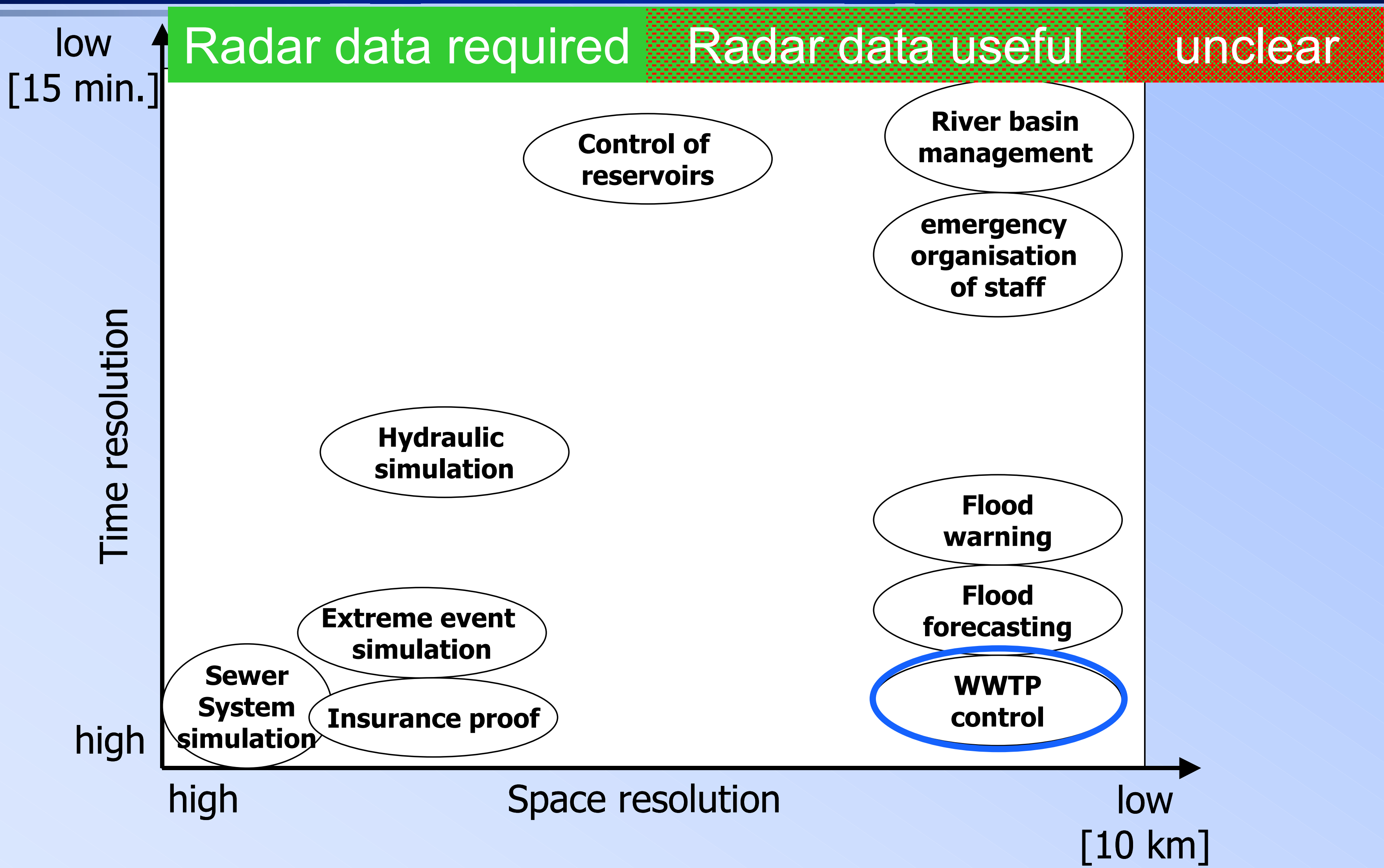






Fire brigade activity

Examples



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unclear
low
[15 min.]
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River basin management
emergency organisation of staff
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Flood forecasting
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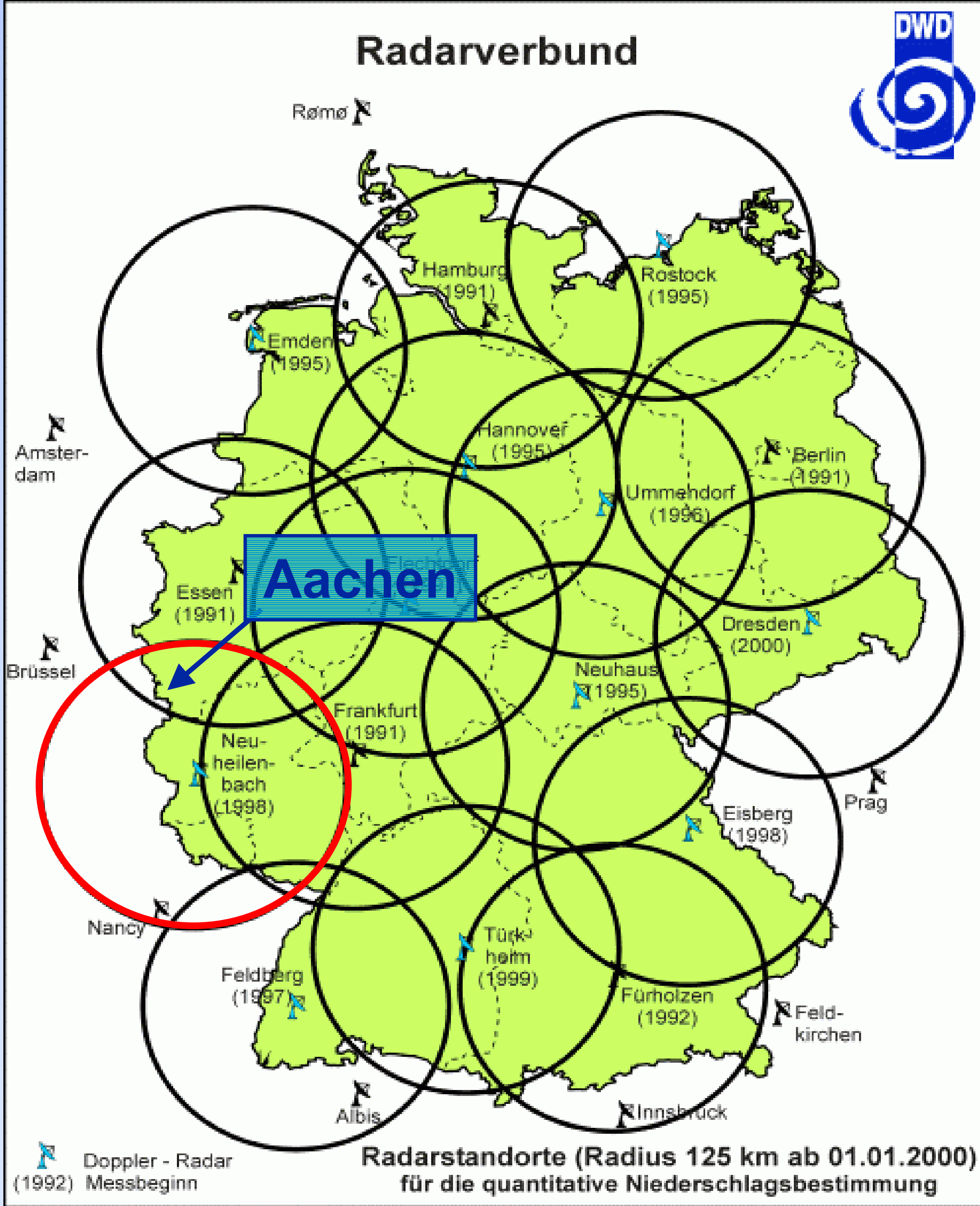
WWTP control


Radarverbund
DWD
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(1991)
Rostock
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Emden
(1995)
Amster-
dam
Hannover
(1995)
Berlin
(1991)
Ummendorf
(1996)
Aachen
Essen
(1991)
Dresden
(2000)
Brüssel
Neuhaus
(1995)
Frankfurt
(1991)
Neu-
heilen-
bach
(1998)
Eisberg
(1998)
Prag
Nancy
Türk-
heim
(1999)
Feldberg
(1997)
Fürholzen
(1992)
Feld-
kirchen
Albis
Innsbruck
Doppler - Radar
(1992) Messbeginn
Radarstandorte (Radius 125 km ab 01.01.2000)
für die quantitative Niederschlagsbestimmung

Example: WWTP inflow warning

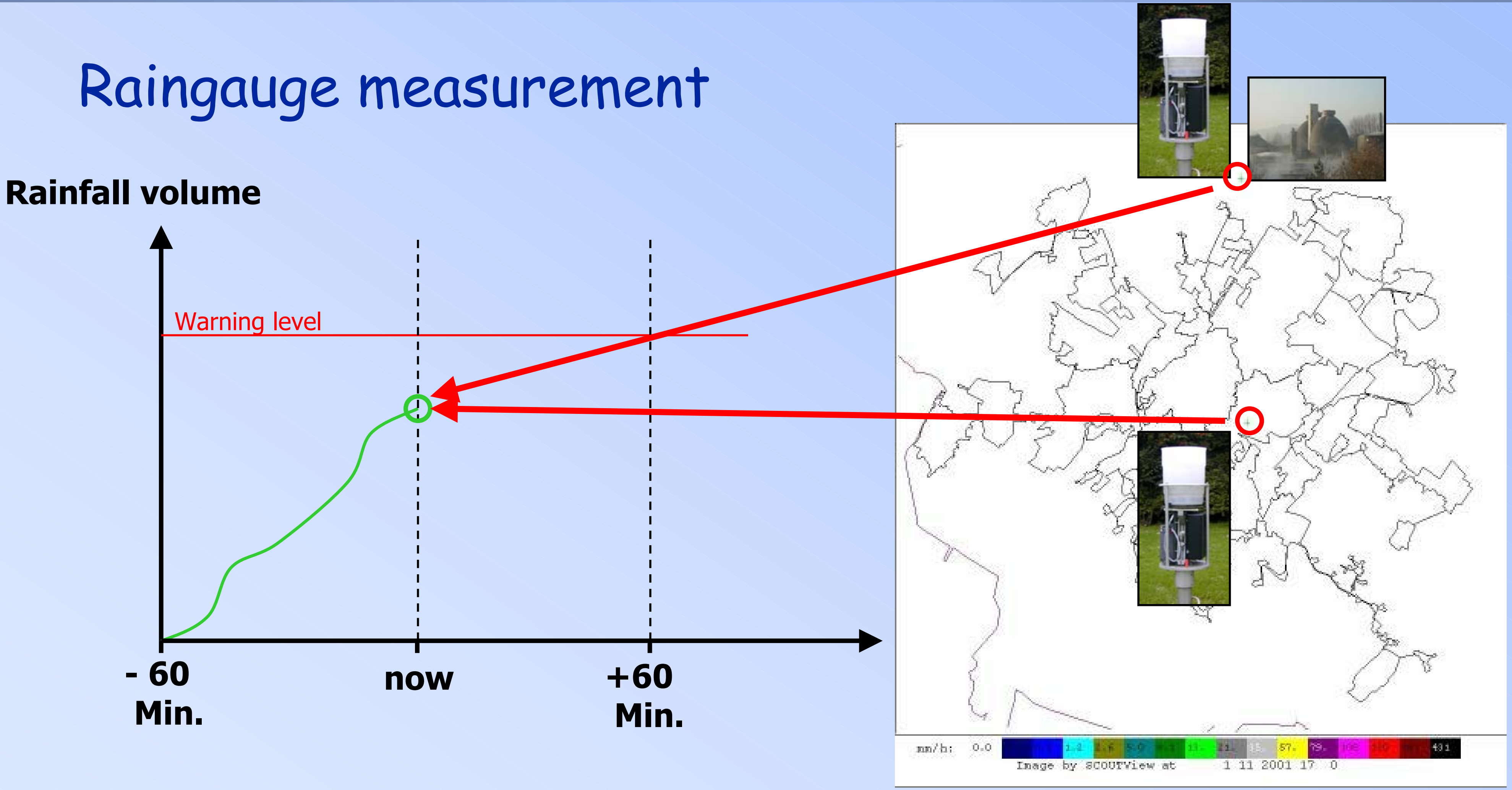
Technical objective: Warning of the inflow rise above 2*dry weather flow

Steps:

- Raingauge measurement
- Radar measurement
- Radar forecast
- Warning

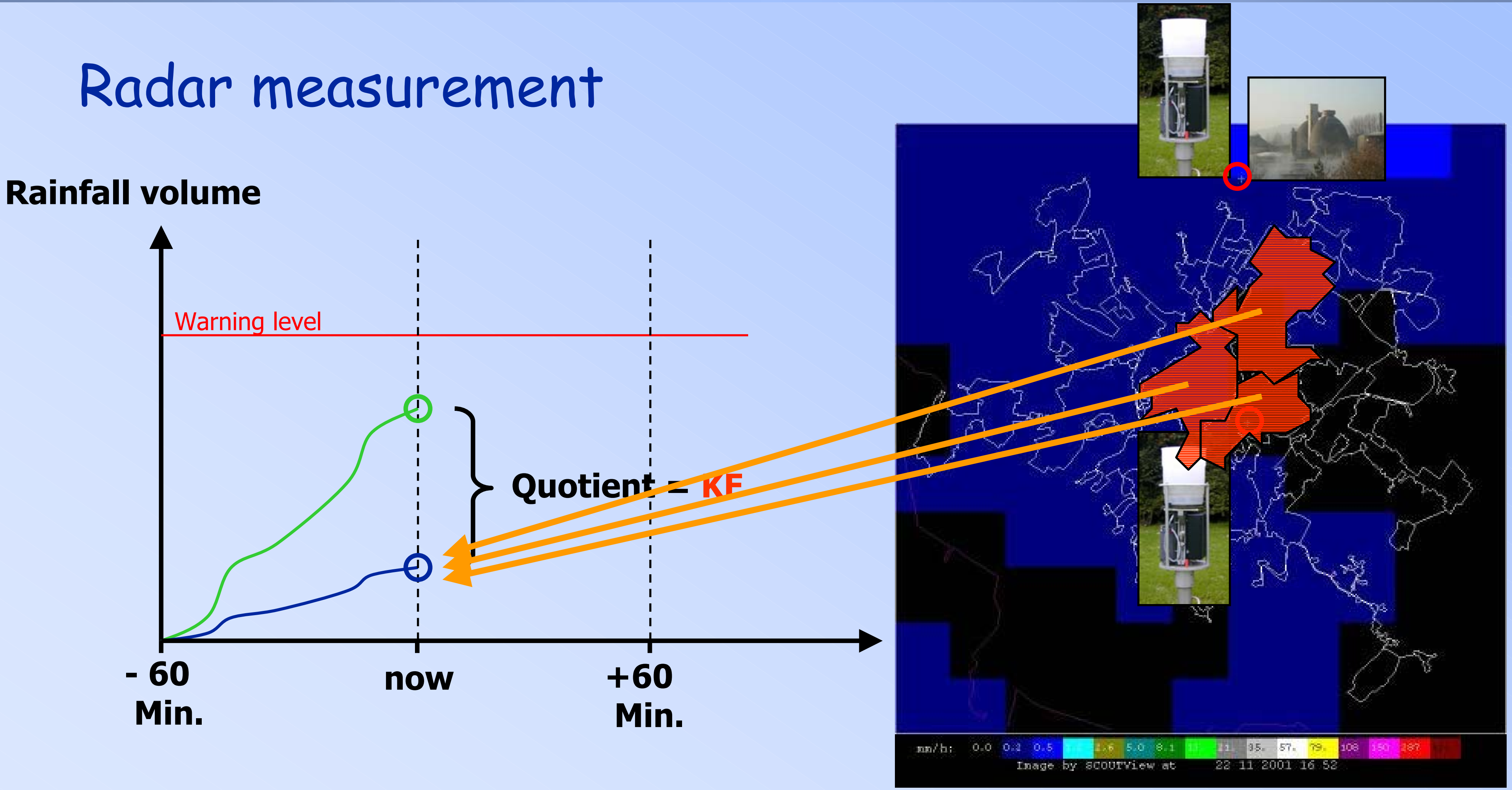
Example: WWTP inflow warning

Raingauge measurement



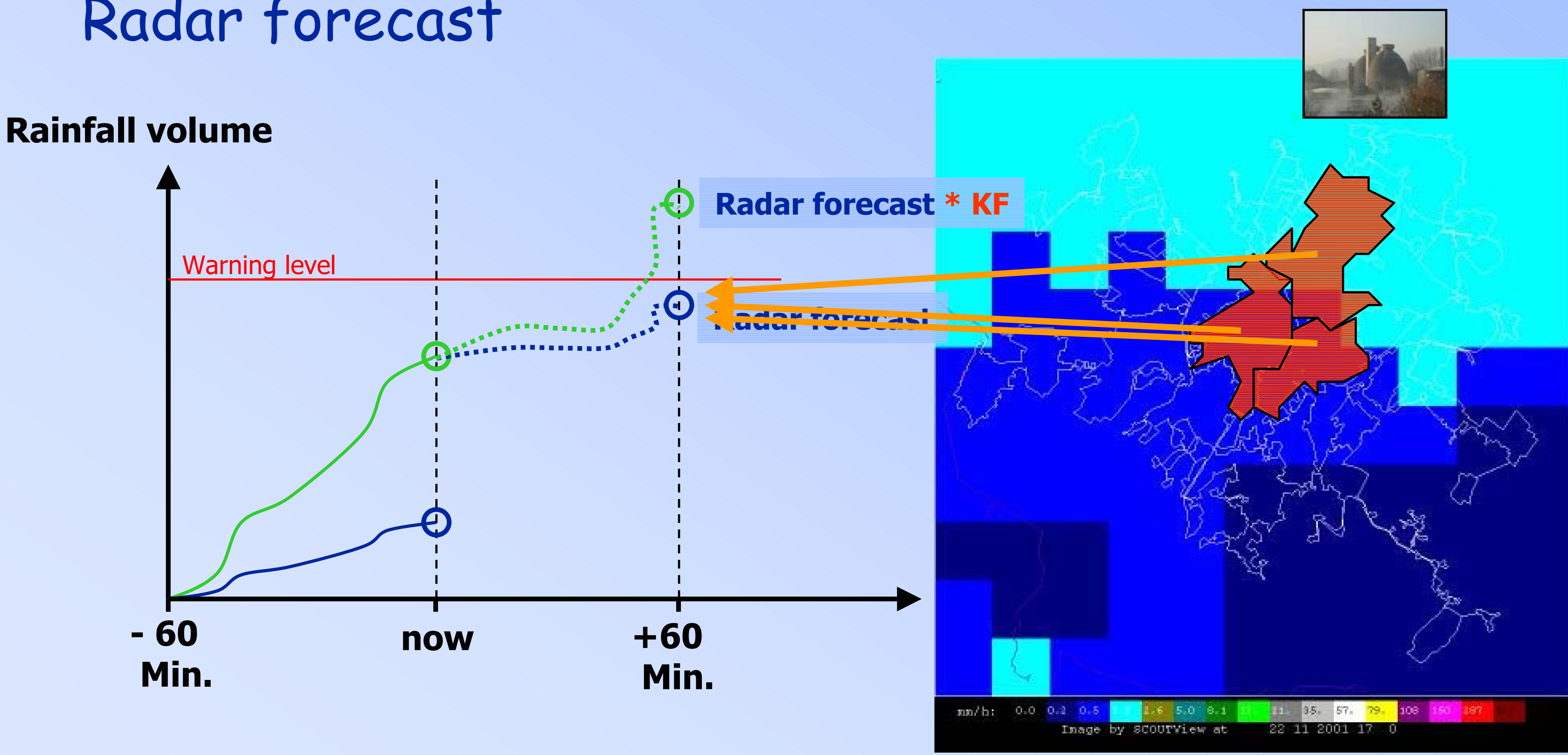
Example: WWTP inflow warning

Radar measurement



Example: WWTP inflow warning

Radar forecast



Example: WWTP inflow warning

Warning

Result

(Base: offline measurements of 6 months, 30 / 60 minutes warning horizon):

- Probability of detection: 90% / 66%
- False alarm rate: 10%

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Conclusions

- Radar data are a useful complement to raingauge data
- Data quality is of prime importance for any use
- The use of radar data in hydrology is becoming more frequent
- A guidance for hydrologists has been developed before they use radar data
- Standards on data quality and data exchange are lacking and preventing a more widespread use of reliable radar data
- The additional gain by radar data has to be worth the additional effort for preparing them

THANK YOU !

For more information:

- COST 717:
  - » http://www.smhi.se/cost717
- VOLTAIRE:
  - » http://www.voltaireproject.org
- thomas@einfalt.de

  or
- http://www.einfalt.de

V. Vukmirović, J. Plavšić, D. Pavlović and J. Despotović

Statistical analysis of rainfall – a basis for planning and design in water resources engineering

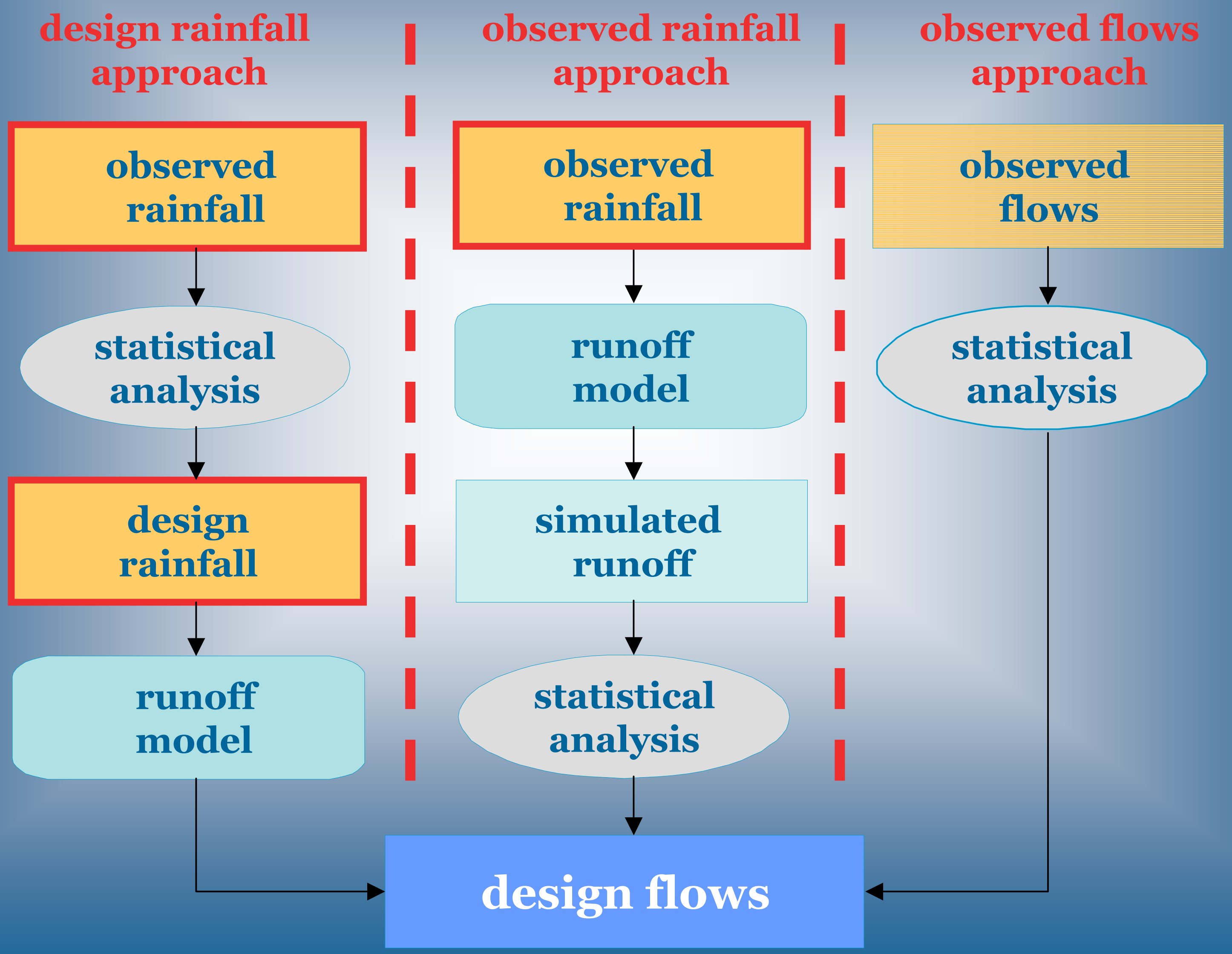
Jasna Plavšić

Faculty of Civil Engineering
University of Belgrade

Rainfall analysis

- Rainfall data for planning and design in water resources engineering
  - Historical (observed) data
    - daily, monthly, annual precipitation
    - continuous rainfall record, both wet and dry periods
    - individual events
  - Statistically analyzed data
    - design storms
    - assumption: extreme rainfall results in extreme runoff/floods

Design vs. observed rainfall for design purposes



Statistical analysis in hydrology

- Objective
  - to relate magnitude of extreme events with their frequency of occurrence, described by a *probability distribution*

frequency or probability of occurrence P ↔ **magnitude X**

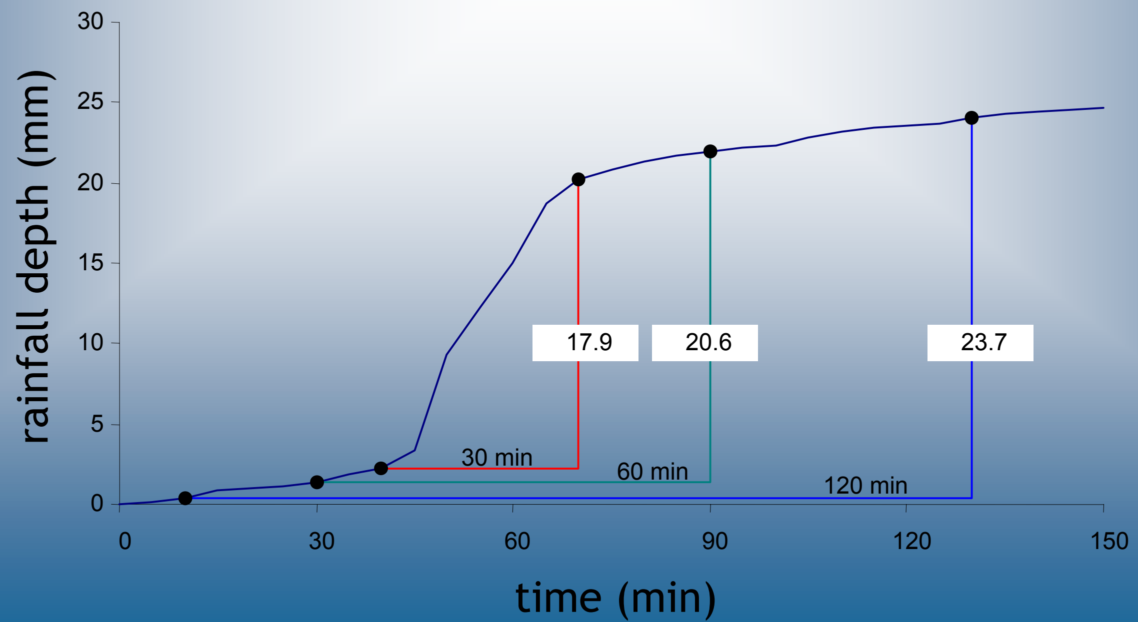
- Basic source of information
  - the record of observations of extreme events in the past ("historic data")

Statistical analysis of rainfall data

- Procedure
  - Extraction of maximum rainfall depths in predefined time intervals (rainfall durations)
  - Formation of data series for each duration
    - annual maxima / partial duration series
  - Statistical analysis for all durations
  - DDF and IDF curves
  - Statistical analysis of storm profiles (hyetograph shapes)

Historic rainfall data for statistical analysis

- Extraction of maximum rainfall depths in predefined time intervals (rainfall durations)
  - e.g. 5, 10, 15, 20, 30, 45, 60, 90, 120, 180, 240, 360, 540, 720, 1080, 1440 minutes



Historic rainfall data for statistical analysis

- Formation of data series for each duration
  - annual maximum series
  - partial duration series

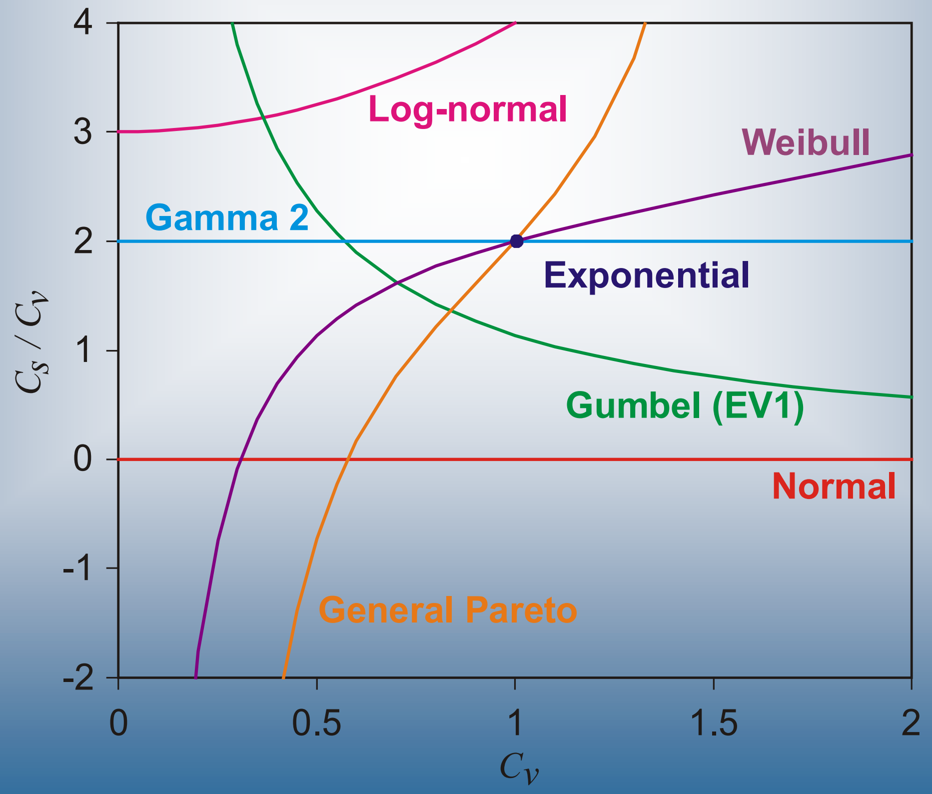
Duration (min)	Annual maximum depths (mm)					
	1959	1960	1961	...	1985	1986
5	8.2	4.0	7.7		4.0	4.8
10	15.5	7.8	10.6		6.3	7.5
15	20.5	11.1	12.0		6.4	9.3
20	23.6	14.5	12.9		6.9	9.8
30	29.8	18.7	13.4		8.0	10.1
45	39.3	20.3	15.2		9.0	11.1
60	41.3	20.7	16.7		10.4	14.5
90	42.7	21.8	19.2		11.0	16.2
120	43.5	22.1	21.9		12.4	18.3
150	45.1	22.1	23.3		13.8	22.6
180	46.4	22.5	24.3		14.6	25.1
240	48.0	23.9	25.8		16.6	30.7
360	48.3	25.1	29.2		20.9	36.0
540	48.3	25.3	31.4		25.3	36.0
720	48.4	25.8	35.0		28.4	36.0
1080	48.4	27.3	38.8		29.6	36.0
1440	49.8	27.3	44.7		29.6	36.0

Statistical analysis of annual maxima

- Classical approach for everyday practice
- Distribution fitting
  - gamma family (2-par. gamma, Pearson III, log-Pearson III, 2- and 3-par. Weibull, generalized 3-par. gamma or Kritski-Menkel)
  - parameter estimation methods (moments, maximum likelyhood, PWM)
  - goodness-of-fit tests (Kramer-von Mises, PPCC)
  - moment ratios and moment diagrams are useful criteria for selecting a distribution

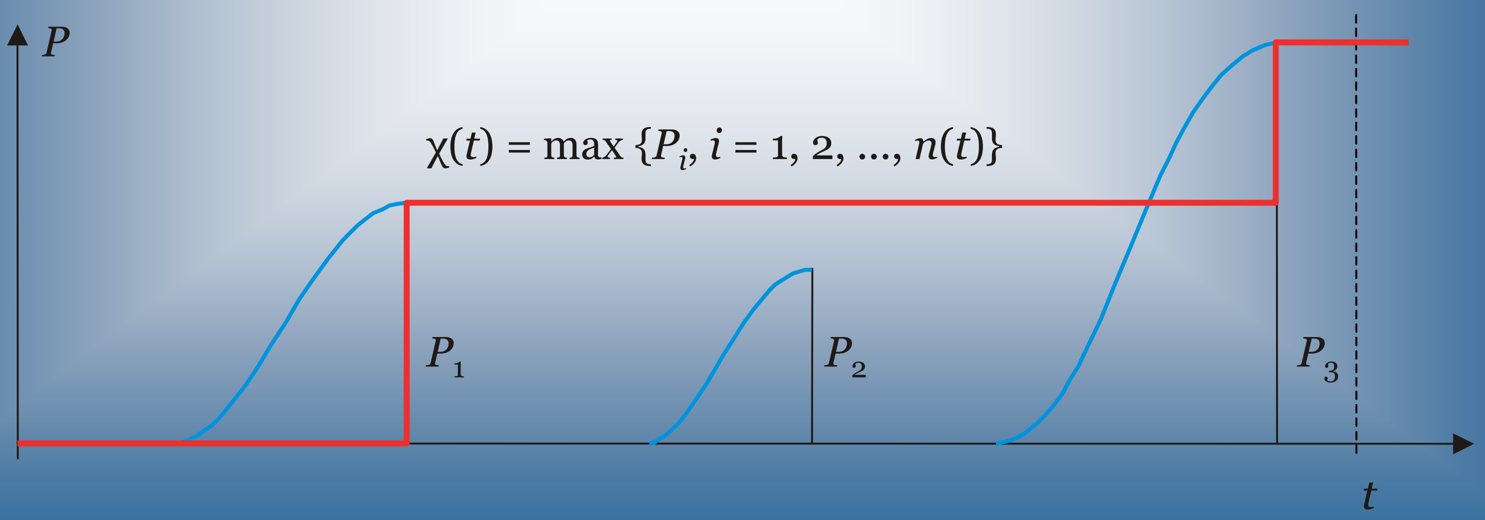
Statistical analysis of annual maxima

- moment ratios and moment diagrams as a criteria for selecting a distribution



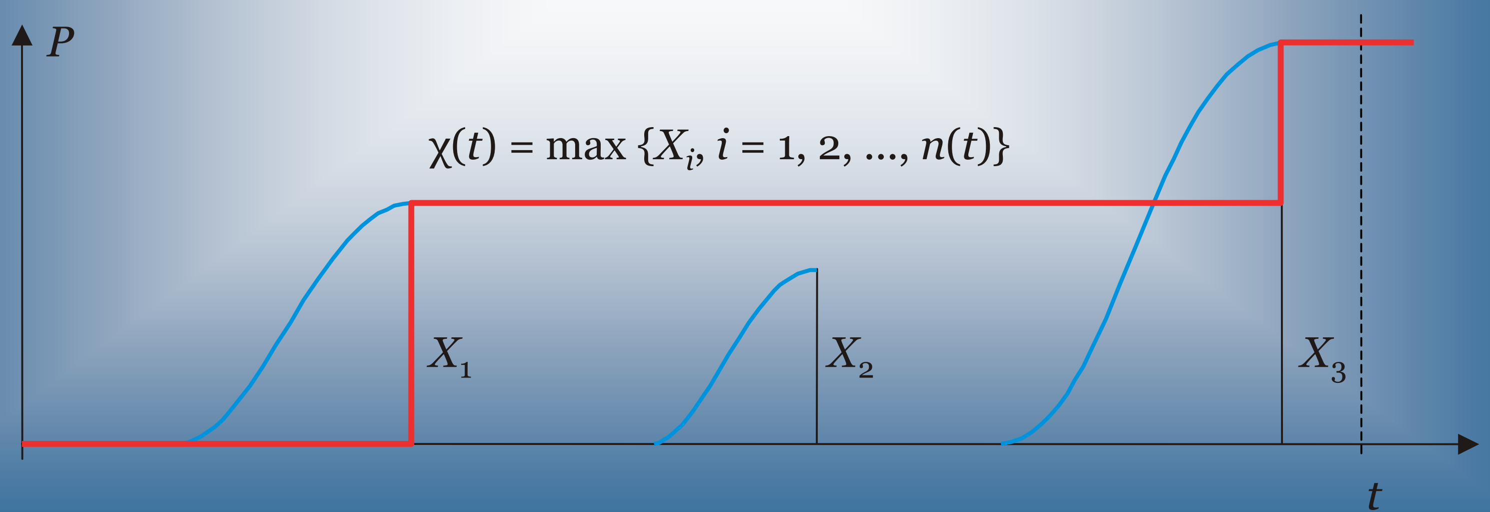
Statistical analysis of partial duration series

- Partial duration series:
  - events with depths exceeding certain threshold



Statistical analysis of partial duration series

- Components:
  - number of events n as a random variable
  - exceedances X_i as a random variables
  - largest exceedance χ



Modelling of PDS

number of exceedances
n

distribution:
$P\{ n = k \}$

exceedances
$X_1, X_2, \ldots, X_n$

distribution:
$H_i(x) = P\{ X_i \leq x \}$

largest exceedance
$\chi = \max \{ X_1, X_2, \ldots, X_n \}$

distribution:
$F(x;t) = P\{ \chi \leq x \}$

Statistical analysis of partial duration series

- Distributions for number of exceedances
  - Poisson
  - binomial
  - negative binomial
- Distributions for exceedances
  - exponential
  - 2-par. Weibull
  - general Pareto

- Distribution of largest annual exceedance:
  - Todorovic (1970)

$$F(x) = P\{\chi_{AN} \le x\} = P\{n = 0\} + \sum_{k=1}^{\infty} P\{n = k\} \cdot [H(x)]^k$$

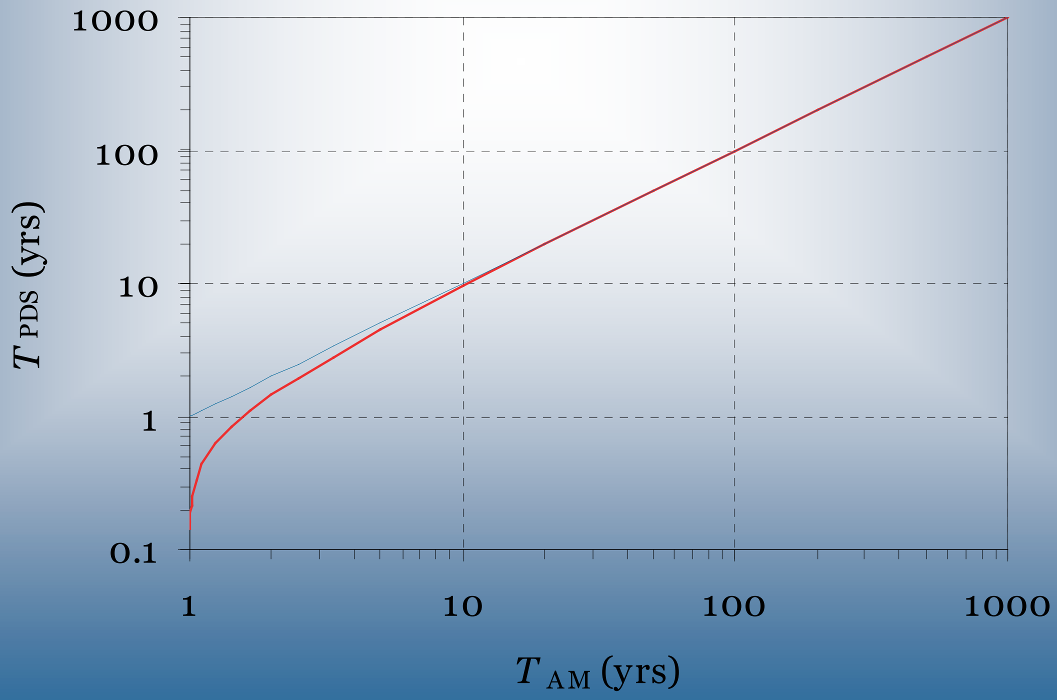
$$P + E: \quad F(x) = \exp\{-\Lambda \exp[-x/\mu]\}$$

Statistical analysis of partial duration series

- Return period in PDS

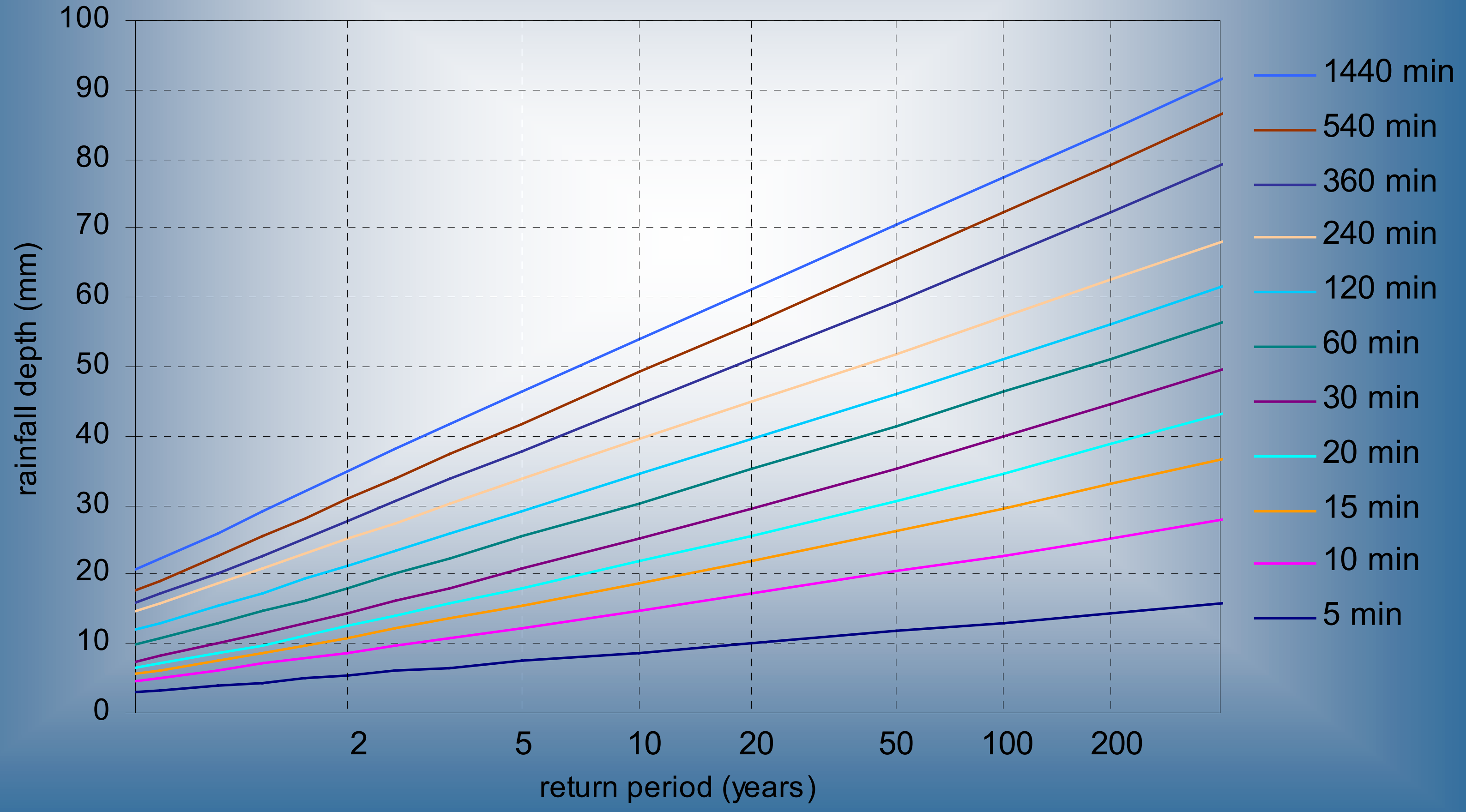
$$T_{PDS}(x) = \frac{1}{\Lambda[1 - H(x)]}$$

$$T_{AM}(x) = \frac{1}{1 - F(x)}$$



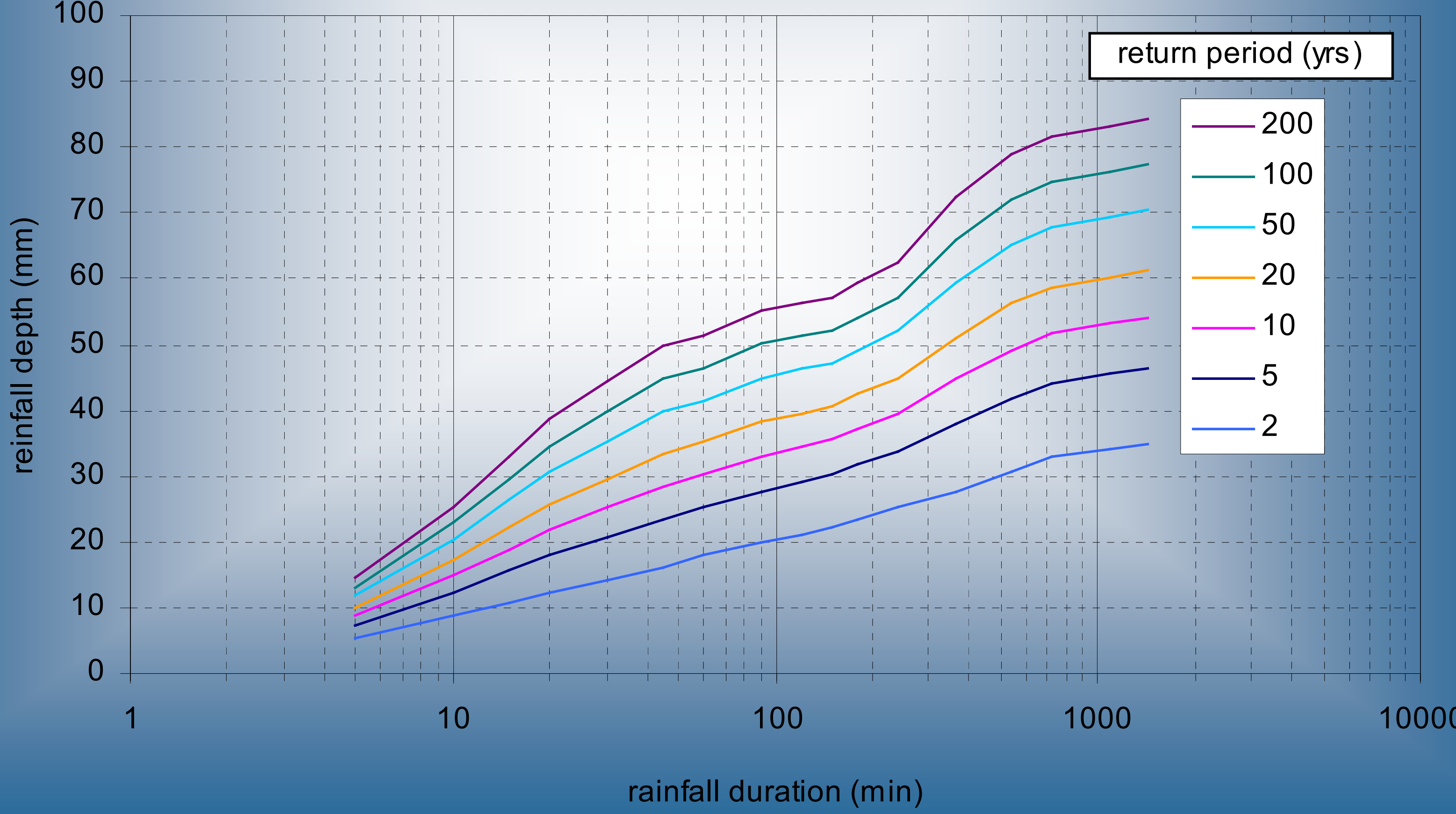
'Final result' of statistical analysis

- Rainfall depth distributions for all durations



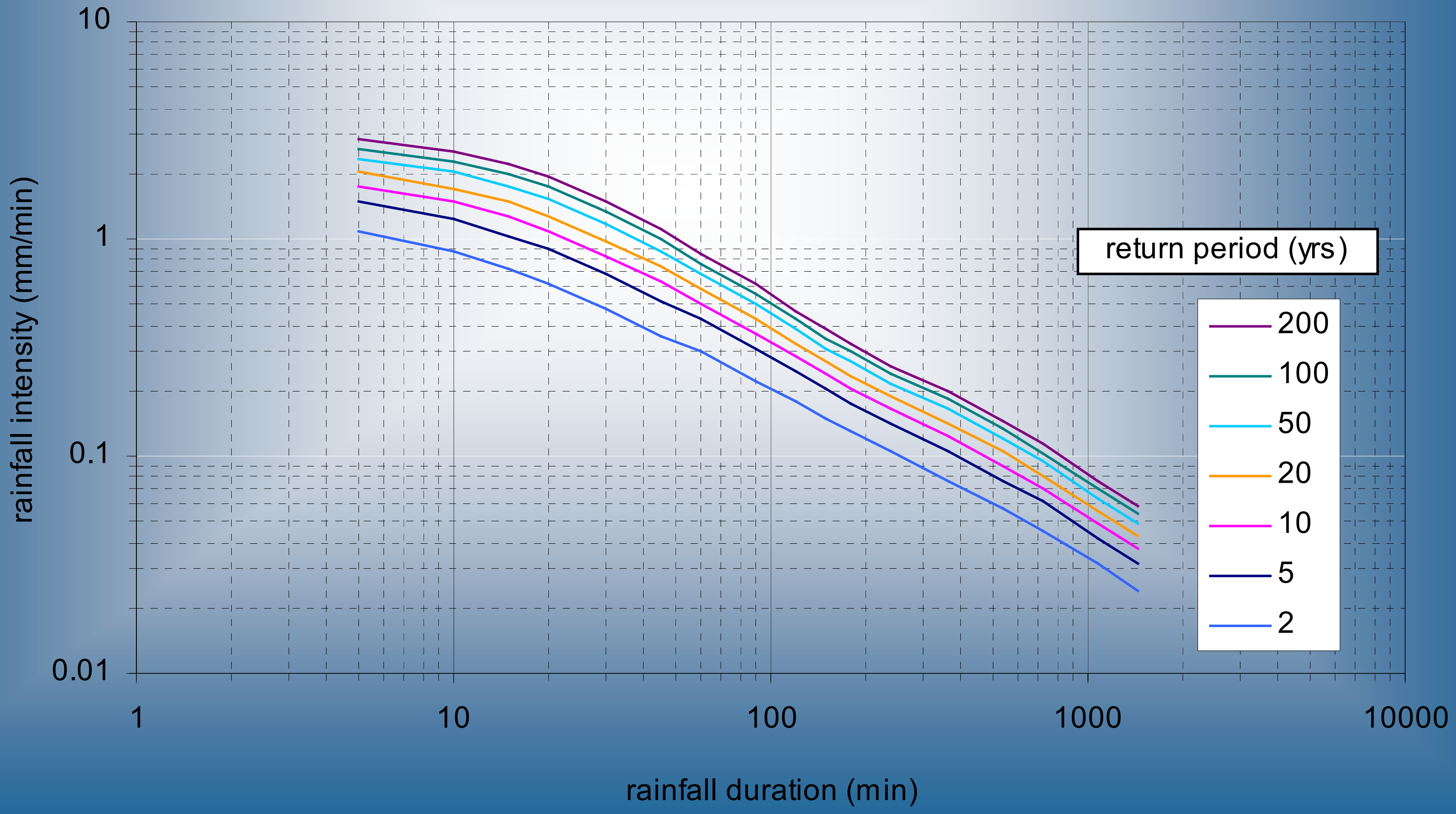
‘Final result’ of statistical analysis

- DDF curves



‘Final result’ of statistical analysis

- IDF curves
  - representing mean rainfall intensity



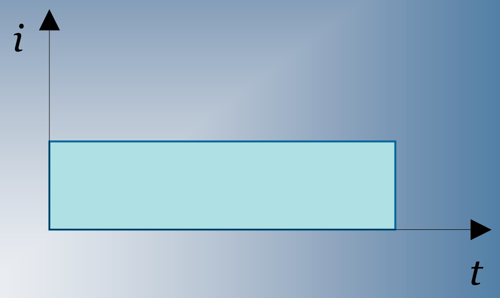
‘Final result’ of statistical analysis

- IDF curves
  - representing mean rainfall intensity
  - equations for IDF curves

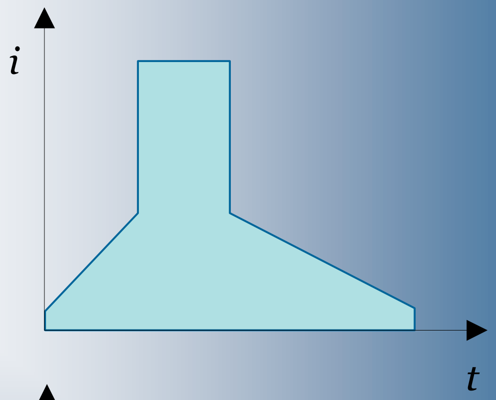
$$i = \frac{A}{(t_k + C)^B}, \quad i = \frac{AT^D}{(t_k + C)^B}, \quad i = \frac{AT^D}{t_k^B + C}$$

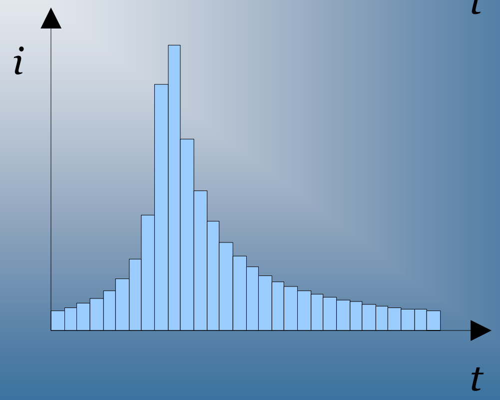
Temporal distribution of design rainfall

- Block storm
  - from IDF curves



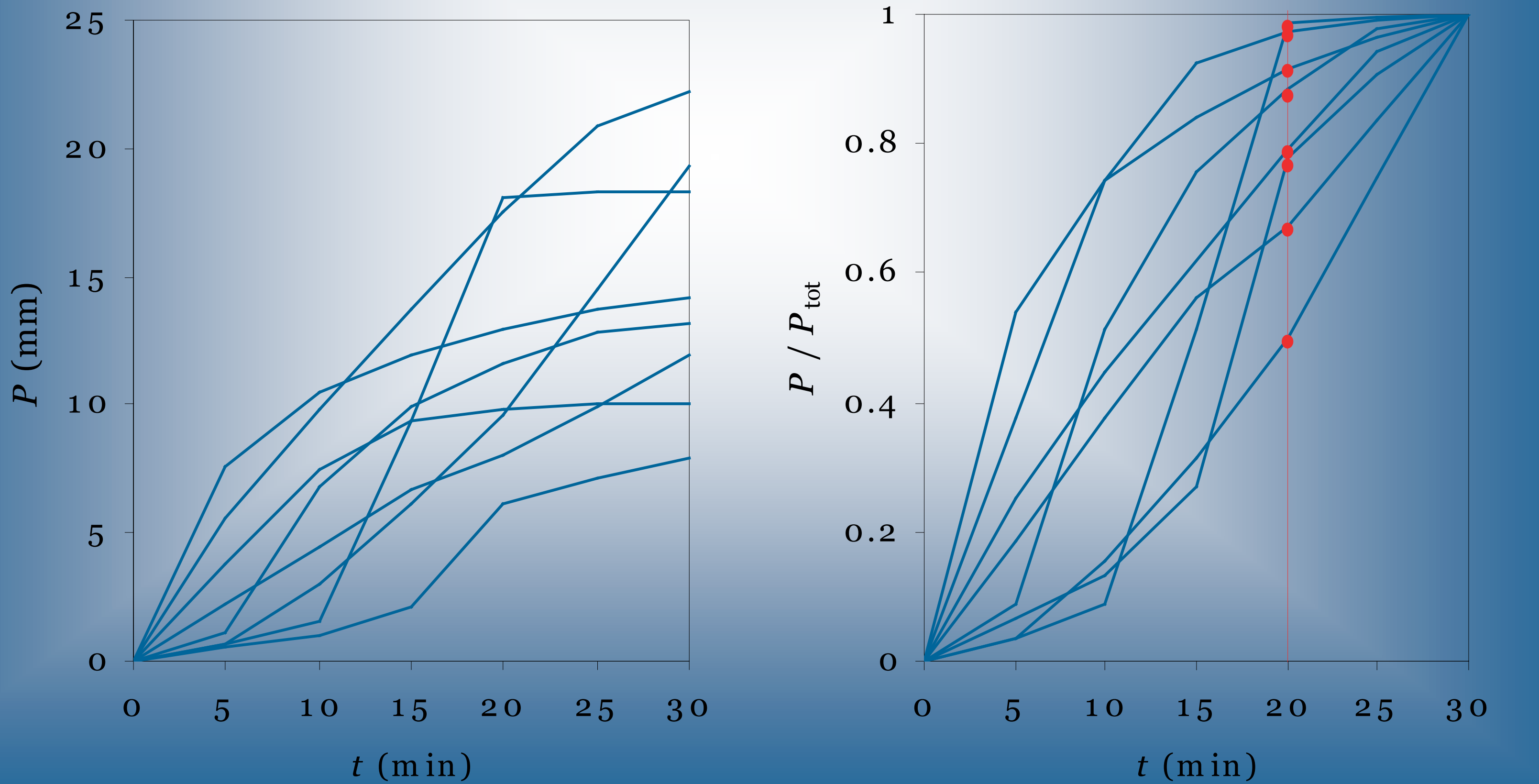
- Synthetic storm profiles
  - e.g. Sifalda storm or Chicago storm





Temporal distribution of design rainfall

- Statistical storm profiles
  - statistical analysis of shapes of historical rainfall



Temporal distribution of design rainfall

- Statistical storm profiles
  - statistical analysis of shapes of historical rainfall
  - non-dimensional depth analyzed at selected time intervals

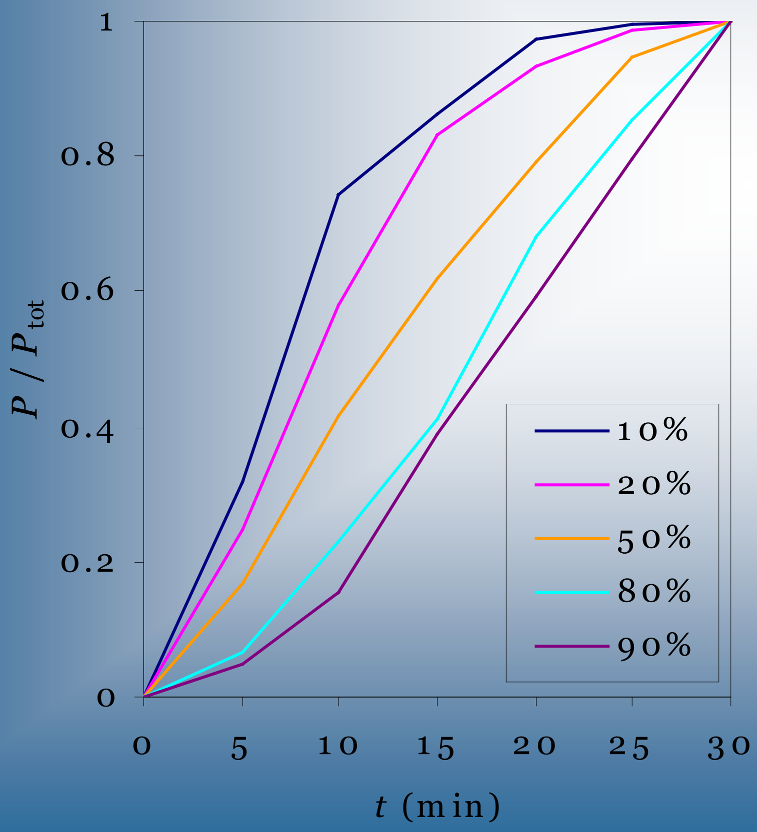
$$\pi(t) = \frac{P(t)}{P(t_r)}$$

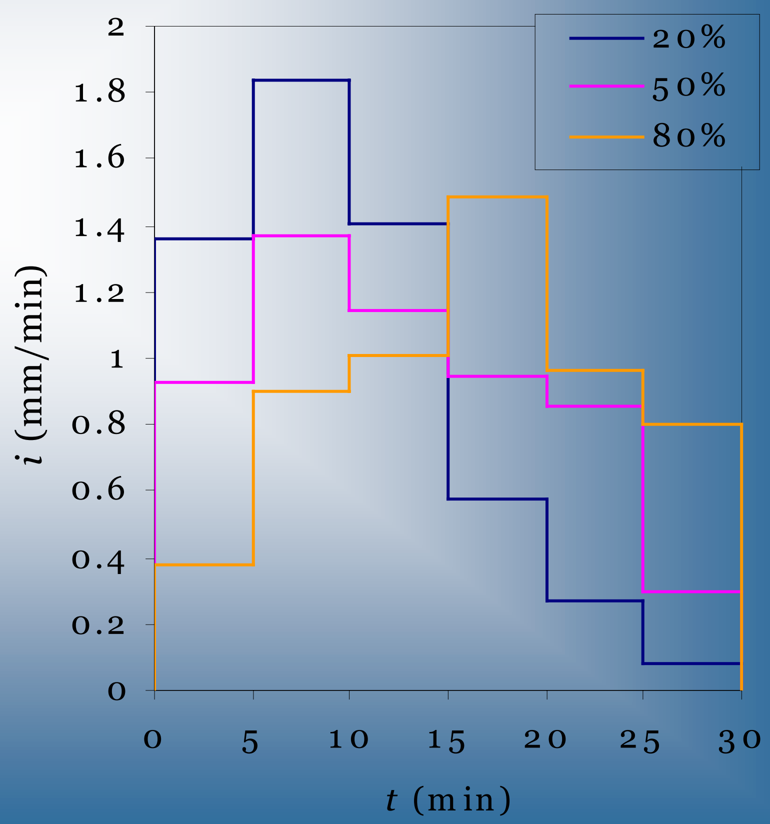
  - beta distribution for $\pi(t)$, since $0 \le \pi \le 1$:

$$F(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}$$

Temporal distribution of design rainfall

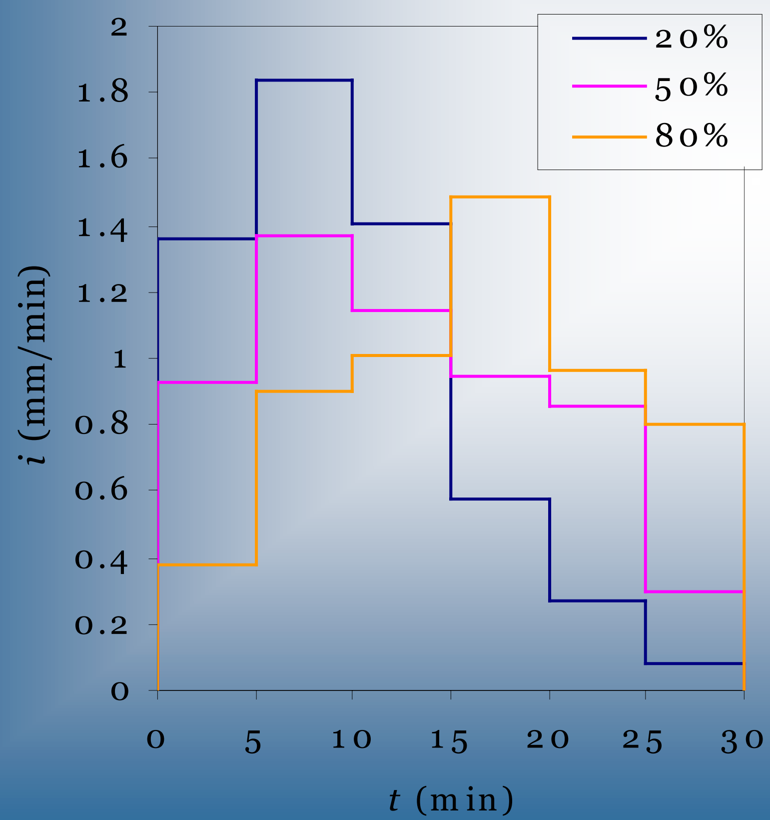
- Statistical storm profiles
  - statistical analysis of shapes of historical rainfall





Temporal distribution of design rainfall

- Statistical storm profiles
  - check intensities against ITP curves



- intensity in each interval Δt should not exceed intensities for duration Δt from ITP curves

Other topics

- Detection of outliers
- Regional statistical analysis
- Statistical methods for rainfall spatial interpolation
- Detection of trends, non-stationarity, etc.
- Uncertainty resulting from statistical analysis, its implication to runoff modelling

Regional cooperation context

- Important role of rainfall statistical analysis in a regional project
  - provides basis for objective comparisons
  - can contribute to more reliable filling of gaps in records when applied in regional context
  - leads towards production of a rainfall atlas for the region

BOSNIA-HERZEGOVINA
FEDERAL METEOROLOGICAL INSTITUTE
Prepared by: Muhamed Muminović

CURRENT PRACTICE IN RAINFALL MEASUREMENT, COLLECTING, PROCESSING AND DATA ANALYSIS

1. SITUATION IN THE RAINFALL MEASURING NETWORK IN BOSNIA-HERZEGOVINA UP TO 1992.

► 21 professional, main meteorological stations
► 120 climatological stations
► 520 rainfall stations with Helmann type rain gauges

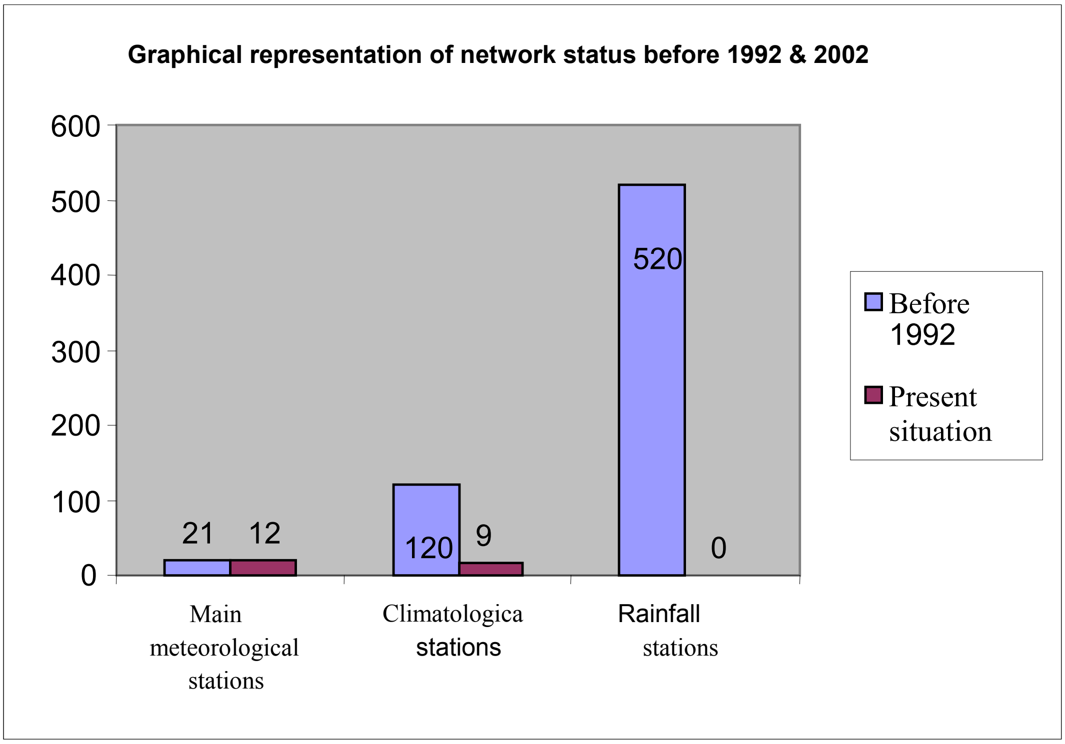
2. CURRENT SITUATION IN THE RAINFALL MEASURING NETWORK IN FEDERATION of B&H (AS IN THE YEAR 2005)

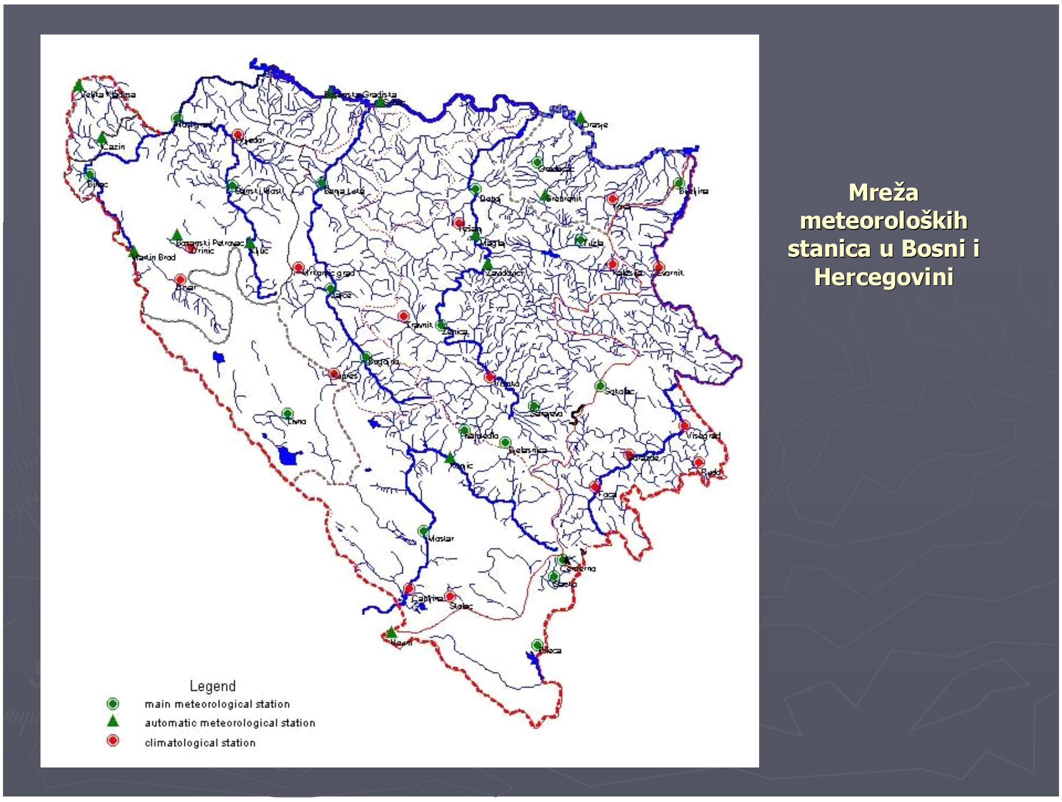
► 12 main meteorological stations

► 9 climatological stations

► 0 rainfall stations with Helmann type rain gauges

► 12 automatic meteorological stations with on–line data transmission





Meteorological stations network in Bosnia-Herzegovina

3. HYDROLOGICAL STATIONS

- On the territory of Federation of Bosnia-Herzegovina during 2005 there were 67 hydrological stations. Of which 52 are automatic with on-line data transmission, 4 are limnigraph type, and 11 are with manual observation.

Mreža hidroloških stanica u Federaciji Bosne i Hercegovine

Hydrological stations network in Federation of Bosnia-Herzegovina

4. RAINFALL MEASUREMENTS

- 3 Main synoptic stations, Sarajevo, Bjelašnica, and Mostar, report observations every hour. Rainfall measuring are in 00, 06, 12 and 18 hours UTC. All data transmiting to international exchange trough Regional Basic Synoptic Network (RBSN) and Regional Basic Climatological Network (RBCN).

- Other Main stations have measurements every 3 hours, rainfalls measurements are at 06 and 12 hours UTC.

- Automatic meteorological stations have data registration at different intervals i.e. every 15 minutes, 30 minutes, or another timings as they are adjusted.

- Rainfall data from Main stations are daily everyday using phone or radio transmission.

.

- Rainfall data from climatological stations are collected trough climatological registers (diaries) and delivered to the Institute once a month by regular post.

- Rainfall data from automatic meteorological stations are collected occasionally by modem connection, land or GSM phone connection ("real-time reports").

5. CLASSIC METEOROLOGICAL INSTRUMENTS USED FOR RAINFALL MEASUREMENTS.

- The Main stations which collect rainfall data use Helmann type rain gauges (Lambrecht).
- During the period from 30.4. to 31.10. each year, for rainfall data collection, daily mechanical drum recording rain gauges (ombrographs) Helmann type (Lambrecht) are used on stations, calibrated to the 1 mm.
- Period for using of ombrograph can be prolonged or shortened depending on weather situation.

6. CONTROL, ANALYSIS, AND USE OF DATA

- After collecting and controlling of data, the process of registering begins. Main elements of data in our archive are digitalized.
- We have started installation of Oracle database along with software package Clidata. Oracle is donation of Czech republic.
- Problems with non-homogeneity of data are being solved with application of standard statistic methods.

- We are excepting advancement in co-operation with Meteorological services of Croatia and Serbia and Montenegro. Specially, for us will be important receiving of data from border stations. Use of such data can simplify procedures for tag of missed data.

► Rainfall data in our Institute use hydrological and meteorological department who are authorized for activities in this field. Data from the Institute are available in form of various products trough information's, warnings, bulletins, forecasts, yearly reports etc… are forwarded to:

- Institutions authorized for activities in water management
- Public information services
- General public
- Any other requesting agency

7. PRIORITIES OF HYDROMETEOROLOGICAL SERVICE OF FB&H IN AREA OF RAINFALL DATA MANAGEMENT

► Expansion of existing network of rainfall stations
► Modernization
► Introduction of "real-time report" method of work
► Automatization of data transmission
► Operative exchange of hydrological and meteorological data and information inside country and regionally.

Torough those priorities it is possible to improve measurement process, collecting, handling and distribution of data. This is specifically important in the system of early warning and theforecasting of floods and other extreme meteorological events.

RAINFALL DATA MEASUREMENT, PROCESSING AND ANALYSIS IN BULGARIA

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1. Rainfall data measurement

The precipitation measurements supported and managed methodically by National Institute of Meteorology and Hydrology (NIMH) are carried out in 42 synoptic stations (8 synoptic and 3 climate obs/day), 96 voluntary climatological stations (3 climate obs/day) and 296 voluntary precipitation stations. The density of the network for precipitation measurements is approximately 250 km2 / 1 raingauge (equipped with standard Wild raingauge). The intensity of rainfall is measuring using Russian pluviographs in 43 stations. NIMH is making some experiment to use automatic raingauge (Bulgarian and Danish construction). Most of them have deferent kind of problems either with accuracy or with telemetry. Some of them should be regularly cleaned from vegetation insect falling leaves etc. It seems that OTT raingauge based on the weighting principal are the most reliable and accurate one.

NIMH is developed a multi-functional automated radar system ARS on the base of MRL-5 from 1991 (e.g. Petrov et al. 2003). ARS is placed in South Bulgaria and one of the purposes is the use for precipitation observation and data records over area depending of topography disposition. The precipitation-measuring block RAIN works along with automated hydro meteorological stations. This block performs two main tasks: building a map of the rainfall intensity in compound regions and map of the integrated total of the precipitation in the range of rainfall measurement (averaged on 2x2 km unit area).

2. Meteorological (incl. precipitation) data processing and analysis

At present current meteorological information from above described national meteorological network is collected and digitized into computer-compatible form at the hydrometeorological observatories or the Regional Centers of the NIMH and then is delivered for importing into section Meteorological database and services(MDBS) of the NIMH in Sofia. Digitizing of current and past historical data into computer-compatible form is completed by means of specialized programs, as follows:

SYNOPD – Hourly synoptic data (incl. rainfall amount for 6 hours intervals);
SVK – Hourly climate data and atmospheric phenomena;
RJO – Daily data from precipitation stations

These programs execute data entering, correcting and examining. They make control for incorrect symbols, syntax errors, permissible values of elements, belonging to a certain interval of values or code table, etc. Also the programs have appropriate ASCII output for direct data importing into the corresponding database tables.

2.1. Standard processing of precipitation data in MDB

Standard processing of precipitation data in MDB is performed by store procedures written in Transact SQL by specialists from the MDBMD according to the normative documents in the operative practice of the NIMH, as follows:

- Daily, decade, monthly or annual precipitation totals;
- Monthly and annual precipitation reports, using data from all available stations in the database.
  All stored procedures have input parameters and missing data is taken into consideration.

In Fig. 1 the annual report from 2004 is presented for 2 precipitation stations

Year 2004 — MONTHLY AND ANNUAL REPORTS FOR PRECIPITATION STATIONS

Month	Max R for 24 h in mm	Date of max R	Monthly sum of R in mm	Number of days with: rain	snow	rain &snow	hail	sleet	R >= 0.1 mm	R >= 1 mm	R >= 5 mm	R >= 10 mm	R >= 15 mm	R >= 25 mm
Kalenik														
1	17.0	16	79.3	8	7	2	0	0	15	14	6	4	2	0
2	9.4	29	19.9	6	0	2	0	0	6	5	1	0	0	0
3	9.0	10	30.5	6	2	1	0	0	8	6	3	0	0	0
4	18.5	14	36.8	9	0	0	0	0	9	6	2	1	1	0
5	5.5	14	35.7	13	0	0	0	0	13	11	2	0	0	0
6	35.0	5	97.2	11	0	0	0	0	11	7	5	4	3	1
7	15.0	28	20.0	6	0	0	0	0	6	4	1	1	1	0
8	7.5	9	18.6	6	0	0	0	0	6	4	2	0	0	0
9	13.0	18	53.2	7	0	0	0	0	7	7	4	3	0	0
10	8.7	15	36.1	11	1	0	0	0	12	10	1	0	0	0
11	23.0	15	61.3	9	2	0	0	0	11	8	3	3	1	0
12	7.4	22	30.2	7	2	0	0	0	9	8	2	0	0	0
Annual	35.0	5. 6	518.8	99	14	5	0	0	113	90	32	16	8	1
Kula														
1	21.0	20	79.1	8	3	3	0	2	11	11	5	3	2	0
2	10.5	25	39.1	6	1	3	0	1	6	6	4	1	0	0
3	15.2	10	37.0	7	1	1	0	0	7	6	3	1	1	0
4	14.0	14	27.9	9	0	0	0	0	5	5	2	1	0	0
5	22.0	14	56.6	11	0	0	1	0	10	9	2	2	2	0
6	17.8	5	56.3	10	0	0	0	0	8	8	4	2	1	0
7	10.6	23	30.0	6	0	0	0	0	5	5	2	1	0	0
8	6.7	14	13.2	5	0	0	0	0	4	3	1	0	0	0
9	8.5	19	32.7	6	0	0	0	0	6	6	4	0	0	0
10	10.3	15	46.1	11	0	1	0	0	10	10	4	1	0	0
11	19.2	15	69.5	9	1	0	0	0	9	9	4	3	3	0
12	6.8	21	27.9	8	1	1	0	0	8	8	2	0	0	0
Annual	22.0	14. 5	515.4	96	7	9	1	3	89	86	37	15	9	0

Fig.1. Monthly and annual reports for 2 precipitation stations

Month 8 Year 2005 — Precipitation totals (R) measured in precipitation stations in mm

Номер	Име	I-st ten days sum	II-nd ten days sum	3-th ten days sum	Monthly sum	Number of days with R >=0.1mm	24-hour sum	Type of max R	Date of Max.R
62525	Tavalichevo	55.5	12.7	34.2	102.4	11	33.0	60	23
62535	Sapareva banja	102.0	41.3	45.9	189.2	11	52.0	60	6
62540	Rilski manastir	78.4	10.0	34.8	123.2	9	39.5	60	6
63406	Chuypetlovo	96.8	20.6	33.2	150.6	11	53.7	60	5
63415	Radomir	68.7	37.4	39.3	145.4	13	51.2	60	5
63430	Glavanovtzi	67.8	27.9	62.4	158.1	12	48.0	60	5
63440	Dolna Melna	62.9	21.8	38.0	122.7	13	38.6	60	5
63460	Kalishta	55.8	51.0	41.6	148.4	11	38.0	60	23
63490	Dren	124.9	29.6	44.7	199.2	11	87.6	60	5
63500	Breznik	85.9	17.6	41.4	144.9	14	59.3	60	5
64401	Rashkovo	169.4	34.4	41.4	245.2	10	70.0	60	6
64420	Etropole	179.0	81.6	48.5	309.1	13	105.1	60	5
64430	Pravetz	195.1	51.4	11.5	258.0	10	135.8	60	5
64460	Svode	126.4	99.0	41.6	267.0	9	43.6	60	6
64501	res.Topolnitza	148.7	34.9	18.4	202.0	9	106.0	60	6
64505	Kostenetz	260.7	38.3	21.3	320.3	12	134.5	94	5
64507	Dolna Banja	221.7	41.2	28.0	290.9	11	111.7	60	5
64525	Anton	77.1	58.3	36.9	172.3	14	57.0	60	6
64540	Mirkovo	200.4	46.1	27.2	273.7	13	123.7	60	5
64555	Smolsko	101.6	85.6	12.4	199.6	9	81.1	60	5
64565	Shindara	266.8	27.3	19.7	313.8	6	155.8	60	6
64610	Stargel	311.6	112.0	27.8	451.4	10	216.0	60	5
64645	Levi Iskar	106.6	60.8	14.3	181.7	12	57.0	60	5
64650	Reljovo	78.5	31.5	26.5	136.5	10	37.1	60	6
64660	Kovachevtzi	65.3	41.1	22.1	128.5	11	31.3	60	5
64665	Gorni Okol	129.5	45.0	22.5	197.0	10	67.0	60	5
64670	Elin Pelin	214.2	102.9	19.8	336.9	13	143.2	60	6
64680	Kurilo	146.8	73.7	35.0	255.5	11	82.0	60	6
64690	Lakatnik	159.8	39.3	30.8	229.9	12	92.4	60	6
64695	Svoge	179.4	49.9	57.0	286.3	13	108.0	60	5
64700	Gintzi	178.6	86.6	33.2	298.4	12	109.4	60	5
64710	Godech	158.0	52.0	37.0	247.0	12	82.0	60	5
64715	Buchin prohod	216.4	161.0	59.0	436.4	13	115.0	60	5
64725	Kalotina	87.3	58.4	29.7	175.4	13	37.1	60	17
64735	Slivnitza	127.0	26.6	42.0	195.6	12	80.0	60	5
64755	Kremikovtzi	130.1	79.2	15.5	224.8	10	70.0	60	6
64761	Orlandovtzi	118.2	53.4	28.9	200.5	12	64.5	60	6
64770	Ovcha kupel	52.0	26.5	4.5	83.0	10	16.5	60	6
64775	Ivan Vazov	155.0	22.4	32.5	209.9	12	68.5	60	6
64780	Simeonovo	103.5	18.9	29.7	152.1	10	51.2	60	6
64785	Bojana	141.8	13.9	29.7	185.4	11	65.5	60	6
64800	Kokaljane	81.0	28.5	23.0	132.5	10	53.0	60	6

Fig.2. Monthly reports for data precipitation control from precipitation stations.

2.2. Precipitation data quality control in MDB

It is regularly completed, as follows: Verification for missing observations, missing values, permissible values and intervals of variation, correspondence with the code tables, etc.; Expert control on the basis of monthly reports (Fig.2) and comparison with near meteorological stations.

2.3. MDB precipitation data visualization on the map of Bulgaria

In Fig.3 a map of precipitation in Bulgaria in % from the climate norm (1961–1990) is given for the extreme rainfalls (04-08 August 2005) led to disastrous floods, using the data from representative meteorological stations for the territory of the country. The period 1961–1990 is recommended by the World Meteorological Organization (WMO) for determining the norms of the different meteorological elements.

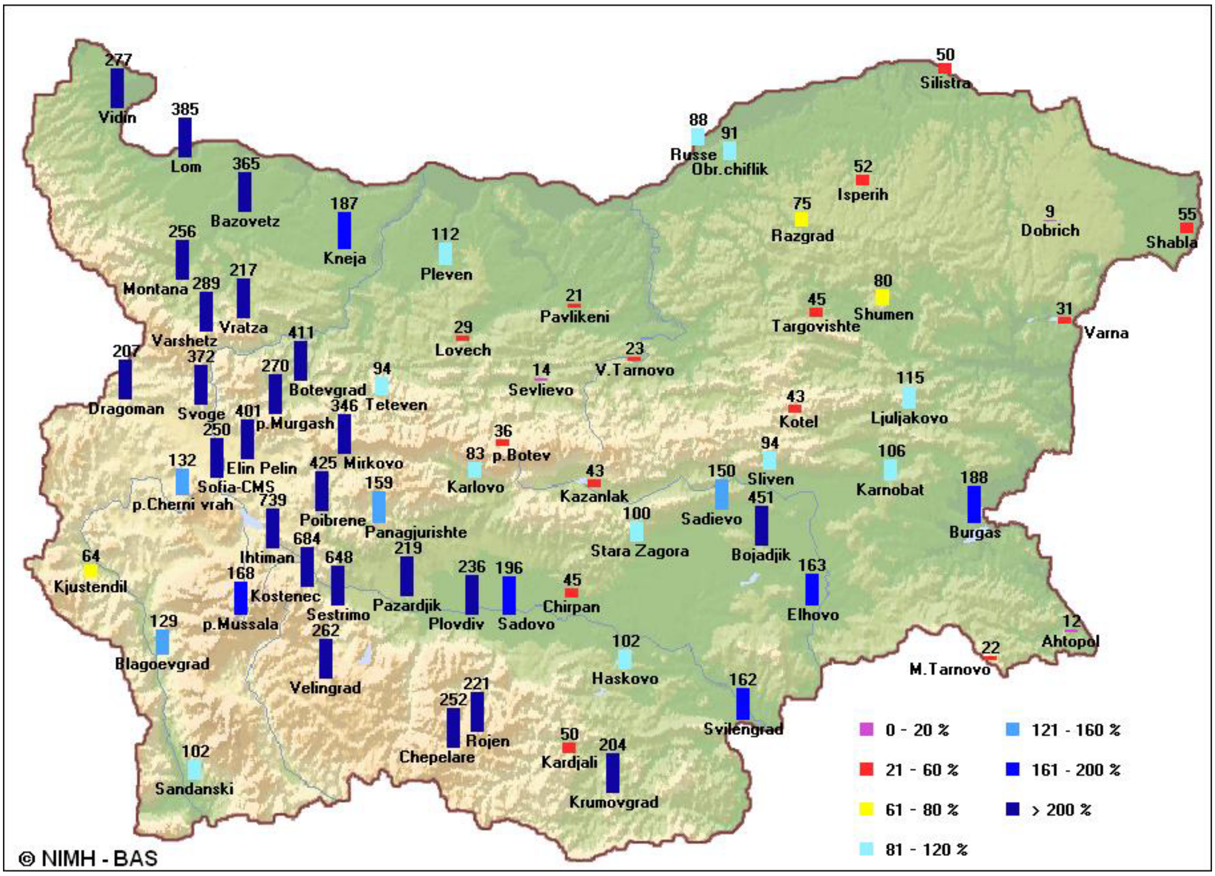


Fig.3. Precipitation totals for 05.08-08.08.2005 relative to mean monthly (1961-1990).

2.4. Precipitation data for some international Projects provided by NIMH base of data

- World Weather Records (WWR) issued in Germany: 1981 – 1990 and 1991 – 2000 series (monthly and annual totals of precipitation for 6 synoptic stations – Vratza, Pleven, Razgrad, Burgas, Plovdiv-Maritza, Cofia-CMS);
- GPCC (Global Precipitation Climatology Centre-Offenbach), WMO – Monthly precipitation totals for the periods: 1986 – 1992, 33 synoptic stations; 1993 – 2004, 27 stations. Climatological normals for the period 1961 – 1990. Time-series of daily data from 3 stations for the period 1931 – 2004;
- Project: "The common Meteorological Metadata base of the Countries Sharing the Danube Catchment" within the International Hydrological Programme (IHP) of UNESCO;
- Atlas_Project: The Climate of Europe (Coordinator and Editor Meteo-France) – precipitation data (1961-2000) from 27 stations.

3. Other applications of precipitation data

3.1. Research on climate variability and change

Rainfall data is wide used in country and some regional climatological researches and some agro meteorological applications (see Alexandrov et al. 2004). For example, using Caussinus-Mestre method for homogeneity testing of last Century data series a decreasing trend in annual and especially summer precipitation from the end of the 1970s was found. The other way about the winter precipitation during the last century – a statistically positive trend was observed. Recent study of Koleva (personal communication) shows some tendency to annual precipitation increasing.

We were used the data from about 50 meteorological stations for operative assessment of extreme rainfall and precipitation amounts. Such brief climatological assessment of summer (May-September) precipitation anomaly in 2005 is illustrated on Fig.4 (Simeonov et al). It can be seen follow as criteria for extreme precipitation quantity $Qi \geq Qmean + 2\sigma Q$ that 2005 is at third place after 1975 and 1979. The wet summer seasons of 1976 and 1991 are much closed to the threshold line.

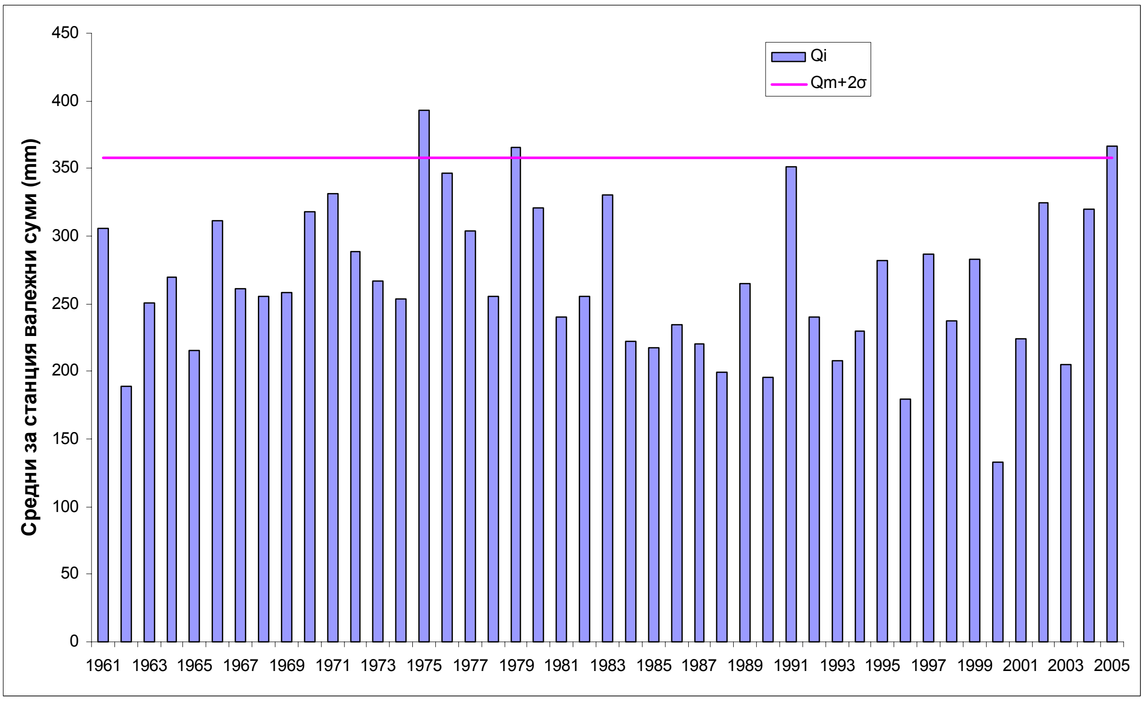


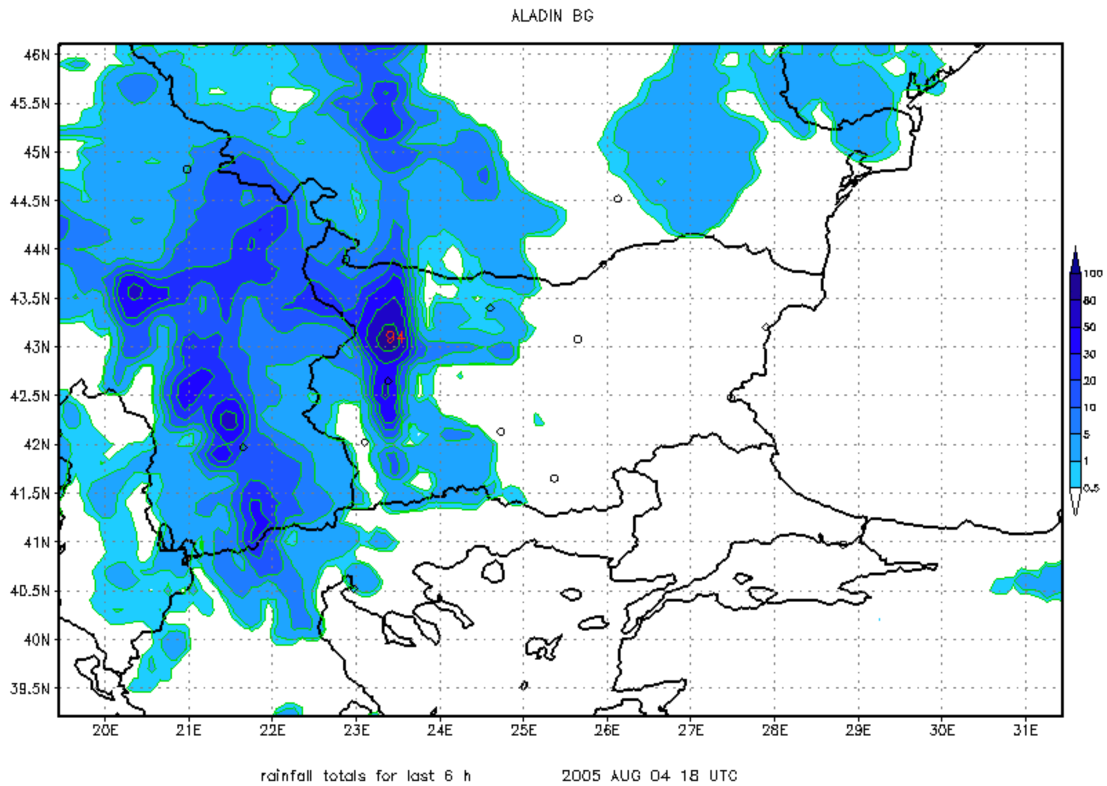
Fig.4. Averaged seasonal precipitation totals (May - August) for 42 lowland stations over 1961 – 2005, against the Qmean+ 2.st.dev. 1975, 1979 and 2005 are well outlined

3.2. Current hydrological and meteorological and hydrological assessments and prediction.

The NIMH rainfall observation system and expert capacity was urgent tested in the extremely wet 2005 season (May-September). The hydrologists selected 5 flood waves in the summer: 25-30.May, 06-08.June, 01-04.July, 04-08.August and 18-23.September *(Dimitrov and Gospodinov 2005)*
The use of forecasting models as ALADIN for heavy rainfall prediction in combination with the statistical approach for flood warning permitted to make very complete test this wet summer (see the case illustrated in Fig. 5 and Fig 6.

It might be accepted that as consequence of climate changes the amplitude of water cycle parameters variations is increasing rapidly last several years.

Several locations this summer registered exceptionally high (over 220 mm) daily total: Ihtiman, Bebresh, Chernozemen, Shabla. Below is the probability distribution of Ihtiman daily totals.



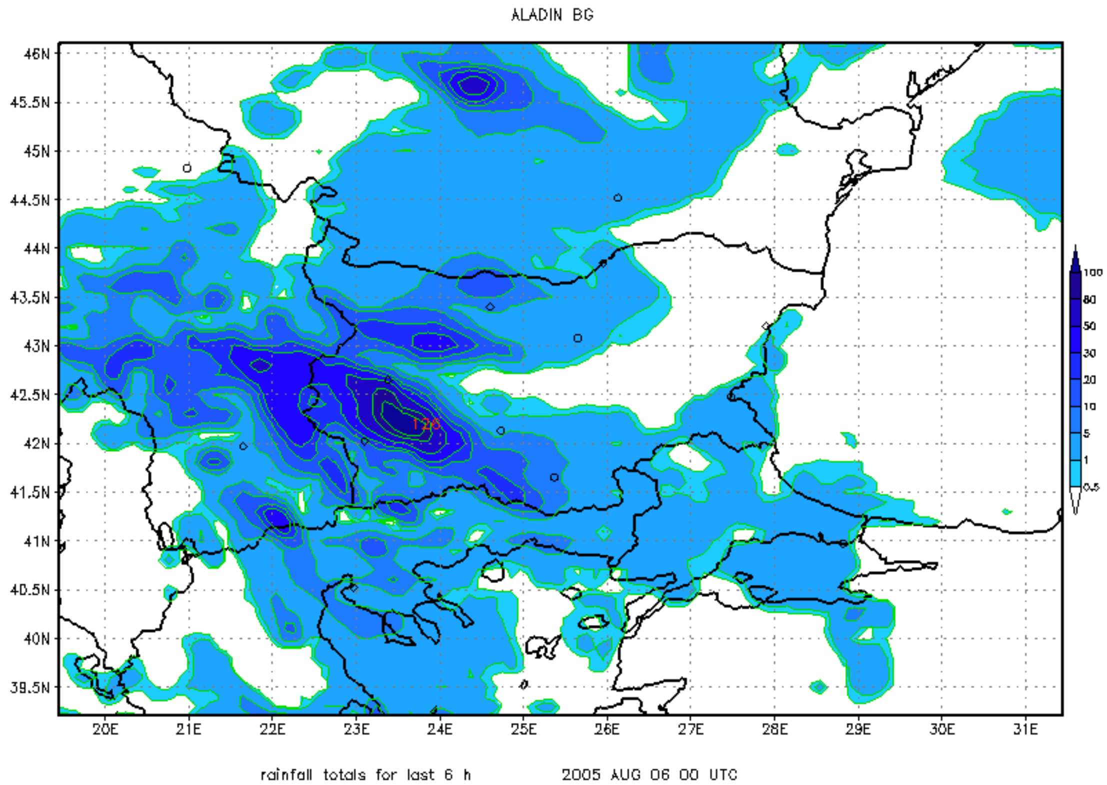


Fig.5. The precipitation patterns of 04-05 August and 05-06 August 2005, forecasted by the ALADIN

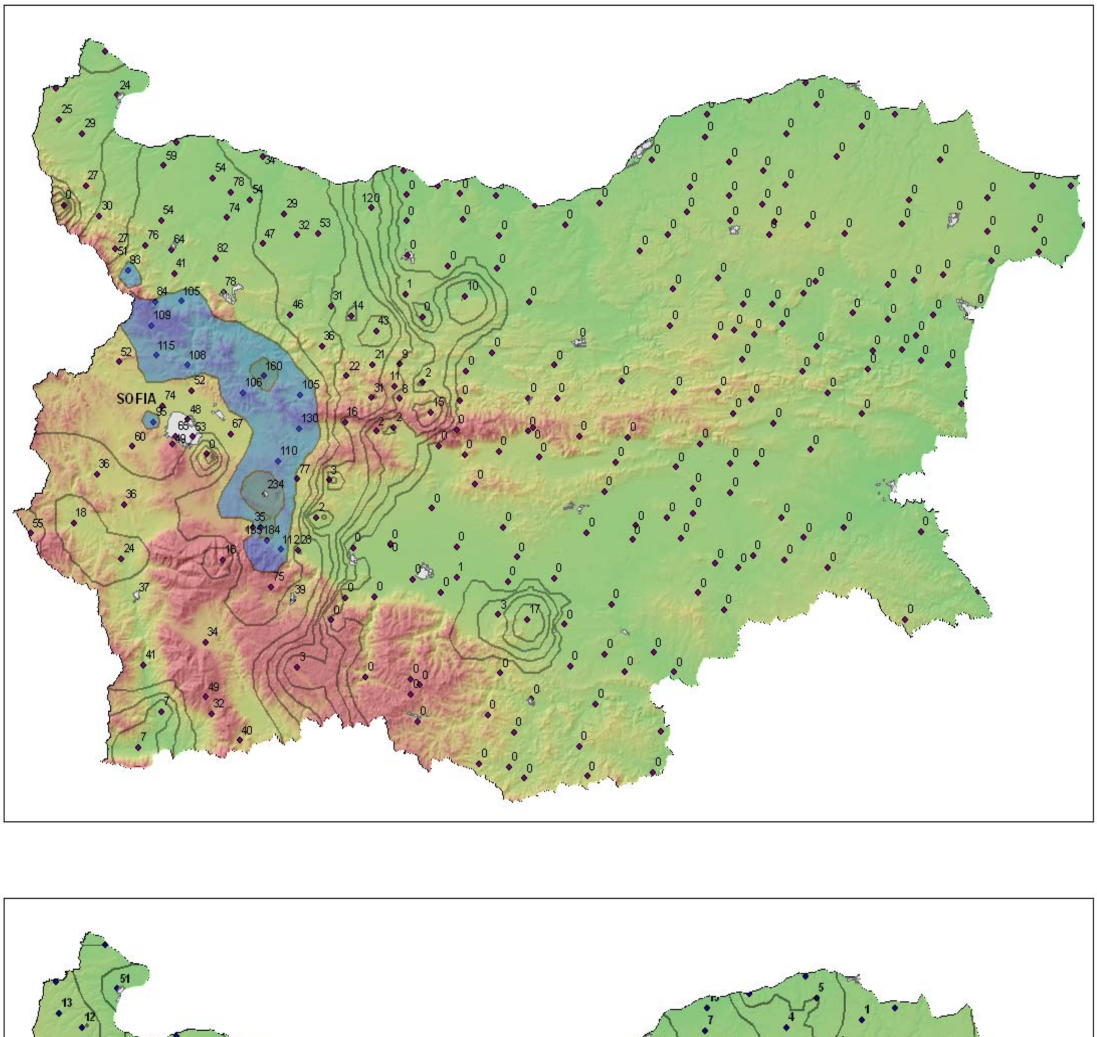


Fig.6. Daily precipitation totals measured on 05 and 06 August 2005

Using ARC MRL-5 for heavy rainstorm warning the precipitation quantity is measured each hour. The totals are calculated for defined time (day, month, year) for all catchments in the representative radius of ARC observation. An illustration of measured precipitation amount for 30 June and 01 July 2005 is shown in Fig.7. It can see very spotty distribution of precipitation values. The maximum value reach up 86.5 mm (see on the table in right side of image).

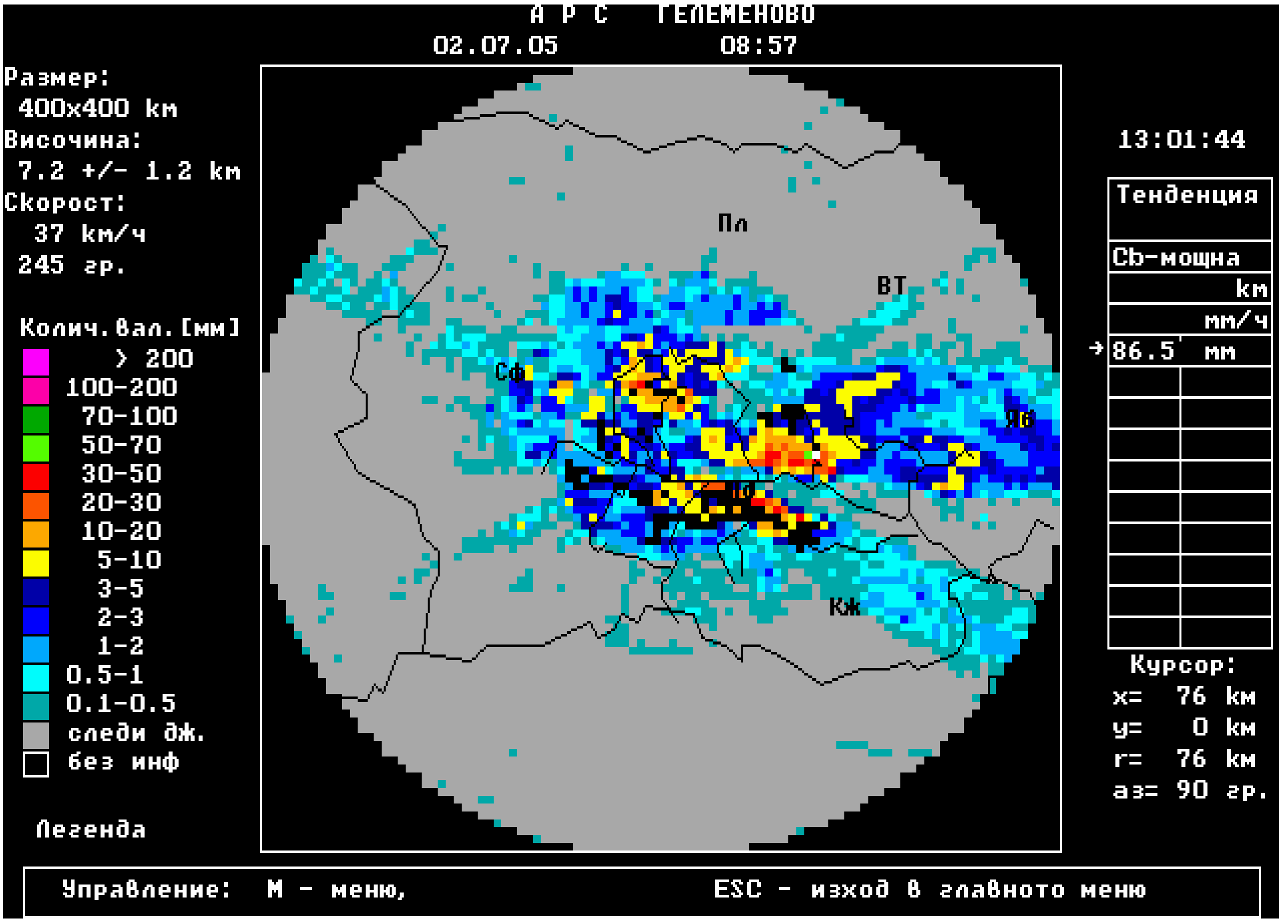


Figure 7. Precipitation amount from 30 June and 01 July 2005 measured by NIMH ARS in Gelemenovo.

It might be accepted that as consequence of climate changes the amplitude of water cycle parameters variations is increasing rapidly last several years.

4. Conclusions

4.1. Methodological help needed in:

- modelling the flood phenomena, high flow forecasting;
- modelling the flooded areas for high flows with different return periods;
- harmonising the alarm thresholds;
- EU compatible methodology to quantify water cycle parameters in case of droughts, e.g. evapo-transpiration and infiltration for the reporting to EuroStat;

4.2. Equipment needs:

- urgent restoration of the 27 totally destroyed hydrometric stations during the floods;
- hourly observation of precipitation and river levels by automatic telemetric stations.

Acknowledgments:

Acknowledgments are addressed to Dr. Tania Marinova, Dr. Dobri Dimitrov, Dr. Rangel Petrov and Dr. Vesselin Alexandrov for their help and willingness for assistance.

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Alexandrov V., M. Schneider, E. Koleva, and J.-M. Moisselin. Climate variability and change in Bulgaria during the 20th century, *Theor. Appl. Climatology*, 79(3-4), 133-149, 2004.

Dimitrov D. and I. Gospodinov. The floods in 2005 and their prediction**.** *Proc. Scientific-Practical Conf. on Managing of Extraordinary Situation and Population Protection,* 10 Nov., Sofia, 2005 (in Bulgarian press).

Petrov R., P. Simeonov, and K. Slavov. On Application of Radar Data in Hydrometeorological Services, In: *Proc., Sixth European Conf. on Applications of Meteorology*, Roma, Italia, September, 2003, (CD-version, 5 pp.).

Simeonov P., L. Bocheva and T. Marinova. Risk assessment for dangerous meteorological phenomena from severe convective storms during warm half of the year. *Proc. Scientific-Practical Conf. on Managing of Extraordinary Situation and Population Protection,* 10 Nov., Sofia, 2005 (in Bulgarian press).

Precipitation measurements (at UL FGG)

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Abstract for the presentation

Chair of hydrology and hydraulic engineering of the UL FGG performs precipitation measurements for the needs of work of postgraduate students and scientists and research which is part of international scientific and research projects. Measurements are also carried out for the needs of contractors in Slovenia. Precipitation measurements are mainly done with tipping bucket rain gauges (equipped with data loggers) and totalisators (manual gauges).

Rain gauges and limnigraphs are placed on the river Reka representative basin with the intention to carry out base studies of hydrological processes. Measurements of interception precipitation are made on the Dragonja experimental basin. Monitoring of precipitation is done on the Macesnik, Strug and Stože landslides and in the lower Sava river region, where a chain of hydroelectric power plants is being built. Before the 2005 winter, we set up rain gauges for measuring snowfall and snowmelt on several locations in Slovenia.

Several small-size rain gauge networks in the study regions were established, enabling us to compare the precipitation data from the rain gauges, eliminate measurement errors and replace the missing data with correlation. The collected data from the rain gauges are stored in a database supported by Microsoft Access. After precipitation data is transferred in the database, the correction of time is done. The main statistics, 10-minute, hourly, daily and monthly values of the precipitation are calculated automatically.

Data analyses of the measured precipitation are applied to figure out rainfall erosivity, the impact of reforestation on the water balance, the influence of snowmelt on groundwater dynamics and erosion processes, precipitation seasonality and similar.

Slovenian contribution to the Rainfall Meeting in Beograd

December, 1-2. 2005

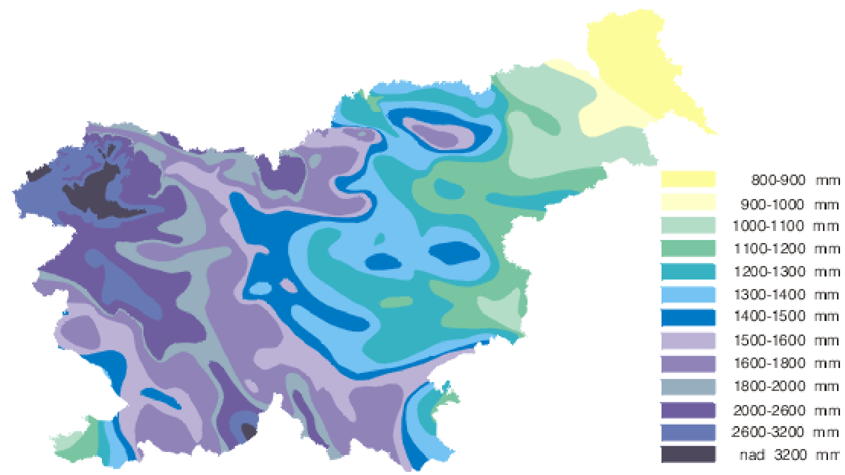
Kay Sušelj

Outline of the talk

- General information about the precipitation in Slovenia
- Precipitation and related atmospheric measurements in Slovenia
- Forecasting of precipitation
- Utilization of precipitation measurements and forecasts
- Way forward

High variability in the orography and position between Mediterranean Sea and Pannoninan lowland → high variability in the (climate) of precipitation

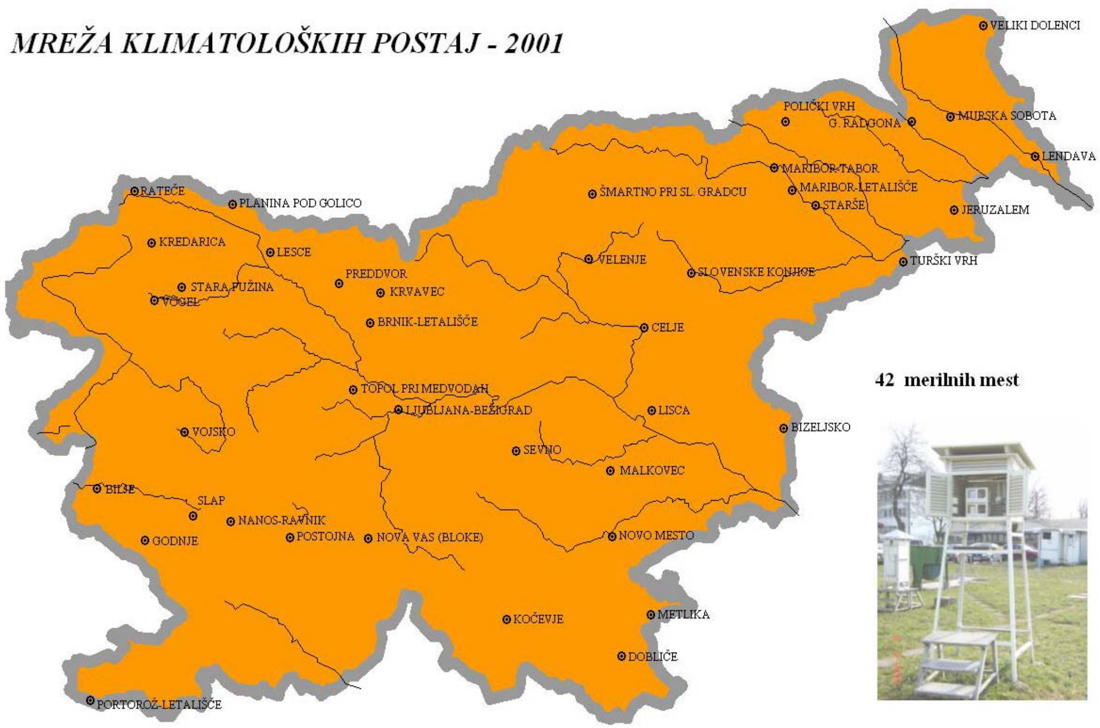
Orography



Precipitation climatology 1960-1990

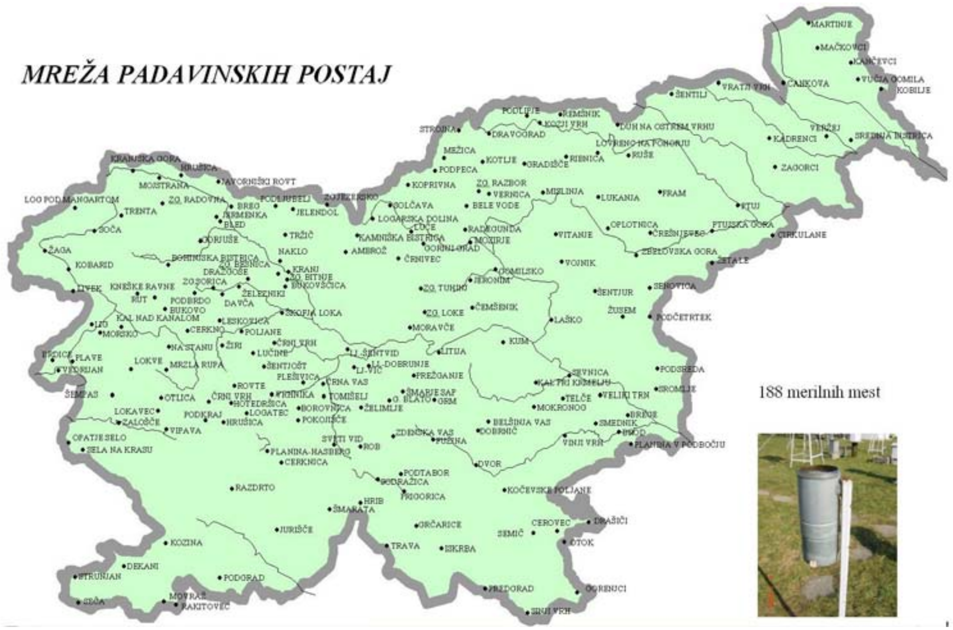
Climatological stations:

- Data available every on 12 hour time step, with low latency, most of the station measure snow cover
- 42 stations, located mainly in the populated areas, few stations located in the mountains



Precipitation stations:

- Daily accumulation of precipitation, data available with delay of approximately 1 month, 188 stations, number decreasing
- Observations of other precipitation related phenomena (thunderstorms, hail, …)

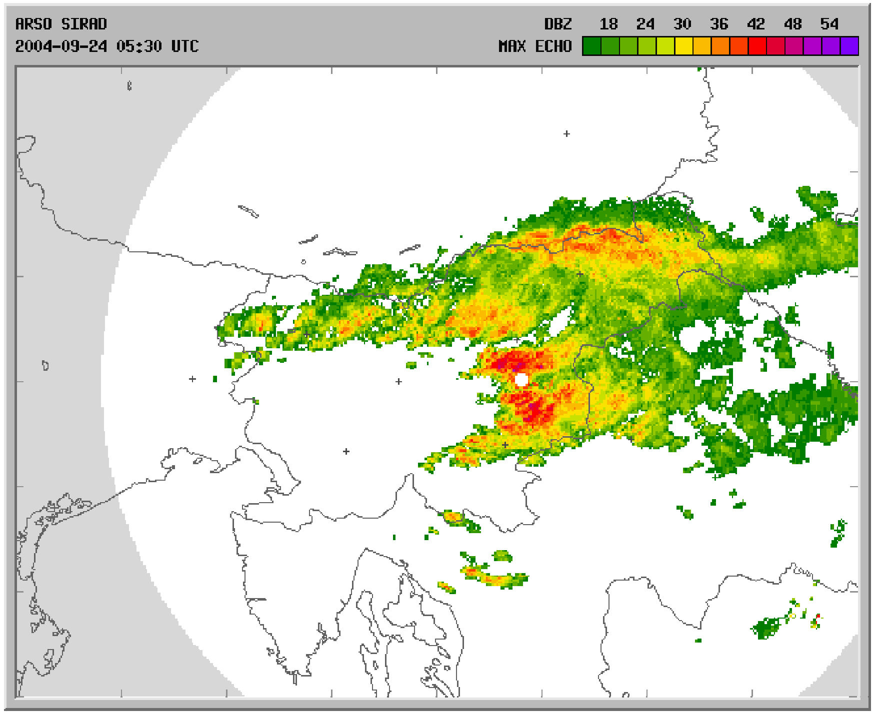


Automatic stations and self recording stations

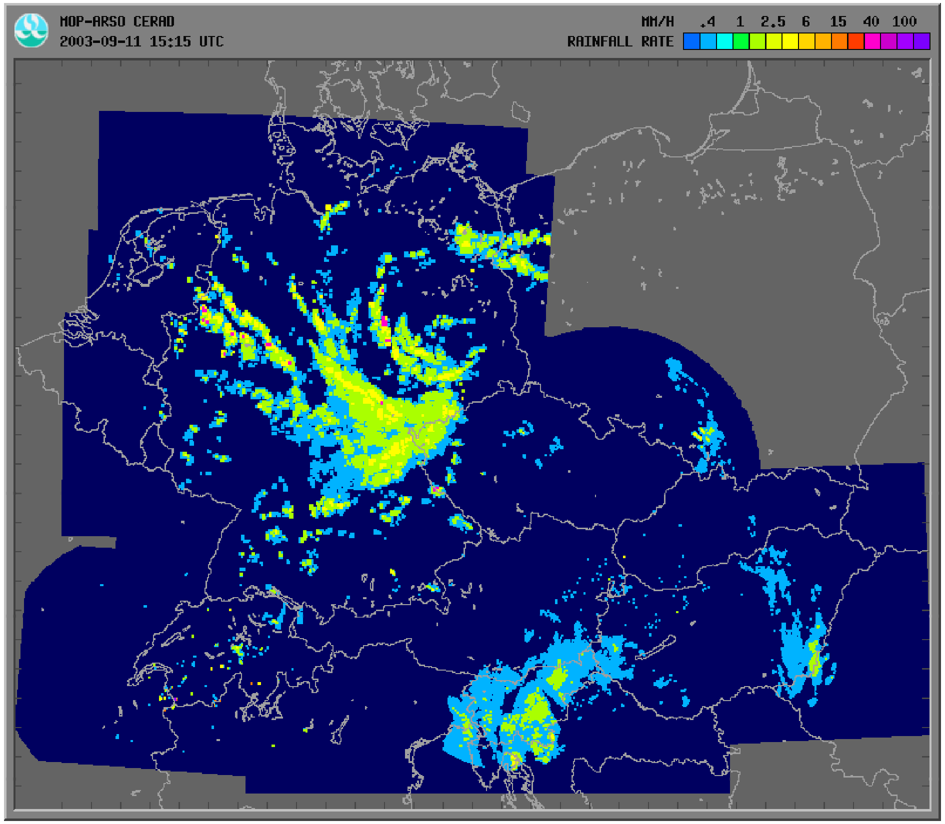
- 5 (30) minutes accumulation of precipitation
- Around 35 automatic stations, data available in real-time
- Few self recording stations without online data transmission

S-band radar located in the SE part of Slovenia

- Not-well calibrated for hydrological purposes
- Unreliable measurements for the NW part of Slovenia due to the orography (beam blocking)

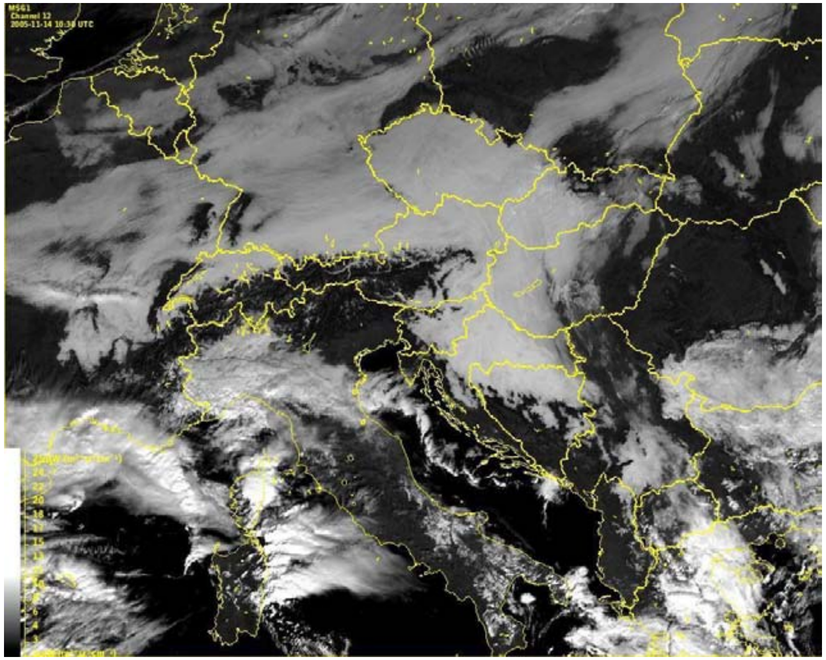


European radar image composite over central Europe, Alps and northern Adriatic

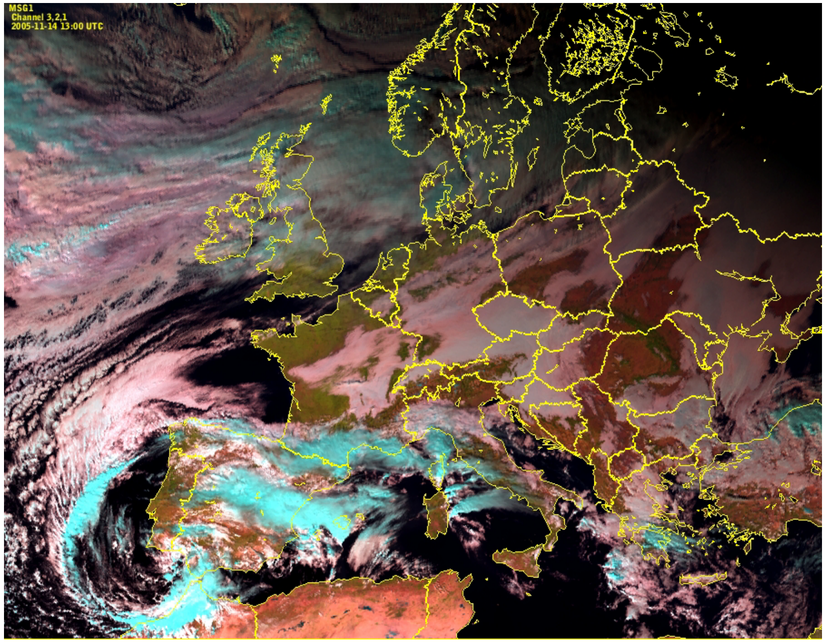


Images of Meteosat, second generation (MSG):

- 12 passive chanells
- information on cloud systems, properties and development



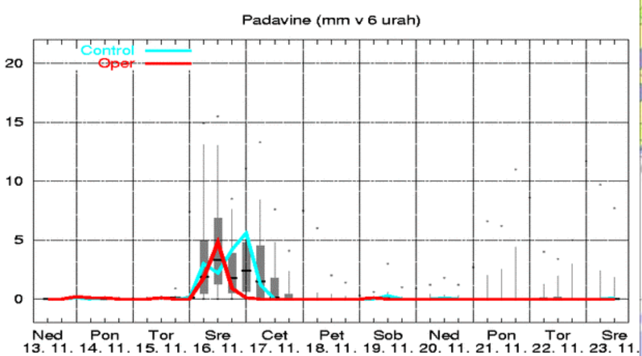
MSG channel 12 (visible)

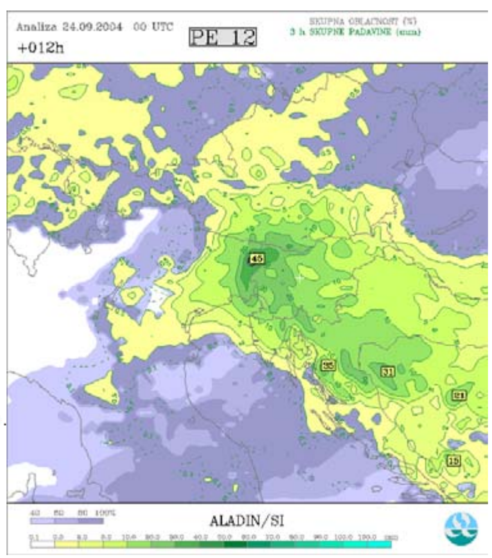


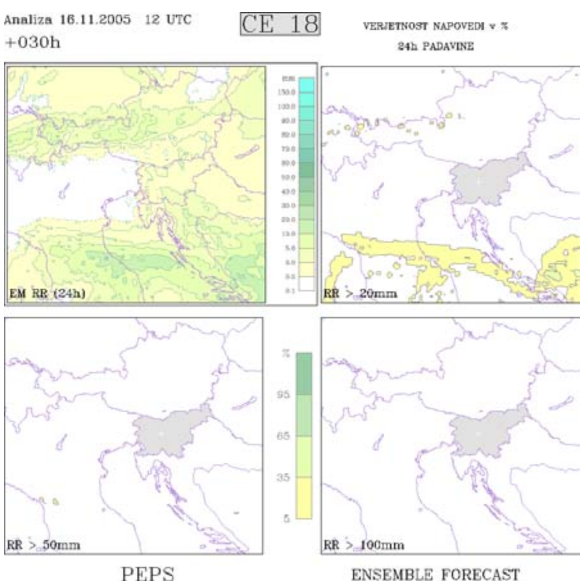
MSG combination (false coloring) of channels 3 2 and 1

Results of numerical weather prediction models:

- Deterministic and probabilistic ECMWF results (10 day forecast)
- Deterministic results of local ALADIN/SI model (2 day forecast)
- Probabilistic Poor man ensamble (PEPS) forecast (local models)

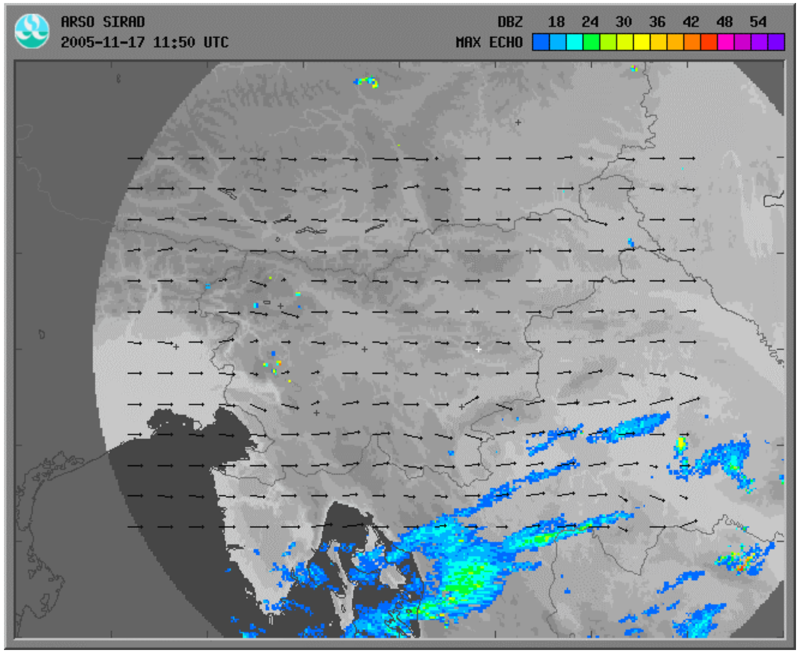


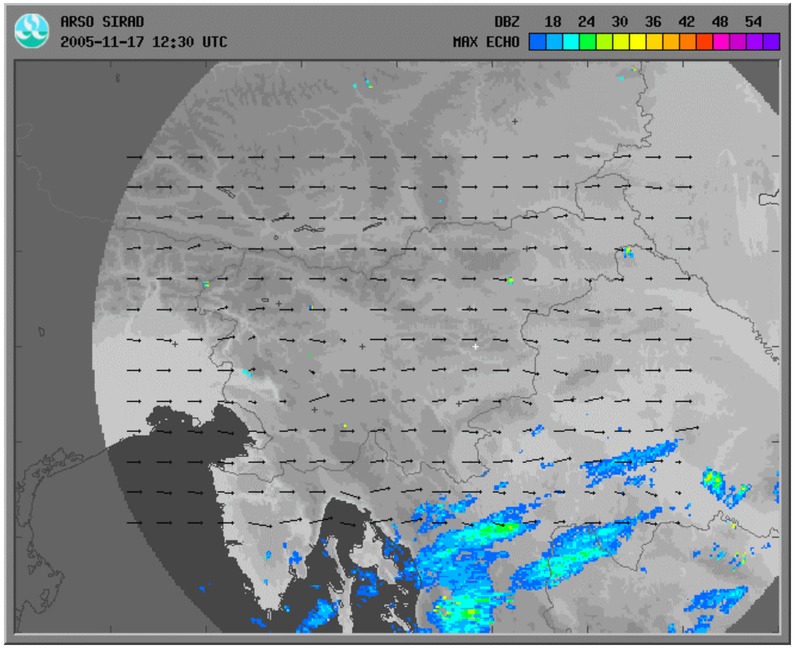




Nowcasting:

- Advection of cloud systems detected by satellite or radar
- Latent heat nudging (from radar measurements)





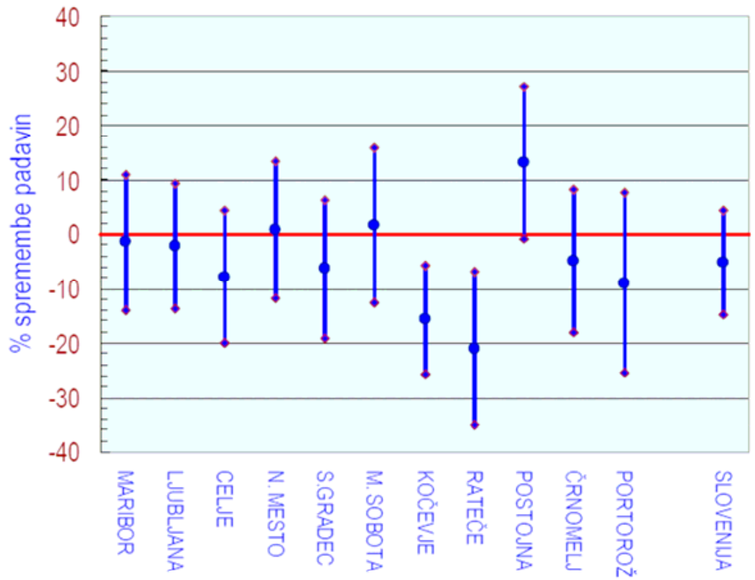
Utilization of precipitation data

Hydrology:

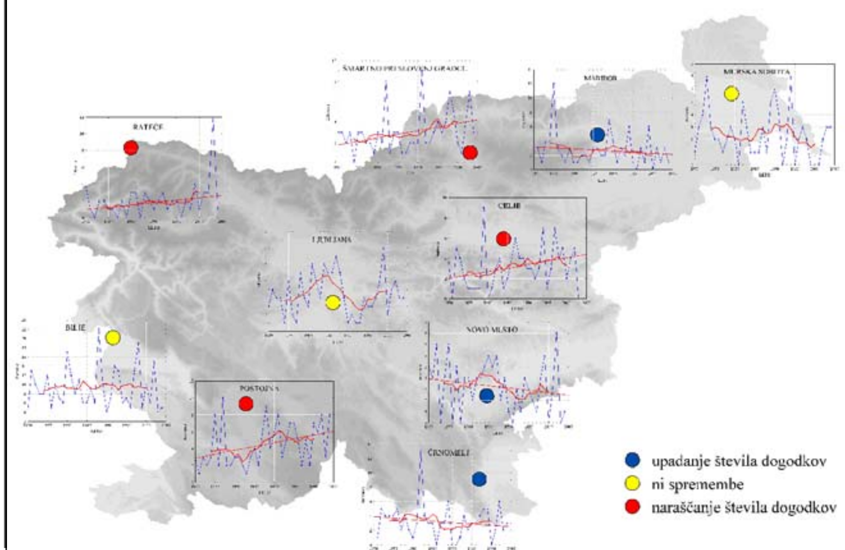
- Input to hydrological models (conceptual, regression)
- Estimation of flash flood probability (precipitation radar measurements, instability indices)
- Prediction of landslides and mudslides

Climatological studies:

- Climate charts of precipitation
- Detection of interannual to centerial variability of precipitation and long term trends
- Relation of precipitation to large scale climate variabilities (NAO, MO)

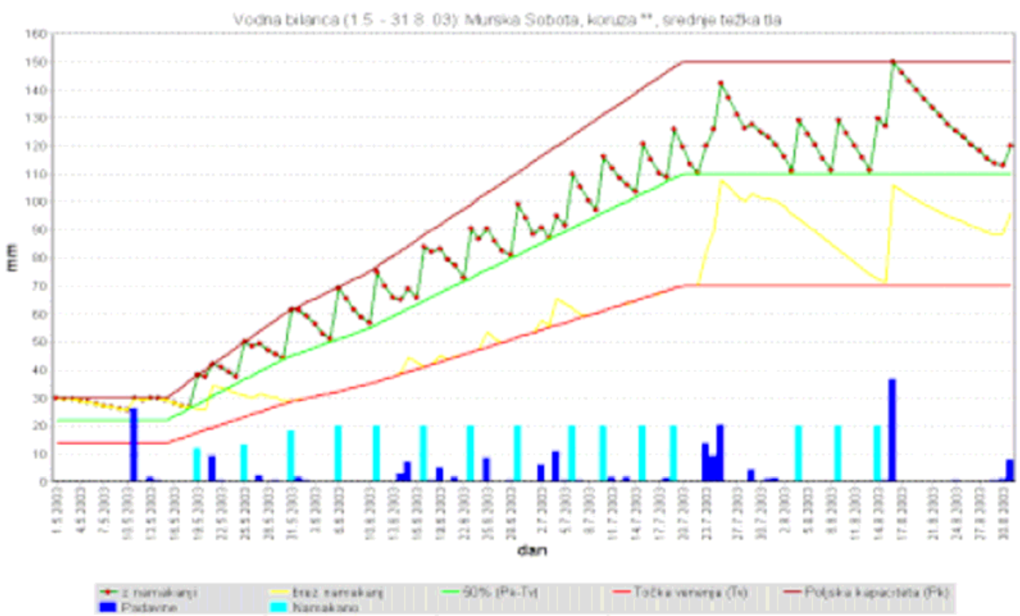


Relative change of precipitation amount from 1950-2000



Agrometeorology:

- Prediction of necessary irigation
- Climate change impacts on agronomy



Improvements of the precipitation network:

- Building new automatic precipitation stations, especially in the sparsely covered areas
- Measurements of snow depth (and water content of the snow)
- Building new X-band radars in the narrow valleys

Measurement processing:

- Producing the maps of precipitation on high temporal and spatial resolution using all available measurements (e.g. radars, ground stations)
- Implementing the procedure to the data processing in real-time

6th International Workshop on Precipitation in Urban Areas
4-7 December 2003, Pontresina, Switzerland

The wind induced loss of thunderstorm precipitation measurements

by

Branislav Chvila and Boris Sevruk

SHMÚ

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Poland
Liesek
Czech rep.
Žilina
Trenčín
Bohunice
Trnava
Nitra
Banská Bystrica
Prešov
Košice
Ukraine
Austria
BRATISLAVA
Hungary

The wind induced loss D:

$$D\,[\%] = \frac{R_P - R_E}{R_E} \cdot 100$$

Method used for the identification of convective and non-convective precipitation.

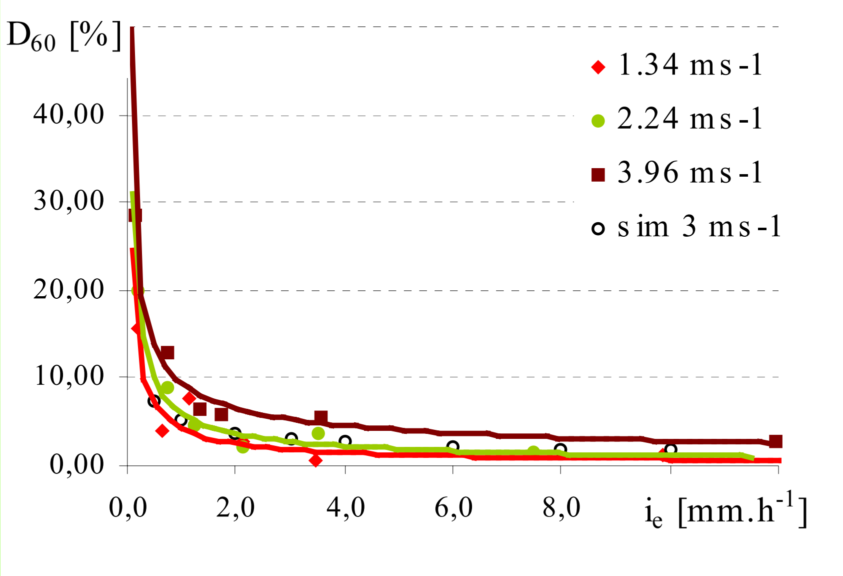
Explanation of the cloud's symbols: As – altostratus, Cb – cumulonimbus, Cu – cumulus, Ns – nimbostratus, Sc – stratocumulus, Sc cugen – stratocumulus cumulogenitus, St – stratus.

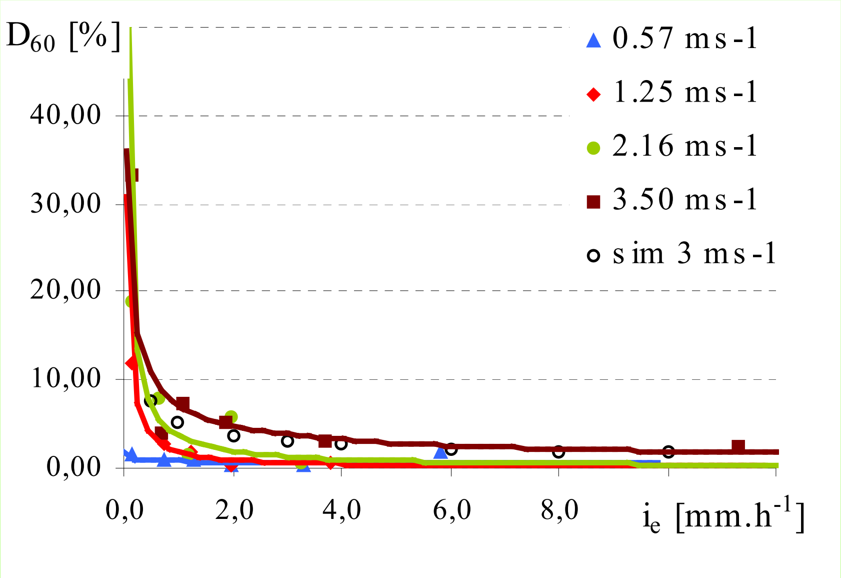
Type of precipitation	1st step present weather	2nd step clouds	3rd step synoptic situation
convective	shower, thunderstorm	Cu, Cb, Sc cugen	cold front
non-convective	rain	St, Sc, As, Ns	warm front

The subdividing of the precipitation intensity and wind speed

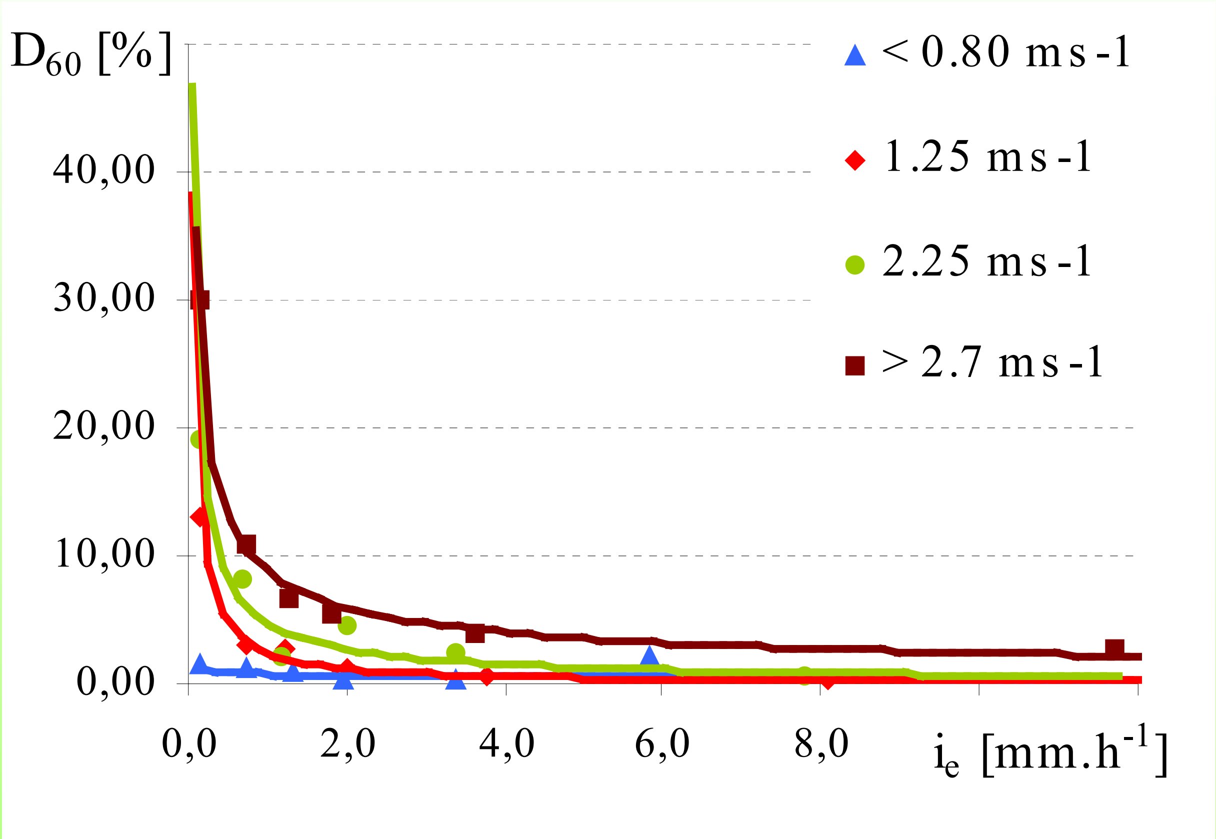
	Intensity of precipitation
	interval
1.	less than 0.5 $mm.h^{-1}$
2.	0.50 - 0.99 $mm.h^{-1}$
3.	1.00 - 1.49 $mm.h^{-1}$
4.	1.50 - 2.49 $mm.h^{-1}$
5.	2.50 - 4.99 $mm.h^{-1}$
6.	5 $mm.h^{-1}$ and more

Average wind speed	Class of wind speed
interval	assigned as
less than 0.8 $m.s^{-1}$	< 0.8 $m.s^{-1}$
0.8 až 1.7 $m.s^{-1}$	1.25 $m.s^{-1}$
1.8 až 2.7 $m.s^{-1}$	2.25 $m.s^{-1}$
more than 2.7 $m.s^{-1}$	> 2.7 $m.s^{-1}$

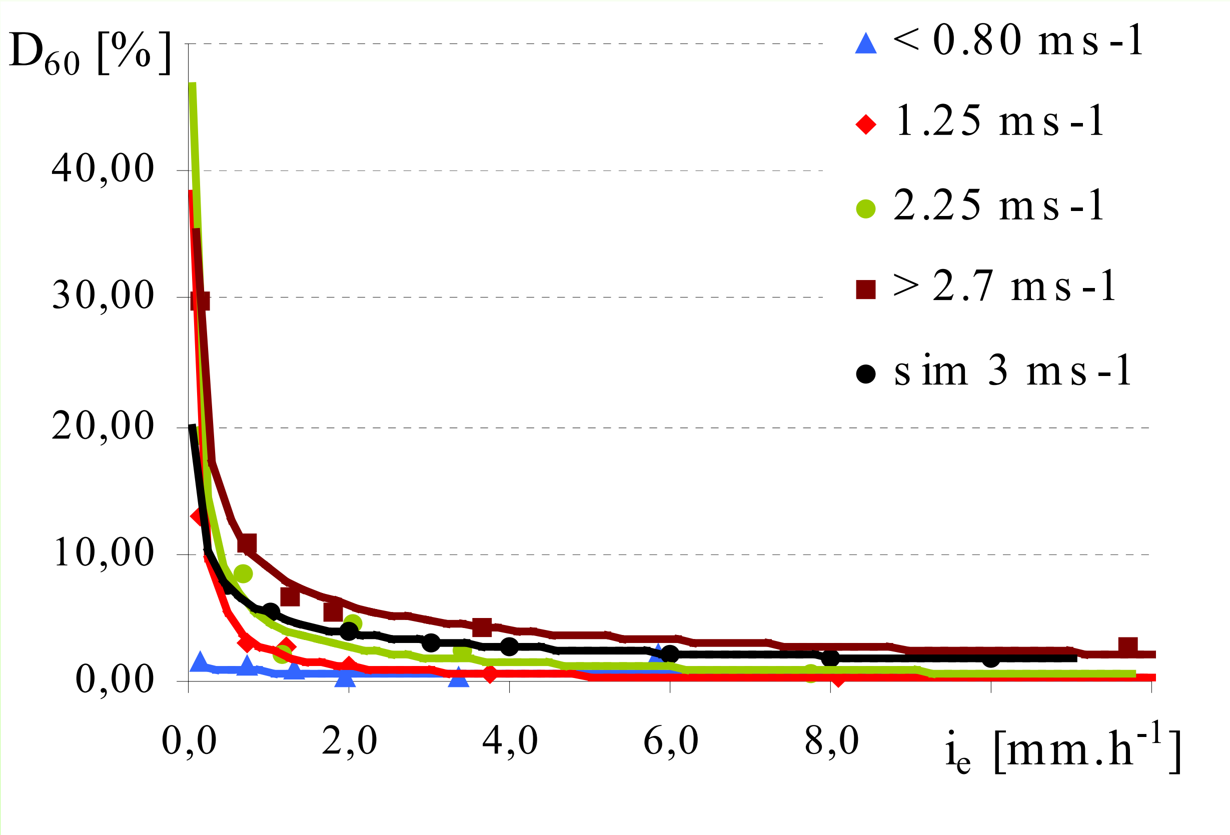




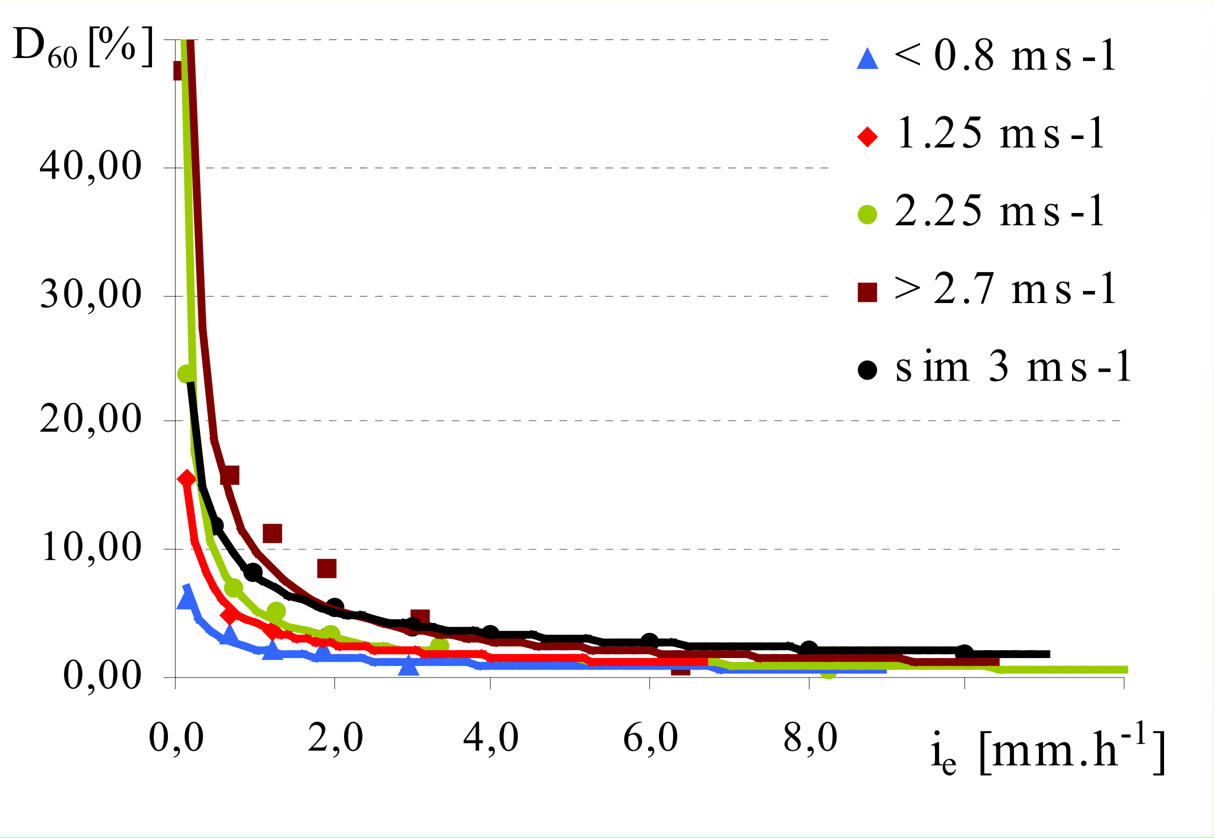
The percentage wind-induced loss D_{60} related to elevated gauge as a function of precipitation intensity i_e and wind speed for the convective precipitation and the measuring time interval of 60-minutes. Empty points indicate the results of the numerical simulation for thunderstorms and wind-speed of 3 m·s^{-1}. Jaslovské Bohunice (*left*) and Liesek (*right*), Slovakia, 2001-2003.



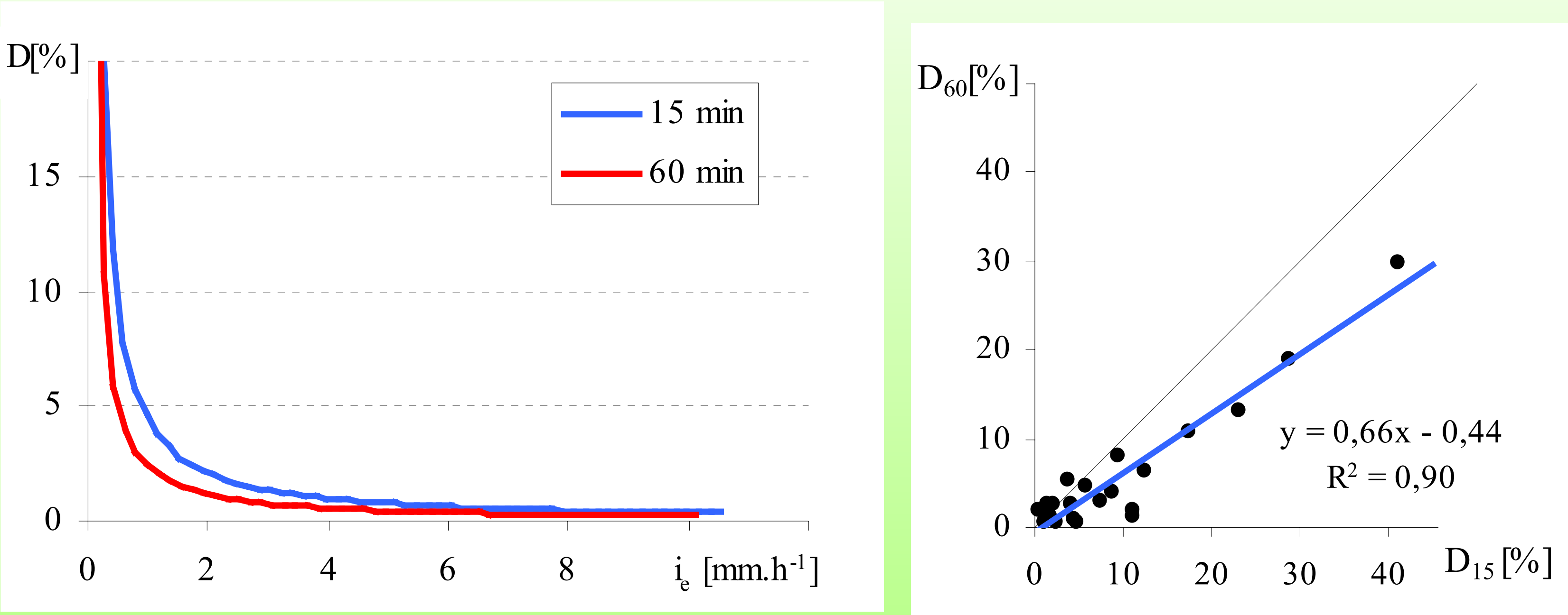
The percentage wind-induced loss D_{60} related to elevated gauge as a function of precipitation intensity i_e for four different wind speed classes for the convective precipitation and the measuring interval of 60-minutes. Empty points indicate the results of the numerical simulation by Nespor (1998).
Jaslovské Bohunice and Liesek, Slovakia, 2001-2003.



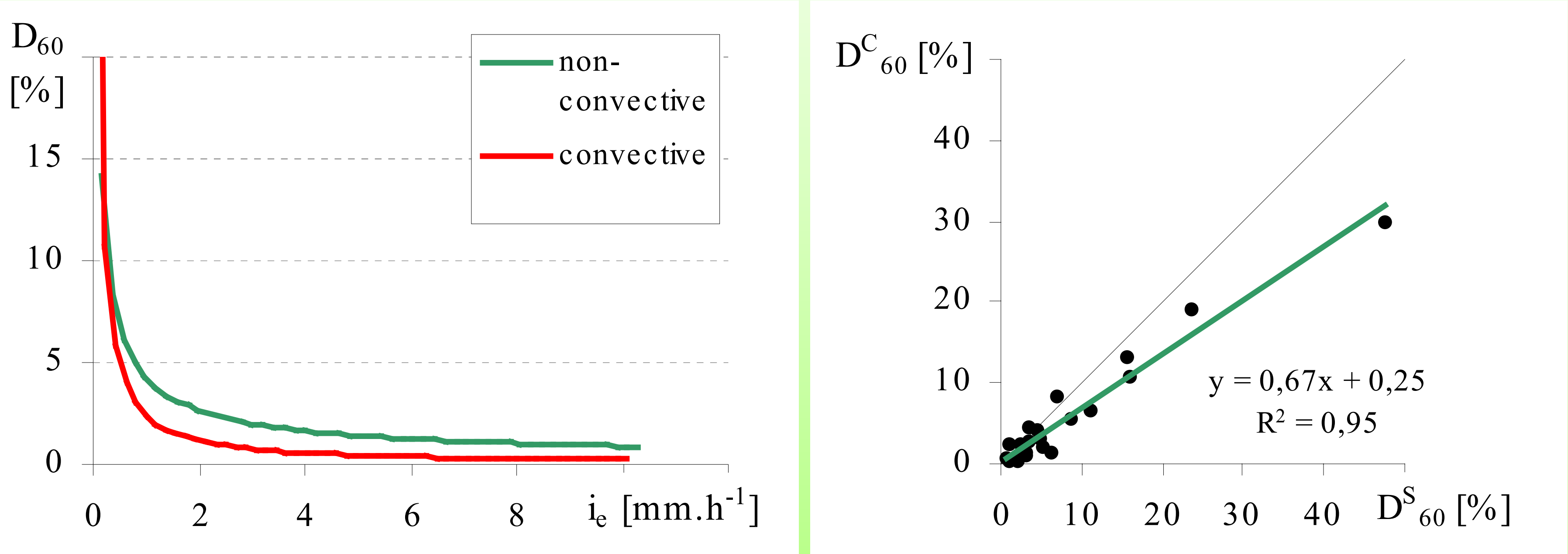
The percentage wind-induced loss D_{60} related to elevated gauge as a function of precipitation intensity i_e for four different wind speed classes for the convective precipitation and the measuring interval of 60-minutes. Black line indicates the results of the numerical simulation by Nespor (1998).
Jaslovské Bohunice and Liesek, Slovakia, 2001-2003.



The percentage wind-induced loss D_{60} related to elevated gauge as a function of precipitation intensity i_e for four different wind speed classes for the non-convective precipitation and the measuring interval of 60-minutes. Black line indicates the results of the numerical simulation by Nespor (1998). Jaslovské Bohunice and Liesek, Slovakia, 2001-2003.



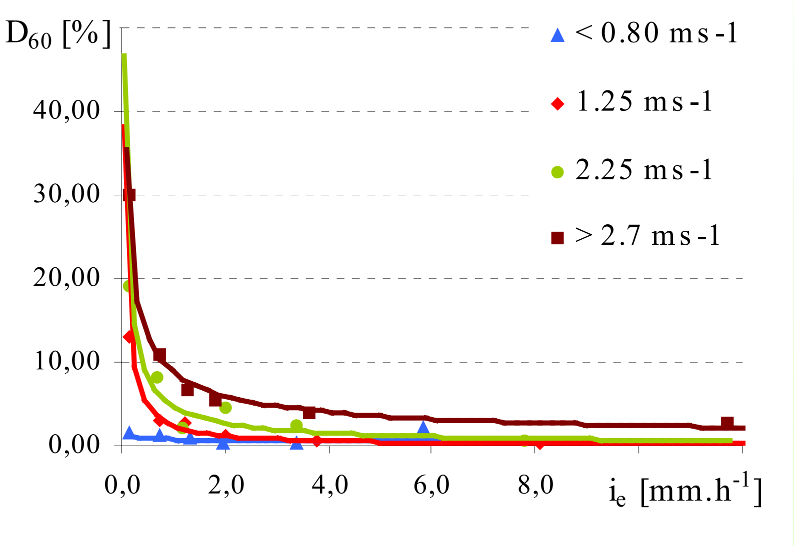
The percentage wind-induced loss of convective precipitation for the two different measuring intervals of 15 (D_{15}) and 60 minutes (D_{60}). Left – the wind-induced loss as a function of precipitation intensity for wind-speed class of 1.25 $m \cdot s^{-1}$. Right – the comparison with the regression line.
Bohunice and Liesek, Slovakia, 2001-2003.

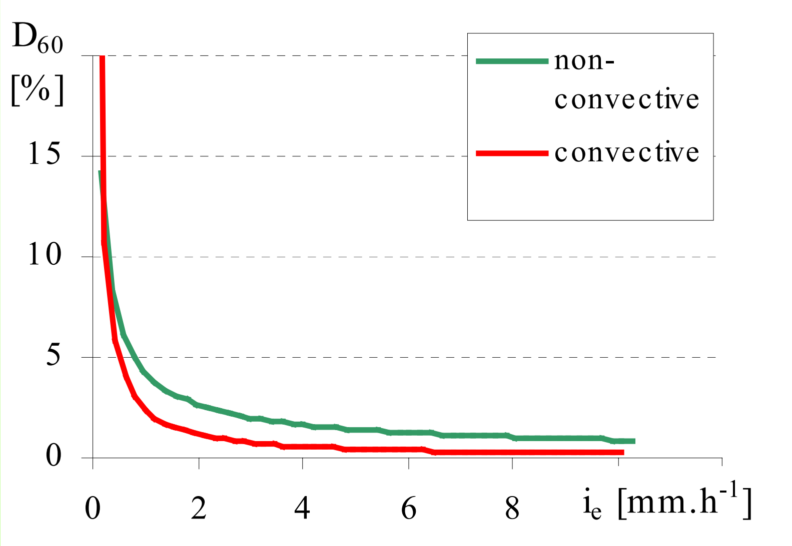


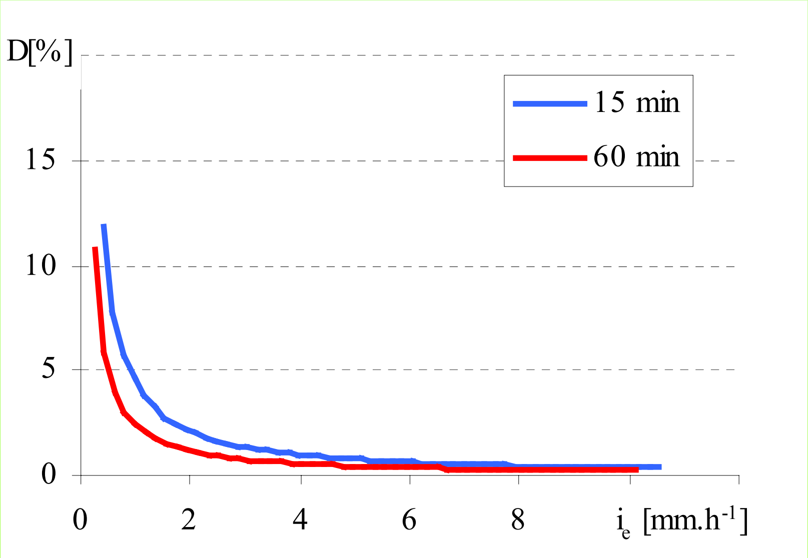
The percentage wind-induced loss for the two different types of precipitation: the convective (D^C) and non-convective (D^S). Left – the wind-induced loss as a function of precipitation intensity for wind-speed class of 1.25 $m \cdot s^{-1}$. Right – the comparison with the regression line. The measuring interval of 60 minutes.

Bohunice and Liesek, Slovakia, 2001-2003.

Conclusions







ON RAINFALL MEASUREMENT, PROCESSING AND ANALYSIS IN SERBIA

by
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ABSTRACT

Serbia has a long tradition in precipitation measurements, which dates back to 19 century. Currently, there are in the country over 800 non-recording rain gauges, for measuring daily rainfall sums, and around 40 recording stations, equipped with pluviographs, for continuous registration of rainfall intensity; the recording stations being of paramount importance for determining design rainfall characteristics that are needed for a variety of hydrological studies, estimation of design floods in small un-gauged river basins, studying runoff regime and design of storm drainage in urban areas, roads, airports, etc. Processing and analysis of measured short duration rainfall data, in particular the pluviographic records, started in Serbia in early 1950s. More focused attention to analysis of rainfall intensity and storm rainfall regime in the country dates back to, and began in earnest from, mid 1970s on. The aim of majority of works undertaken so far in this domain has been to establish rainfall Intensity-Duration-Frequency (IDF) and/or Depth-Duration-Frequency (DDF) relationships at measuring points. Attempts have also been made to look at spatial rainfall distribution and to regionalize IDF/DDF parameters characterizing storm rainfall regime so as to be able to calculate with reasonable accuracy the design rainfall intensity at the un-measured sites. The paper presents basic data about rainfall measurement network in Serbia and then concentrates on presenting the historical background and current practices and methods used for processing and analysis of storm rainfall regime in the country. General conclusion is that even though a number of rainfall studies have been carried out in Serbia the two key issues remain, namely to process/digitize in systematic manner a wealth of the available historical rainfall chart records from pluviographic stations, and to undertake, on the basis of processed data, a detailed regional analysis of short duration storm rainfall (from 5 minutes up to 24 hours) in the whole country.

Key words: rainfall measurements; rain gauge; pluviograph; statistical analysis; storm rainfall; design rainfall; IDF/DDF curves; flood; design flood; storm runoff; regional analysis; urban storm drainage.

1. INTRODUCTION

1.1 Serbia - Geographical Position and Basic Climate Features

Serbia is a small southeastern European country located in the central part of Balkan Peninsula (Figure 1). The main climatic characteristics of the country are in general determined by its geographical position and it is in the centre of the northern temperate zone, it should have a typical temperate-continental climate. However, since climate depends not only on geographical position but is also affected by local conditions (i.e. the relief, distribution of high range air pressure, terrain exposition, the presence of the river systems, vegetation, urbanization, etc) there are considerable climatic differences and a number of regions with distinct climatic features can be distinguished in the country. Among the geographic attributes characteristic for synoptic situations that influence significantly weather and climate in the country, one should mention the Alps, the Adriatic and Mediterranean sea and the Bay of Genoa, great Panonian plain and the valley of the Morava river, the Carpathians and Rodopi mountain as well as the hilly-mountainous part with valleys and plateaus. Prevailing meridian position of the river valleys and great Panonian plains in the northern part of the country permit deep intrusion of polar air masses to the south. Thus, Vojvodina and East Serbia (Timočka krajina) are exposed to climatic influences of North and East Europe. Pomoravlje, due to a northern exposure, is under the influence of continental climate from Central Europe, while regions of the West and Southwest Serbia, because of mountainous relief and proximity to the sea, have quite specific climatic conditions.

Figure 1. Serbia, general geographical location

Altitude of the terrain has a pronounced influence on climate. In Serbia it varies from 30 masl. (end of the Danube valley near Prahovo) to 2 656 masl. (Ćeravica, peak on the Prokletije mountain). In this range of over 2 600 metres there are high, medium and low mountains, hills, valleys and highlands, as well as deep and wide valleys of the Danube, Sava, Tisa, and Morava rivers.

1.2 Precipitation – General Overview

Precipitation varies significantly in the country depending on the region. Mean Annual precipitation below 600 mm is typical for the regions of Niš-Leskovac, Vranje and Gnjilane, followed by Kosovo plateau, while most of the northern plains of Vojvodina receive precipitation between 500 and 700 mm. With the increasing altitude precipitation increases in other parts of the country, and on the highest parts of mount Prokletije reaches an annual amount of around 1 500 mm.

Precipitation represent key ‘driving force’ of hydrological cycle, or, as some hydrologists often like to say, major ‘surplus’ component in water balance equation. It is then understandable why rainfall regime plays such an important role in hydrology, water sciences and the related technical fields, in addition to its significance for implementing various types of climatological studies. To investigate floods, runoff and river flow in general one need to have reliable data and information about spatial and temporal characteristics of rainfall regime over the catchment area under study. Hence, there has always been a general interest in establishing a dense and reliable network of stations for precipitation measurements in the country, and then in operating and maintaining the network for a long period of time..

Based on long period of rainfall data records, measured at various points in the network, for engineering design applications it is necessary to determine rainfall intensity/depth of given duration and frequency, i.e to define Intensity-Duration-Frequency (IDF) or Depth-Duration-Frequency (DDF) curves at each measurement point. The next step is to define the regional DDF/IDF relationships, which are the main result of the rainfall frequency analysis and geographic regionalization of the DDF/IDF curves and allow to calculate for any unmeasured point within the analyzed region the design rainfall intensity, or depth, for a given exceedance probability over a range of durations (notably for durations as short as a few minutes up to 24 hours, and in some cases up to 3 to 7 days). They have many applications and are used extensively in the country in the design of systems and structures to control and/or route flood runoff – including dams, spillways, levees, urban drainage systems, roads, parking lots, airports, culverts, etc. Another use of rainfall DDF/IDF curves is for compilation of rainfall-runoff, river-flow and flood prediction models, which incorporate precipitation characteristics.

To arrive at such regional IDF/DDF relationships is, however, not a straightforward task. It requires, inter alia, a dense network of recording and non-recording rain gauges, and a long historical record of measured rainfall data. Even if this fundamental prerequisite is fulfilled (which is not always the case) there still remains an effort to be made to process large volume of historical pluviographic strip/drum chart records, perform data quality control, and create a specialized rainfall database, with should also contain observed series of daily data from the network of non-recording raingauges. The next steps are to deal with data assimilation and extraction of annual and/or POT series of maximum rainfall depths for a number of predetermined durations, statistical analysis of the extracted series and the subsequent extensive regional studies aimed at geographic regionalization of IDF/DDF curves established at different measured points in the region.

This paper aims at reviewing the historical background and the current practices in Serbia in measuring, processing and analyses of rainfall regime. The focus is on the convective short-duration storm rainfall episodes, which produce intense and highly variable rainfall rates that are known to be the major cause of flooding in small river basins and urban catchment areas of Serbia.

Apart from this introduction, the rest of the text is organised as follows: In the next section - entitled Precipitation Measurements - basic information is given about the network of recording and non-recording stations for rainfall measurements in Serbia. It further touches on the prevailing practices and the type of recording raingauge instruments used in the network as well as on the available historical data. The subsequent chapter on processing and analysis of rainfall data outlines routine procedures used by the Republic Hydrometeorological Service of Serbia (RHMS) for primary rainfall data processing and provides details on several projects undertaken so far, which have dealt with systematic processing of pluviographic strip/drum chart records. This chapter then describes some of the major studies of storm rainfall regime in Serbia, and the results achieved. In the conclusion an attempt has been made to summarize shortly the current status and propose the course of future activities.

2. PRECIPITATION MEASUREMENTS

2.1 Network of Non-Recording (Ordinary Raingauge) Stations

To start with, the rainfall data acquisition in Serbia is the responsibility of the Republic Hydrometeorological Service of Serbia (RHMS). Rainfall measurements in the country date back to the late 80s of the 19th century. The first known ordinary raingauge for measurement of daily rainfall depth was installed in 1887 at the Meteorological observatory in Belgrade.

The precipitation network has gradually expanded ever since so that at present daily rainfall sums are measured by the Hydrometeorological Service of Serbia (RHMS) in the network consisting of over 800 ordinary raingauge stations. The current network of ordinary precipitation stations in Serbia is presented in Figure 2.

Figure 2. Network of ordinary, non-recording raingauge stations in Serbia

Keeping in mind the size of Serbia (88,391km^2) and the number of stations (800) in the network operated by RHMS, it follows that, on average, the network density in the country (one raingauge per an area of around 110 km^2) is pretty high compared to the recommended (WMO, 1994) minimum density. According to Palmar (1995), the length of available data record at the majority of ordinary precipitation stations is between 35 to 50 years while just a few stations have daily rainfall data series for periods longer than 60 or shorter than 25 years. Unfortunately, most of the earlier daily rainfall records, observed in the second half of 19th and the first half of 20th century, have been either lost or destroyed during the WW1 and/or the WW2. Nevertheless, from the foregoing it can be concluded that the density and the available historical record of daily rainfall data series allow for detailed point and regional studies of rainfall regime in the country.

It has, however, to be noted at this point that, by necessity, such studies can only be carried out for daily rainfall sums (i.e. those accumulated over a 24-hour period) or for any longer period of time that represents multiple of one-day measurement period (i.e. for 2, 3, 4, 5, 6 days, week, decade, month, year). Although very useful for many purposes, including various climatological studies in the country, this type of analysis alone is usually of limited value for determining flood runoff from small catchment areas and for the important engineering applications concerned with design of systems and structures that control storm runoff and prevent flooding. For this purpose, in addition to the ordinary non-recording raingauge network and classical climatological studies a separate network of recording stations, for continuous rainfall measurements, is needed.

2.2 Network of rainfall recording stations

The first two recording stations in Serbia were installed by the RHMS after the WW2, i.e. in 1949, in Zajecar and Pristina. Since then, this important network has also been gradually expanded so that currently Serbia has around 40 rainfall recording stations. Over 95% of them are equipped with a classic Hellmann's float type pluviograph with siphon; there are also several stations equipped with Hidrometeor pluviograph but the two operate on the same principle and don't differ significantly from each other. In Hellmann's instrument the rainfall is fed into a float chamber containing a light float. As the level of the rain water rises in the chamber, the vertical movement of the float is transmitted, by a suitable mechanism, into the movement of the pen on to a chart. The chart itself is fixed on a cylindrical drum with clock mechanism, which rotates on a vertical axis and makes a full circle in 24-hour period. This way the pen movement registers, continuously in time, the amount of rainfall collected in the chamber; Once the float chamber is full (after accumulating 10 mm of rain at most of the stations in Serbia) the collected water is automatically and instantly siphoned out of the chamber so that the chamber and the whole mechanism are ready to continue recording new rain that falls into the float chamber. One drum chart therefore contains continuous rainfall record for 24-hour period and has, in principle, to be changed every day unless the preceding day(s) was rainless, in which case the same chart can be reused.

The majority of pluviographs in the network do not have a heating device inside the gauge and are thus sensitive to temperatures below zero. For this reason the pluviographic stations in Serbia are in operation during the warmer period of the year only, which lasts from the 1st of April till the 31st of October.

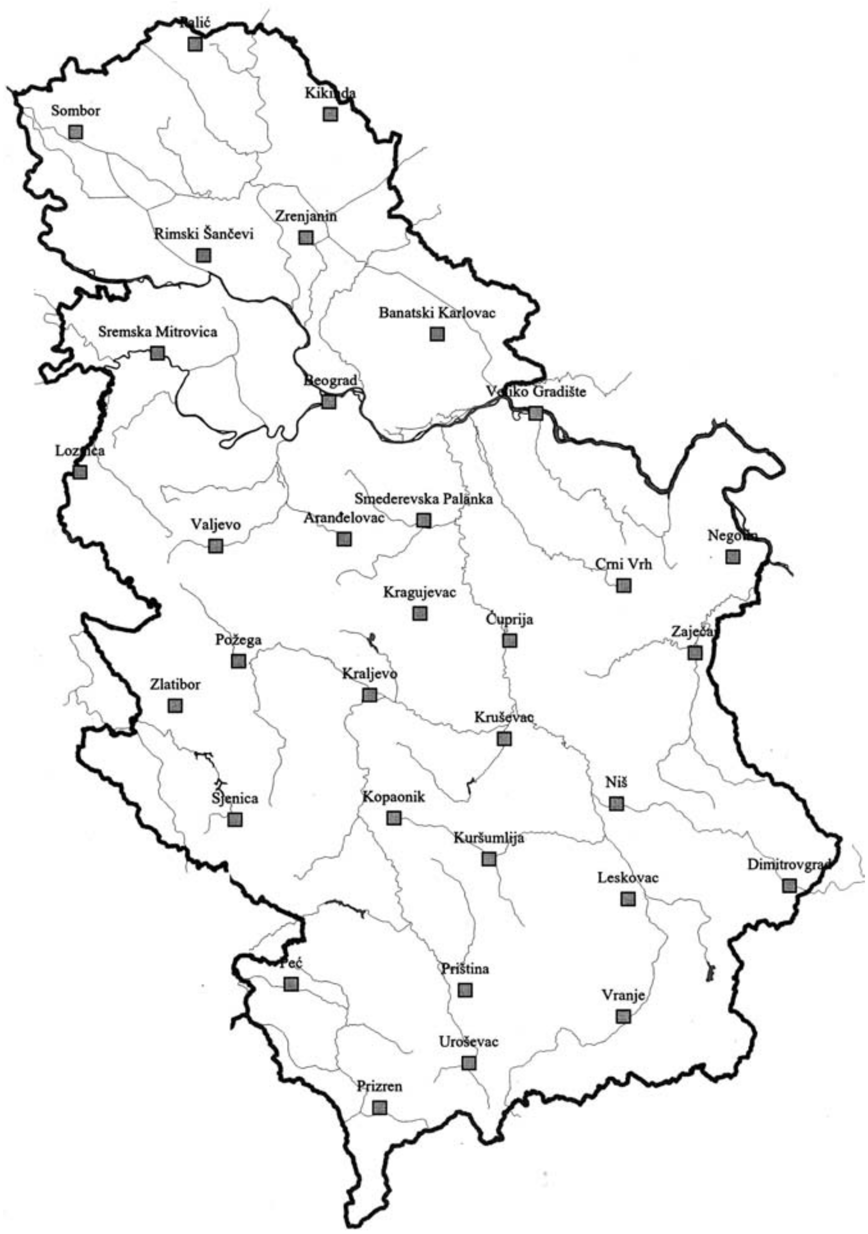

Figure 3 Network of recording stations (pluviographs)for continuous rainfall measurements in Serbia

Based on data given in Andjelic & Jovanovic (1983), the table 1 below sums up some basic characteristics of the current rainfall recording network in Serbia (i.e. number of stations and station density in function of the length of observation).

Table 1. Basic characteristics of the rainfall recording network in Serbia

Length of observation [year]	No. of stations	Density [area in km^2/station]	Length of observation [year]	No. of stations	Density [area in km^2/station]
Over 55	3	29,464	Over 35	34	2,600
Over 50	15	5,893	Over 30	35	2,525
Over 45	27	3,274	Over 20	36	2,455
Over 40	31	2,851	Over 1	40	2,209

It can be noted that the recording pluviographic network operated by RHMS is fairly satisfactory in most of the regions in the country. On the average, the network density for stations that have been over 20 years in operation (one recording raingauge per an area of 2,455km^2) is practically the same as that recommended by WMO (WMO, 1994) for minimum network density in mountainous areas. The situation is better if all the stations are taken into account regardless of the operation period, in which case one recording raingauge covers, on average, an area of 2,209km^2. The above figures are, however, far from favorable when it comes to urban areas, where one recording station should cover an area not larger than 10-20 km^2. Most of the urban areas in Serbia are apparently not covered adequately by the recording stations operated by the RHMS. Even though it is known that the municipal authorities in some cities have installed and operate their own recording stations for urban planning purposes, data from these stations are rarely available to other users. One can also argue that densities recommended by WMO represent an absolute minimum; as such they should be treated just as guiding indicative figures, which need to be verified and if warranted modified (usually upward, i.e. density increased) in accordance with (a) the specific requirements; and (b) the geographic and climatological characteristics of the region under consideration.

The length of rainfall records at the majority of pluviographic stations is over 20 years (see Table 1). Not all the original strip/drum charts have been preserved in the archives - some charts are missing for almost each recording station. Even so, it is fair to say that the overall density and the available historical record of continuous rainfall data in Serbia represent a solid base for a detailed point rainfall analysis and fairly detailed regional studies of short duration storm rainfall regime, which are always to be enhanced and enriched with the necessary information based on studies of daily and longer duration rainfall data.

3. PROCESSING AND ANALYSIS OF RAINFALL DATA

3.1 Processing of Rainfall Data

Within the RHMS, operation and maintenance of the precipitation measurement network, including both the non-recording and recording stations, is under the responsibility of two Departments: the Department for Meteorological Observing System of Serbia, responsible for network operation, maintenance and data collection; and the Department of Climatology, which is in charge of data processing and archiving.

However, while the procedures for processing and archiving of daily rainfall data, collected from the network of non-recording stations, have long been consistent and fully standardized in the Department, the situation is a bit more complicated when it comes to processing and archiving the pluviographic charts collected from the network of recording stations. Traditionally, climatologists are only interested in, and use simple procedure to extract, the following basic information about the rain storm episodes recorded on pluviograph charts:

- Total duration of the episode and time of occurrence;
- Total rainfall amount/depth; and
- Average rainfall intensity during the episode.

The charts are thereafter archived and kept in custody in hard copy. As a consequence, wealth of data about storm rainfall regime registered at the recording stations remains in effect unprocessed and unused. Unless, that is, a specific request has been made by a user for higher level processing of the charts and extraction of more detailed information for the specific stations and years.

Predictably, hydrologists and water engineers have always been (and still are) the major force behind the initiatives and demands for a systematic and standardized higher level processing of all the pluviographic charts collected from the network of recording stations. To this effect, a broad based project was launched in early 80s by Hydrology Department of the now defunct Federal Hydrometeorological Institute (FHMI) of Yugoslavia, the objective of which was to:

(i) digitize in systematic manner all the historical pluviographic charts in former Yugoslavia (including Serbia) and create a separate rainfall database for storage of digitized rainfall data;
(ii) develop, test and adopt a coherent methodology for secondary processing of short duration rainfall intensities (from 5 minutes up to 24 hours) and write and test computer software for the purpose;
(iii) carry out mass computer processing of storm short duration rainfall data in accordance with adopted methodology and by using the developed software packages;
(iv) complete a comprehensive analysis of spatial and temporal characteristics of rainfall regime aimed, inter alia, at developing IDF/DDF curves at all the measuring points and establish regional IDF/DDF relationships for the whole country.

More details on this project can be found in Andjelic & Djokovic (1981), Andjelic et all (1981) and a special publication of FHMI (1983) entitled Round Table on Methodological Aspects of Processing and Analysis of Rainfall Intensity. The project enjoyed at that time a broad support of hydrologists, scientists and water professionals in Yugoslavia; however, for various reasons, including political, it has never been completed except for the objectives (i) and (ii), which were only partially executed in some republics of former Yugoslavia, including Serbia.

3.2 Studies of Storm Rainfall Regime in Serbia – a Short Overview

Even though the primary processing and digitization of all the archived pluviographic charts in Serbia has not been fully implemented, this did not preclude specialists from carrying out a number of analyses and studies of storm rainfall regime in the country. The considerable volume of work accomplished so far has provided much needed information for solving many and varied practical engineering problems concerned with flood management and water resources assessment. It also lent a helping hand in gaining experience and better insight into the storm rainfall characteristics in various regions of the country.

Review of these and other rainfall studies provides a fairly realistic picture regarding the state of the art in this domain in Serbia. Without ambition to go into all details of the works carried out so far, some of their major achievements are shortly summarized in the text below.

The first attempt at rainfall analysis in the country dates back to early 1950s, when Milosavljevic (1952) published her pioneering work on intensity of storm rainfall in Belgrade, Vrnjacka Banja and Prilep. Although Djordjevic (1969) has made a new analysis of storm rainfall for Belgrade, rainfall intensities of short duration began receiving more focused attention from 1976 on. Thus, Petkovic (1976) applied at several stations in Serbia a methodology developed by Alexeev (1966, 1969) that was widely used in USSR for computation of rainfall intensity characteristics. A number or works and papers followed, e.g. Vukmirovic (1976), Zelenhasic i ost.(1978,1979,1980) Vukmirovic i Jovanovic (1979), Radic i Jovanovic (1979), Markovic (1979), Andjelic i Djokovic (1981a, 1981b), Andjelic i Jovanovic (1983), Prohaska i ost. (1981) Vukmirovic i Despotovic (1984, 1985, 1986), Savezni Hidrometeoroloski Zavod (1982, 1983), Despotovic (1984, 1994), Jankovic (1994), ,Jankovic & Kapor (1995) Palmar (1995) and many others.

In general, it can be noted that a full fledged, comprehensive regional study of short duration storm rainfall regime in the county does not still exist. By far the largest number of works is related to classical statistical analysis of rainfall intensities by using annual extremes, and determination of IDF and/or DDF curves at the recording stations' points. The works of this type can be found in e.g. Djordjevic (1977, 1979), Zelenhasic et all (1978, 1979, 1980), etc. To this group also belong partially the works of e.g., Despotovic (1984), Despotovic & Vukmirovic (1991) Vukmirovic & Despotovic (1985, 1986), Vukmirovic & Jovanovic (1979), etc., which dealt with statistical point rainfall analysis by using POT (Peak Over Threshold) rainfall series.

There have been a few attempts at establishing regional IDF/DDF relationships. Here is to mention the work of e.g. Prohaska et all (1981) who presented results of regional analysis for the Velika Morava river basin; and Vukmirovic & Despotovic (1982) who carried out regional analysis of storm rainfall regime for the municipal area of Belgrade.

The works of Jankovic (1994) and Jankovic & Kapor (1995) have come closest to the IDF/DDF regionalization paradigm in Serbia. In these studies the authors attempted and succeeded to some extent to regionalize parameters of the following analytical expression of IDF curve,

$$I(D,T) = I_0(T)/(aD + 1)^b, \qquad (1)$$

where **I(D,T)** is rainfall intensity for given duration**- D** and frequency (return period)- **T**; **a & b** are dimensionless coefficients; while **I_0(T)** is the instantaneous rainfall intensity of very short duration - when duration -**D** approaches zero value, i.e.

$$I_0(T) = \lim I(D,T), \text{ when } D \rightarrow 0 \qquad (2)$$

Jankovic & Kapor have successfully regionalized parameters **a** & **b** of the above analytical relation and mapped them in the form of isolines for the whole country (Figure 4),

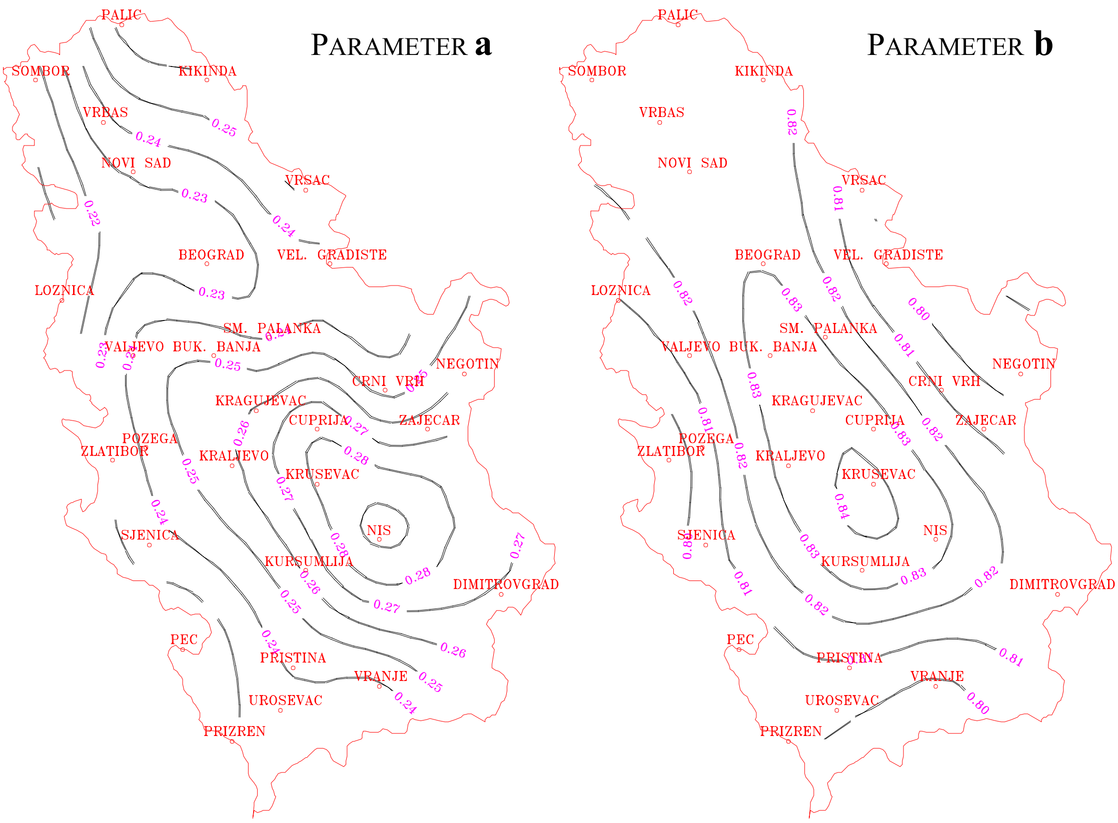

*Figure 4. Maps with isolines for parameters **a** and **b** for the territory of Serbia*

As for the values of the instantaneous rainfall intensity **I_0(T)***,* it was shown that they can be determined via the maximum daily rainfall **P_d** for the same return period **T***.* To do so, it was necessary first to determine the relationship between **P_{1440}** and **P_d**, where **P_{1440}** represents the maximum annual rainfall of duration 1440 minutes determined from the pluviographic record, while **P_d** is the maximum annual rainfall depth observed from the ordinary raingauge at the same station (at which the total rainfall amount is measured every day at fixed time intervals).

It was shown that the **P_{1440}** and **P_d** are directly proportional, i.e.

$$P_{1440} = k\,P_d \qquad (3)$$

Based on analysis of data from 30 pluviographic stations in the country, it was found that the coefficient of proportionality - ***k*** changes insignificantly from station to station, hence an average value of ***k* = 0.91** was adopted for the whole territory of Serbia.

For the known values of the three above parameters ***a, b*** and ***k*** and for defined frequency distributing function for daily maximum rainfall series P_d, the values of highest intensity for given return period **T**, $I_O(T)$, can then be determined by knowing $P_d(T)$,

$$I_0(T) = \frac{k(1440a+1)^b}{1440} P_d(T) \qquad (4)$$

and finally, the **I(D,T)** for any duration **D** and return period **T,**

$$I_0(D,T) = \frac{k(1440a+1)^b}{1440} \frac{P_d(T}{(aD+1)^b} \qquad (5)$$

The above procedure was tested and the authors demonstrated successfully that there was no real need to regionalize values $I_O(T)$ by the isoline chart, thus eliminating the need to make a series of additional regional charts, separately for each desired return period ***T.***

Lastly, before concluding this short overview it may be worth mentioning the work of Despotovic (1994), who made a comprehensive survey of the state of the art procedures concerned with analysis and design of storm runoff drainage in the country; and Andjelic & Jovanovic (1983) who attempted for the first time to open the issue of establishing regional IDF/DDF relationships in the country through a concerted effort, and by using unified approach and methodology in rainfall data processing and analysis.

CONCLUSIONS

As a general conclusion it may be stated that even though a number of storm rainfall studies have been carried out in Serbia the two key issues remain to be dealt with;

(a) to process/digitize in systematic manner a wealth of the available historical rainfall chart records from the network of pluviographic stations operated by the RHMS and create a separate storm rainfall database; and
(b) to carry out, on the basis of processed data, a detailed analysis of short duration storm rainfall (for durations from 5 minutes up to 24 hours) at all the measuring points in the network and establish regional IDF/DDF relationships for the whole country.

When it comes to rainfall measurements and processing, a lot remains to be accomplished, but the following two issues require immediate action. Namely, it is necessary to radically modernize:

(c) the aging precipitation network by replacing the outdated Hellmann's pluviographs and ordinary raingauges with electronic instruments capable of digital recoding and storage of rainfall data; and
(d) the procedures currently in force in RHMS for primary and secondary data processing of all the measured rainfall data.

Last but not least, the authors' position is that cooperation with other states in the region is desirable and highly recommended. It should in particular endeavor to promote:

(e) standardization of instruments, methods and procedures used in the region for rainfall data measurement, processing and analysis;
(f) establishment of working mechanisms for exchange of data, as well as of experience and know-how in this specific area; and
(g) joint efforts in carrying our regional studies of storm rainfall regime keeping in mind practical importance of such studies for many scientific and engineering applications.

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WEATHER RADAR - A Detecting and Measuring Equipment in Meteorology and Hydrology

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Abstract:

Since the starting days of radar meteorology, radar was considered as a powerful tool to describe and understand the meteorological phenomena related to precipitation, and a promising technology for hydrology. Even nowadays, weather radar is still the unique instrument able to provide a description of the precipitation field with the resolution required in hydrological modeling (spatial resolution about les then 0.1 km^2 and temporal resolution of 5 to 10 minutes). Those requirements are far away of the conventional rain gauge networks densities (usually about 1 rain gauge per 50-200 km^2).

This important role radars could play has been widely understood, and almost all countries around the world have carried out significant efforts to install radar networks.

Republic Hydrometeorogical Service of Serbia is owner of fourteen weather radars covering almost all technological solution implemented in this area (ten non-Doppler, three pulse-Doppler, one of them with dual polarization, and one dual wavelength). Unfortunately, they do not make the radar network in the true sense of the word, because they are not connected, each of them acts individually. The non Doppler radars, MITSUBISHI RC-34A, are able to perform reflectivity measurements of meteorological phenomena and to calculate precipitations, according to adopted model. These radars are installed in Serbia region (without Vojvodina), and they have been upgraded for the needs of hail suppression system. It was domestic research and development of very complex system dedicated for increasing hail suppression activities effectiveness.

The pulse Doppler radars, GEMATRONIK Meteor 400S/500S, perform all measurements known in nowadays radar meteorology and hydrology: reflectivity, radial velocity, spectrum with and polarization of reflected electromagnetic waves. A huge number of meteorological and hydrological products can be generated from these parameters. They are installed in Vojvodina.

Finally, one is dual wavelength radar, Russian MRL-5, installed in Belgrade for the weather radar forecasting.

At the first sight, the number of radars in Serbian weather radar network is too large for meteorological and hydrological forecasting. However, the purpose of all radars, except MRL-5, is hail suppression activity and this number of radars was dimensioned according to the methodology implemented in it. This dense network, on the other side, enabled radar covering of the whole state territory and parts of neighbor countries on all relevant heights which is, also, very important and useful for meteorological and hydrological forecasting.

One remark, the whole Serbian weather radar network or part of it (if they are used on the right way) are able to perform all world's known meteorological and hydrological measurement and get all relating products. These are meteorological and hydrological forecast, relevant radar measurements and data analysis.

The groups of products available from the Serbian weather radar network are:

- Standard and extended meteorological products
- Hydrological products
- Wind shear detection products
- Warning and forecasting products
- Phenomena detection products
- Aviation products

The fields that acquire great, sometimes essential, benefits from this weather radar network are: meteorological and hydrological science (in that scope, exchange radar measured parameters within European radar network), agriculture, civilian air traffic, cities public services, road maintenance, traffic, protection of the environment, informative services, media, tourism, etc.

Although this operational network has been designed from purely meteorological criteria and requirements (especially for hail suppression activities), commonly it is considered as a tool to improve hydrological models and forecasting systems. Nevertheless, up to now it has essentially been used for qualitative applications. Its quantitative applications are still rare. The present situation is that this promising tool has not been able to fulfill the hopes of the hydrologists as potential users, and radars are still seldom used in operational hydrology.

The main reason for this situation is that radar measures rainfall in an indirect way, which needs a sequence of very complex correction procedures. Procedures that only have been clearly established since the early 1990s, when hydrologists working on the problem of radar rainfall estimation have begun to take a physical approach to study the principle of radar measurements from a hydrological perspective, leading to what it is now known as 'radar hydrology'. Thus the advancements of the last 20 years have allowed us to state that the hydrological applications of weather radar can be achieved if a systematic correction of the errors and inaccuracies, inherent to radar measurement, are corrected.

Apart from conventional rain gauge, operational weather radars and the numerical weather prediction models offer a new opportunity to hydrology to improve flood forecast and prediction of water resources by utilizing distributed hydrological modeling approach. In nowadays, operational weather radars cover the majority of land areas in Serbia and the interpreted precipitation from radar measurement is available from several sources. Some research projects have to be initiated for studying the applicability of the radar precipitation for flood forecast and water resources management. One of main objectives is to identify the effect to hydrological responses by the spatial distribution of precipitation and examine applicability of the radar rainfall for flood control.

Future radar requirements for hydrological models are the main items for discussion. The main points of which are:

1. Existing radar data is not being used to its full potential by the hydrological community.

2. Radar data must be continuously available for operational use. Failures must not be correlated with weather events with serious consequences.

3. Dual polarization radar will be useful for quality control, improved quantitative estimates of precipitation and identification of precipitation type.

4. Archiving of data for post event analysis and for design purposes is required

5. Data quality should be continuously improved,

6. Education on how uncertainty information is generated and operational procedures to use uncertainty (both data and modeling uncertainty)

7. For large river basins we need timely production of data from many sources.

8. The hydrological future for radar is part of a multi-sensor/multi-source (with data quality information) which includes rain-gauges, satellites, NWP and new technologies.

9. Meteorologists and hydrologists need to get together to understand how to use uncertainty on a scientific basis for decision making for flood management (control & warning).

OVERWIEV OF SISTEMATIC MEASUREMENT OF PHYSICOCHEMICAL COMPOSITION OF PRECIPITATIONS AT MONTENEGRO AREA

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ABSTRACT

Systematical measurement of physicochemical composition of precipitation at Montenegro area started in 1983.y., by Department for Environment of Hydrometeorological Institute in Podgorica.

Measuring network consist of 15 stations, in all bigger cities. Stations are located at meteorological stations. In 30-days sample is measured content of main ionic species (Ca, Mg, Na, K, NH_4) and SO_4, NO_3, Cl, HCO_3). In 24-hour sample is measured value of pH and conductivity, from six station only.

From 1993.y. all samples collect during 24-hour, from 7h previous, to 7h next day, according UTC.

Samples collect in inert-plastic sedimentator, on the manual way. The outside funnel surface has fixed size. Work methodology is standard for hydrometeorological service (by WMO guidelines).

At Podgorica station a rough separation of wet and dry deposition is done, from 2001.y.. Data shoes important difference of chemical composition of these depositions and confirms a thesis about maritime influence on the precipitation structure at main Montenegro area (Djuraskovic, 2003). Next researches shoe difference of precipitation composition into same rainfall wave (Djuraskovic, 2004).

Acid rains are noted about 10% of all samples, in bigger urban areas (except Pljevlja area), exspecialy at forest areas (Kolasin, Zabljak).

Transport and deposition of desert aerosols from North Africa is sometimes very frequent phenomenon, in dependence from meteorological conditions, which has important influence on terestrial ecosystems, in these circumstances. Factor of enrichment goes to 100, for iron (Djuraskovic 2002).

Regional Cooperation on Rainfall Measurement

OVERVIEW OF SYSTEMATIC MEASUREMENT OF PHYSICOCHEMICAL COMPOSITION OF PRECIPITATIONS AT MONTENEGRO AREA

Pavle Đurašković
Hydrometeorological Institute, Podgorica

Belgrade, Dec 2005

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PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

General

- Systematic measurement of physicochemical composition of precipitations at Montenegro area started 1983.y. This activity carried out Department of Environment of Hydrometeorological Institute in Podgorica.
- The beginning measurement program included 30-days sample, but now (from 1993.y.) is analyses 24-h sample.
- Measurement station located at meteorological stations, in all bigger cities, over the country.
- Measurement network is shown on the next picture.

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Measurement Network stations

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Methodology

- The precipitation sample is taken from 7h previous, to 7h next day, according UTC, if it was measuring quantity of rain.
- Samples are collected into inert plastic collectors, by the manual way.
- Bottles with samples are transferred to Department's laboratory, one time per month, usually.
- Measuring program includes determining of content of main ionic species (Ca, Mg, Na, K, NH_4, and SO_4, NO_3, Cl, HCO_3), and pH and conductivity value, too.
- The measuring procedure is harmonized with requested guidelines (WMO, EMEP).

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Methodology

- EMEP program:

  Content of main ionic species (like national monitoring program), and content of some heavy metals (Hg, Pb, Cd) in precipitations (Station Zabljak).

- MED POL program:

  Content of main ionic species (like National monitoring program), and content of some heavy metals (Hg, Pb, Cd) in precipitations (Station Herceg Novi).

- Radioactivity in precipitation:

  Measuring of exposed dose of gamma radiation is done in three climatological times, at the stations in Herceg Novi, Podgorica and Zabljak.

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Overview of the found state

- ***Deposition***

-Dynamic of precipitations, in both quantity and quality sense, is under influence of Mediterranean regime, at the biggest part of Montenegro area. In that cases precipitation are result of transfer of air mass from south direction.

-Orographic factors make that main quantity of rain is disposed on the sea coastal area, or in its rear. Crkvice village at the rear of Boka Kotorska Bay, is the place with the biggest amount of rain sediment in Europe (4210mm annual average, 7067mm annual maximum, and 500mm max per 24h). A whole rainfall wave is usually extended to the next chain mountains (on the Durmitor-Bjelasica direction).

-Precipitations are most frequent in the autumn or spring.

-A single case or long period of continuity (a month or two, sometimes), with downpour of rain and big amount of sediment, appearance of thunderstorm, are typical characteristics of these precipitations.

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Overview of the found state

- ***Acidity***

-Appearance of acid rain is a moderate, to 10% of total number of rain cases. The value of acidity decreases sometimes under 4 pH units, but not under 3.

-Most often, acid rains are noted at the Podgorica area, as well as at the area of Kolasin and Zabljak, where are the most important forest region in Montenegro. Acid rains are appeared at Coastal area, but in less percentage.

-Rain acidity increases in wet deposition but mainly doesn't come from local sources. The main currier of this acidity is SO_2 in the air, which source is emission from developed countries in South-West Europe..

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PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Overview of the found state

- ***Structure***

-Chemical structure of wet deposition of precipitation is under maritime influence. The contribution of ions is as follow (Djuraskovic,2001):

Dry deposition

Ca → Mg → Na → NH4 → K

HCO3 → SO4 → Cl → NO3

Wet deposition

Ca → Na → NH4 → Mg → K

SO4 → HCO3 → Cl → NO3

-Maritime characteristic of precipitations are preserved to high mountain areas on the north, what could be seen from the correlation analyze between ionic species from Herceg Novi (sea coast) and Zabljak stations (Djuraskovic,2003).

-Structure of dry deposition shows influence of re-suspension of dust from land.

-Investigation showed that contribution of some ionic species changes during multi-days rainy period (Djuraskovic,2004).

PRECIPITATIONS COMPOSITION MEASUREMENT AT MONTENEGRO

Overview of the found state

- ***"Yellow rains"***

-Geographical location of Montenegro and regarding meteorological factors make conditions for deposition of desert dust aerosols from North Africa, on its area.

-This phenomenon can be very frequent (especially during spring and autumn season), with some important consequences on terrestrial and aquatic ecosystems, as well as human health.

-Enrichment factor for iron (Fe), as constituent of aerosols, comes to 100, in comparison with "usual" precipitations (Djuraskovic,2002).

- Forecast Transportation and Deposition Modeling of Sahara dust aerosols on Montenegro area is done, in cooperation of HMI, Podgorica and University of Malta. Now, the model is in practical evaluation.

Abstract

Pluviometric network in Albania

Procedure of measurements and elaboration methods

Bojko Themelko
Vangjel Mustaqi
Hydrometeorological Institute of Albania

In this paper are presented data about distribution of pluviometric network of Albania, procedure of measurements and gathering data. Because of the high variability of the precipitation over territory (700-2900 mm/year) the pluviometric network in Albania is relatively dense. Actually there are 130 stations spread out over territory (before 1990 there were 220 such stations) equipped with pluviometers and 25 of them with pluviographs. Also methods of data quality control and filling of gaps are described. The homogeneity of long-term precipitation series is analyzed using Mann test and Double Mass test. Valuation of precipitation layer is carried out using Tissen and Akin methods.
From the application of Grubbs test on the 24 hours maximum precipitation results that in 70 series are evidenced outliers. Kalman filter method is used for elimination of the influence of outliers in evaluation of 24 hours maximum precipitation for different return period

Pluviometric network in Albania
Procedure of measurements and elaboration methods

Bojko Themelko
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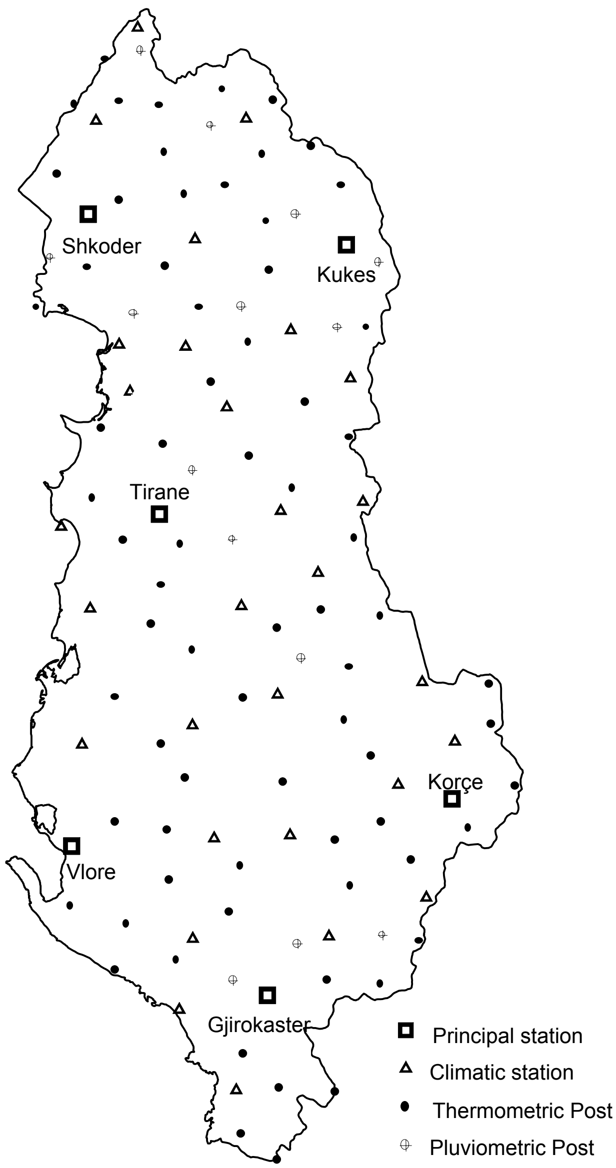
Averagely in Albania during a year fall about 1400 mm precipitation. But it is important to say that the space distribution varies in high range, from 700 mm in south east part to 2900 mm in Albanian Alps. For this reason the pluviometric network in Albania is relatively dense. Actually there are 130 stations spread out over territory (before 1990 there were 220 such stations). In Fi. 1 is given the map with position of the stations.



Pluviometric Network

The determination of the total number of the stations is done based on evaluation of optimum distance between 2 stations to have an error of estimated precipitation layer of 4 %. From the calculations result that for this threshold (4%) 150 stations are needed in territory of Albania. Measurement instruments are pluviometers with collected surface 1000 cm^2 in altitudes 1.5 m over earth surface. Only 25 stations are equipped with pluviographs. Precipitation measurements are made once per day in hour 7^{00} (local time) and only in 25 stations twice per day in 7^{00} and 21^{00}. From 15 stations we receive this information each day while for the others we receive the pluviometric information once a month by post.

Quality control of data.

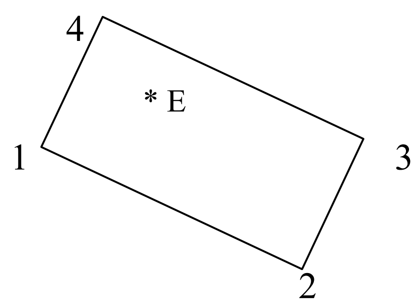
After ejection of great errors (<0 or >350 mm) the space control is made. Daily precipitation will be considered doubtful when the difference between it and those of 3 stations around it is greater than 90 %. Mathematical expression is

$$| Pi - Pj | > 2.0 + 0.9 * \max \{Pi,Pj\}$$

The coefficient 90 % is relatively high in order not to eject stormy days when the difference of precipitation for 2 close stations is great.

Reconstruction of missing data.

Reconstruction of missing data is done using weighted mean of precipitation of 4 around stations. This procedure is carried out in the case when the observations are interrupted for a period less than 15 days.



Mathematical expression of this calculation is:

$$X_E = \frac{1}{4} \Sigma N_E/N_i * X_i$$

Where
- X_E daily precipitation to be filled
- N_E multiannual mean of station E
- N_i multiannual mean of station i
- X_i daily precipitation of station i

In the case of missing measurement more than 15 days per month we fill only the monthly value of precipitation using ratio method between two neighbor stations.

Homogeneity control of series

For verification of annual precipitation series homogeneity are used two tests: double mass test and Mann test. Double mass test is based on the comparison of cumulative precipitation between two neighbor stations. When the straight line changes inclination a heterogeneity is verified. Mann test verifies the heterogeneity regarding stability of mean and dispersion and also the lack of correlation between consecutive terms.

The variable of Mann test is

$$t_i = [T_i - E(T)]/\sigma(T)$$

Where $T_i = \Sigma_j n_j$

$E(T) = n*(n-1)/4$

$\sigma(T) = (2n3 + 3n2 - 5n)/72$

n length of series

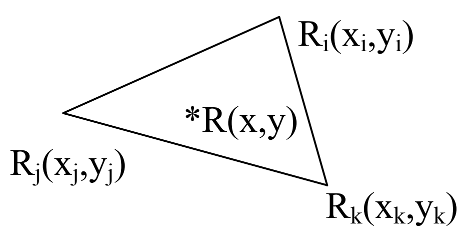
$\mathbf{n_j}$ number of terms less than term “j”

If all $\mathbf{t_i}$ are less than table value of normal distribution for a given significant level then the series is called homogenous.

Precipitation layer

Mostly the evaluation of precipitation layer is made using arithmetic mean of precipitation for all stations situated in given territory.

Another method used to evaluate precipitation layer is that of Akin. By this method are drawn triangles where their corners are pluviometric stations.



The precipitation in whatever point inside the triangle, with coordinates x,y is given by equation

$$R_n(x,y) = {}_n\alpha_1 + {}_n\alpha_2 X + {}_n\alpha_3 Y$$

and total volume of precipitation over surface of this triangle is given by the surface integral

$$Rn = \iint ({}_n\alpha_1 + {}_n\alpha_2 x + {}_n\alpha_3 y)dx\, dy$$

Average precipitation layer for all territory will be

$$R = \frac{\Sigma\, Rn}{\Sigma\, Sn}$$

While the Tissen polygon method is used in very rare cases.

Maximum 24 hour of precipitation.
Data elaboration of 24 hours maximum precipitation has very wide practical usage.
In this frame the evidence and elimination of the effect of the outlyer presence in these series is very important.
Existence of outliers in series of 24 hours maximum precipitation is determined using Grubbs test. The statistics of test is:

$$G = \frac{Max\,|\,Yi - Ym|}{s}$$

From the application of this test on 220 series of Albania results that in 70 of them are evidenced outliers.
To avoid the effect of the existence of outlyer in a series for calculationof values for a return period, often is used substitution of the outlyer with the second maximum of that year. In this case return period of the outlyer will be very high in spite of that this event is observed.
We propose to use Kalman Filter method for calculation of α and U parameter of Gumbel distribution. For this distribution we have a linear relation between precipitation and reduction parameter y_i:

$$X = 1/\alpha * y + U \qquad \text{where} \qquad y_i = -\ln(-\ln(i/n+1))$$

Kalman filter is an iterativ method which readjust two parameters α and U in each step (i for 1 to n). By Kalman filter theory, state of a physical sistem changes according to the equation

$$X(t+1) = F(t) * X(t) + w(t)$$

and the readjusting of parameters in each step is made by equation

$$X(t/t) = X(t/t-1) + K(t) * \nu(t)$$

The readjusting of parameter we extended over outlyer (keeping as as observed values the amount of outlyer) so steps up the calculated value is less than outlyer one. In ranked series "n" term (last term) is an outlyer. The cumulative probability for each term in ranked series up to "n" term is calculated by formula

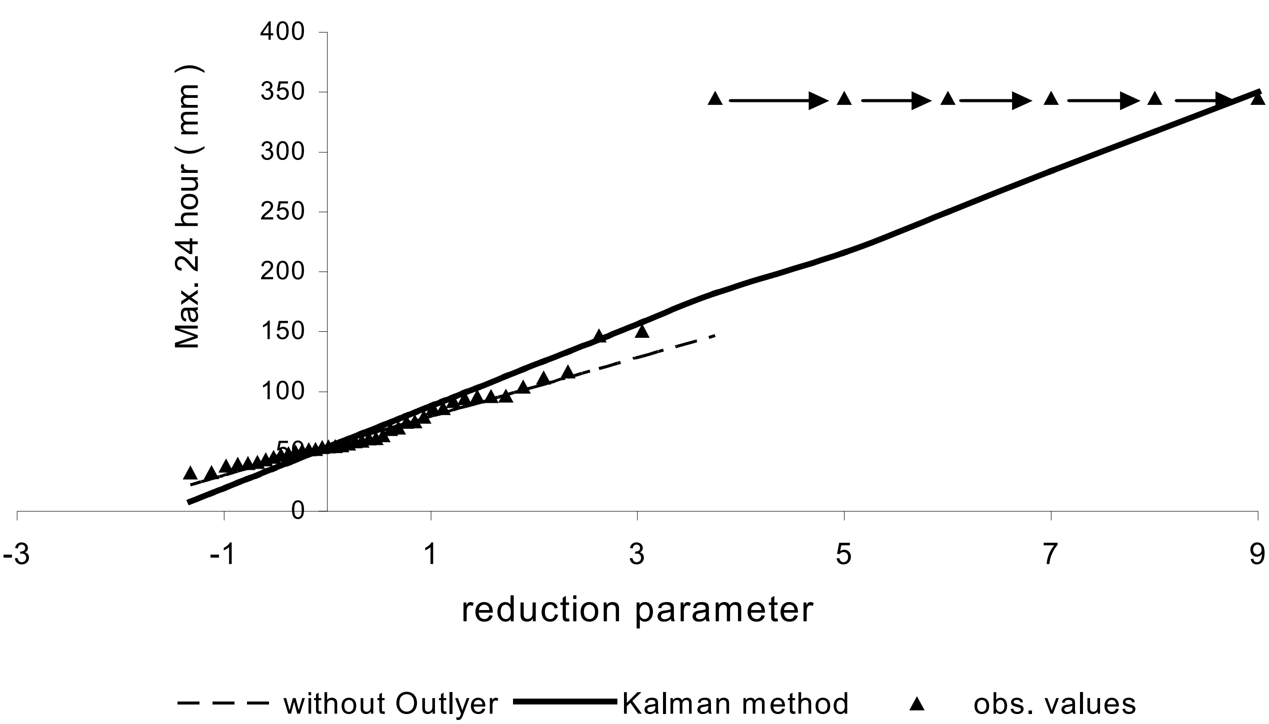
$$Fi = i/(n+1)$$

While for terms over outlyer cumulative probability is calculated by Suzuky method. In case of Gumbel (after some operations) distribution cumulative probability of next step is

$$F_{n+1} = F_n^{\exp(-(n+1)/n)}$$

Let give an example of 24 hour maximum precipitation for Fieri station. In Fig. below is presented ranked series against cumulative probability (reduction parameter). It seems that last value (344mm) is very despart from the others and from Grubbs test is considered as outlyer. Also in this figure are drawn the lines of Gumbel distribution for two cases: without outlyer and by Kalman filter. In this case Kalman filter is run 5 steps up to achive fulfillment of above condition.

Fig. Gumbel distribution (Fier station)



In case of substitution of outlyer with second maximum value of that year, the return period of outlyer is 109000 years while by Kalman filter 5000 years. Calculated value for 100 year return period in first case is 168 mm while in the second 211 mm. From this figures seems that Kalman filter methods gives more credible results.

CURRENT LEVEL OF RAINFALL NETWORK OF TURKEY

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Abstract: Turkey has a surface area of 779 452 km^2 and. The Asian part; Anatolia is a plateau rising progressively towards the east. Turkey has a variety of climates, changing from the temperate climate of the Black Sea region, to the continental climate of the interior, then to the Mediterranean climate of the Aegean and Coastal Mediterranean regions. The long term mean annual rainfall in Turkey varies between 242.8 mm (at Igdir) to 2301.4 mm (at Rize) with an average of 642.6 mm and this corresponds to an average annual rainfall of 501 km^3. Turkey is divided into 26 river drainage basins to study the water and land resources as extensively as possible.

Turkish State Meteorological Organization (DMI) is the sole responsible for the meteorological network and weather forecasting of Turkey. Some more state organizations such as agricultural research institutes, state farms, forest ranger and highway maintenance units, and university research laboratories also make precipitation observations but they are local and continue for a limited period of time and after completion of the work the results are transferred to DMI.

Rainfall observations are made mainly by Turkish State Meteorological Organization (DMI), Turkish State Hydraulics Works (DSI) and General Directorate of Agriculture Research (TAGEM) (former General Directorate of Rural Service (GDRS)).

According to 2005 statistical data in hand, DMI set up and operates 451 Hellman type pluviometers, 255 Hellman Siphon type pluviographs. Observation stations are located mainly at urban areas and mainly for climatic information. At present 206 automatic weather observation stations were set up within “Turkey Emergency Flood and Earthquake Recovery - TEFER” project area and also 25 automatic weather observation stations are located mainly at civil and military airports.

DSI started in 1956 to operate rainfall observations by Hellmann type pluviometers at their meteorological stations, and at present DSI operates 349 stations located mainly at upper reaches of the reservoirs watersheds. DSI has also 320 more precipitation stations which are out of service at present, but they operated for a certain period of time in the past for project purpose and the data collected at that time, are saved in archives. Out of 349 stations, 92 are for precipitation measurement, 271 for the measurements of both precipitation and evaporation from free water surface. DSI meteorological stations are equipped with 244 pluviographs of Bellfort weighing types, 256 Class-A type evaporation pans, and 36 Mount Rose type snow samplers. The data collected from 37 rainfall observation station and 206 Automatic meteorological stations which are located at TEFER project area is transferred to the central operation office at Ankara by telemetric system.

General Directorate of Agriculture Research-TAGEM (former General Directorate of Rural Service-GDRS) has 12 Agricultural Research Institutes in Turkey. At each research institute, there are well monitored small representative basins, to improve the yield and quality of irrigated crops through the design of efficient management systems. For these purpose TAGEM operates meteorological observation stations at these research basins to collect the necessary climatic data including rainfall by about 50 pluviographs. The collected data is shared by DMI.

In data analysis for the elimination of errors, percentile, normal-ratio, double mass curve methods and correlation techniques are employed by all the data collecting organizations. The error free data can be purchased from the organizations.

In this paper, a detailed survey of current situation of Turkish rainfall observation network, rainfall measuring instrumentation, and the methods used in the analysis of rainfall data is presented.

Key Words: Turkey, Rainfall Observation network, instrumentation

1. RAINFALL MEASUREMENTS IN TURKEY

1.1 Historical background

The first rainfall observations had been started in 1579 by Rait Takittin at Istanbul during the Ottoman Empire. The first official meteorology observation station had been established in 1868 in Istanbul, then 14 more meteorology station had been established in the Anatolian. These stations had been collaborated with the European meteorological observation stations Then different organizations of Turkey Republic had started meteorological observations after 1925 (Aytaç, 1965). Turkish of State Hydraulic Works (DSI) had been established in 1929 (www.dsi.gov.tr), Turkish State of Meteorology Service (DMI) had been established in 1937 (DMI, 2005), and General Directorate of Agriculture Research (TAGEM) (former General Directorate of Rural Service (GDRS)) had been established in 1984 (www.khgm.gov.tr).

1.1.2. Current situation

Turkish State of Hydraulic Works (DSI) and Turkish State of Meteorology Service (DMI) are two main organizations operating rainfall observation network, processing and analyzing rainfall data. Additionally General Directorate of Agriculture Research (TAGEM) (former General Directorate of Rural Service (GDRS)) is another organization operating meteorological observation stations at 12 Agricultural Research Institutes. Meteorological observation stations which have been operated by Turkish State of Meteorology Service are located at urban area, meteorological observation stations of Turkish State of Hydraulic Works and General Directorate of Agriculture Research, are located at the rural area. Also some state farms, forest directories, highway maintenance units and university laboratories are operating rainfall observation stations for their projects, during a certain time period.

Long term, annual average rainfall depth is 642.6 mm in Turkey and its total volume is 501 km^3. Long term average rainfall depths for the seven geographic regions of Turkey can be presented as; Mediterranean Region: 750.7 mm, Marmara Region: 640.6 mm, Agean Region: 672 mm, Central Anatolian Region: 388.8 mm, Eastern Anatolian Region: 611.2 mm, Black Sea Region: 816.5 mm and Southeastern Anatolian Region: 609.8 mm (DSI, 2003). According to the rainfall data of 153 meteorological observation stations of DMI during

1961-1990 observation period; maximum rainfall depth was 2180 mm at Rize and the minimum rainfall depth was 255 mm at Iğdır. 24 hour total maximum rainfall depth was 466.3 mm at Marmaris in 1992 and 24 hour total minimum rainfall depth was 34.3 mm at Iğdır in 1972. For 15 minute rainfall duration; maximum rainfall depth was 70.7 mm in at Hopa in 1988 and minimum daily rainfall depth was 11.2 mm at Hakkari in 1993 (DMI, 2005). The annual total normal rainfall depth distribution of Turkey can be seen in the Figure 1a. 24 hour maximum rainfall depth distribution of Turkey can be seen in the Figure 1b.

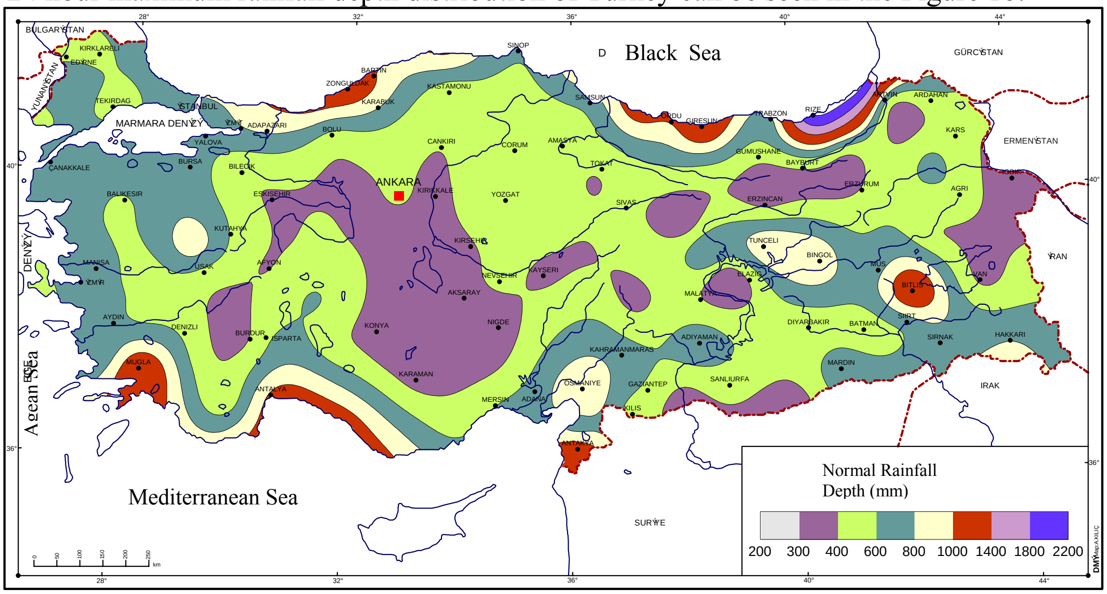

Figure 1a: Annul total normal rainfall depth distribution of Turkey (DMI, 2005)

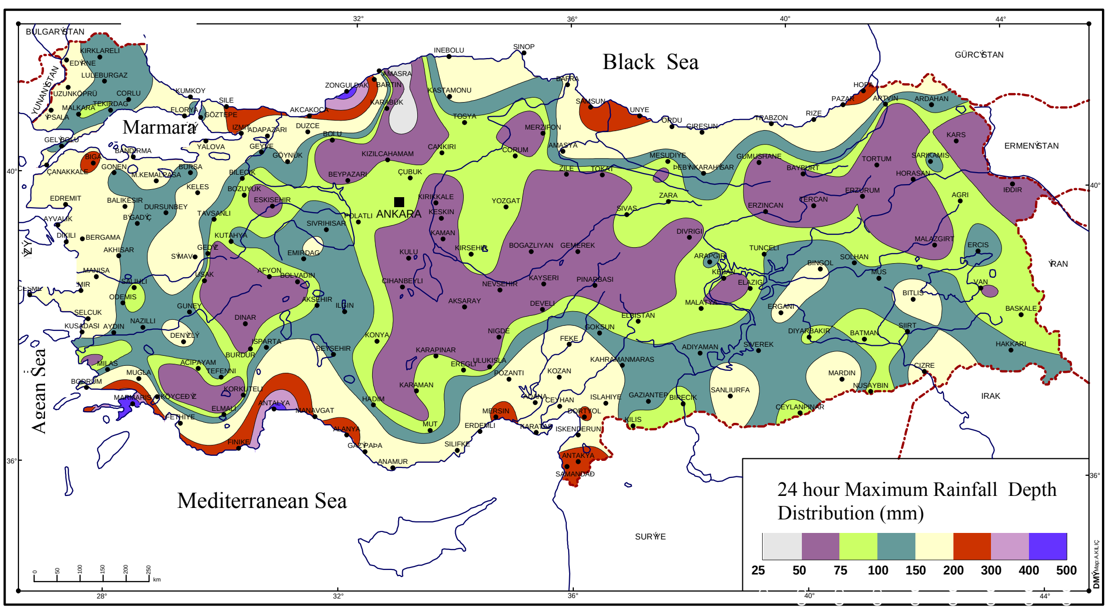

Figure 1b : 24 hour maximum rainfall depth distribution of Turkey (DMI, 2005

2. OBSERVATION NETWORK

Turkish State of Meteorology Service (DMI) operates 411 active meteorological observation stations (Gençer et al., 2005). At the meteorological observation stations of DMI, synoptic observations are made in every 3 hours and total 8 times in every day. Synoptic observations are rainfall depth and total rainfall depth, daily evaporation, radiation, wind magnitude and wind direction, temperature, atmosphere pressure, relative humidity, snow depth, sunshine hours and soil temperature (DMI, 2005). At present DMI operates 451 Helmann type pluviometers and 255 Helman Siphon type pluviographs. As an addition DMI operates total 231 Automatic Weather Observation Stations (AWOS); 206 of them are used for the climatic observations at TEFER Project (Turkey Emergency Flood and Earthquake Recovery Project) and 25 of them are used for the aviation at the airports. Aim of TEFER Project is the forecasting the probable flood in Turkey. Real time data from DSI and EIEI (General Directorate of Electrical Investigation) hydrometric stations, DMI Automatic Weather Observation Stations data, radar data and numerical weather prediction data from DMI are collected and these data are sent to MIKE-11 flood prediction software. TURKSAT1-C satellite is used for the real time data transfer from radar and Automatic Weather Observation Stations. MIKE View and MIKE 11 GIS are used for the digital mapping studies (Özdemir and Karaca, 2005).

According to 2005 statistical data, DSI operates 349 meteorological observation stations located at rural areas. DSI has also closed 320 precipitation stations, which had been used for the previous projects. Out of these 349 stations, there are 92 stations for precipitation measurement, and 271 stations for the measurements of both precipitation and evaporation from free water surface (DSI, 2003).

General Directorate of Agriculture Research (TAGEM) operates about 50 pluviographs at 12 Agricultural Research Institutes in Turkey, to develop scientific base for its infrastructural services. Agricultural research projects are developed to improve the yield and quality of irrigated crops through the design of efficient management systems for irrigation and drainage. (http://www.khgm.gov.tr/institutes.htm).

Meteorological observation stations of DMI and DSI can be seen in Figure 2a and Figure 2b respectively.

(a) **(b)**

Figure 2a: DMI Meteorological observation station at urban area (DMI, 2005)
b: DSI Meteorological observation station at Kovalı Dam

3. INSTRUMENTATION

3.1. Pluviometers (Precipitation gauge)

Helmann type pluviometer is mainly used both at DMI and DSI meteorological observation stations in Turkey. Mouth diameter of Helmann type pluviometer is 15.96 cm, its mouth area is 200 cm^2 and this instrument is used 150 cm above the ground. Rainfall depth is measured in mm unit. 1 mm rainfall represents 1 kg rainfall amount at 1 m^2 area. Glass scale capacity of this type pluviometer is 10 mm.

3.2. Pluviograph (Precipitation recorder gauge)

Pluviograph measures the precipitation and records the measurement data to its diagram automatically. This instrument is more sensitive than the pluviometer. DMI use Helman type siphon pluviographs and DSI use Bellfort weighing type pluviographs. Mouth diameter of Bellfort weighing type pluviograph is 20.32 cm, its mouth area is 324 cm^2 and its diagram capacity is 300mm.

Helmann type pluviometer and Helmann type siphon pluviograph can be seen in Figure 3 below.

Pluviometer

Pluviograph

Figure 3: Pluviometer and pluviograph instruments used by DMI (Çakmak, 2005)

3.3. Totalizators

Totalizator is located at the high plateau where the continuous precipitation measurement is very difficult, this instrument measures seasonal and annual precipitation. Observer measures the precipitation amount by using totalizator, at the beginning of winter and at the end of winter; two times in every year. Totalizator mouth surface area is 200 cm^2 like pluviometer. Totalizator is also called as “mount pluviometer”.$CaCl_2$ is used to prevent the freeze of the precipitation and vaseline oil is used to prevent the evaporation of the precipitation amount in the totalizator (Gençer et. al, 2005). At present DMI has 37 totalizators equipped with Tretyakof type wind shield. Totalizator can be seen in Figure 4.

Figure 4: Totalizator (Gençer et.all, 2005)

3.4. Automatic Weather Observation Stations (AWOS)

Automatic weather observation station (AWOS) measures the rainfall depth, wind direction and magnitude, air temperature, soil temperature, relative humidity, evaporation, pressure, radiation and sun shine hours, records these observation data and plots observation graphics automatically. Turkish State of Meteorology Service operates total 231 Automatic observation stations; 206 of them are used for the climatic observations for TEFER Project and 25 of them are used at the airports. Automatic observation station can be seen in Figure 5 (DMI, 2005).

Figure 5: Automatic observation station in Turkey (DMI, 2005)

3.5. Radar

Radar is electronic radio wave detection and ranging instrument which can determine the objects from long distances. Meteorology radar system produces electromagnetic radio waves and measures the magnitude of the reflected electromagnetic waves (signals) and determines the distance of the precipitation clouds from the radar system. Radar is used for warning people for the flood danger, hurricane and it can also be used for the short term (6 hour) weather forecast. There are four meteorology radar system at Ankara, İstanbul, Zonguldak and Balıkesir in Turkey. These are used for TEFER Project. Radar system can be seen in Figure 6.

Figure 6: DMI Radar System (DMI, 2005)

3.6. Satellite Images (Remote Sensing)

Satellite observes global atmospheric events by using its sensors, records these data and satellite sends these data to the ground satellite stations globally. Locations of precipitation clouds, ozone amount, atmospheric temperature, soil and sea surface temperature can be determined by the satellite images. Satellite images are used for the weather forecasting. Turkish State of Meteorology Service (DMI) is the member of Europe Meteorology Satellite Operation Organization (EUMETSAT). DMI use METEOSAT 7, MSG and NOAA satellite data for the meteorological observation. Satellite images of Turkey can be seen in Figure 7.

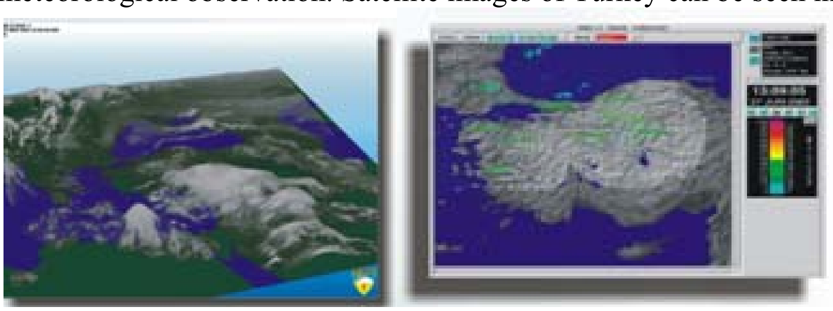

Figure 7: Satellite images of Turkey (DMI, 2005)

4. DATA ANALYSIS METHOD

Rainfall data is important for the design of sewage systems and other hydraulic structures against the flood danger. DSI uses rainfall data to plot depth-area-duration, intensity-duration-frequency and rainfall mass curves and time series, maximum probable precipitation analyses. Log-Normal Distribution, Extreme Value, Pearson type III, Log-Pearson type III, Gama and Gumbel distribution functions are most commonly used for the frequency analysis. Selection of the best fit distribution function is very important so χ^2 and Kolmogorov –Smirnov tests are applied to the precipitation data series to check the selected distribution function (DSI, 1990). Thissen polygon, isohyet map and arithmetic mean methods are used to find out the average areal rainfall from point rainfall observations.

DMI use daily rainfall, atmospheric pressure, temperature, wind direction and wind velocity data to prepare daily meteorology maps. Meteorology maps are used to determine the locations of the precipitation clouds, pressure and temperature variation. These maps are also used for the weather forecasting (DMI, 2005). One of meteorology map of DMI can be seen in Figure 8.

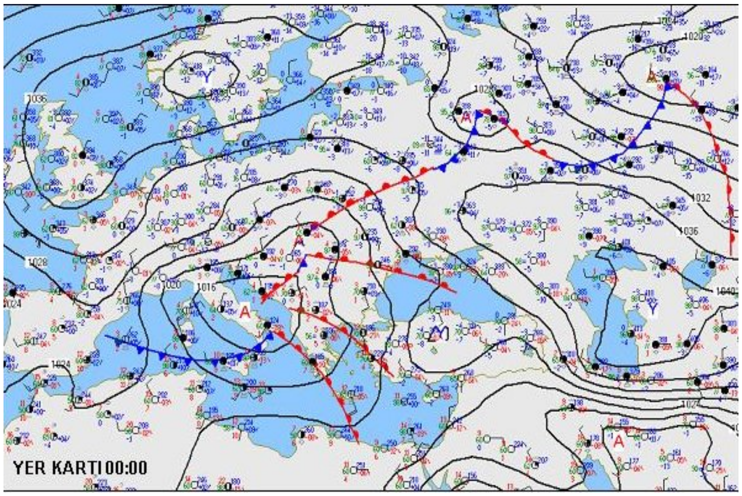

Figure 8: Meteorology map used by DMI (DMI, 2005)

5. TYPES OF ERRORS

All the errors of point observations of the rainfall can be expressed as a linear equation as given below (Dahlström, 1970) :

$$R' = R + \Delta R_{EC} + \Delta R_S + \Delta R_A + \Delta R_W + \Delta R_P + \Delta R_D + \Delta R_R \qquad (1)$$

where:

R' :observed rain amount
R :true rain amount (the value that would be observed if there were no error)

The error deviation is due to:
ΔR_{EC} :evaporation from the rainfall gauge
ΔR_S :splashing from or into the gauge
ΔR_A :aerodynamic effect on the raindrop trajectories caused by the gauge
ΔR_W :water for wetting the gauge
ΔR_P :unsuitable position of the gauge
ΔR_D :defects of the gauge (pure instrumental error)
ΔR_R :reading errors and effects from unforeseen incidents (error caused by the observer)

ΔR_{EC} , ΔR_S , ΔR_A ,ΔR_W and ΔR_P are the errors due to the combined meteorological and instrumental factors (Gürer, 1975).

6. ERROR ELIMINATION

The observed rainfall data had to be analyzed by the statistical homogeneity tests (for example: Run Test (Swet- Eisenhart), Up and Down Test, Serial Correlation Test (Wald-Wolfofitz)), before the use of rainfall data at the projects. If the data serial is not homogenous then one of error elimination method had to be used.

In order to determine the true rainfall data, one of error elimination method is the multiplication of the observed rainfall data by the correction factor. For rainfall corrections, pit gauges are used as reference. Struzer(1965), Bogdanova (1965) and Uryvaev et al.(1965) were used the expression as given below :

$$K_l = \frac{P_p - P_l}{P_p} \times 100 \qquad (2)$$

where:

K_l :correction percentage of rainfall data
P_p :rainfall total collected by pit gauge (mm)
P_l :rainfall total collected by gauge at 2 meters (mm)

Average correction factor is about +7 % but this factor varies according to the wind speed and rainfall drop size so this factor may change from month to month (Gürer, 1975).

Least square and correlation methods, double mass curve method, percentile method and normal-ratio method are used by DMI and DSI for the elimination of the missing data. Regression line equation is determined by using rainfall data of the two stations at the least square and correlation methods, missing data is found from the regression equation. Cumulative rainfall amounts of two stations for each year are used to plot double mass curve, missing monthly average rainfall data is found out from this curve. Double mass curve can also be used for the homogeneity control and error elimination of the average annual rainfall data. Normal-ratio method equation can be shown below:

$$P_X = \frac{1}{N}\left(\frac{N_X}{N_A} P_A + \frac{N_X}{N_B} P_B + \frac{N_X}{N_C} P_C + ...\right) \qquad (3)$$

where;

N :number of rainfall stations
N_X, N_A, N_B, N_C :long term annual rainfall data of X, A, B,C … stations
P_X :missing data
P_A, P_B, P_C :rainfall data of A, B, C stations for the missing period.

7. DATA DISSEMINATION

Engineering project companies, university researchers and the other organizations which are dealing with the rainfall data can purchase rainfall data from the statistical departments of DSI and DMI in Turkey.

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KEY DATES

Submission of abstracts	April 15, 2006
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Submission of full paper and final registration	August 31, 2006

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AIM

The apparent increase of storm rainfall related damages points out the need of improving the knowledge of extreme precipitation structure and behaviour, their observation by means of combination of data from different sources and their modelling, and the evaluation of the uncertainties associated with both measurements and model results. A quantitative assessment of the uncertainties is particularly important for operational purposes, especially in urban hydrology, which is characterised by small time and space scales.

Following the tradition of the previous workshops (1989, 1990, 1994, 1997, 2000 and 2003)* the main objective of this event is to provide a forum for exchanging ideas and information in order to bridge the gaps between scientific achievements and critical issues that need to be addressed in practice. Accordingly, contributions meeting the workshop themes are welcome on both application oriented basic research and operational urban hydrology.

* Proceedings of the previous workshops were published as special issues of "Atmospheric Research", vol. 27 (1991), vol. 42 (1996) and vol 77 (2005), of "Water Science and Technology", vol. 37 (1998) and vol. 45 (2002).

WORKSHOP THEMES

1) Extreme precipitation events

- Quality control of raingauge and radar data; methods to artificially enhance space and time resolution of data;
- Accuracy of rainfall measurements for extreme events and formulation of accuracy criteria based on event characteristics;
- Predictability of rainfall extremes at fine resolution scales, including both real-time and simulation frameworks;

2) Uncertainties in precipitation measurement and modelling

- Analysis of spatial and temporal rainfall variability including trend analysis; non-stationarity of rainfall series;
- Detection of natural and anthropogenic effects and accounting in design oriented modelling;
- Scaling vs non-scaling methods in space and/or time rainfall modelling;
- Impact of rainfall uncertainties on hydrological processes.

3) Combining multisource precipitation data for operational applications

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DATE AND LOCATION

The workshop will be held from 7 to 10 December 2006 in St. Moritz, Switzerland.

TRAVEL INFORMATION

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CONFERENCE FEE

The costs will be approximately 750 Sfr. Conference fee, hotel, full board and coffee breaks are included in this price.

PROCEEDINGS

Preprints of papers will be distributed at the workshop. Peer re-viewed selected papers will be published after the workshop.