

STATE OF ART REPORT

Scientific Contribution  
No.: INCOH/SAR-18/99

## FRONTIER AREAS OF RESEARCH IN HYDROMETEOROLOGY

A.R. Subramaniam

**INDIAN NATIONAL COMMITTEE ON HYDROLOGY**  
(Committee Constituted by Ministry of Water Resources, Govt. of India)



INCOH SECRETARIAT  
NATIONAL INSTITUTE OF HYDROLOGY  
ROORKEE-247 667, INDIA

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*The presentation of material throughout the publication does not imply the expression of any opinion whatsoever on the part of Indian National Committee on Hydrology (INCOH) or the publishers.*

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## PREAMBLE

It has been estimated that the total world population will be about 6.5 billion by the year 2000, with the most rapid growth in the developing countries. By that time the countries within the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence, it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

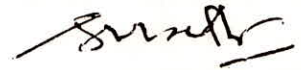
Hydrometeorology is the science that deals with the waters of the Earth, their occurrence, circulation and distribution and their interaction with the environment. The report gives hydrometeorological research work and specific areas in which future studies should be taken up. While it is not claimed to be comprehensive, efforts have been made to compile information relating to work done in major Institutions in India, where hydrometeorological research work is being done. Further both in research publications and in the reports supplied by various institutions, work relating to hydrometeorology & hydrology has been mixed up. While every attempt has been made to sort out hydrometeorological work it is possible that some work in hydrology is also included as it has relevance to work on hydrometeorology.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of UNESCO and is the National Committee for International Hydrology Programme (IHP) of UNESCO. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.



The Indian National Committee on Hydrology with the assistance of its erstwhile Panel on Surface Water has identified this important topic for preparation of this state-of-art report and the report has been prepared by Dr. A.R. Subramaniam, UGC Emeritus Fellow, Andhra University, Vishakhapatnam. The guidance, assistance and review etc. provided by the Panel are worth mentioning.

It is hoped that this state-of-art report would serve as a useful reference material to practising engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilisation of the water resources of the country.



**(S.M. SETH)**

Executive Member, INCOH  
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## **INTRODUCTION**

Water is as essential to our existence as the very air we breath. We can survive without food for several weeks; but without water would die in a few days. We drink it, cook in it and wash in it. As vast assortment of activities of everyday life depend on adequate supplies of it; agricultures and industry, power production, inland transportation, sanitation and public health services, to mention some of the more important. We need about 2,500 kg of water to produce one loaf of bread and the flour it contains, 17,000 kg of water to produce half a kilogram of beef and 2,90,000 kg of water to make one ton of steel. Major natural disasters, most notably the Sahelian droughts and the loss of tens of thousands of lives in coastal and river floods, have brought the whole subject onto the world stage in recent years. The spotlight has focused on the common problems being faced by both poor and rich countries and the need to use a correct mix of advanced and basic technology in their solution. This has brought to the fore the importance of international cooperation as regards water and the links between hydrology on the one hand and meteorology on the other.

Hydrometeorology is the science that deals with the waters of the Earth, their occurrence, circulation and distribution and their environment.

The hydrometeorologist measures, analyzes and models a variety of water resources on the surface and below the ground. Among his many activities, the hydrometeorologist,

- \* Concerns himself with precipitation in the form of rain, snow, hail, etc.,
- \* Estimates the amount of snow cover;
- \* Measures water levels and flows of river, lakes, reservoirs and estuaries;
- \* Investigates the quantity of groundwater and soil moisture;
- \* Evaluates surface and groundwater resources through a nationwide network of stream-gauging stations and groundwater observation wells, as a part of a country's data-gathering system;
- \* Prepare and supplies processed information for water-resource development designers, planners, managers and users;
- \* Provides hydrometeorological forecasts of floods and for the operation of water supply schemes;



## Frontier Areas of Research in Hydrometeorology

Arranges the publication and distribution of enormous amounts of data widely used by government, municipal officials, and the private sector.

These then are some of the important highly technical tasks performed by the the hydrologist. Without his knowledge and skills in collecting basic water data-often covering decades - and in making forecasts for the future, much economic activity would be hazardous if not impossible.

Throughout the world Meteorological and Hydrological Services operate over 150,000 rainfall stations, 10,000 evaporation stations and 60,000 stream flow stations, besides thousands of water-level, sediment and water-quality stations. Much of the activity of these stations has a close connection with meteorology. Indeed, hydrological information is frequencely completed, interpolated and extrapolated by the meteorological data that are usually obtainable for more locations and for a longer duration than those relating of water. The water essential for everyday needs can also threaten our very existence. Periodically, in many countries, rivers overflow their banks and flood, driving thousands from their homes and destroying millions of dollars worth of the property. Close co-operation between hydrologists and national Meteorological Services is necessary in forecasting of floods and issue warnings of potential disasters so that action can be taken by individuals and authorities to save lives and protect property.

The economic and social importance of hydrometeorological forecasting can be illustrated by the example of Asia. In that vast region of estimated average annual cost of flood damage amounts to over US \$ 3,000 million (Rs. 90,000 million). This puts an enormous strain on financial resources. The value of the human lives lost is incalculable. Improved forecasts for the operation of river systems composed of dams, reservoirs and irrigation schemes have substantial economic advantages. The forecasting of river flow relies on prior knowledge as to how the river basin and river channel would respond to precipitation of various intensities and durations. For this, it is necessary to study past records of rainfall, snowfall and river flow in the vicinity, and to develop a relationship between the various factors concerned. These relationships are increasingly presented as "hydrological models" : numerical-mathematical descriptions of water. They are normally presented and used in the form of computer programs.

Recent developments in computer technology and advanced instrumentation have greatly facilitated the use of Hydrometeorological models in operational hydrometeorology. Parallel developments in electronics and telecommunications have had a similar impact on the speed and precision with which hydrological and meteorological data can be transmitted.



## **RESEARCH WORK DONE SO FAR IN INDIA**

In India research organisation like, National Institute of Hydrology (NIH), Hydrology Study Organisation of Central Water Commission, India Meteorological Department, Snow & Avalanche Study East, Indian Institute of Tropical Meteorology, Centre for Water Resources Development and Management, etc., are actively engaged in the field of hydrometeorology.

The Indian National Committee on Hydrology (INCOH) constituted by the Government of India under the Ministry of Water Resources has taken up wide ranging programmes under the International Hydrological Programme (IHP). The INCOH has its headquarters at the National Institute of Hydrology at Roorkee. The NIH covers almost every area of research under hydrology with centres and fields sites established all over India. NIH takes up both basic as well as applied research theoretical as well as experimental.

NIH is continuously bringing out publications on various hydrological and Hydrometeorological problems providing facilities for educational training and research. It also organises frequently seminars, symposia and workshops to focus attention on different subjects in hydrometeorology.

The Hydrology Study Organisation of Central Water Commission (Hq. : New Delhi) is mainly attending to the appraisal work of the hydrological aspects of water resources project and is also undertaking the work of special studies in hydrology where necessary as an assistance to States and other agencies. One of the important aspects of hydrological appraisal and studies is the appraisal of hydrometeorological aspects.

This would mainly consists of the following items of work :

- \* Checking of the rainfall figures presented by the project authorities;
- \* Computation of catchment rainfall of various projects;
- \* Examination of variation of the rainfall with higher or lower elevation and its influence on the rainfall pattern;
- \* Use of techniques for filling up the missing gaps in rainfall;
- \* Isohyetal analysis of the severe rainstorms and computation of depth duration, or area depth duration values.
- \* Studies relating to moisture adjustment factor including persistence dew point temperatures with reference to maximum values.

## Frontier Areas of Research in Hydrometeorology

- \* Hydrometeorological aspects relating to Flood forecasting;
- \* Studies relating to evaporation depths;
- \* Comments on miscellaneous hydrometeorological aspects.

The hydrology study Organisation Officers are also associated with the development of Indian Standards and are represented on the various sub-committees which Bureau of Standards has formed for this purpose.

The research activities in Hydrometeorological of India Meteorological Department is spread over the areas involving problems associated with design of small to large projects in which rainfall storms are used as basis of work out probable maximum precipitation (PMP) and standard Project Storm values. The time distribution of storm rainfall is another area of interest. The generalised PMP maps have been prepared for many areas with immediate practical use. Efforts are being made to develop techniques for moisture maximisation for the PMP storm. Every year about 10 to 15 projects are being provided with these values for the proper stability of their hydraulic structures. The rainfall frequency analysis using extreme rainfall statistics is utilised in the design of minimum structures like bridges and culverts. In the external distribution the studies of outlier have also been attempted.

For meteorological inputs to flood forecasting, the problems of quantitative precipitation forecast (QPF) remains a formidable challenge worldwide. In IMD efforts are under way in this direction to find out ways and means for solving many complex problems involved in this endeavour. Study of synoptic weather charts, satellite imageries and advisories from the field are some of the tool utilised to develop analogues to provide the QPF. some models towards estimation of QPF with statistical techniques are also being tried.

The network design of rainfall stations in the country is another area in which this department is greatly interested. Rainfall statistics on different spatial and temporal scales form the basis of a variety of economic and strategic planning. Weekly and seasonal rainfall summaries which are being prepared operationally help to monitor areas of flood and drought in the country. Intensive research into this field involving trend analysis based on rainfall series has helped in picturing the scenario. With about 11,000 rainfall stations in operation in the country, the network design studies are important for the choice of stations to make area representation effective.

Another area of research interest is glaciological study. Meteorological data collected by IMD Scientists during expedition to snowbound areas as well as



glacier basins have helped in better understanding of the process of snowmelting and metamorphism on snow. The present objective is to understand meteorological conditions under which snow cover influences the performance of monsoon over the country. The problem of parameterisation of albedo of snow is also currently attracting attention.

Water budgeting studies are also in progress as it is of great importance for the proper use of water resources. Recently, weekly computation of potential evaporation by Penman's equation in the Mahanadi river has been started.

A study to correlate rainfall data with the radar measurements of water drops is in progress in the IMD.

Snow & Avalanche Study Est, situated in Manali (Himachal Pradesh) is working in the field of snow with more emphasis on snow avalanches. As such not much work has been done in hydrometeorology. This organisation that look into the only hydrometeorological aspects are : (a)

- \* Point Energy - Exchange at snow surface for the calculation of snow melt produced;
- \* Free water content of snow; and
- \* Process of Melt Water percolation within snowpack.

These three aspects are studied with an aim to develop snow cover model for better avalanche forecasting.

Indian Institute of Tropical Meteorology, Pune, actively, engaged in research in hydrometeorological studies of different river basins of the country in the following areas :

- \* Depth-Area-Duration analysis of severe rainstorms and studies of storm temporal patterns;
- \* Design rainfall analysis for use in a wide range of design and construction of water resources projects;
- \* Estimation of point and areal extreme or probable maximum precipitation (PMP) for design purposes;
- \* Determination of trends, periodicities and variability in seasonal and extreme rainfall series;

## Frontier Areas of Research in Hydrometeorology

- \* Floods and droughts studies;
- \* Frequency analysis of rainfall and runoff series;
- \* Short duration rainfall analysis;
- \* Evaporation, evapotranspiration and water balance studies;
- \* Influence of tropical disturbances on rainfall distribution in different parts of the country;
- \* Rainfall and water resources studies.

Systematic rainfall data is published from for about 3000 stations in India are available for the period of over 80 years. This valuable data source has been utilised in different ways in a large number of hydrometeorological studies. A resume of the results of some of the important studies are attached.

The Centre for Water Resources Development and Management (CWRDM) is one among a chain of autonomous research institutes established by the Government of Kerala under its progressive Science and Technology policy. CWRDM has been functioning since early 1978. The main objective of CWRDM is to carry out basic and applied research on several aspects related to occurrence, development and management of water resources. While there is a justifiable emphasis on those aspect of water resources which are of particular relevance to the State of Kerala, the national and global perspectives of water resources development and management are always borne in mind. This is achieved through execution of a number of research projects formulated and implemented in CWRDM. Most of these research projects are being sponsored by International, National and State level funding agencies.

Thirty three projects internally funded by CWRDM and sixteen more with grants from external funding agencies have been completed till now. Three projects internally funded by CWRDM and Twenty three more with grants from external funding agencies are being currently implemented. These projects have resulted in significant contributions being made towards.

- \* Generation of meteorologic, hydrologic and hydrogeologic data base with reference to Kerala state :
- \* Mathematical modelling of rainfall-runoff process, estuarine dynamics, two phase salt water-freshwater flow in coastal aquifers, and ground water movement in low transmissibility lateritic and hard rock aquifers;



## Frontier Areas of Research in Hydrometeorology

- \* Application of remote sensing and geophysical techniques in water and related land resources evaluation;
- \* Evaluation of sedimentation, erosion and landslides in Western Ghats Region, estimation of ground water induced inundation in a lime stone mine and assessment of effects on hydrological parameters due to deforestation;
- \* Better land and water management techniques through micro irrigation, alley cropping and control of weeds;
- \* Qualification of soil-plant-water relationships with special reference to plantation corps;
- \* Assessment of quality of surface and ground water for different water uses;
- \* Development of water resources for weaker sections, like Tribals.

In addition to formulating and implementing research projects, CWRDM has been offering consultancy and advisory services to several Government agencies and other institution on the basis of specific request from them. Some of the major items of work attended to for the State and Central Governments are,

- \* Check dams and sub-surface dams as drought control measures;
- \* Water and energy needs of Palghat region;
- \* Hydrologic studies for water supply schemes to be implemented with World Bank assistance;
- \* Pavaratty water supply project of the Kerala Water Authority to be implemented with assistance of the Royal Netherlands Government.
- \* Census of Minor Irrigation Schemes in Kerala State.

## **USAGE OF ADVANCED TECHNOLOGY IN HYDROMETEOROLOGICAL STUDIES**

Hydrologic processes are phenomena that vary rapidly in space and time. Remotely sensed data have the inherent properties of being able to provide synoptic observations with higher observational densities over larger areas than in situ or point measurements. Satellite remote sensing technology was introduced in India recently. Indian Space Research Organization (ISRO) and its allied branches in various parts of India now engaged in measuring different hydrological processes. The processes are as follows :

- \* Snow observation;
- \* Evapotranspiration;
- \* Soil properties and vegetation conditions; Groundwater studies
- \* Disaster prevention;
- \* Cloud development;
- \* Runoff and Flood monitoring;
- \* Drought studies, etc.

And many other organization are using this data to find out the problems which occurring in respect of hydrometeorological forecasting.

The Earth Environment Observation Committee (Japan) proposed some advanced sensors in order to observe the hydrometeorological process using satellite remote sensing. They are briefly described here.

### **Dual-frequency Precipitation Radar (DPR)**

DPR provides measurements of 3-dimensional precipitation, which is an important element of the global atmospheric circulation and water cycle. Also makes it possible to measure rainfall and snow parameters to high accuracy, and to estimate sea surface wide velocity.

### **Advanced Microwave Scanning Radiometer (AMSR)**

AMSR will measure column water vapour content, precipitation, water content of cloud and ocean surface wind as atmospheric hydrological elements,

and soil moisture and water equivalent of snow as hydrological elements in land. Precipitation is measured in combination with the DPR.

### **Global Imager (GLI)**

GLI will carry out medium resolution imaging of the land surface and clouds with multi-spectral bands from visible to thermal infrared, looking nadir, forward and backward.

### **LIDAR atmospheric sounder (LIDAR)**

LIDAR will measure the water vapour profile. By observing simultaneously with the AMSR, the 3-dimensional distribution of water vapour can be estimated.

### **Multi-frequency and Multi-polarization Synthetic Aperture Radar**

This Radar (M<sup>2</sup>SAR) will measure soil moisture and snow water equivalent, which regulate the land-air water budget and heat budget.

### **Investigator of Micro-Biosphere (IMB)**

This sensor has the principal objective of understanding the vegetation classification and vegetation structure, which are basic information for understanding the water budget including evaporation in vegetated areas.

### **Laser Atmospheric Wind Sounder (LAWS)**

Laser will measure the 3-dimensional distribution of atmospheric wind in order to determine the movement and convergence of water vapour in the atmosphere, and also to understand the structure of atmospheric wind systems.

In India also, some of the above sensors are being used in observational technology, but some sensors like DPR, AMSR, IMB, M<sup>2</sup>SAR, are not introduced till today. If we introduced these sensor, in India, it may improve our capability in observational technology and we may get accurate results. Recent developments in computer technology have greatly facilitated the use of hydrological models in operational hydrology, and hydrometeorology.



## **AREAS FOR FUTURE WORK**

The following areas are the thrust areas for future work :

- \* Preparation of generalised PMP charts and SPS charts for areas up to 5000 sq. m. and duration ranging from one to two days.
- \* Design storm studies of large catchments - Basins.
- \* Establishment of Task Force for rationalisation of design storm parameters.
- \* Surface runoff resources; in connection with climatic change.
- \* Sea level rise : in connection with climatic change.
- \* Land degradation : in connection with climate change.
- \* Water quality and groundwater resources.
- \* Soil moisture;
- \* Applications of hydrometeorological aspects in agriculture.
- \* Hydrodynamics and hydrometeorology.
- \* Numerical studies and computer application.
- \* Floods and droughts.
- \* Irrigation technology with the specific reference to tree crops.
- \* Water quality and related environmental issues with special reference to the coastal zone.
- \* River Basin Development and watershed management.
- \* Training of Professionals.



## **TOWARDS THE 21ST CENTURY : RESEARCH AND OPERATIONAL NEEDS**

The ninth quadrennial session of World Meteorological Organization (WMO) Commission on Hydrometeorology took place at the International Conference Centre in Geneva from 5 to 15 January 1993. The Commission issued the following statement :

The Commission considered the several important recent events related to hydrology and water resources, particularly issues raised by the International Conference on Water and the Environment (ICWE) (Dublin, Ireland, January 1992), by the UN Conference on Environment and Development (UNCED) (Rio de Janeiro, Brazil, June 1992), and by the review of national capabilities embodied in the WMO/UNESCO Report on Water Resources Assessment, carried out in 1990-91 as a followup to the Mardel Plata Action Plan. Agenda 21, adopted at UNCED, describes a range of actions agreed by governments in the field of freshwater management. These will require the effective support of decision-makers and the general public; this statement addresses these actions.

There is common recognition that :

- \* Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and the protection of the environment;
- \* The deteriorating capability in many countries to assess accurately the status and trend of their freshwater resources, in terms of both quantity and quality.

The needs are :

- \* More effective management and conservation of fresh waters, particularly to protect human health and welfare in areas of diminishing water resources, to ensure a safe water supply for future generations and to ensure the continued health of aquatic ecosystems by counteracting the negative impacts of human activities;
- \* Broad commitment and concerted action by international agencies, including WMO, to enable the effective and world-wide assessment, development and management of fresh waters;
- \* Improved monitoring of the global water cycle, together with ready access to the data which are required for the validation of global circulation models and for use in the international programmes of the Global Climate Observing

## Frontier Areas of Research in Hydrometeorology

System (GCOS) and the International Geosphere Biosphere Programme (IGBP); and

- \* The equitable management of international river and aquifers.

The objectives are, therefore to ensure :

- \* The ability of National Hydrological services to assess and manage their countries fresh waters;
- \* The availability of hydrological information at the global scale, in support of international investigations of the global water cycle and climate systems.

The necessary actions are :

- \* To promote a global hydrological observing network covering the continents and the oceans and including the principal components of the water cycle, as regards both quantity and quality;
- \* To ensure continuous and uninterrupted operation of the global basic hydrological network according to agreed guidelines ;
- \* To provide technical assistance, including education and training, to countries where the WMO/UNESCO Water Resources Assessment Report has identified serious shortfalls or network deterioration;
- \* To develop the data archiving processing and analysis techniques required for interpretation of trends or evaluation of hydrological variability on global scale.

The commission is convinced that WMO has a mission to promote the establishment and operation of the global network, in conjunction with existing national networks. Due consideration should be given to extending facilities to provide hydrological information in areas of sparse data.

Without appropriate action the ambitious global and national plans on protection of environment and sustainable water management, set out in Agenda 21, cannot be implemented.

The World's water resources are coming under increasing stress, indeed in some countries a crisis has already been reached. Accelerating demand due to a rising population and growing water consumption per head, as affluence increases, is the chief cause. But the growing volume of pollution is a further factor



and droughts intensify the difficulties. Hydrometeorology, the science of the World's fresh waters, offer opportunities to overcome these problems and those of floods and other water related natural disasters.

At the same time many nations lack the capability to apply hydrometeorology to their problems and to undertake the research needed. Their institutions are weak and fragmented and they have few educational and training facilities, often because government have cut funding and staff. At the root of these difficulties is a lack of awareness amongst politicians and the general public and an appreciation of the gravity of the situation.

The participants at the UNESCO/WMO/ICSU International Conference on Hydrometeorology meeting in Paris from 22 to 26 March 1993 and building on the results of the International Conference on Water and the Environment and the Development made a number of recommendations for action, based on their discussions on hydrometeorological research, operational hydrometeorology, interdisciplinary studies and capacity building, training and education. These recommendations are :

1. To increase awareness of the value of water and information about water, on the part of decision makers and the community at large.
2. To improve the contribution of hydrometeorological and related water sciences, by promoting interdisciplinary research focused on well defined projects of importance to society, by improving understanding of the hydrometeorological cycle and by providing a scientific basis for the sustainable management of water.
3. To increase the effectiveness of operational hydrometeorology, by better identifying and addressing users' needs, adopting modern management practices such as quality management, assessing and planning human resource requirements, and by closer coordination between scientific and operational hydrometeorology programmes and those of other related disciplines.
4. To further enhance the acquisition and transfer of technology and knowledge, by sustaining research and educational programmes and capacity building in developing countries, the effective use of international training courses, and the development and dissemination of appropriate technology.
5. To invite UNESCO and WMO to continue their programmes in hydrology and water resources during the remainder of the Century and to set up a ICSU task group to consider with ICSI how closer cooperation should be effected at the national and international levels between their programmes and those of other UN agencies and Non-Governmental Organizations.

## **HYDROMETEOROLOGICAL RESEARCH**

Hydrometeorological research is a fundamental element of any successful operational hydrometeorological organization. It provides the technical underpinnings upon which are based the understanding of natural process in the field. Without technical understanding and an institutional mechanism to maintain and enhance this understanding, operational programmes are unlikely to succeed. This is particularly true in a fast developing science such as hydrometeorology.

Hydrometeorological research encompasses activity at all field scales and in the laboratory. It contributes to the understanding of the quantity and quality of water in its natural state and to the development of methods and tools, such as digital computer models and geographic information systems, to conduct the science. It is multidisciplinary in nature, requiring cooperation with the related sciences of meteorology, chemistry, biology, physics and many others. The value of a hydrometeorological research team within a water resource organization is not only to make technical advances to ensure technical adequacy but also to invigorate the atmosphere in which the science is accomplished.

### **Past Achievements**

The hydrometeorology programmes of UNESCO and WMO have made important contributions to the advancement of the science of hydrometeorology. One of these contributions is providing an international focus for hydrometeorological research. This support has contributed to notable technical advances in the science of hydrometeorology, including the coupling of ground and surface water models, innovations in isotope hydrometeorology, the incorporation of geographical information systems, and improved understanding of the relationship between the atmosphere, land surface, and hydrological systems, vital to the understanding of global change. Moreover, the support for hydrometeorology provided by UNESCO and WMO has contributed directly to the development of sound basic data, a fundamental element in understanding hydrometeorological systems. The activities of the organizations have also had the benefit of facilitating the transfer of hydrological knowledge and understanding between nations.

Naturally, difficulties have been encountered along the way, associated more with the science and practice of hydrometeorology than with the programmes themselves. One difficulty is associated with data and is universal. Sufficient data to analyse the hydrometeorological problems with which we are faced are not readily available. Not only are data commonly scarce but too often their quality is unreliable. Moreover, data are seldom collected with sufficient attention to protocol and are not stored in such a way as to facilitate retrieval by subsequent



users. These are issues which all organizations funding hydrometeorologic research must work to remedy.

A second hindrance to effective hydrometeorological research has been inadequate interaction between scientists in related fields. An example is hydrometeorologists working on the problem of water quality in a stream without the close co-operation of biologist. This problem is not unique to international funding organizations, and along with the rest of the hydrometeorological community. UNESCO and WMO are moving swiftly to make the execution of hydrometeorological research a true multidisciplinary exercise. The emergence of interdisciplinary issues such as global change has served to increase such co-operation, as has the recognition that surface water quality investigations can be carried out more economically and with significantly improved insight with the help of aquatic biologists.

Another problem concerns progress in modelling which, although technically important, may have outpaced both theoretical and field validation. In fact, there has been a proliferation of more complicated mathematical formulations which have not been particularly useful to the advance of scientific understanding or to practical application in the field.

### **The present situation**

The pressure on the availability of fresh water for many nations of the world is accelerating and in many areas has reached or will reach crisis level in our life time.

It is within this reality that international organizations are attempting to promote and support hydrometeorological research. It is obvious to those in the science that the information that we develop in our daily work is vital to the resolution of many serious water problems. Unfortunately, that fact is not so clear to many of those in leadership positions who, when faced with difficult budget situations, make decisions to curtail hydrometeorological programmes fundamental to the effective management of their water resources. It is clear that hydrometeorologists must do a better job of acquainting national leaders with the contributions using long-term hydrometeorological record and their interpretation can make to the well-being of the people. We may have been too content to publish in the professional literature, forgetting to inform and educate the general public as to the use and benefits of our information. The unfortunate results have been, that although water resources issues are quite visible to our leaders, the science of hydrometeorology is much less so.

## **Frontier Areas of Research in Hydrometeorology**

An aspect of the reality within which international organizations must deal is the insufficiency of funds available for the purpose, of supporting hydrometeorological research. Although funding for research has never been plentiful, the decrease in recent years has had a particularly negative effect on the ability of the hydrometeorological community to support field studies. More painful, perhaps, has been the degradation in hydrometeorological gauging networks brought about by the insufficiency of funds to maintain the number of stations or to repair stations after damage by storm, simple wear and tear, or vandalism. It is difficult and sometimes impossible to compensate for the loss.

The most basic result of the curtailment of funds, of course, is the decrease in ability to support basic hydrometeorological research and study around the globe. This is reflected in the curtailment of many experimental catchment programmes since the 1980s. The research products from programmes such as these rank among the most important achievements of the IHD / IHP. It is tragic that funding support for such activities is decreasing at a time when we are becoming aware that the earth is a single system and that ecological catastrophe on the continent could have a catastrophic effect on other continents as well. There is a clear and serious need for improved understanding of hydrometeorological processes every where in the world but particularly in nations of the "South".

There is a question regarding the number of international organizations involved in hydrometeorological research, specifically whether that number might be reduced without losing effectiveness and perhaps even improving the situation. The question is an interesting one in that it also pertains to the number of organizations in individual nations.

Most countries are burdened with badly fragmented water programmes : Some measures, perhaps, of the universal importance of the resource. It is possible that reducing the number of organizations, through combining one or more (leaving total funding intact) would provide a larger, more visible entity, capable of achieving greater financial and programmatic support.

### **The future**

The need for additional hydrometeorological research, basic as well as applied, is substantial. The issue of resource vulnerability is fundamental to the concept of sustainability. Without a reliable water supply and safe sanitation, it is highly unlikely that developing nations can continue to progress.

An area within which a great deal remains to be accomplished concerns ground-water in both the unsaturated and saturated zones, these areas having been less intensively studied in comparison to surface water. Such interactions are particularly crucial to the improved understanding of groundwater quality and



again to the issue of vulnerability. Our groundwater resources are at risk and the fact that they do not recover easily or quickly from over exploitation or from the introductions of contaminants means that, in many cases, human being millennia from now will be living with the consequences of our action or inaction in dealing with this element of our water resource.

One of the greatest needs in the hydrometeorological community is to communicate the importance of our potential contribution to the leaders of nations. So far, we have not been effective in that regard and this ineffectiveness has resulted in a lack of understanding of our relationship to relevant social issues and a consequent lack of support in the budget process. It is frustrating to see a crisis in the making, to have the skills that could be useful in managing the crisis, and to be unable to bring these skills to bear.

We must work harder and be more effective in communicating with non-technical audiences. One way to accomplish this objective is to publish in a wider range of journals with an increased focus on those less technical.

There is a need for a better integration of related sciences in our hydrometeorological models in order to present a way of understanding the broader environmental system within which water exists. The issue of scales and how to move from one to another needs to be resolved.

The issue of buffering in natural environments relates to the ability of a terrain to accept a certain amount of contamination and, through processes such as biodegradation, withstand the introduction without presenting an immediate or long-term health risk to living organisms. This "natural remediation", particularly in ground water systems, is a promising area for hydrometeorological research.

There is a need to address more effectively the issues of non-stationarity in hydrometeorological time series and the development of regionalization methods. Addressing the latter could also help to address the problem of technology transfer of humid temperate research results to the "South".

Research emphases should be given to scale problems, issues related to ecohydrometeorology, connections between hydrometeorology and climate, and the vulnerability of the water resources.

In addition to these specific areas, other supportive of them exist. Among those are :

- \* Revitalization of experimental field sites and studies;



## Frontier Areas of Research in Hydrometeorology

- \* Hydrometeorology studies to improve the understanding of physical process;
- \* Support for sustained hydrometeorological research in developing countries, particularly those in the humid, semi-arid, and arid parts of the tropical world; and
- \* Development of integrated models that take into account the atmospheric hydrometeorological and ecological processes in different land spaces and at different scales.

An issue which must be faced by all international organizations and national governments is the disparity between developed and developing countries in the ability to deal with water resource issues. In many developing countries sufficient funds are not available to support either hydrometeorological research or adequate data collection, and yet it is often in these countries that water resources are under the most pressure.

If one accepts the concept of global sustainability and the intercontinental links of global change, then it is clear that we are all equally responsible and funds to support the understanding and wise management of the water resources of all the nations of the world must be found.

### Institutional Changes

The question has been raised as to what if any institutional changes, nationally and internationally, might contribute to improvement in the environment for hydrometeorological research. It is clear that many organizations at all levels of government, currently have responsibility of some aspect of hydrometeorology and, as a result, the focus for hydrometeorological research is unclear. Such a fact suggests either that the responsibilities of several agencies be folded into one or that greater importance be placed on communications and co-ordination between agencies. The issues of consolidation are complex and beyond the scope of this conference. If the co-ordination option is followed it should be pursued vigorously within and between research and operational organizations to include programmes from conception to conclusion, publications, meeting and conferences, research strategies etc.

What are the most urgent issues facing international agencies related to the support of hydrometeorological research? There are several, each addressed in varying detail earlier in this Section.

- \* One of the most important is to work more closely together, avoiding duplication of activities so as to optimize the use of limited resources and to derive benefits from cross fertilization;

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- \* The next is to provide funds and leadership to assist developing nations in establishing and maintaining long-term water data networks to support the wise management of the water resource;
- \* Another is to encourage the hydrometeorological community in improving its ability to carry not only the message of the importance and vulnerability of the water resource, but also the necessity and importance of hydrometeorological research to those in leadership positions and to the general public;
- \* And finally perhaps the most urgent need of all is to support staunchly hydrometeorological programmes in the developing nations in recognition of the fact that their fate will not be divorced from that of all nations.



## **OPERATIONAL HYDROMETEOROLOGY**

Operational hydrometeorology is fundamental to the management, assessment and forecasting the quantity and quality of water, and providing the information needed to mitigate floods, droughts, pollution incidents, and similar water-related hazards.

Operational hydrometeorology is a technical discipline. Its scope includes:

- \* Collecting, analysing and supplying information about the quantity, quality and bio-chemical characteristics of both surface water and groundwater;
- \* Developing and applying technology, including instrumentation, observing systems, standards, data processing and archiving systems, forecasting and water resources management.

International effort in operational hydrometeorology aims to ensure that all countries have these capabilities, by transferring technology and providing appropriate technical assistance.

Operational hydrometeorologists call upon many other disciplines, including meteorology, micro-biology and physics, and experts in such areas as electronics, engineering and analytical chemistry. Their customers include planners, resource managers, civil defence workers, indeed, all sectors of society and the general public. Operational hydrometeorologists are responsible for providing decision-makers with the information they require, when and where it is needed, and in an easily usable form. Operational hydrometeorology must respond to a rapidly changing world.

Operational hydrometeorologists in the developed world now have a very sophisticated ability to collect, store and analyse water-related information, and to supply it to their customers. To do this, they make use of advanced instrumentation and remote sensing technology, data transmission systems such as radio and satellites, computer hardware and software, and highly developed sets of procedures for data collection and quality assurance. This ability has been applied in many countries:

- \* To assemble data-banks of historical information as a basis for project design;
- \* To provide real-time information for water resource management;
- \* To forecast conditions, enabling the impacts of water-related hazards to be reduced or avoided.



Operational hydrometeorology has enabled the construction and operation of a great range of water-related projects; such as those for irrigation, hydro-electricity, water supply and waste disposal and water transport.

Nevertheless, not all countries have been able to develop the capability themselves, and the status of water resources on the global scale is still only approximately known. A key role of the international organization with water-related responsibilities has therefore been to arrange technology transfer and technical assistance to those countries which need it. Notable achievements in this process include the preparation of guidance materials, instruction manuals and other documents; the provision of training courses and higher education to hydrometeorological personnel, technology transfer, intercomparison, and demonstration projects, the establishment of international databases to support projects on regional and global scales.

Even now, however, many developing countries still have poorly equipped and ineffective hydrometeorological services.

Obstacles have included :

- \* Competition for scarce financial resources, in countries which are still struggling to provide the basic amenities of life of their people, as operational hydrometeorology often has not been recognized as a priority;
- \* Disorganization, where operational hydrometeorology is carried out in several agencies with little or no coordination;
- \* Inability to benefit from available technology, because of language difficulties or lack of knowledge of what is available.
- \* Pressure on water resources from the rapid growth in population, which has outstripped the ability to provide the necessary hydrometeorological information;
- \* Deficient information on, in particular, groundwater, water quality and aquatic biology, because of a limited view of what types of water-related informations are required.
- \* Inability to access data from other sources;
- \* Lack of trained technical and managerial staff, and the "brain drain" to other organisations and countries where career prospects are better.

In some countries, such gains as there have been are threatened by adverse economic conditions.

## Frontier Areas of Research in Hydrometeorology

### The present Situation

There are four key considerations :

The climate is highly variable, and may be progressively changing in response to both natural and man-induced processes, with consequent impacts on water resources;

The most severe resource management issues exist under extreme conditions: in time, during floods and drought; in space, in arid, semi arid, and tropical areas, and in coastal areas;

Global environment issues must be faced; the environment is increasingly seen as a unity; natural resources including water must be managed in an integrated, holistic way, and in the context of social and economic systems;

Operational hydrometeorologists must see their role in this context, and be ready to extend their activities beyond current boundaries. They should recognize that the resources available to pay for environmental (including water) information may well not increase significantly, but will be spread across a widening range of variables.

### Financial and organization Considerations

Obstacles which have prevented the satisfactory development of operational hydrometeorology are almost all, in the end, financial or organizational in nature. The funds available are limited, both to develop technology and - perhaps more importantly - to attract and retain staff who are able to make the most effective use of the available resources. There are a number of specific consequences of limited funds, at the country level.

Firstly, observation networks for "traditional" hydrometeorological variables, precipitation and stream flow, are inadequate in many areas. Hydrometeorological observation networks are in decline in many developing countries. Other types of hydrometeorological information needed for resources management, such as on groundwater, water quality, soil moisture, and evaporation, are scarce in most developing and in some developed countries. Related types of information, for example, water use for fresh-water fisheries or aquatic ecosystems, may be entirely lacking, because their need has not been recognized or skills are not available to collect them.

Secondly, new technologies may be accessible to those countries which most need them, because of their high initial cost, lack of the high level skills



needed to operate them, and the difficulty of ensuring ongoing maintenance. The new technologies including remote sensing from satellites, telemetry of data, weather radar, solid-state data loggers which can be downloaded directly into computers, and state-of-art computer software -provide opportunities for acquiring information more cheaply and efficiently, and to higher standards of quality. On the other hand the very latest technologies may not be appropriate or sustainable, and premature adoption may result in wasted resources and loss of data.

Thirdly, inexperienced management and unpredictable resources may introduce major inefficiencies. Inefficiencies are also likely to be present where several agencies have water-related responsibilities, and there is no provision for coordination between them. Apart from duplication of effort, there may be other undesirable effects, such as that data may not be readily transferable, or may be lost or discarded when their original purpose is served, even though another agency could use them.

A major financial and organizational issue which offer both opportunities and threats is the trend towards commercialization of hydrometeorological services and products. Commercialization has many potential benefits, including the ability to adopt more entrepreneurial management methods; the opportunity to develop new sources of revenue; perhaps the ability to use pricing to manage demand.

The cost of commercialization is that it introduces the threat that, if misused, it can irreparably harm the integrity of long-term data collection programmes. It introduces many new requirements, such as the need to establish very close relationship with customers to ensure that all work relates to existing or reasonably foreseeable needs, an emphasis on careful costing of products and services, development of policies on changing information which are appropriate to local circumstances, and the probable need to introduce new legal provisions. A crucial need is to establish the principle that hydrometeorological information is a public good which benefits the whole community and, in particular, future generations.

At both national and international levels, other over-riding financial consideration is that funds are limited. Nevertheless, they are available in other related areas, for development projects, environment programmes, and through agencies whose particular responsibilities impinge on water issues. This, of course, raises the need for effective co-ordination among the 24 UN system bodies and agencies with responsibilities related to water.



## **The future**

The following pressing needs have been identified :

### **(1) Hydrometeorological data acquisition**

- \* Adequate, purpose-driven and integrated observation networks, including water quality, soil moisture and other variable;
- \* Automated, reliable, accurate field stations, telemetered for real-time information, where appropriate;
- \* Simple, manual observation networks, where appropriate;
- \* Design methodologies for cost-effective, multipurpose networks;
- \* Extended use of satellites for provision of hydrometeorological data sensors;
- \* Area estimation using remote sensing, especially of precipitation and soil moisture;
- \* Implementation of the World Hydrometeorological Cycle Observing System (WHYCOS).

### **(2) Hydrometeorological data banks**

- \* Data quality control and assurance systems;
- \* Accessible, integrated (multi-agency and multi-variety) data banks, with full provision for long-term maintenance;
- \* Co-ordinated international data banks, with free exchange of data for international projects, enhanced capability to provide for analysis of data, and provision of analytical methods for use by member countries;
- \* Improve delivery of accurate, scientifically validated information to decision-makers.

### **(3) Forecasting and warning systems**

- \* Improvement of forecasting system effectiveness, incorporating weather radar information;
- \* Enhancement of seasonal forecasting capability;

- \* Development of storm surge forecasting;
- \* Drought and low flow forecasting;
- \* Improved risk management practices.

**(4) Technology transfer**

- \* Enhancement, effective promotion, and wider use of HOMS, including more training courses;
- \* Wide promulgation of standard techniques and method.

**(5) Financial resources**

- \* Development and use of methods for estimating the value of products and services;
- \* Running hydrometeorological services on a full-cost basis, carefully controlled commercialization of products where appropriate;
- \* Close links between hydrometeorological services and customers;
- \* Availability of sufficient resources to maintain hydrometeorological programmes on a long-term basis;
- \* Marketing hydrometeorology to increase its visibility.

**(6) Inter-agency collaboration**

- \* More effective mechanisms for collaboration and data interchange between agencies with water-related functions;
- \* Integration of scientific and operational hydrometeorology networks.
- \* Facilitating the assessment and management of water in shared river basins and aquifers.

**Institutional Changes**

Recommendations for institutional change focus on enhancing collaboration and co-ordination :



## **Frontier Areas of Research in Hydrometeorology**

- \* Providing effective mechanisms for co-ordination amongst agencies with environmental (including meteorology and water related) responsibilities;
- \* Establishing a single hydrometeorological service, and/or a national hydrometeorological archive;
- \* Close co-ordination of the national activities of IHP and OHP, and co-ordinating work with other relevant national actions;
- \* Joint planning meetings should be more frequent and supplemented by regular meetings throughout the implementation phase of the IHP Bureau and its Advisory Working Group
- \* Establish joint UNESCO / WHO programmes for publications, meetings and training (including HOMS).

## **INTERDISCIPLINARY ACTIVITIES IN HYDROMETEOROLOGY**

Interdisciplinary activities cut across hydrometeorological research, operational hydrometeorology and education, training and capacity building in hydrometeorology and education components should, all three, involve a strong concern for interdisciplinarity.

The main issues to deal with in future water resources development and management are the following :

- \* Environmental and social consequences;
- \* Land-water linkages ;
- \* Allocation of water among competing uses and users;
- \* Achieving effective implementation.

All these four issues imply clearly the need for interdisciplinarity at different levels. As an illustration of the disciplines which should be involved in the interdisciplinary effort in hydrometeorology and water resources, references is made to two important aspects;

- \* Development of integrated water resources planning and management;
- \* Development of new technologies for the management of water resources systems.

The development of integrated water resources management requires co-operation between hydrometeorologists and other specialists such as meteorologists, climatologists, geologists, soil scientists, biologists, physicists, chemists, ecologists, agricultural and forest experts, anthropologists, public health specialists, engineers of different backgrounds, economists, social scientists, demographers, lawyers, regional and urban planners and political scientists.

The development of new technologies for the management of water resources systems equally involves the co-operation of several types of experts such as operational researchers systems analysts statisticians, geographers, remote-sensing and, GIS experts, and computer specialists.

Obviously the degree of interdisciplinarity changes with the scale of each particular water resources problem, from local through regional and continental to the global scale. For instance, in global scale problems the framework for



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interdisciplinary co-operation is defined in this wide perspective by including the wide range of specialists required to consider the interactions between the hydrosphere, geosphere, biosphere and atmosphere established through the global inter-relationships set up by the hydrometeorological cycle, the energy cycle and the biogeochemical cycles.

### Past Achievements

Joint study of hydrometeorology phenomena started in the 1950s through the involvement of adjacent disciplines which are today accepted as part of the hydrometeorological sciences. This work was initially designated as "multidisciplinarity" to indicate the addition of contributions from different disciplines, rather than "interdisciplinarity", including mutual influence, an approach which started being developed only at a later stage. Since then, an increasing tendency has developed among hydrometeorologists of work interdisciplinarily.

In the initial period, a number of good examples of interdisciplinary activities can be mentioned, namely the preparation of the World Water Balance and the Hydrological Maps of Europe, as well as the efforts to bridge hydrometeorology and chemistry, and terrestrial ecology and hydrometeorology. In more recent times and in a broader perspective, important interdisciplinary initiatives were the creation of WCRP and IGBP as well as the organization of the Second World Climate Conference and the Dublin Conference on Water and the Environment. IHP started incorporating and interdisciplinary concern in IHP-III, and this was strengthened in IHP-IV.

Major regional and global programmes for environmental data collection and research, including water, are also co-ordinated through IGBP and other programmes under the agencies of ICSU. Efficient co-ordination is vital in deriving the maximum possible benefit from hydrometeorological research and operational activities.

During the period of development of interdisciplinary activities, a number of difficulties were, nevertheless, encountered. In general, it can be stated that although interdisciplinary was considered useful, there were no suitable frame works or mechanisms to implement it in an efficient way. Consequently many disciplines with close links to hydrometeorology have not developed co-operation. This was due to a number of reasons, including : cognitive barriers and protection of the traditional territories of some professions; insufficient co-ordination of water-related agencies at national or international levels; and university education or continuing education not normally encouraging an interdisciplinary attitude.

## **The Present Situation**

It is generally recognized that the need for interdisciplinary efforts is growing, and that responding to this need has become an urgent matter. There is also growing awareness of the need for broad-based teams for project planning or environmental impact assessment studies. However, the response to the perceived needs for interdisciplinarity in hydrometeorology and water resources is limited by funding and financing constraints, and by current organizational and institutional arrangements.

With regard to the financial constraints, there is a particularly severe problem in Third World Countries where the situation has clearly worsened over the last ten years. In developed countries, where funding is ensured mainly by national institutions and by international grants, there is a need for better co-ordination in order to make the best possible use of the funds available. At the regional level the situation has, in some cases, improved, thanks to donors increasingly supporting regional studies, as with certain river basin work.

With regard to organisational and institutional arrangements, the problems of sectorization and reflected in co-ordination difficulties at both national and international levels. In the latter case overlaps and duplication of activities are very obvious. This is partially because countries are not always coherent in the views they convey to different international organizations.

## **The Future**

There is clearly an urgent need for an organized framework to achieve a more coherent approach to the study of water-related issues and the implementation of the most appropriate solutions. Emphasis should be placed on the most acute problems, such as escalating water scarcity, due to rapid population growth, urbanization and increased drought and flood impacts as a result of human action. The possible impact of global environment changes, even though it may not have immediate consequences, should be taken seriously and continue to be studied, as its short and long-term effects could be source of great concern in certain regions particular when associated with demographic growth. The solution of all these problems clearly requires an interdisciplinary approach. Finally, improvements in the decision-making processes are crucial, with a clear need for aspects such as bridging the gap between scientists and decision-makers, integrated information to support the decision-making process, and to facilitate the education of decision-makers.

To face the problems of the future, some institutional changes will be required both at national and international levels. In particular, it is important to



## **Frontier Areas of Research in Hydrometeorology**

ensure that professionals of different disciplines work together within each organization, and also that different organizations work together. Barriers between national governmental agencies and international organizations should be overcome. The establishment of interdisciplinary teams to deal with integrated research topics can also be a useful measure.

In order to face the present difficulties, the necessary steps towards achieving an integration of the activities of IHP (UNESCO) and OHP (WMO) should be taken as a matter of urgency. An interdisciplinary perspective should prevail in this integration and, in particular, a coherent approach to water and land management on the international level should be sought. The long-term goal could be the establishment of a joint structure for both the IHP and the OHP.

Steps should also be taken in order to achieve a rationalization of the activities of the various UN agencies which have water-related activities and to provide an international forum, such as the "World Water Council" proposed at the ICWE, to enable international governmental views on global water issues to bear on the activities of the UN water Agencies.

## **CAPACITY BUILDING, TRAINING AND EDUCATION**

Capacity building consists of the following three basic elements :

- \* Creating an environment with the appropriate policy and legal frameworks;
- \* Institutional development, including community participation;
- \* Human resources development and strengthening of managerial systems.

The importance of capacity building in water resources as an essential input to sustainable development has been given increased recognition by many national and international bodies in the last two decades. The recommendations on public information, education, training and research suggested in the Mar del Plata Action Plan of 1977 represent an important landmark in that direction. It emphasized the need for world-wide efforts in developing these essential elements. These recommendations were consolidated through, amongst other, the New Delhi Statement (1990), the Delft Declaration (1991), the Dublin Statement (1992) and the Agenda 21 of UNCED (1992).

Many national and international bodies have contributed to capacity building. However, the deficiency in quality is so great that huge contributions are still needed to meet ever-increasing problems at local, regional and global levels. Many of these problems have been identified in the previous sections. It is worth mentioning here that considerable contributions have been made by many UN organizations such as the UNESCO (IHP) and WMO (OHP) programmes which have specifically been designed to meet certain parts of these requirements.

### **Past Achievements**

Hydrometeorological education and training issues were less complicated in the past. It is considered that the following elements represent the most important past contributions:

- \* The excellent technical and popularized documents produced as a result of the various IHP projects;
- \* The IHD / IHP of UNESCO contributions towards education and training of professionals and technicians in hydrometeorology;
- \* The technical publications, including teaching materials, that addressed issues directly relevant to developing countries;



## **Frontier Areas of Research in Hydrometeorology**

- \* The WMO contributions through the HOMS programme.

The main drawbacks and difficulties encountered in the past included :

- \* Funds were in short supply;
- \* National committees and focal points were ineffective;
- \* Text books and courses were not relevant to local needs;
- \* Public awareness programmes were lacking, as were educational programmes at primary school level;
- \* Trained staff in developing countries, in most cases, left the job for which they were trained after a relatively short period of employments;
- \* UNESCO publications were not translated into the languages of many countries;
- \* WMO efforts to survey needs were not successful and hence actual requirements were not identified.

### **The Present Situation**

The developed world has tried to make the adjustments in the educational system to adopt to the increasingly rapid and unpredictable changes taking place in the world today; this is clearly reflected in the increasing variety and contents of training courses; improved training methods and the fact that wider sections of the population are addressed.

The situation is completely different in most developing countries where education is still conventional and emphasizes knowledge rather than developing skills and professional attitudes. In most countries inadequacy in staff and teaching facilities adds to the poor results attained from education and training courses. A common problem is that most institutes use text books or teaching materials primarily published for the developing world and which are, in many cases, irrelevant to local conditions.

The most important facts at the present time are as follows:

- (1) The trainee opportunities and the documentation resulting from UNESCO (IHP) and WMO (OHP) programmes have greatly contributed to capacity building in many developing countries.

However it is felt that :

- \* The number and quality of qualified hydrometeorologists and technicians is inadequate;
  - \* The "brain drain" effecting trained staff is too high;
  - \* Technology is still balanced with the skills of the users;
  - \* UNESCO and WMO publications do not reach sufficient end users.
- (2) Pure hydrometeorology first-degree courses are not as widely available as desired.
  - (3) In some countries there are insufficient jobs for hydrometeorologists.
  - (4) The participation of women and young people in water-related education is poor.

Financing of capacity building activities is inadequate in many developing countries. However, in a few cases the constraints are related to poor co-ordination and implementation plans. The conference strongly recommends that more funds be secured from donor agencies as well as UN bodies for capacity building purposes.

The main organizational and institutional matters that require urgent consideration are :

- \* Effective co-ordination between UN agencies involved in the water field;
- \* Improved documentation elements of the HOMS programme.

Capacity-building programmes should be flexible in approach and give due considerations to differences between countries and their corresponding needs in time and space. Furthermore, the confusion in the definition of the terms that make up capacity building must be resolved and standardized to allow a universally accepted framework.

### **The Future**

Numerous needs have already been identified at various international meetings, especially the Mar del Plata Action Plan, The Dublin Statement and Agenda 21 of UNCED. However, the following complimentary issues are suggested for consideration :



## Frontier Areas of Research in Hydrometeorology

- (1) Water should be viewed as an economic good, a concept which deserves to be stressed in the education and training programmes of the future.
- (2) UNESCO and WMO should encourage and assist countries in performing regular surveys of their manpower situations and capacity-building needs and consequently prepare appropriate action programmes for meeting these needs.
- (3) Education and training programmes should be drawn up and implemented with a better understanding and appreciation of the multi-disciplinary nature involved in water resources development and utilization.
- (4) Special and well designed education and public awareness programmes should reach all citizens, including decision-makers, pupils in the schools, end users and the public at large.

The present UNESCO/WMO courses should be maintained, regularly evaluated and improved to meet new as well as local/regional conditions. New courses should be added, mainly in developing countries, if the above surveys identify new needs :

The material of these courses should :

- \* Be adapted to local and regional conditions and needs ;
  - \* Address water resources management issues as well as hydrometeorology.
  - \* Be based on text and notes that are relevant to the region
  - \* Include more field work, experimental and practical aspects;
- To improve the efficiency of these courses it is suggested that :
- \* Regular support be provided for teaching facilities and staff development;
  - \* Feedback from participants be incorporated in the system of evaluation;
  - \* Short refresher courses be regularly offered at local levels;
  - \* More emphasis be put on the training of technicians and water resources managers in developing countries;
  - \* UNESCO/WMO publication be translated by local experts into the languages of the various countries.

**Institutional Changes**

It was suggested that the following changes be considered :

- \* Effective co-ordination and linkage programmes should be provided between education and training institutes, the employers, the local professional societies and relevant Environment disciplines (including meteorology);
- \* The IHP National Committee and OHP focal point should coordinate their efforts towards more action-oriented activities in their water field;
- \* Water-related teaching should be introduced into the primary and secondary school curricula.

The following changes are suggested at international level :

- \* Linkages and academic exchange programmes between education and training institutes of the developed and developing world should be improved;
- \* The level of co-ordination between NGOs and UNESCO/WMO secretariats should be raised for more effective results. The COWAR UNESCO/WMO partnership sets a good example in this respect;
- \* Networking of education and training institutes and twinning of IHP National Committee should be encouraged;
- \* Fellowships from UNESCO, WMO and other donor bodies should reach potential users in good time.



## WORK DONE AT THE INDIAN INSTITUTE OF TROPICAL METEOROLOGY, PUNE

### DEPTH-AREA, DURATION ANALYSIS OF SEVERE RAINSTORMS :

Severe rainstorms from 1880 to the present which have occurred in different parts of India have been analysed. This analysis revealed that in rainfall records three rainstorms predominated which gave the highest rain depths for different area and durations. These are the storms of September 17-18, 1880 over northwest Uttar Pradesh, the rainstorm of July 26-28, 1927 over Gujarat and that of July 2-4, 1941 over south Gujarat-north Konkan. The quantitative analysis of these storms further showed that among the most severe rainstorms, the July, 1941 ranks highest for durations of one to three days. This rainstorm generated 39 cm, 59 cm and 80 cm for 1, 2 and 3 days duration respectively over an area of 10,000 mi<sup>2</sup>. A comparison of areal raindepths of July, 1941 rain storms. with the areal rain depths of most severe rainstorm of USA and Australia showed that areal rain depths of 1941 rainstorm exceeded the records of USA and Australia excepting for small areas in the range from 100 mi<sup>2</sup> to 1000 mi<sup>2</sup>. The rainstorm efficiency ratios (P/m) of these three most severe rains storms were also found to be higher when compared with USA rainstorms.

The rainstorm of 28-30 August, 1982 over the uncontrolled catchment of Mahanadi river which produced an unprecedented peak discharge of 44830 m<sup>3</sup>/sec at Naraj was analysed. It was found that the rainstorm of August, 1982 was not the severe most rainstorm in the catchment though it produced the maximum peak discharge. The unprecedented peak discharge was due to antecedent wet conditions of the soil due to occurrence of a heavy rainstorm prior to this storm.

From an analysis of a large number of rainstorms in different parts of north India, relationships between maximum central rain depth and its areal extent have been derived as

$$\frac{P}{P_m} = -KA^n,$$

where P is the average rainfall for an area A, P<sub>m</sub> is the maximum point rainfall and K and n are constants. For 1, 2 and 3 days durations the values of K are 0.0016, 0.0030 and for n are 0.6614, 0.6306 and 0.5691 respectively. The areal rainfall can be estimated for design purposes for small size basins from the observed maximum point rainfall in the problem basin.

**Design rainfall analysis for use in wide range of design and construction of water resources projects :**

Systematic long period rainfall data of different river basins of the country where water resources projects are being planned have been analysed for the purpose of application of the results to design storm studies. Different sections of the basins for the rivers Yamuna, Beas, Baitarni, Mahanadi, Bhima, Godavari, Krishna, Mahi, Subarnarekha, Betwa Narmada, Karanja, Indravati, Kallada and Kharkai were studied with a view to obtain the following :

- (1) Space-time distribution of storm rainfall,
- (2) Estimates of design storm upto different dam sites and
- (3) Estimates of PMP.

The design storm studies have revealed that in the most severe three day rainstorm about 50% of basin rainfall is obtained on the heaviest of the three days, 30% on the second heaviest day and only 20% on the third day. Further it was observed that three day maximum basin rain depths vary from 13 to 42% of the respective mean annual basin rainfall. In the majority of basins, however this ratio varies from 20 to 29%, thereby showing that more than one fifth of the annual rainfall over a basin can occur in the course of three days.

A comparative spillway design storm study was carried out for three north Indian river basins; the Mahi, the Betwa and the Subarnarekha. These basins although located in the same latitudinal belt of 20°-25°N, are located in different rainfall regions of north India. This study has shown that the magnitude of spillway design storm for different durations is independent of the mean annual rainfall of the region in which the problem basin is located. River basins in the low rainfall regions can have higher design storm magnitudes when compared with basins located in high rainfall regions of the country.

**Estimation of point and areal extreme or probable maximum precipitation (PMP) :**

- (i) Recognising the great importance of PMP in the design of spillways, for large dams and in the estimate of probable maximum flood, one of the standard statistical techniques for determining PMP was extensively used for a very large number of Indian station (2000). Based on these estimates generalised PMP charts were prepared for different states of Indian Union. It was found that 1-day PMP varied between 35 to 105 cm over India.



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(ii) A generalised method of estimating areal PMP for the Indian river catchment has been developed. This is done by pooling together all the rainfall data from a very large area. The rainfall depths are normalised for such factors as storm dew point temperature, distance of the storm from the coast, topographic effects and any intervening mountain barrier between the rainfall area and the moisture source. These normalised values can then be applied to any individual catchment with the appropriate adjustment factors. The generalised technique was applied to estimate areal PMP for 1000 and 5000 sq. miles for 1-day duration over different locations in the north-western Indian region. The one day PMP for 1000 and 5000 sq. miles were found to vary between 60-100 cm and 40-70 cm respectively.

(iii) Areal PMP for areas of 1000 and 5000 sq. miles for one-day duration were estimated using a combination of point PMP and depth area model for stations in north Indian plains. Two generalised charts depicting spatial pattern of 1-day PMP for these two areas were prepared. The PMP estimates of 1000 and 5000 sq. miles were found to lie between 40-80 cm and 30-60 cm respectively for 1-day duration. The estimates obtained by this method were compared with those derived from storm transposition and maximisation method. The arrangement was found to be good.

(iv) Depth-area-duration model of severe most rainstorm which occurred in July, 1927 over Gujarat Region was developed to convert the storm centre rainfall to a real rainfall. The model was used to estimate areal PMP for different areas ranging from 1300 to 13000 sq.km. The area PMP for 1300, 2600 and 13000 sq.km. were worked out to be 75, 70 and 50 cm respectively. These estimates were found to be in close agreement with those obtained by the moisture maximisation of the storm in situ.

### **Determination of trends, periodicities and variability in seasonal and extreme rainfall series :**

(i) The long term trends in the annual rainfall series of three sub-division of Karnataka state were studied. The analysis indicated an increasing trend in the annual rainfall series of coastal Karnataka, south interior Karnataka and the state as a whole while no such trend was noted in the rainfall of north interior Karnataka.

(ii) An analysis of 100 years rainfall series of Tamil Nadu showed no significant increasing or decreasing tendency in the seasonal and annual rainfall.

(iii) The annual rainfall data of six heavy rainfall stations (Bhagamandala, Gangabavada, Matheran, Mahabaleshwar, Neriamangalam, Peermade) in the Western Ghats were subjected to trend analysis which showed no definite increasing or



decreasing trends in rainfall except at Mahabaleshwar and Neriamangalam station where decreasing trend in rainfall was noticed.

(iv) The trend analysis of the rainfall over Upper Narmada catchment was carried out using daily rainfall data of about 40 stations from 1901 to 1980. The analysis showed that there was significant increase in rainfall during 1901 to 1945 however, during the last three decades there was no significant change in rainfall over the Upper Narmada Catchment.

(v) Fluctuation characteristics in the individual areal maximum rainfall series ranging from 1 to 30 day durations of south and north Kerala were studied using 80—years rainfall data from 1901 to 1980 for 75 stations. The trend analysis showed a significant decreasing tendency in the individual maximum rainfall series of 1-3 day durations in north Kerala and 1 to 30 day durations (excepting 3-8 day) in south Kerala. As regards annual rainfall, a significant decreasing trend in south Kerala and no trend in north Kerala were found.

(vi) The trend in the southwest monsoon and annual rainfall series of 14 stations along the east coast of India lying between the latitudes 8°N to 22° 30'N were studied using the rainfall data of the 80 years period from 1901 to 1980. The trend analysis showed a significant decreasing tendency in annual rainfall of Nagapattanam and Visakhapatnam. However, Balasore rainfall during the monsoon season showed an increasing tendency. No other station showed either decreasing or increasing tendency in rainfall over the record period.

#### **Floods and droughts studies :**

(i) **Incidence of floods :** From an examination of the highest flood data of all the major rivers of the country, it was found that 11 major rivers of the country at about 22 sites recorded the highest floods which were 5 to 18 meters above their respective danger levels. The highest ever recorded flood in India was 18.1 meters above the danger level and this happened on the Teesta and Anderson Bridge in north Bengal on 4 October, 1968. This flood was caused by the intense rainfall associated with the braking up of a Bay depression over sub-Himalayan West Bengal during the period 3 to 5 October, 1968. The next highest flood occurred in the Narmada at Garudeshar in Gujarat on 6 September, 1970. On this occasion the Narmada was 17.9 metres above the danger level. This flood was caused by the incidence of very heavy rainfall between 5 to 7 September over the Narmada basin in association with the passage of a westward-moving land depression.

(ii) **Incidence of droughts :** The drought years in the different sub-divisions of India from 1891-1970 based on rainfall deficiency were examined. The areas of the country which were susceptible to frequent droughts were delineated. It was



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observed that there were nine years in which a large number of contiguous sub-divisions of the country experienced moderate to severe drought conditions. The sub-division worst affected by these droughts were generally found to be those which lie to the west of longitude 80°E.

Further, it was noticed that there was no systematic time interval between any two successive drought years but on an average one of these worst drought years can be expected in a decade. It was further observed that the sub-divisions of the country liable to frequent drought are those whose mean annual rainfall is less than 1000 mm. During the period 1891 to 1970 the drought of 1918 was the most severe from the consideration of areal extent, while from the rainfall deficiency point of view the drought of 1899 was the worst.

The study of droughts based on water budget method seems to provide a more realistic approach than on rainfall alone. The frequency and pattern of variation of the drought situations for a group of 9 stations in Andhra Pradesh during the last 70 years have been studied by computing aridity indices values from water balance considerations. It has been observed that a minimum of 3-4 effective drought years may be expected over each station in a decade and that liability to drought is maximum in Nellore. An examination of the year to year changes in climate shows that the disastrous droughts years generally became arid in nature.

### Frequency analysis of maximum rainfall series :

(i) Frequency distribution of annual maximum 1, 2, 3, 6, 12, 24, 36 and 48-hr rainfall recorded at Colaba observatory, Bombay from 1924 to 1984 was studied using Gumbel and Gamma distributions fitted by moments as well as maximum likelihood methods. Gumbel distribution fitted with method of moments is found most suitable as indicated by minimum value of absolute relative deviation and quadratic deviation.

(ii) For the purpose of providing information to engineers for designing small hydraulic structures maximum point rainfall for different return periods for a very large number of stations were worked out. Nomograms were prepared for determining the maximum 1-day rainfall for any return period ranging from 2 to 25 years for a station from its normal annual rainfall. A simple procedure was also developed to estimate maximum 1-day point rainfall of 5 to 100 year return periods using a combination of 2 year rainfall, district average ratio map of 2 to 100 years rainfall and frequency nomogram.

**Short duration rainfall studies :**

(i) Hourly rainfalls of six most intense 1-day rains recorded at Bidar station located in Karanja catchment, Karnataka were analysed to determine the temporal pattern of design rainfall for use in conversion of probable maximum precipitation to probable maximum flood. The analysis showed that during 1-hour period as much as 56% and in two hours 73% of total one day rainfall can occur. Further, the general occurrence of greatest inter-hourly intensity seems to be during periods from 17 to 24 hours.

(ii) Maximum 1-hour rainfall recorded at 9 stations (Bangalore, Hyderabad, Kodaikanal, Madras, Mangalore, Tiruchirappalli, Trivandrum, Vengurla and Visakhapatnam) in the southern half of Indian peninsula has been studied on the basis of 10-year data from 1951 to 1960. Magnitudes of maximum 1-hr rainfall for return periods 2, 3, 4, 5, 10, 25 and 50 years have been calculated. It has been found that the highest 1-hr rainfall of 4 inches, recorded at Hyderabad has a return period of about 120 years.

**Evaporation, evapotranspiration and water balance studies :**

(i) The normal monthly Potential Evapotranspiration (PE) Values of 240 stations distributed uniformly in India have been subjected to harmonic analysis to study the annual and half yearly oscillations. It has been observed that first two harmonic account almost a complete characterisation of the space time distribution in PE. The annual wave has its maximum amplitude ranging from 2 cm in the southernmost parts of the Peninsula to about 10 cm over west Rajasthan. In the west coast the annual oscillation attains its maximum. Around 1st March and data progresses to 30th June in the northwest India. The occurrence of the maximum amplitude is however, delayed by about 2 to 3 months in the south eastern parts of the peninsula as compared to the west coast. The highest amplitude of the second harmonic is about 4 cm which is observed over central India.

(ii) The potential evapo-transpiration values computed by Thornthwaite's and Leeper's formulae for a group of 16 representative stations in Andhra Pradesh were discussed. The potential evapotranspiration values by Leeper's method are less by 2 to 8 cm for hot weather period and by 10 to 13 cms in monsoon period than those computed by Thornthwaite's method. However, there is a fairly close agreement between the values for the winter and post monsoon season.



**Influence of tropical disturbances on rainfall distribution in different parts of the country :**

The influence of tropical disturbances on the rainfall distribution in the individual monsoon months and the season as a whole using 80-year record of rainfall and tropical disturbances over the Indian land area was examined. The correlation coefficients were computed between rainfall of individual monsoon months and the season as a whole with the corresponding frequency of tropical disturbances. This analysis showed that the increased frequency of tropical disturbances in the individual monsoon months showed a significant relationship between the rainfall and the corresponding frequency of tropical disturbances but the monsoon season taken as a whole did not show a significant relationship.

Studies were also carried out to investigate as to what extent the absence of these disturbances affect the rainfall in the individual monsoon months. It was found that over north Indian plains the average deficiency in rainfall during June, July, August and September months could be of the order of 7, 13, 13 and 41% respectively. The month of September gets worst affected by the absence of these disturbances. The subdivisions of Orissa, West Rajasthan, East Rajasthan, Gujarat and Saurashtra-Kutch were found to be worst affected by the absence of these disturbances.

**Rainfall and water resources studies :**

(i) Based on rainfall data for about 3000 stations for the period 1891 to 1970 the mean annual rainfall of the country has been estimated as 117 cm. The mean annual rainfall of 117 cm over the country is equivalent to a volume of water of about 384 million hectare metre. The annual surface water flow in rivers including ground water recharge from rainfall has been estimated as 180 million hectare metre. This shows that roughly 40% of the annual rainfall is converted into surface runoff and the remaining 51% is lost to the atmosphere by evapotranspiration. Owing to the limitations imposed by topography, geology and soil conditions only about 70 million hectare metre of surface water could be used.

Taking into account the enormous water potential available to this country, an examination was made to see as to what extent of this water is being exploited at present by various storages. It was found that only between 5 to 15% of monsoon rainfall is currently stored in various reservoirs and dams of the country and that the rest is virtually wasted. Although high priority has been given in the development of water resources in India over the past 35 years, there is still scope for the conservation of the natural resources by storage in existing as well as proposed reservoirs. The optimum storage of monsoon rainfall in reservoirs will to a large extent help to protect the country from frequent floods and will also be potentially useful for irrigation and energy generation.



(ii) A study was undertaken with a view of identifying those stations in the country which receive heavy rainfall. A heavy rainfall station was considered to be one whose mean annual rainfall was 500 cm or more. This study has shown that there are about 14 stations in the country whose mean annual rainfall was 500 cm or more. Of these 14 stations, 4 are located in north east India (Denning, Buxa, Cherrapunji and Mawsynram) and the remaining 10 stations (Matheran, Mahabaleshwar, Amboli, Gaganbawda, Agumbe, Bhagamandala, Pulingoth, Makut, Neriamangalam and Peermade) are located in the Western Ghats of peninsular India. It was observed that Mawsynram station, which is located 16 kms to the west of Cherrapunji is the rainiest station in India, receiving annually on an average about 1,190 mm of rain more than Cherrapunji. It was also observed that the world's highest record rainfall for durations of 15 days to 2 years. The world's highest point rainfall envelope curve for different durations follows the equation  $R = 76.9 D^{0.475}$ , where R is the rainfall in inches and D is the duration in days. In case of Cherrapunji the enveloping rainfall curve was found to have the equation  $R = 49 D^{0.485}$ .

(iii) Study on precipitation climatology of Nepal Himalayas describing meteorological causes of heavy precipitation, rainfall distribution during breaks in monsoon, its variation with elevation and highest one-day rainfall ever recorded was carried out. The highest one-day rainfall in this region varies from 15 to 41 cm which constitutes about 9 to 32% of the mean annual rainfall.

(iv) Onset of the monsoon over Kerala : The rainfall characteristics over south Kerala during May and June were studied using the 80 year rainfall data of 44 stations from 1901 to 1980. Objective criteria for fixing the onset date of monsoon were developed and the onset dates were fixed for the individual years of 80-year period. The mean onset date of SW monsoon over south Kerala was found to be 30 May with a standard deviation of  $\pm 8.8$  days.

(v) The usefulness of co-efficient of variation (CV) in determining rainfall probabilities in the humid region has been examined using monthly, seasonal and annual rainfall data from 1901 to 1970 for 80 rainfall stations well distributed in Kerala. Variation in four selected rainfall probabilities e.g. probability of occurrence of no rain, equal to or less than one and a half mean, equal to or less than one and a half mean separately, with changing co-efficient of variability is studied.

(vi) The highest recorded 24-hr rainfall from 1975 to 1982 for about 300 stations were plotted and isohyetal drawn to delineate the homogenous zones of heavy rainfall. The isohyetal pattern indicated an unsteady increase from less than 20 cm in the far west and far north to over 50 cm or near the coasts. At a few inland stations outstanding amounts have been recorded but these are randomly distributed in space and time. Besides these, there existed a densely gauged area in the



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central Peninsula between latitudes  $8^{\circ}\text{N}$  to  $21^{\circ}\text{N}$  within which more than 20 cms of rain in 24-hrs have never been recorded. The area which will be treated as meteorological homogeneous with regard to the occurrence of heavy rainfall includes virtually the entire Indian region excepting the far western extremity, the northern area bordered by the Himalayan and the central peninsular region. The correlation coefficient between the highest rainfall and elevation indicated no significant relationship.

(vii) The rainfall distribution along the southern slopes of the Himalayas and the adjoining plains were studied for 14 break monsoon situations using daily rainfall of 515 stations. A two to four fold increase of rainfall over normal was noticed east of  $80^{\circ}\text{E}$  along the foot hills of the Himalayas while to the west and south there was a decrease in rainfall.

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\* indicates papers which deal with design storm analysis.

**BRIEF REPORT OF THE WORK DONE IN THE DEPARTMENT OF  
METEOROLOGY AND OCEANOGRAPHY AT ANDHRA UNIVERSITY**

Several areas have been studied in Hydrometeorology at Andhra University, since the department was started in the year 1947. However, work has been intensified after Prof. V.P. Subramanyam who worked with Prof. C.W. Thornthwaite (U.S.A.) returned after training under him. The use of Climatic Water Balance was applied to studies in Hydroclimatology for the first time in India. Studies were made on Floods & Droughts. Forecast of river discharges, Soil moisture models, rainfall analysis, urban Hydrological studies, characteristics of high-low stream flows, yield river basins, flood mapping and drought monitoring, desertification, consumptive use of evaporation, evapotranspiration, water requirements of crops, moisture availability periods, agricultural droughts etc. were studied.

Subsequent to the studies made by late Prof. V.P. Subramanyam work was extensively carried out by Prof. A.R. Subramaniam & Dr. A.A.L.N. Sarma. A list of some publications that were published are herewith appended.



## **SELECTED LIST OF RESEARCH PUBLICATIONS**

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20. Occurrence of drought in relation to stability of moisture regime. Accepted for presentation in the National Seminar cum Workshop on Atmospheric Science and Engineering, Sept. 18-22, 1984, Univ. of Jadavpur, Calcutta.
21. Occurrence of Aridity and droughts - SW Monsoon, Accepted for presentation in the international Conference on Environmental education held in New Delhi, India, during March 4-9, 1985.
22. Studies on the incidence of droughts through seasonal aridity index. Presented in the international symposium on "Variations in the Global Water Budget" which was held at Oxford, U.K. during 10th to 15th August, 1981, and subsequently published in *Mausam*, 1986, 37, 2, 207, 210.
23. Climatic Variability in relation to seasonal effectivity of Moisture. Presented in the Symp. on the influence of Climatic changes and Climatic Variability on Hydrological Regime and water Resources, that was held under IAHS at IUGG, Vancouver, 1987.
24. Occurrence of aridity and droughts - Southwest monsoon. Presented in the Workshop in hydrological Sciences in Developing Countries" that was held at IUGG, Vancouver, 1987.
25. Modelling of Water Budget Elements - Extreme events presented at the International Symposium on "Global Energy and Water Fluzed" IAMAP '89, that was held at University of reading, U.K.
26. Studies on Hydrological Aspects of Storms- Urbanization, Included in the Symposium. Proceedings on the 5th International Conference on "Urban storm Drainage" that was held at May Theater, Fuita, Osaka, Japan during 23-27, 1990.

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1. "Snow cover estimation and runoff simulation for a Mountain watershed in the Himalaya, N. Mohana Rao & D.B. Bandopadhyay. Journal of geology, September 1988.
2. "Included snowmelt - An analysis of the problem of accelerating and augmenting snow and ice melt by surface dusting" - B.K. Bandopadhyay & N. Mohan Rao, Presented at the Workshop on Snow Hydrology, Nov. 1988 at Manali, India.
3. "Snow melt Runoff for a sub-catchment of Beas basin". -Lt.Col. K.C.Agarwal, Virendra Kumar and Tilok Das.
4. "Estimating Glacier Melt during ablation period for energy balance studies on Chhota Shigri Glacier, HP (India) - M.R. Bhutyani, National Meet on Himalyan Glaciology, 1989.



**ABSTRACTS OF SOME  
SELECTED PAPERS**

## SPATIAL AND TEMPORAL INHOMOGENEITY OF GLOBAL PRECIPITATION DATA

*Sevruk, b. Swiss Federal Institute of technology, Zurich*

A serious drawback of point precipitation measurements is that they are biased. They are related to a particular observational method used and to environmental condition of a particular gauge site. Since all these variables show a distinct spatial variability, precipitation observations are spatially inhomogeneous. Beside this the temporal inhomogeneity exists owing to either changes of gauge types or exposure degrees. Both kinds of inhomogeneity can be eliminated only when the correction procedures particularly for the wind-induced measurement error are applied. Such procedures have been based on time consuming field inter comparison measurements using special gauges as reference. However, using computational parameters seems to be a more convenient alternative. The correction procedure could be derived for any type of gauge using adapted software and no field tests will be needed. Thus it would be possible to obtain a homogenous global precipitation data set.

**Keywords** precipitation measurement error correction time series homogeneity

## OCEAN RAINFALL OBSERVATIONS

*Thiele, O.W., Short, D.A., Wilkerson, J.C., NASA/Goddard Space flight Centre*

For the first time, it has become possible to evaluate rainfall variability over an open ocean environment in the west Pacific without any land mass influence even from small coral atolls. In 1992, an array of radars and optical rain gauges were deployed on buoys and ships in west Pacific in Connection with the TOGA Coupled Ocean Atmosphere response Experiment (COARE). The observations were focused around an Intensive Flux array (IFA) centered at 2°S latitude and 156°E longitude and conducted during an intensive 4-month period from November 1, 1992, through February 28, 1993. The time series is rather short, but optical rain gauges on two west Pacific equatorial mornings extend back more than a year. A preliminary analysis shows a relatively consistent morning peak in the diurnal component, but on occasion, the late afternoon or early evening maximum is somewhat higher. On the longer time scale, there appear to be cycles of organized convection moving through at intervals of 35 to 40 days which is consistent with the reported Madden—Julian periodicity.

**Keywords** : rainfall variability, ocean rainfall



## **HEATED RAIN GAUGE SYSTEM DESIGNED BY EDF APPLICATION TO THE HYETOCAP RAINGUAGE**

*CH. Lallement, electricite de France*

For more than 40 years, EDF (the French Electricity National board) has been managing an important tele-collected rainfall network : 300 rain recorders, setup in mountianeous regions, between 400 and 2200 m. Therefore EDF has developed several generations of heated rain sensors; tipping buckets with an orifice area of successively 2000, 200, 400 square cm and the HYETOCAP" weighting sensor.

The development of a heated rain recorder is based on the results of crosses experiments:

- Laboratory experiments, by optimizing the characteristics of the heating system by infrared thermography and evaporation evaluation in given situations.
- The field experiments, through the use of manual gauges results compared to the data provided by the real time network. The results and observations, lead to optimized implementations of the sensors, mean while tested and validated by the laboratory experiments. All these elements have been analysed in order to design the Hyetocap, a solar heated weighting rain sensor.

**Keywords** : Solid precipitation/Heated rainfall recorder/intercomparison

## **MEASUREMENT OF PRECIPITATION AT SEA**

*Hasse, L., Grossklaus, M., Uhlig, K.,  
Institute for Meereskunde, Kiel*

Measurements of precipitation at sea are an important part of the WCRP and GAW. Unfortunately, because of high wind speed, conventional instruments fail at ships. An effort has been made to construct new rain gauge types for use at voluntary observing ship. Two types are presently tested at sea : The mechanical ship rain gauge has a horizontal and a vertical collecting surface and is used with a cup anemometer for local flow velocity. From these three information rain amount is calculated by algorithm. The second device is an optical disdrometer of the light extinction type. The active volume consists of an illuminated cylinder of 2.2 cm diameter and 12 cm length. Drop size is obtained from pulse height of extinction. Rain rate is calculated from measured rain drop distribution by an PC assuming terminal velocity of drops. This measurement is independent of up-or down drafts imposed by flow around the ship. Results from several cruises will be reported.

**Keywords** : ship rain gauge, disdrometer, rain at sea

### **MEASUREMENT OF PRECIPITATION**

*Aaltonen, A., Elomaa, E., Tuominen, A., Valkovuori, P., Finnish Meteorological Institute, Finland*

During the WMO solid precipitation measurement inter comparison several types of precipitation gauges has been compared. In addition weather sensor has been tested. Most of the gauges were manually operated. Automated gauges were tipping buckets, weighted buckets (vibrating wire) and an optical sensor ( a forward scatterometer).

### **IMPROVED DESIGN OF PRECIPITATION GAUGES BASED ON AERODYNAMICS PRINCIPLES**

*Wiesinger, T., Institute for Meteorology, University of Vienna, Austria*

The collector design is based upon inviscid flow simulations over a Karman-Treffitz airfoil profile. Angle of attack and the ratios of the center collector height divided by its radius were altered and the flow fields were studied. The theoretical considerations resulted in 5 similar collector shapes, shallow bowls with inward turned lips, that were field tested in Japan and their performance was compared to reference gauges. The new collector's performance is significantly improved compared to standard instruments. It caught 98% of rain compared to a pit gauge, 11% more than the standard gage. In winter it caught 98% of the Double Fence Int Reference Gage's catch (88% for snowfall only), 109% compared to the snow board and 122% compared to the standard snow gauge. This low-cost instrument can be combined with all common measuring and recording devices and needs power line supply for winter operation.

**Key words** : aerodynamic collector

### **ALGORITHMS FOR CORRECTION OF ERROR TYPES IN A SEMI-AUTOMATIC DATA COLLECTION.**

*Madsen, H. the Danish Meteorological Institute*

A semi-automatic quality control system for daily precipitation measurements with a non-parametric technique, in which the daily standardized median value for the measurements occur as a reference value for the other measurement, has been developed.

In this system manual checking will be devoted to data deriving from convective cells or other small-scale systems. In case of large-scale precipitation systems most of the detected erroneous observations can be corrected and



interpolated by the automatic control system. But in some cases, as for example, when rainfall are noted the wrong day for a whole month, or part of the month, and in case of accumulations and incorrect time of observations, the situation is more complicated.

However, studies have been made to find reasonable programmable algorithms, so that both detection and correction of erroneous data in such conditions will be possible.

**Keywords** : quality control daily precipitation error types.

### **CORRECTION OF THE PRECIPITATION USING PRESSURE FLUCTUATION INSIDE OF THE GAUGE**

*Ohno, H.T. Wiesinger and S. Takami, Hokuriku National Agricultural Experiment station, Joetsu 943-01, Japan*

The air pressure inside of the cylindrical precipitation gauge depresses and fluctuates during windy conditions. This suggests that it is possible to establish a new method to correct a measured precipitation using standard deviation to interior air pressure. On accordance with the theory of surface boundary layer and Bernoulli's principle, Standard deviation of the interior pressure is proportional to the square of the mean wind speed. This method may be superior to the usual method which uses the wind speed measured at the different point because it reflects the condition of wind just above the orifice in principle. A waterproof pressure sensor installed in the bottom of a cylindrical container is able to detect both of the caught precipitation and the standard deviation. Two methods were compared using this gage from January through March in 1993. A Valid Fence Gage was prepared as the reference. The performance of the method would be presented.

### **PRECIPITATION CORRECTIONS IN SWITZERLAND**

*Sevruk, B., W. Kirchofer, R. Tihlarik and L. Zahlavova Swiss Federal Institute of Technology, Zurich, Swiss Meteorological Institute, Zurich and Slovak Technical University, Bratislava*

The estimates over the territory of Switzerland of the mean annual corrections for systematic losses of precipitation measurement due to wind and wetting are based on the mean monthly precipitation values primarily from the Hellmann gauges, mainly without wind shield, and the shielded storage gauges. The missing input variables for correlation procedures at the gauge sites without direct measurements were assessed by analogy (wind speed) and regionalized vertical gradients (temperature and fraction of snow). The degree of exposure was assessed from the station history records. Corrections were computed from the

difference between the corrected and measured precipitation values in 1x1 km grid. The grid values and the isohyets were derived by vertical gradient of precipitation and kriging. The map of corrections shows different regional patterns. The corrections in the Alps are four to ten times greater than in the lowlands.

**Keywords** : precipitation systematic measurement error map regionalization.

### **CORRECTION OF IN SITU RAIN RATE MEASUREMENTS**

*Gro Bklaus, M., Uhlig, K. Hasse, L.  
Institute. f. Meereskunde, Kiel (FRG)*

The ship-borne rain gauge from the IfM/Kiel simultaneously measures the local rain rate as well as the liquid water content of the atmosphere. Both measurements include an error which depends on the local wind speed and the rain rate. Especially in windy conditions these errors require correction by an additional term in the calibration algorithm. The coefficients used in this term are deduced by multiple nonlinear regression. The calibration requires reference values. These are obtained by using a new optical disdrometer. The kind of instrument can be calibrated directly. Side effects by grazing incidence and multiply occupancy of the active optical path need to be considered. The correction techniques used with the optical disdrometer and the mechanical ship-borne rain gauge are presented. Also, results from field measurements are given.

**Keywords** : ship rain gauge, optical disdrometer, correction verification

### **AN EMPIRICAL BASIS OF MODELLING THE EFFECT OF WATERSHED TOPOGRAPHY IN THE LOCAL DISTRIBUTION OF WIND-DRIVEN RAINFALL**

*D. Sharon & A. Arazi (Hebrew University of Jerusalem, Israel)*

The errors for the half daily and monthly uncorrected and corrected precipitation amounts have been carried out. The proposals are submitted to incorporate measurements of characteristics of precipitation structure around air flow turbulence into the research programme of the national and Regional Precipitation centres.

**keywords** : precipitation gauge, error correction

### **PRELIMINARY RESULTS OF WMO SOLID PRECIPITATION MEASUREMENT INTERCOMPARISON AT TIANSHAN GLACIOLOGICAL STATION, XINJIAN, CHINA**

*Daging yang and Ersi Kang  
Lanzhou Institute of Glaciology &  
Geocrylogy, Chinese Academy of Sciences, Lanzhou 730000, P.R. China*



## Frontier Areas of Research in Hydrometeorology

In 1987, Tianshan Glaciological Station of Lanzhou Institute of glaciology and Geocrylogy, Chinese Academy of Sciences, participated in the Solid Precipitation measurement Inter comparison and started precipitation measurement experiment at 6 hydrological and climatic stations situated from the high alpine glacier area to the low land of Urumqi city in Urumqi river basin in Tianshan Mountains. A WMO reference gauge (DFIR) was installed at the highest elevation site in the upper streams and chinese standard gauge, Tretyakov wind shield and Hellmann gauges were used. The inter comparison data up to August 1991 have been digitally archived. Preliminary analysis indicates that the Chinese standard gauge at 0.7m catches 73% of the DFIR in dry snow measurements.

**Keywords :** DFIR, Chinese gauge, snowfall measurement

### **SOLID PRECIPITATION MEASUREMENT INTER COMPARISON IN SLOVAKIA**

*Lapin, M., Slovak Hydrometeorological Institute, Bratislava, Slovak Republic*

The meteorological observatory Bratislava, Koliba is a basic station for intercomparison of different national gauges (shielded and unshielded METRA (CSFR), unshielded HELLMANN (Hungary), shielded Tretyakow (Russia) and others. The results of about 15-year measurements are presented in tabular form. It follows from the results that the shielded METRA gauge measures the highest totals, and unshielded METRA gauge the lowest ones. There are some significant changes in annual course of differences between totals measured by various gauge.

**Keywords :** solid precipitation, intercomparison, measurements

### **WMO PRECIPITATION MEASUREMENTS INTERCOMPARISONS**

*Sevruk, B. Swiss Federal Institute of Technology, Zurich*

Field intercomparison measurements were used for centuries to check the performance and to improve the construction of precipitation gauges. Well-known intercomparisons have been organized by Symons in the last century in the U.K. and by Poncelet in Europe and by Struzer in the former U.S.S.R. thirty years ago. In the last forty years the WMO organized three international intercomparisons. All showed considerable differences between precipitation catches of different types of gauges and indicated the necessity to correct precipitation measurements for systematic error. Otherwise, precipitation figures between countries using different types of gauges show systematic differences and are not comparable. At present intercomparisons are used to develop correction procedures for the wind-induced error. The WMO standard reference for rain is the pit gauge and for snow the double-fence gauge. The historical perspective of intercomparisons and the chronology of the doublefence gauge are presented and the results discussed.

**Keywords :** Precipitation measurement error history

### **INTERCOMPARISON OF THE PRECIPITATION TOTAL MEASUREMENTS IN POPRAD**

*Nieplova, E. Slovak Hydrometeorological Institute, Bratislava, Slovak Republic*

14-years time series of daily precipitation total measurements by the unshielded and shielded (Tretyakow) METRA gauges in Poprad (Slovakia) is discussed. Differences between totals are analysed in dependence both on wind velocity and type of precipitation (solid and liquid). The results achieved in this study are one of the contributions to the estimation of precipitation measurements accuracy in higher altitudes of Slovakia.

**Keywords :** precipitation, intercomparison

### **PHYSICS OF PRECIPITATION GAUGES**

*Sevruk, B. Swiss Federal Institute of Technology, Zurich*

Studies into the physics of precipitation gauges are reviewed including field intercomparison measurements, wind tunnel experiment and computational fluid dynamic. The focus is on the effects of precipitation gauge parameters on the wind-induced error and on the application of the knowledge of physical laws to the solution of such practical problems as the selection of suitable design criteria for sensitive parts of a gauge or for the assessment of the possible error magnitude. Beside the proportions of the body of a gauge (the best form is a shallow plate) or wind shield use the most important constructive parameter affecting the wind-induced error seems to be the gauge orifice rim. Slight deviation in the shape and thickness of orifice rim can cause considerable changes of the wind-induced error.

**Keywords :** precipitation gauge parameters wind-induced error wind tunnel tests numerical simulation.

### **A PC-BASED DATABASE OF PRECIPITATION DATA WITH HIGH RESOLUTION IN TIME AND SPACE**

*Bergmann, H., Zeyringer, T., Graz University of technology, Austria*

In the experimental basin of Pollau in Eastern Austria continuous measurements of precipitation are made since 1979 by recording the time intervals between the tipplings of the 0.1 mm buckets used in the rain gauges. This method allows an investigation of rain events with an extreme high accuracy. The experiences made in 14 years and the different resource used are discussed and results of the investigations (space-time model, connections to runoff) presented. The data are



now collected on a PC forming a unique database. The question how of efficiently build up and use such a database is also addressed.

**Keywords** : precipitation, resolution, database, gauge

**THE NEED FOR A GLOBAL DATABASE OF SUB-HOUR RAINFALL MEASUREMENTS**

*Barrying, L, Dept. of Physical Geography, University of Lund, Sweden*

Autographic recording or tipping-bucket rain gauges have been widely used for many years and are still in operational use. The need for high-resolution measurements has been known to hydrologists for a long time but presently the data collected from these instruments are not compiled into a database having anything like global coverage. However, with the growing concern for effects of possible climatic changes, such a database would offer unique information on variations, and possible changes of the processes that generates precipitation and of hydrologically important precipitation parameters (eg. events of extreme intensity). This paper discusses the steps necessary for compiling a global database of sub-hour rainfall measurements. A first step will be to identify computerized data sets and archive raw data not yet computerized. At this stage, active participation by persons and organizations involved in observational programmes will be crucial.

**Keywords** : rainfall intensity, data management, data compilation

**THE GLOBAL HISTORICAL CLIMATOLOGY NETWORK PRECIPITATION DATA**

*Thomas, C. Peterson, Global Climate Laboratory, National Climate Data Center, Asheville, NC 28801 USA and Russel S. Vose, Carbon Dioxide Information Analysis Center, Oak Ridge Nat. Lab., Oak Ridge, TN 37831 USA*

The Global Historical Climatology network (GHCN) is a long term, monthly, global base line data set of temperature, pressure, and precipitation, GHCN version 1.0, which was released in 1992, includes data from 15 different source data sets with precipitation data from 7,500 stations world wide. Our current work on GHCN includes expanding data coverage by adding more stations and increasing the length of the digitized records for existing stations (e.g. digitizing data from European colonial archives) as well improving data quality and adjusting the data for in homogeneties. In addition to describing GHCN, this paper will focus on the approach used to adjust precipitation data for discontinuities and other in homogeneties. The effects these adjustments have on calculation of regional trend in precipitation will be discussed.

## PRECIPITATION NETWORK AND DEVELOPMENT OF FLOOD FORECASTING ON DANUBE RIVER

*Mozlesikova, K., Slovak Hydrometeorological Institute*

Danube river for water stage in Bratislava belongs to upper part of basin, which dominate area is situated in Germany and Austria. The poster shows of network operation used for forecasting of water level and discharge. The precipitation data are used for operational hydrology. On the sample of different situations (especially connected with flood) are illustrated connected by forecasting methods. Comparison of results employed approach will be done and commented.

**Keywords :** synoptical network, operative hydrology

## GERMAN PARTICIPATION IN THE WMO SOLID PRECIPITATION INTER COMPARISON : FINAL RESULTS

*Gunther, Th., Deutscher Wetterdienst*

The paper presents results of a statistical analysis on the basis of the data sets established within the WMO Solid Precipitation measurement Intercomparison. The following gauges have been included in the national analysis; Hellmann, unshielded - National Standard; Hellmann, shielded; Automatic gauge (volumetric, heated; Treyakov; Double Fence Intercomparison Reference (DFIR)).

The catch ratios- Comparison gauge/DFIR - were calculated. Results show the percentage catch of the Hellmann unshielded gauge (German National Standard) to be between 46% (snow only) and 87% (rain) compared to DFIR. The percentage catch of the Hellmann unshielded gauge in dependence on wind speed differs in the case of snow only between 19% ( $v \geq 5,0 \text{ ms}^{-1}$ ) and 67% ( $v \leq 1,0 \text{ ms}^{-1}$ ).

The seven year data set allowed a detailed investigation of the gauge catch ratio-the relation of gauge catch to the DFIR-independes on different factors (wind speed; air-temperature; depth, duration and intensity of precipitation) and considering separately the various types of precipitation (snow only, mixed precipitation rain). Starting with simple linear regression equations multiple linear and on linear regressions were finally derived. The important factor of influence is mean wind speed which forms the decisive contribution to the correlation coefficient ( $r^2$ ).

**Key words :** winter season precipitation; correction, comparison



**COMPARISON RESULTS OF PRECIPITATION MEASURED BY THE SIMILAR TYPE GAUGES OVER THE SURFACES WITH DIFFERENT ROUGHNESS**

*Golubev, V.S., Simonenko, A. Yu., Stte Hydrological Institute, R•ussia*

Evaluation of systematic and random errors of precipitation measurements at the observation point is discussed. The comparison of simultaneous precipitation measurements by the national gauges with the measurements by the WMO Reference (DFIR) have been made. The evaluation of manual, gauges were measured both volumetrically and by weighing using a digital balance twice a day. Time resolution of the weighted automated gauges were ten minutes and that of the optical sensor fifteen second and for intercomparison the values of precipitation intensity and water volume has been calculated to the intervals corresponding to the results gained with the other instruments. Snowfall intensity were first time recorded in Finland. Reliability of the three types of measurements and preliminary results of the intercomparison are presented.

**ON THE REDUCTION OF RADAR RAIN GAUGE ERRORS CAUSED BY MTI FILTER**

*Shidawar, M. Aichi Inst. of Technology Yamaguchi, T., Matsumoto, Y. Inst. of River and Basin Integrated Communications  
Masukura, K., Public Works Research Inst.*

MTI ((Moving Target Indicator) filter is commonly used for weather radars in Japan to eliminate the ground clutter. Two problems of MI filter are treated in this paper. One is the suppression of the output of MTI filter near the radar site due to the failure of the assumption of the filter algorithm that the successive pulse signals do not have correlation. The dependence of the suppression of wind shear is clarified. The reduction of this error by the use of wind observation is discussed. The other problem is based on the bit size of A/D converter just after the log-amplifier. The increase of bit size is shown to decrease the error.

**Keywords** : weather radar ground clutter

**ACCURACY OF RAINFALL OBSERVATION BY A DUAL LINEAR POLARIZATION RADAR AND A PROJECT FOR ITS OPERATIONAL USE**

*Yoshino, F., Masukura, K., Fukami, K., Sakao, M., Kouchi, Y.  
Public Works research Institute, Ministry of Constriction, Japan*

Radar network system has been widely used to monitor precipitation field immediately in Japan. In order to improve the accuracy, the Public Works Research Institute has conducted a research to develop a dual linear polarization radar, using a experimental one : DND radar. The authors report the rainfall - observation accuracy of the multi-parameter radar on the basis of observational

data by the DND radar since 1988. In addition, a project to apply dual linear polarization radars to operation use in Japan are described.

**Keywords** : precipitation, multiparameter, radar

**PRINCIPAL MODES OF VARIATION OF RAIN RATE PROBABILITY DISTRIBUTIONS**

*Thomas L. Bell and R. Suhasini, NASA/Goðdard space Flight Center, Green belt, Maryland, U.S.A.*

Radar or satellite observation of an area generate sequences of rain-rate maps, from which sequences of distributions (histograms) of rain rate can be extracted. The histograms vary as precipitating systems in the area evolve and decay, attributable to changing amounts of convective and stratiform rain in the area. A method of decomposing the histograms into linear combinations of just a few components distributions has been developed, using principal-component (EOF) analysis as a starting point. Two components that resemble stratiform and convective rain distributions emerge naturally from an analysis of a GATE (tropical-Atlantic) radar data set. The two types of rain have different time scales and diurnal cycles. The method offers a very informative tools for describing variability in a data set composed of sequences of frequency distributions.

**Keywords** : principal components radar

**MEASUREMENTS OF PRECIPITATION INTENSITY BY METEOROLOGICAL RADAR**

*Jarosova, M., Kanak, J., Kotlarikova, D., Slovak Hydrometeorological Institute, Bratislava, Slovak Republic*

An article treats of momentary rainfall intensity measurements by means of radar MRL-5, which is located at Maly Javornik near Bratislava. Rainfall intensity is determined by radar-measured cloud reflectivity, using Marshall-Palmer Z-R relationship in squares 8x8 km and 4x4 km, respectively. The information on rainfall intensity is distributed to users in a code form by means of long-wave transmitter and it serves particularly for the hydrological purposes.

**Keywords** : Marshall-Palmer Z-R relationship, hydrological purposes.

**MANAGEMENT AND ANALYSIS OF PRECIPITATION DATA ON A ROUTINE BASIS**

*Rudolf, B., Global Precipitation Climatology, Centre (GPCC), Deutscher Wetterdienst, Postfach 10 04 65, D-6050 Offenbach/Main, Germany.*

The GPCC has been initiated by the World Meteorological Organization for the purpose, to provide global monthly precipitation analyses on an operational basis. The GPCC is operated by the Deutscher Wetterdienst as a contribution to



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the World Climate Research Programme. Its specific functions comprise the collection of monthly precipitation data (world-wide), checking and error correction, calculation of gridded areal mean precipitation over land on the basis of data gained from conventional measurements, and the merging of these data with precipitation estimates from satellites images and the results of weather prediction models to obtain complete global precipitation maps are gridded data sets.

**Keywords :** Quality control, Global analysis, Global climate change

### PRECIPITATION TIME SERIES IN FINLAND

*Heino, R., Finnish Meteorological institute, Finland*

The construction of precipitation time series in Finland is introduced. There are more than 70 precipitation records with continuous records of 80 years of more. Major inhomogeneity breaks include 2-3 gauge changes, several station relocations and some environmental changes. Their effects are discussed and correction presented for all the long-term precipitation records. The magnitude of the corrections may rise up to 50% at single stations in winter months. Homogeneous precipitation records are studied by using various statistical methods. Regional variations in Finland are discussed as well as differences between the normal periods. The results are also compared with the neighboring countries. Explanations for the observed changes are finally discussed.

**Keywords :** precipitation changes.

### COMPARISON OF TIME SERIES FLUCTUATION FOR MEASURED AND CORRECTED PRECIPITATION TOTALS

*Brazdil, R., Dobrovolny, P., Masaryk University, Brno, Czech Republic Fasko, P., Lapin, M., Slovak Hydrometeorological Institute, Bratislava, slovak Republic*

The data from four stations (Hurbanovao, Bratislava, sliac, Strbske Pleso) representing lowlands, hollows and mountains in Slovakia have been analysed. Time series of monthly and yearly totals in the period 1961-90 have been tested both for the measured and corrected precipitation. Corrections of systematic errors due to wetting, evaporation and wind effect have been carried out according to the methods developed in CSFR. Various statistical methods were used there. A hypothesis about influence of corrections to precipitation variations is the final result.

**Keywords :** corrected precipitation, time series analysis

**ON THE RELIABILITY OF LONG-TERM CLIMATOLOGICAL RECORDS**

*Tihlarik, R., Slovak Technical University, Bratislava, Slovak Republic*

Secular Records of temperature, wind speed and precipitation measurements at six High Tatras (Slovakia) climatological stations were investigated to obtain information about potential inhomogeneity origins. Analysis of data and metadata specified sources of random errors due to human factors, which could be interpreted either as inhomogeneities or trends. Proportions of the climatic trends and the potential random error's disturbance in data series were compared and the degrees of interpretation reliability of time series in climatological research outlined.

**Keywords** : temperature, precipitation, wind speed, random errors, trends

**ESTIMATION OF PAST CHANGES IN PRECIPITATION GAUGE SITE EXPOSURE**

*B. Sevruck, Swiss Federal Institute of Technology, L. Zahlavova, Slovak Technical University*

An indirect method of estimation of the past and present changes of exposure from the station history records using photos, sketches and written reports of gauge sites as found in the archives of national meteorological services is suggested. Four classes of exposure ranging from open to protected gauge sites are used. They are characterised by the average vertical angle of obstacles around the gauge as measured in eight directions of the wind rose. In Switzerland, 398 gauge sites have been classified back to the last century. The average record length was 80 years, spanning 10 to 173 years. The results showed that (i) there is an average one change of gauge site exposure per 27 years, that (ii) the number of changes increases with the observation period length, and (iii) that the increase accelerates for periods longer than 100 years. The most frequent exposure change was one class and more (130 out of 398).

**AUTOMATIC DIGITAL SYSTEM FOR MEASURING LIQUID AND SOLID PRECIPITATION**

*Peters, E., Wilhelm Lambrecht GmbH, Göttingen, Germany*

A modular automatic digital system for measuring liquid and solid precipitation and the results of a long series of measurements will be presented. Special attention will be played to the accuracy to temperature control in order to minimize evaporation losses when melting solid precipitation. The data logger and the software for evaluation of the results will be prescribed.

**Keywords** : Precipitation measurement instruments



**NUMERICAL SIMULATION AND WIND TUNNEL MEASUREMENTS : AERODYNAMIC OF PRECIPITATION GAUGES**

*V. Nespov, Slovak Technical University, Slovakia*

A numerical procedure for estimation of the wind-induced error is tested on an example of the English Mk<sup>2</sup> precipitation gauge. The flow around the gauge is numerically simulated for the free stream velocity of 3 m.s.<sup>-1</sup> and compared with measurements in the wind tunnel. The computed three-dimensional velocity vector field is used for simulation of precipitation particle movement. The wind-induced error is evaluated for different drop diameters and one wind speed. The results indicate that this procedure can be used relatively easily for various gauges and also for different types of precipitation or dust particles.

**THE DIURNAL CYCLE OF PRECIPITATION IN JAPAN AND HUMID TROPICS**

*Oki, T.K. Musiaka, Institute of Industrial Science, University of Tokyo, Japan*

The diurnal cycle of precipitation is discussed both in Japan and humid tropics countries, Malaysia and Thailand. It is very important to know the diurnal cycle of precipitation for the estimation of observational error by non-geostationary satellites. Cluster analysis has been applied for the annual mean diurnal cycle of precipitation in Japan and the stations were classified into mainly two clusters. The geographical distribution of the result show evening peak in mountainous regions and morning peak in coastal regions. The diurnal pattern of mean rainfall intensity is much smaller than the diurnal cycle of rainfall amount. It suggests that the diurnal cycle of the rainfall occurrence dominates the diurnal cycle of rainfall. The diurnal patterns in humid tropic countries have similar characteristics, but the amplitude is around ten times larger than that of in Japan.

**Keywords** : intercomparison of precipitation mean rainfall intensity satellite observation

**SYNTHETIC ANALYSIS OF ROMANIAN REGIONAL PRECIPITATION ANOMALIES VARIABILITY**

*Busuioc, A., Bojariu, R., National Institute of Meteorology and Hydrology, Bucharest, Romania*

The Romanian monthly regional precipitation anomalies are represented as complex numbers. The real component represents the duration of the anomalies while the complex component represents the intensity to the corresponding duration. The resulted series have been analysed by using the spectral analysis and certain nonparametric tests, the analysis achieving the real component, complex component and the magnitude, separately for the positive and negative anomalies. Some periodicities of the droughty intervals (2-2.5 interval periods) have been pointed out as well as the transition moments between prevailing intervals with certain characteristics of the anomalies

**Keywords** : complex series periodicities

### **HYETOGRAM ANALYSIS FOR SAHELIAN MESOSCALE CONVECTIVE SYSTEMS**

*Amani, A<sup>(1)</sup>, Rousselle, J<sup>(1)</sup>, Taupin, J.D.<sup>(2)</sup>, Lebel, T<sup>(2)</sup>*

- (1) Ecole Polytechnique de Montreal
- (2) ORSTOM, Mission au Niger

Spatio-temporal pattern of sahellan mesoscale Convective systems is characterised by analysing hyetograms recorded through the EPSAT-Niger network rain gauge (1990, 1991). The technique of crossing is used to obtain the class and the order of the hyetogram at each gauge for each major rainfall events. To study the influence of time step on the class and the order of the hyetogram, different times steps are considered. We observe that more than ninety presents of hyetogram have the same order and more than eighty presents have the same class. Our study confirm the nature of sahellan Convectives rainfall; fast and intense.

**Keywords** : hyetogram, sahelian, crossing

### **A BIVARIATE STOCHASTIC MODEL FOR DAILY RAINFALL AT SAO PAULO, BRAZIL**

*Sansigolo, C.A., CPTEC/INPE, Brazil*

A bivariate stochastic model is fitted to 54 years daily rainfall data at Sao Paulo City, Brazil. Two-state Markov chains with non-stationary transition probabilities are used to describe the precipitation occurrence process. Gamma distributions with means continuous varying in time describe the rainfall amounts. Finite Fourier series model the periodic seasonal fluctuations of the parameters. All the variance analyses, regressions and tests, based on generalized linear models, were made through the software GLIM. The predicted and actual values for the monthly totals and number of rainy days, used to check the model, presented similar statistical properties.

**Keywords** : stochastic model daily rainfall

### **A RAINFALL MODEL BASED ON BREAKPOINT DATA**

*Sansom, John; National Institute of water and Atmospheric Research, New Zealand*

The time continuum can be divided into time when a rainfall event is taking place and times when one is not. These events can be either of rain or pf showers within which precipitation can either be actually falling or not. Thus there are 5 distinct states; rain event with rain falling -Rw; rain event but no rain falling -Rd; showerer event with shower taking place -Sw; shower event but no shower taking



place-Sd; dry time between events - D. If, for example, a change from  $R_w$  to  $R_d$  does not depend on what happened prior to the  $R_w$  period then the process is Markovian. Further more, it is semi-Markovian as self-transistors are disallowed and they do not take place at fixed intervals. The dwell times in the dry states are controlled by log-normal distribution and in the week states by a random sum of a sample taken from other log-normal distributions. In breakpoint data only the durations of constant rain intensities are known and not the character of the participation thus, apart from knowing that the processes is a wet or dry state, the states are hidden.

**Keywords** : hidden simi-Markov process, intensity Paper.

### **SPATIAL DIFFERENTIATION OF THE MAXIMAL DAILY AND MONTHLY PRECIPITATION IN THE AREA OF CENTRAL POLAND**

*Klysik, K., Fortuniak, K., University of Lodz, Poland*

The data of maximal daily and monthly precipitation from 114 stations in central Poland were analysed. They cover the period 1957-89. The region consists mainly of the lowlands, and there is the elevated area in the southern and south-eastern part. For each station we used log normal distribution Pearson's distribution type III and Gumbel's distribution to climate the maximal daily and monthly precipitation. The standard estimation error and  $\chi^2$  values were used to select the best match. To Compare the results, non-parametric kernel's method was used simultaneously. The maps of the spatial differentiation of maximal precipitation were made using the Gumbel's distribution. The maps of spatial differentiation of maximal daily and monthly precipitation with 10% and 1% probability of occurrence are very similar.

**Keywords** : Gumbel's distribution, parametric and nonparametric methods

### **ANALYSIS OF SEASONAL EXTREME PRECIPITATION IN MOUNTAIN REGIONS**

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Probability distribution of extreme precipitation in mountain regions of Bulgaria is of great practical importance. Winter precipitation here are mainly solid and form snow cover, which is an important water reservoir for vegetative seasons. Probability of flooding and other disasters can be derived from it too. Data from 3 high mountain stations (above 2000 m). situated in different Bulgarian mountains with complete records from more than 50 years are used.

For each station Lognormal distribution is fitted. Quantities of seasonal precipitation are obtained.

**Keywords** : seasonal precipitation extreme distribution

**NORTH - WESTERN PRECIPITATION LONG SERIES: DATA AND ANALYSIS.**

*Anselmo, V., Ferrari, S Istituto of Idraulica Agraria, University of Torino, Italy,  
Mercalli L., ESAP, Torino, Italy*

Six ultra- secular daily precipitation series recorded in North- western Italy were retrieved and checked from original documents. The data set ranges since 1802 through 1992. The analysis pointed out the general stochastic features, scaling properties of the series and the extreme values recurrence time.

**Keywords** : daily precipitation, extremes, rainfall models

**VARIABILITY OF PRECIPITATION IN KRAKOW WITH RELATION TO ATMOSPHERIC CIRCULATION CHANGES.**

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Krakow, ul. Borowego 14 poland*

The paper presents the variability of precipitation in the polish part of the Tatra Mountains during the period of 1896-1992. The greater annual totals occurred from 1960 to 1980, but a relatively dry period has prevailed since 1981 up to now. The heaviest precipitation is usually associated with northern or northeaster cyclonic conditions. In order to investigate the annual variability of the atmospheric circulation conditions in southern. Poland, the German, Austrian and Polish synoptic maps from the period of September, 1873- December 1992 have been analyzed. The annual values show the rapid increase of the intensity of the westerly circulation from 1977 up to now. The periods with the great amounts of precipitation are generally connected with the positive index of cyclonicity during the period 1965-1975.

**Keywords** : precipitation variability circulation

**PERIODICITY OF ANNUAL PRECIPITATION IN DIFFERENT CLIMATE REGIONS OF CROATIA**

*M.Gajic -Capka(Meteorological and Hydrological) Services, Croatia*

**PRECIPITATION FLUCATUATIONS IN AUSTRIA SINCE 1845**

*Auer, Ingeborg, Central Institute for Meteorology and Geodynamics.*

Using the results of 62 homogenized data sets the temporal variations of precipitation over Austria are presented. The calculation of 11 grid points avoids biases by no steady station distribution for the computation of a mean Austrian precipitation time series starting in survey about epochs with increasing or



decreasing precipitation, in many cases, however there are shows subregions for which the Austrian precipitation curve shows to representation over longer periods. This can be quantified using maps of precipitation of deviations for each decade since 1981. Neither the annual nor the seasonal precipitation totals have shown an increases of variances or variation coefficients within the last years, as higher amounts of precipitation are connected to higher standard deviations and variances in principle, whereas variation coefficients are decreasing with increasing precipitation.

**Keywords :** homogeneity of time series, fluctuations of precipitation and variances, validity of mean precipitation time series

#### **LONG TERM VARIABILITY OF PRECIPITATION RECORDED IN EUROPE**

*Bazac, G., Cotariu, R., National Institute of Meteorology and Hydrology, Bucharest, Romania*

The study is based on data concerning monthly and yearly precipitation recorded at 65 meteorological stations in Europe along an interval of 150 years. Gamma function parameters were calculated for each station, then the occurrence probabilities were estimated. The probabilities fields were interpolated and new probabilities values were obtained within a 5 step grid between 30 and 75 northern latitude and 15 western longitude and 40 eastern longitude. Plotting the evolution in time of the probabilities values in the grid points situated on 25 East meridian (which crossed Romania), allows estimation of the phenomenon's evolution.

**Keywords :** Gamma function, probability

#### **THE AIR TEMPERATURE AND PRECIPITATION TRENDS IN ALBANIA OVER THE PERIODS 1888-1990 AND 1931 -1990**

*Borici, M., Demiraj, E, Hydrometeorological institute, Tirana, Albania*

The average air temperature trend (1890-1990) and precipitation trend (1930-1990) are discussed. Air temperature values of a station in north west of Albania (Shkoder), existing from 1888 are considered. For the air temperature and precipitation during 1930-90 the meteorological data of 4 stations are used. These stations are respectively in the north west, west, middle and south west part of the country, Through the diagrams and tables the time linear change of above mentioned meteorological parameters is represented. Meanwhile the hottest and wettest periods are represented, pointing out the climatic change during this long observation period.

#### **TREND AND VARIABILITY OF RAINFALL, OVER BULGARIA**

*Koleva Ek. Institute of Meteorology & Hydrology, Sofia , Bulgaria*

The aim of the present study was to reveal long-term change in rainfall in Bulgaria and to determine their tendency and rate. Variability of the the annual and seasonal precipitation were analysed. Trend analysis was carried using visual estimation of smoothed time curve and fitted 8-order polynomial. To identify the trend character of the climatic data, the Spearman and Mann-Kendall rank statistics were used. The general trend in annual precipitation was negative.

**Keywords :** precipitation variability trend

### **AN APPROACH TO THE ASSESSMENT OF CLIMATIC TRENDS**

*Nemesova, I., Huth, R., Klimperova, N., Institute of Atmospheric Physics, AS CR*

The synoptic- climatological approach is used to study the winter precipitation series of the Milesovka observatory. A computer- assisted weather categorization is based on the principal component analysis and a clustering technique. Relationships between weather types determined on the basis of selected meteorological variables recorded daily, and the precipitation amount are investigated. Both, frequencies of occurrences of the weather categories chosen and within-category changes in cumulative rainfall amounts are examined in a long- time span. Trends in the frequencies of the categories and within - category trends in precipitation amounts are assessed.

**Keywords :** Precipitation, weather categorization, climatic trend

### **LONG-TERM RAINFALL VARIATIONS DURING GROWING SEASON OF SOME CROPS IN BULGARIA**

*Alexandrov, V.A., National Institute of Meteorology and Hydrology, Sofia 1184, Bulgaria*

Long - term rainfall variations during potential and real growing seasons of some crops are discussed. The spatial distribution and basic trends of rainfall throughout the investigated seasons are presented. Although these trends are positive, the obtained mean values show the necessity of irrigation. A linear relationship between rainfall amount in the course of real and vegetative ( sowing-silking ) periods of maize was found. It can be used to estimate rainfall during period of maize reproduction. A simple method for generating daily rainfall data was developed for climatic conditions in Bulgaria. The matrix analysis was used to simulate rainfall occurrence. This model provides numerical experiments.

**Keywords :** statistic, simulation, model



**CLIMATE CHANGES AND PRECIPITATION- EXAMPLE FROM THREE LONG MONTHLY PRECIPITATION SERIES MEASURES CROATIA**

*Bonacci, O., Denic, V., Civil Engineering Faculty, Split University, Croatia*

The paper attempts, by using statistical analyses of the monthly rainfall series for Osijek (I 1882-XII 1990), Vrana (I 1926-XII 1991) and split (I 1926-XII 1927), to find out whether the climatological changes influenced the relatively long series of precipitation. It can be concluded that the certain changes have occurred, such as dry periods during the last decade and certain re-distribution of precipitation during the year which affected more intensive drought periods. However it can be generally stated that the noted changes belong to the expected random variations, which have been observed in the past periods, so that it is impossible to conclude, according to the processed data, whether there have been any general changes in the precipitation and hence in the climate of the wider region of Croatia.

**Keywords** : climatological changes, analysis, precipitation, series

**ESTIMATION OF LOCAL HYDROLOGICAL PARAMETERS REFLECTING CLIMATE CHANGE FOR LAKE BALATON**

*Weidinger, T., Matyasovszky, I., Eotvos L. University, Budapest, Hungary Bogardi I., University of Nebraska, USA*

Monthly precipitation, evaporation and natural change of water balance for Lake Balaton were analysed for the summer and winter periods. Statistical structure of these parameters had been determined, furthermore parameters of monthly distribution and their relation to typical monthly classes made by Hess Brezowsky macrosynoptic situations. Periods of investigation was 1921 -1990.

Climate model T21 developed by Max Planck Institute in Hamburg was used to determine the new frequency distribution of typical monthly classes by making a use of Hess Brezowsky catalogues for 10 year for various cases of CO<sub>2</sub> concentration (1CO<sub>2</sub>, 2CO<sub>2</sub>).

Base of the former results expected direction of change of hydrological parameters were estimated. Results gained by using 1 CO<sub>2</sub> and 2CO<sub>2</sub> climate models have shown, that there exists a higher difference for the winter period between the typical monthly frequencies.

The research was supported by the "Fund for Hungarian education and research".

## **DISPLACEMENTS OF SEMI-PERMANENT CENTRES OF ACTION AND VARIATIONS OF REGIONAL CLIMATE**

*Martazinova, V.F., Ukrainian Hydrometeorological Institute, Kiev*

The semi-permanent centres of action (CA) form planetary high-level frontal zone (PHLFZ). The departures of PHLFZ from climatic position causes the anomalous weather conditions. The sharp displacements PHLFZ to the east is noted in the recent decade. The displacement PHLFZ result in the corresponding displacement of North Atlantic crest on 20° to the east caused to the deficit of precipitation in Eastern Europe and strong snowfalls in Volga-Ural region. The analysis of historical data on medium level shows that such sharp displacement of CA from climatic position in revealed only in the latest decade. It is confirmed by climate change in the majority of Northern hemisphere regions. The eastern displacement of CA causes strong intensification of meridional atmospheric processes. The transport of warm air to the North result in diminishing of the temperature gradient poleoquator and the winter contrast "ocean-land".

**Keywords** : anomalous weather pattern

## **THE TIME SERIES CHANGE AND EXTRATERRESTRIAL INFLUENCES**

*Bruzek, V. Czech Hydrometeorological Institute, Czech Republic*

There are many expressive trend in the meteorological time series. Precipitation in Bohemia (1876-1992) shown are increasing trend till 1941. This trend was changed into decreasing one. Both two principal trends are disturbed by quasirhythms. Only a few strict selected synoptical pressure patterns form the long-term trend of our studied series for every month. The correlative and spectral analyses among solar and geomagnetic activities and meteorological elements show very good circulation parameters. Long-term trends are formed by solar activity.

**Keywords** : time-series, solar activity

## **DYNAMIC CLIMATOLOGY AND PRECIPITATION IN MOUNTAINOUS AREAS**

Precipitation climatology in mountaionus areas is generally considered to be very static and annual isohyetal maps are often used for many year to represent precipitation distribution. Analyses of precipitation records are presented demonstrating that spatial and temporal distributions of precipitation in mountaionus areas are highly variable. The need for these dynamic factors to be considered when preparing of updating isohyetal maps is discussed. The need to prepare seasonal precipitation maps, especially in areas of significant winter snowfall, is presented. In many continental areas the influences of topography on precipitation varies greatly from summer to winter. In such areas maps of precipitation should be



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developed for seasonal periods and combined to obtain accurate representation of the annual precipitation. Measurement of precipitation, especially snowfall, in mountainous areas is subject to large error and records should be checked for consistency and adjusted where indicated prior to their use in developing isohyetal maps.

**Keywords** : precipitation, topography, isohyetal, climatology mapping

### INTER-REGIONAL VARIATIONS OF RECENT CLIMATE FLUCTUATION IN ISRAEL

*David Sharon, Hebrew University of Jerusalem, Israel*

### ALTITUDINAL DEPENDENCE OF PRECIPITATION IN THE EASTERN SWISS ALPS

*Blumer, F.P. & H. Lang, Swiss Federal Institute of Technology, Hydrology Section*

On the northern slope of Gamerrugg (Eastern Swiss Alps) precipitation was measured at 5 observation sites in different altitude for a three year period. An increase of precipitation with increasing altitude could not be found. Supposing wind influenced measurement losses in regions with high altitude, a DFIR (double fence international reference) was installed to protect the measurement site on the top of Gamserrugg (2074 m.a.s.l.) Solid precipitation was increasing about 30% at this site, but an altitudinal increase of the annual precipitation amount was not obvious. The total orography and the distance of the observation site of Santis, with 2500 m.a.s.l. the highest peak in the region, seems to be more important.

**Keywords** : altitudinal dependence, wind fence, correction

### DISTINCT DAILY RAINFALL PATTERNS AND WEATHER TYPES IN SOUTHERN SWEDEN

*Linderson<sup>1</sup>, M.L. Oisson<sup>2</sup>, J & Barring<sup>1</sup>, L.*

*<sup>1</sup>Dept. of Physical Geography and <sup>2</sup>Dept. of Water Resources Engineering, Lund University Sweden*

We investigate the possibility to use spatial patterns of daily rainfall observations to classify individual days into distinct groups. For this purpose we use daily data covering 1861-90 from a network of more than 200 rain gauges in Scania, Southern Sweden. Initial analyses showed that the coefficient of variation and the proportion dry stations could be used to distinguish between typical frontal and typical convective situations. A closer examination shows that the discriminating power is related to the form of the frequency function of the daily values. However, many days have a rainfall patterns that cannot be identified as convective or frontal. More elaborated methods, which takes the spatial pattern into account and allow a classification into several groups are investigated. Also,

association between the distinct groups of rainfall patterns and independently evaluated weather types are discussed.

**Keywords** : rainfall modes dense network classification

### **ANNUAL AND SEASONAL PRECIPITATION OF LAKE MAGGIORE DRAINAGE BASIN**

*Carollo, A., Libera V., Rolla, A., Istituto Italiano di Idrobiologia, Italy*

The hydrographic basin of lake Maggiore has a surface area of 6600 km<sup>2</sup> and maximum, average and minimum attitudes of 4633, 1270, 193 m respectively. A map on the scale 1 : 100,000 has been drawn for the annual precipitation on the territory, reporting the average, maximum and minimum values and their usual variation. Lateral small scale diagrams and maps represent the ratios of the first 5 critical cases to the 50 years averages, the frequencies of rainy days, etc. The same elements have been represented on the seasonal maps.

**Keywords** : precipitation

### **SPATIAL DISTRIBUTION OF RAINFALL WITHIN A HAIL SUPPRESSION EXPERIMENT (STUTT GART AREA)**

*Mueller W., Institute 320, University Hohenheim, FRG*

Objective of the study was it to compare daily precipitation amounts and relative frequencies of small nearly equal-sized and adjacent areas around Stuttgart for 4 aerological stratified groups of days, during May - October 1992:

- (1) days with risk of strong convection and thunderstorm - but without AgJ - seeding.
- (2) days with risk of strong convection and thunderstorm.
- (3) rest of days (=all days without (1) and (2)).
- (4) days without (2) (unseeded days).

Criterion for the risk of convection and thunderstorm was a special conceived aerological index.

**Methods used** : the daily data were averaged for each of the 5 areas and compared concerning differences.

**Conclusions** : frequencies and amounts of precipitation are different without significant deviations.

**Keywords** : Spatial rain variability, influence on rain amount and relative frequency.



**ANALYTIC VARIANCE SPECTRUM FOR EMPIRICAL ORTHOGONAL FUNCTIONS**

*Cahalan, R.F., Goddard Space Flight Center, USA*

Empirical orthogonal functions (EOFs) exhibit three characteristic types of sampling error: 1. structure due to the nature of the spatial domain of the data rather than the nature of the climate ("domain error"), 2 structure due to contamination by other EOFs having similar variance ("mixing error") and 3. structure due to the accumulation of uncorrelated variations at a large number of points ("measurement error"). The EOF variance spectra of monthly mean precipitation over the US in January and July are given here, and compared with a known analytic form for the variance spectrum of pure measurement error, as a function of the number of months and the number of grid points. As the number of months increases, more model become distinguishable from the error. Fewer modes can be distinguished in July than in January, presumably due to increased incidence of convective rainfall.

**Keywords :** principal component, rain gauge

**DROUGHT 1992 IN POLAND**

*Eizbieta Cebulak Institute of Meteorology and Water Management 30-215 Krakow, ul. Borowego 14 Poland.*

This paper contains the analysis of the atmospheric drought in Poland. The meteorological aspects caused the drought were considered and their spatial distribution and intensity were determined. There was observed permanent deficit of precipitation in the whole land in the period from April to August. Shortage of precipitation was the longest one in the north western part of Poland and was lasting even to 50 days. Precipitation totals for such long period of 6 months, less than 75% normal on the majority part of the Poland as well as totals even less than 50% normal in the western regions were recorded. The intensity and range of drought such as 1992 was not recorded since 1921.

**Keywords :** precipitation, drought

**MULTIDIMENSIONAL DESCRIPTION OF THE FIELDS OF METEOROLOGICAL ELEMENTS FOR MATHEMATICAL MODELLING OF NATURAL PROCESSES**

*Konovalov, V.G., Central Asian Research Hydrometeorological Institute*

Description of fields of meteorological elements in coordinates : -latitude, longitude, z-elevation above sea level and t-time is used as a basis for new solution of spatial and temporal extrapolation problem of mean monthly and 10 days air temperature =  $(Z, \lambda, \phi, t)$  as well as monthly and 10 days sums of precipitation  $q = q(Z, \lambda, \phi, t)$  in the mountains of central Asia. Data of meteorological

network observations on the territory of the four Central Asian States of CIS as well as Afghanistan, Pakistan, India and China were used for the fields modelling. The method is used in regional models of hydrological and glaciological processes and for runoff prediction.

**Keywords :** 4-D meteorological fields in Asia

### **MICROVARIABILITY OF RAINFALL FIELDS UNDER DRY AND HUMID TROPIC CLIMATES**

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Paris.*

*Jeune equipe DRED, Laboratoire de biogeochimie isotopique, Universite P & M Curie, Paris.*

Space rainfall fields variability is of major concern for some years in rainfall studies. We have conducted microscale fields experiments under dry (Burkina Faso) and humid (French Guiana) tropic climates. According to the experiment from 20 to 30 raingauges have been set within a hectare surface or along a 100 meters line. Rainfall depth and isotopic content ( $^{18}\text{O}$ ) have been measured for some rainfall events. The spatial structure of fields under study have been characterized by geostatistical methods (variogram). At this decametric scale, rainfall depth fields appear continuous for open land, both in Burkina and in Guiana, but entirely random in forested land (Guiana), due to influence of the canopy. Whatever the case, no spatial structure of the isotopical concentration can be shown at this scale.

**Keywords :** rainfall-field, isotopes, geostatistics

### **SPACE STRUCTURE OF PRECIPITATION ON THE TERRITORY OF UKRAINE**

*Maksimov, V.S., Babichenko, V.K., Ukrainian Hydrometeorological Institute*

The distribution of precipitation on the Ukrainian territory is significantly inhomogeneous and spotty which stems from its landscape and synoptical peculiarities. In general the tendency of precipitation decrease from northwest and west to south and southeast can be observed. The maps of precipitation fields and their analysis are presented in this report. The cause-result relations with respect to precipitation field formation are also discussed. For the study of the spatial structure of precipitation fields the main component method was applied. So homogeneous fields with respect to annual precipitation have been outlined. The integral precipitation probability curves on the base of Veibull distribution have been also used. The analysis based on various climatological and statistical approaches with the main precipitation parameters taken into account made it



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possible to outline some regions with homogeneous precipitation fields on the Ukrainian territory - the Ukrainian Carpathians, W. and NW regions, NE and central, E and S. The precipitation regime varies from the first region to the last, from extremely wet to droughty.

**Keywords** : distribution, formation, precipitation field

### **PRECIPITATION VARIABILITY AND CHANGES IN HUNGARY: PAST AND FUTURE**

*Bartholy, J., Matyasovszky I., Department of Meteorology of Eotvos Lorand University, Budapest, Hungary*

We examined the statistics of precipitation averages and extremes on the basis of two observation - station net of Hungary (162 and 905 stations) and one for the region of the lake Balaton (41 stations). We tried to classify the precipitation fields of the territory using various cluster and principal component analysis techniques. Our next task was to reveal the influence in the circulation patterns on the precipitation amount. We used for this work the 1951-90, 1901-90 time series of the above mentioned nets and several macro-circular typesystem. We analysed the frequency changes of those data series in the last century and tried to give tendency forecast in case of CO<sub>2</sub> doubling (data base: T21 GCM output, Max Planck Institute, Hanburg).

**Keywords** : precipitation distributions, cluster analysis, extreme values, tendency, forecasts

### **RAINFALL FIELD ANALYSIS AND ASSESSMENT OF FLOODS HAZARD AT THE REGIONAL SCALE**

*Lanza L., La Barbera, P. & Siccardi, F.  
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The modelling and forecasting of the space and time distribution of precipitation is a major issue among hydrologists since has been recognized that runoff processes eventually leading to disastrous flooding are strongly influenced by the wide variability of rainfall rates within the hydrological basin. The distributed approach to flash flood forecasting has been recently addressed in the framework of regional warning systems oriented to the mitigation of hydrological hazard. In the present paper a statistical analysis of rainfall data is performed on the basis of the generation of three dimensional random fields with specified correlation functions in space and time. Regional curves of hydrogeological risk are derived and a method is proposed for the issuing of flash flood warnings at the regional scale.

**Keywords** : flash floods forecasting warnings

## **LARGE SCALE PRECIPITATION PATTERNS**

*Grietje Miller-Popkes and Rainer Roth*

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Numerical weather prediction models are able to simulate atmospheric process quite well these days. Looking at forecasts of twelve-hour precipitation amounts one frequently observes band like patterns in areas not influenced by orography. In most cases these structures occur at east sides of upper troughs, the tracks of low pressure systems. The fraction of precipitation connected with such structures is determined and relations between the parameters of the precipitation patterns and other atmospheric variables are deduced. The investigations are based on data predicted by the Europamodell of the Deutscher Wetterdienst. One aim of the method developed is to derive precipitation distribution of banded structures from simulations at a lower resolution than NWP models, eg. climate models. Furthermore, attempt are made to evaluate statistical properties of large scale rainfall patterns.

**Keywords** : Frontal rainfall, numerical precipitation forecast

## **INFLUENCE OF CIRCULATORY CONDITIONS ON THE PRECIPITATION IN POLAND**

*Wibig, J., University of Lodz, Poland*

Circulatory conditions were described using mean geopotential heights of 500 hPa level in 80 grid points over the area from 40 W to 50 E (with the step of 10 degree) and from 35 to 70 n (with the step of 5 degree) for the period 1951-90. Monthly totals of precipitation was averaged on the area of Poland on the basis of 39 individual stations. Then the correlation fields between heights were calculated for each month and the circulatory patterns permitting positive (and negative) precipitation anomalies were discussed. On this basis extremely dry summer 1992 was analysed.

**Keywords** : 500 hPa level, correlation, anomalies

## **EXPERIMENTATIONS ON THE EVAPORTRANSPIRATION MEASUREMENT AT THE GROUND SURFACE, UNDER ROMANIA'S CONDITIONS**

*Tibacu, L, National Institute of Meteorology and Hydrology, Bucharest, Romania*

Research of evaporation and evapotranspiration at the ground surface, have started in Romania at two stations by experiments with various types of instruments. The paper includes brief description of the equipment used and it presents the observation assembly as well as the analysis of the data obtained. The Data base allowed the determination of the relationships between the



evaporation and the evapotranspiration at the ground surface, measured with various types of instruments and various types of vegetation.

#### **AUTOMATED RECORDING AND PROCESSING OF LYSIMETER DATA**

*C. Deyhle, Fed. Inst. of Hydrology, Koblenz, Germany*

The water balance in various soils have been the subject of study in eight soils bodies, four of them weighable, at the lysimeter station Koblenz-Nieder werth since 1986. 38 parameters are recorded in high time resolution and stored on PC. Verification and processing of the raw data are performed by PC programs, developed for this purpose. All steps of these plausibility checks and conversions are logged by the PC

A comparison of evapotranspiration data from the different soil bodies reveals characteristic differences, which are most distinct in periods of low precipitation. Evapotranspiration values computed on the basis of meteorological observations by several methods are contrasted with those measurement at the lysimeter and at Class A pan.

**Keywords :** plausibility check, evaporation measurements.

#### **ANALYSIS OF MONTHLY EVAPOTRANSPIRATION AT THE EXPERIMENTAL INFILTRMETER STATION**

*Patricevic, V., University of Osijek, Croatia*

Through a zone of aeration there is an intensive vertical change of water between the groundwater table and the atmosphere. Precipitation, infiltration and evapotranspiration are three basic processes in this change. Evapotranspiration is special important part of them. Their estimations are possible with measures on experimental station "Varkom" which was founded in the year 1988 in Varazdin near river Drava. Results of measurements of hydrological and meteorological values are performed with the corresponding curves and compared with the Thornthwait's empirical method.

**Keywords :** Precipitation, infiltration measuring of vertical water change

#### **PARAMETERISATION OF EVAPORATION OVER ALPINE TUNDRA**

*Bernath, A., Basler & Hofmann, Zurich, Switzerland*

The measurement of the evaporation over complex terrain e.g. alpine tundra using for instance energy-balance or profile method is difficult, expensive and needs a lot of complex equipment. Often direct evaporation measurements for the determination of the water balance of a catchment are not or only at a few places

available. Frequently basic data like temperature, humidity and global radiation is measured in higher spatial density. Several parameterisation methods are compared with the evaporation measurements made during the ALPEX/RHCNEX project in the central Swiss Alps using energy balance and profile method. The different calculating methods, show distinct agreement with the measurements. Nevertheless an estimation of the daily means of evaporation seems possible.

**Keywords** : estimation, comparison, daily means

### **COMPARISON OF VARIOUS METHODS FOR ESTIMATING POOLS EVAPORATION IN THE SAHEL**

*Desconnets, J.C., Taupin, J.D., ORSTOM, Mission au Niger*

In the Sahel the drainage networks are strongly degraded. During the rainy season, the surface runoff is collected into a number of pools, which size varies from one to one hundred hectares. Within HAPEX-SAHEL, a study was undertaken to understand and quantify the direct return of water to the atmosphere through pool evaporation, mainly during the first part of the dry season. Two pools, representative of the two major types of environment, were closely monitored using level recording gauges, evaporimeters and isotope analysis ( $^2\text{H}$  and  $^{18}\text{O}$ ). This allowed to characterise the infiltration processes for each types of pool, and to quantify the infiltrated and evaporated volumes. The isotope method appears to be very well suited to this kind of study.

**Keyword** : Sahel, pools, isotopes

### **METHODOLOGY TO COMPUTE EVAPORATION FORM WATER SURFACE BASED ON LAND-GGI-3000 PAN DATA**

*Vuglinsky, V.S., State Hydrological Institute, Russia*

Methodology has been developed to translate data from land GGI-3000 pan to the floating pan readings (of the same design). An equation is used to check difference in hydrometeorological conditions between land and lake, the terms of this equation are; saturated water vapour pressure and absolute air humidity above the land pan. Subsequent translation of the floating pan data to the lake is made by correction coefficient. This method provides to determine monthly evaporation from lakes with the error of  $\pm 20\%$ .

**Keywords** : water surface, evaporation, computation method, land GGI-3000 pan



**INTRODUCING STABILITY CONDITIONS IN POTENTIAL EVAPORATION MODELS**

*Temu, H.Y., Meteorology Tanzania*

Development and improvements on semiphysical, evaporation/evapotranspiration models, since Dalton's 1802 formulation, seems to have a definite trend. There is a considerable controversy over the equality of the eddy diffusivities. The relationship has been found to depend upon atmospheric stabilities.

It is found that, by using the first order discrete turbulent flow equations of momentum, latent and sensible heat fluxes the neutral conditions based semi-physical models, can be reconstructed to include stability conditions. In this respect Monin and Obukhov similarity scheme, and Bussinger's stability functions have been used to argue the use of Richardson number explicitly.

**Keywords :** models, improvement, turbulence

**AN EXPERIMENT FOR FORECAST OF MONTHLY AMOUNT OF EVAPORATION OF LAKE BALATON**

*Rakoczi, F. Department of Meteorology of Eotvos Lorand University, Budapest Pesti, G. Civil Engineering department, University of Nebraska, Lincoln, U.S.A.*

On the basis of the results of information-theory it may be well assumed that there exist an internal relationship between the data of times series of monthly amount of evaporation. We demonstrate that the time sequence of data of evaporation are not independent from each other.

According to two-dimensional distribution tables it became possible to calculate the information contents :

$$I(X, Y) = H(X) + H(Y) - H(X, Y)$$

Where  $H(X)$  and  $H(Y)$  are the statistical entropies of events  $X$  and  $Y$ , and  $H(X, Y)$  is the same for event  $(X, Y)$ .

Having a data set during 1921-1990 this internal correlation can be used for the forecast of monthly amount of evaporation. In the procedure we forecast a distribution function.

**VARIATIONS OF POTENTIAL EVAPORATION IN ALPINE COUNTRY OF AUSTRIA**

*Gattermayr, W., Nobilis, F. Hydrographischer Dienst in Osterreich*

"The "Hydrographische Dienst in Osterreich" started to measure potential evaporation in 1981. Daily sums of PE (GGI 3000 pans) are available (in general

May to October). The 9 observation stations of the Hydrographical Service are situated between 665m (St. Johann) and 2245 m (Patscherkofel). The measurement itself and the method to complete missing values by parameterization using simple meteorological variables is explained. The statistical parameters in their time dependence and the variability are discussed. The results for the period 1981-1990 will be used as reference values.

Proposals for the improvement of the observation network will be given.

**Keywords** : potential evaporation

### **EVAPORATION AT THE WATER SURFACE ON ROMANIA'S TERRITORY**

*Tibacu, L., National Institute of Meteorology and Hydrology, Bucharest, Romania*

The paper is based on the data of evaporation at the water surface, gathered at evapometric stations on the Romanian territory. Relationships have been established between the evaporation and the main hydrometeorological elements. Beside these, the relationship between evaporation and saturation deficit corresponding to the water temperature  $E=f(d)$  appeared a base for the regionalization. The relationship between the monthly, seasonal and annual evaporation and the altitude have also been established. The maps with annual isolines and the characteristic months have been made for the Romanian territory.

### **STATISTIC CHARACTERISTICS OF WATER EVAPORATION DATA FIELD AND THEIR APPLICATION TO THE PROBLEM OF THE NATIONAL NETWORK SET UP**

*Golubev, V.S., Kokoreva, K.M., State Hydrological Institute, Russia*

Study results of statistics characteristics of water evaporation field based on the network observations at the former USSR territory are set forth. Random and optimal interpolation errors, of monthly evaporation values and plots sufficient density are estimated using the spatial autocorrelation function. The stations real density in different regions and the degree of plots representivity are estimated. The influence of particularities of pan GGI-3000 construction and placing on the evaporation data errors is discussed. The results of simultaneous tests of the network pan and the heat-insulated evaporimeter model in different climatological zones are given. The requirements to the instrument modernization are settled.

**Keywords** : water, evaporimeters, stations, placing



**ESTIMATING POTENTIAL EVAPOTRANSPIRATION AND PRECIPITATION DEFICIT**

*Elomaa, E., Finnish Meteorological Institute, Finland*

Potential evapotranspiration and precipitation deficit is routinely monitored in farm weather service using two types of calculations. From the observations of 30 weather observation stations  $E_p$  is calculated using the Penman-Monteith method where the total resistance of water transfer varies during the growing period and the calculation of the global radiation is based on the cloud cover observations of the stations concerned. At meteorological observatory of Jokioinen a special weather message for farm weather service is sent to FMI once a day including observations of evaporation from Class A-pan. These observations are converted to  $E_p$ -values using an empirical formula derived by Vakkilainen. Long-term statistics have, however, been calculated using a method derived by Ivanov and adjusted by author. The results of the three methods of calculating  $E_p$  in the rather dry summer in Southern Finland are presented.

**FREE WATER EVAPORATION FROM GGI-3000 PANS IN SLOVAKIA**

*Lapin, M., Slovak Hydrometeorological Institute, Bratislava, Slovak Republic*

The results of 20 years measurement at 5 stations in Slovakia are presented. Monthly and pentad means of air and water surface temperature besides free water evaporation totals have been elaborated. Data from each station are tested by methods of the measured and the calculated evaporation comparison. The results show the great importance of the station representativeness and observers' reliability. The correlation coefficients between the measured and calculated pentad evaporation totals exceed 0,9 at the best stations.

**Keywords** : evaporation, free water, estimation

**EVAPOTRANSPIRATION OF AGRICULTURAL CANOPIES AND SOIL WATER BALANCE**

*Novak, V., Institute of Hydrology and Hydraulics, SAS 826 51 Bratislava Trnavska 32*

Evapotranspiration of three agricultural canopies (wheat, spring barley, maize) and its structure was calculated for identical soil and meteorological conditions. It was shown that evapotranspiration and its structure was nearly identical for all the tree canopies under condition of green, dense and fully weathered canopies. Transpiration totals of winter wheat and maize for identical conditions were approximately the same. Evapotranspiration total of spring barley is at about one third lower than for maize or winter wheat. Those difference depend more on length and position of growth period, than on plant properties.

**Keywords** : soil water balance, evaporation

## **INFLUENCE OF PLANT CANOPIES ON EVAPORTRANSPIRATION WITH LOCAL ADVECTION**

*Hurtalova, T., Geophysical Institute of SAS, Bratislava, Slovakia*

Contribution presents the modelling of the influence of various plant canopies on evapotranspiration with local advection. The advection effects were studied at the specific air humidity changes abruptly. There were studied surfaces of the different roughness at the weak, gentle and strong air flow. The empirical relation between the canopy resistance and evapotranspiration were analysed in case of different soil moisture values and at various atmospheric characteristics. Based on Sutton's approach, there was mathematically simulated the one-dimensional distribution of the horizontal advection of the dry air and at various canopy resistance.

**Keywords** : canopy resistance soil moisture

## **MODELLING OF EVAPORATION OVER THE GROWING SEASON**

*Heikinheimo, M., Tourula, T., Vanalainen, A., Finnish Meteorological Institute, Finland*

For routine, long term estimations of evaporation, seasonal changes in vegetation cover make it necessary to calculate evaporation from two compartments; bare soil and the vegetation cover. The sum of these evaporation fluxes at any instantaneous time is influenced by the crop leaf area as well as the phenological stage of the crop. The well known combination type formalism for evaporation flux was tested against field measurements made during three summers at a flat, cultivated site in southern Finland. The model used input data measured at two meter height above the soil surface. Actual evapotranspiration was measured with a Bowen ratio system run continuously for extensive periods during the growing season. Large within season and between season variations in the surface resistance to vapour transfer were in most cases correctly predicted by the model thus giving confidence for routine follow-up the hydrological status of the cultivated field. Applications into regional evaporation assessment are discussed.

**Keywords** : evapotranspiration, agriculture, Bowen ratio method

## **INTERCOMPARISON OF EVAPOTRANSPIRATION ESTIMATES**

*Sir, M. - Tesar, M.\**

*Gambco Ltd., Litvinovice 47, Ceske Budejovice\* Institute of Hydrodynamics, Novy, Dvur 31.384, 72 Zdikov.*

Three methods of computing evapotranspiration (ET) from a vegetative cover in the course of vegetation season (Penman, radiation and pan evaporation) have been studied and compared. Penman's method is probably the most comprehensive



approach to estimate ET and takes into account almost all of the factors which are known to influence ET. The original method used in assessing the ET was developed. ET was numerically expressed as the need of water for cooling the vegetation cover by the energy balance. The paper also brings the results of evaporation measurements from open water-level by means of evaporimeter.

**Keywords :** evapotranspiration cooling of the plants, evaporimeter.

**RELATIONS BETWEEN THE SOIL MOISTURE AND EVAPOTRANSPIRATION FOR VARIOUS CROPS**

*Matejka, F. - Huzulak, J., Geophysical Institute of SAS, Bratislava, Slovakia, Research Inst. of Irrigation, Bratislava, Slovakia*

A mathematical model of the water regime of plant canopies was developed and verified. By means of this model the relations between the soil moisture and evapotranspiration were analysed for various crops and different weather conditions. It was found that the decreasing of the evapotranspiration from closed canopies caused by the drying of the soil depends on the behaviour of stomata and also on the development of the root system. The typical patterns of the relationships between the soil moisture and the evapotranspiration for winter wheat, sugar beet and maize are presented.

**Keywords :** mathematical model, water regime

**THE MODEL GLOBAL-A TOOL FOR ANALYSIS OF WATER REGIME IN SOIL-VEGETATION-ATMOSPHERE SYSTEM**

*Majerčák, J., Institute of Hydrology and Hydraulics, SAS, 826 51 Bratislava, Trnavska 32*

In present paper there is discussed a simulation model of the soil water dynamic as affected by evapotranspiration, soil-water extraction by roots and interception. The simulation model can be applied for layered porous media, composed of five layers with different hydrophysical characteristics. The hysteresis of retention curve and relation between unsaturated hydraulic conductivity and soil-water pressure is considered. The soil moisture profiles calculated and measured in field correspond in acceptable degrees.

**Keywords :** Soil root zone, soil-water dynamics, simulation model

**THE ESTIMATION OF AREAL EVAPOTRANSPIRATION USING CERTAIN LAND SURFACE INFORMATIONS**

*Dobesch, H., Central Institute for Meteorology and geodynamics, Vienna*

To parameterize those 'surface coefficients' which are governing the interactions between atmosphere, plant and soil and which are essential in modelling areal evapotranspiration, informations about the land use of 54 small communities in the test area (approx. 1000 km<sup>2</sup> situated in the east of Austria) were collected from data the Austrian Statistical Central Office are issuing on a 3-year basis. From these data nine surface classes are defined and together with phenological and micrometeorological data necessary resistance for the Penman-Monteith equation are evaluated for each of these classes. Interception losses are calculated by a simple parametrization schemes using effective rainfall and leaf area index. The available soil moisture is updated due to evaporation losses or precipitation gains in the water budget on a daily basis.

**Keywords** : evapotranspiration, water budget, soil moisture

**THE REGIONAL EVAPORATION STUDY : 1. AN ATMOSPHERIC BUDGET MOISTURE APPROACH**

*G.S. Strong, Atmospheric Environment Service, Saskatoon, Saskatchewan, Canada*

Diurnal changes in the atmospheric moisture budget over a 100-km square area of the Canadian Prairies were computed using sequential radiosonde sounding from the 1991 Regional Evaporation Study. The regional evapotranspiration is computed as the residual in the balance of total moisture mass and changes due to moisture advection. These estimates are compared with results using other methods. The suitability of using synoptic soundings at 12-hour intervals to make routine moisture budget computation of evapotranspiration is also evaluated. Better estimates of evapotranspiration using standard synoptic data could lead to improved parametrization schemes for both numerical weather prediction models and GCMs, since such data are readily available.

**Keywords** : evapotranspiration, radiosonde, synoptic

**ESTIMATING ACTUAL EVAPORTRANSPIRATION OVER BELGIUM USING SATELLITE AND SYNOPTIC DATA**

*F. Gellens-Meulenberghs, V. Lacroix, E. Roulin, Hydrology Section, Royal Meteorological Institute, Brussels, Belgium.*

Our study aims to monitor the evapotranspiration over Belgium at daily rate. The proposed method is based on the energy budget equation. The net radiative flux is calculated from Meteosat data. The radiative transfer through the atmosphere is taken into account using the 5S and the Lowtran 7 codes for the visible and



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the infrared channels respectively. Turbulent sensible heat flux is calculated according to the Monin-Obukhov similarity theory. For this purpose, meteorological data measured over synoptic stations network are used, taking Meteosat data topography and land-use information into account. The method has first been applied for selected clear days. Sequences of maps illustrate the daily and annual evolution of the actual evapotranspiration. Moreover, the main features of the landscape may be recognized.

**Keywords** : Meteosat, radiative fluxes, energy balance

### **DETERMINATION OF ACTUAL EVAPORATION IN ARID CLIMATES**

*Sorman, A.U., Abdulrazzak, M.J., KAAU, Dept. of Hydrology, Jeddah*

Knowledge about the infiltration and evaporation processes in wadi channels are lacking in arid regions. This research is conducted to determine the actual evaporation from bare soils in wadi channels in the southeastern region of the Kingdom of Saudi Arabia.

The estimation of soil evaporation is highly dependent on the availability of moisture in the upper layers of alluvial wads at which areal rainfall, flood hydrograph and soil properties do play significant role.

The study is conducted by estimating actual evaporation using soil moisture data, precipitation and runoff depths in one of the representative basins. The results are compared with the potential rates. The actual rates are found to be 1.5 mm/day right after rainy day and decreases to 0.42mm/day. The minimum rate is found around 0.1~0.2 mm/day during dry season. The potential rates are measured to be 9 mm/day in June and July, then decreased to 4 mm/day in December.

**Keywords** : actual evaporation, arid climate

### **ALTERNATE USES OF CLASS A PAN EVAPORATION DATA**

*Bussieres, N., Canadian Climate Center, Canada*

Ground truth is necessary to calibrate satellite-based estimates of a given field, like net radiation. Canada had 23 active net radiation measurement sites in 1988 and 124 active evaporation pan sites. Net radiation influences strongly the evaporation pan values. The author investigates the feasibility of using the pans to augment the number of net radiation ground truthing points.

**VERTICAL CHANGES OF EVAPORATION IN THE WESTERN TATRAS MOUNTAINS**

*Miklanek, P., Institute of Hydrology, SAS Bratislava, Slovakia*

Evaporation is one of main elements of the water balance. It highly depends on other elements of the environment and it varies in wide range in mountainous conditions depending on the elevation of the sites. The direct measurement of the water evaporation using Lambrecht weights were carried on during several summer season in Jalovecky creek basin in the Western Tatras. The measurements were organized in two elevations : 570 m and 1500 m.a.s.l. The results obtained allowed to study the mean vertical changes of the evaporation in the basin in individual months of the summer season and to determine the mean vertical gradients of evaporation in Western Tatras.

**Keywords** : measurement, gradients, altitude

**DISTRIBUTION OF EVAPOTRANSPIRATION ON THE TERRITORY OF SLOVAKIA**

*Tomlain J., Faculty of Mathematics and Physics of Comenius University in Bratislava, Slovak Republic*

Vertical distribution of potential and actual evapotranspiration in Slovakia is discussed. The average monthly sums of evapotranspiration (E) were determined by a complex method based on the mutual solution of both the energy and water balance equations. In mountainous areas of Slovakia, where during the year excess moisture is observed, the actual evapotranspiration shows only small differences from the potential evapotranspiration (less then 4%) and is about 25-30% of the total annual precipitation. With the increase of precipitation E grows according to the altitude until a definite boundary. Then as a result of decreasing with height. On the southern slopes of the High Tatras Mts the vertical gradient of evapotranspiration changes its sign approximately at the altitude of 900 m.

**Keywords** : evapotranspiration, vertical distribution.

**VARIATION OF MASS FLUXES IN THE POLISH COASTAL ZONE**

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Time series of monthly values of hydrometeorological parameters; air temperature, sea surface temperature, wind speed and water vapour pressure were used to estimate annual values of mass fluxes. Analysis of flux series allows to conclude that there are statistically significant changes of annual value of water vapor exchange over the sea surface. These changes are caused by the trends in main hydrometeorological factors and are connected with the intensification of westerly and southerly circulation. In consequence, also changes of sea level



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occur much more intensive in the eastern than in the western part of the Polish coast.

**Keywords** : flux, trend, spectral analysis

### TIME SERIES ANALYSIS OF EVAPOTRANSPIRATION IN BALKANS

*Balafoutis, CH. J., Arseni, A., University of Thessaloniki, Greece*

Some characteristics of the potential evapotranspiration over Balkan are presented. The study is based on the evapotranspiration data which are calculated by the Thornthwaite formula, at 11 Balkanic stations, which dispose long time series. From the fluctuations of all series in observed an important increase of the around 1910 and lasted until 1965 with different form and magnitude everywhere. The fluctuations, in detail, are discussed in respect to possible causes where particularly the role of the atmospheric circulation and the topography.

**Keyword** : evapotranspiration, fluctuation, Balkans

### POSSIBLE IMPACTS OF CLIMATE CHANGE UPON WATER BALANCE IN SLOVAKIA

*Lapin, M., Slovak Hydrometeorological Institute, Bratislava, Slovak Republic*

Possible impacts of the supposed climate change in Slovakia in next 35 years are discussed. Calculation of water balance elements was carried out according to the Zubenok - Budyko method. An assessment of climate warming impacts upon changes of precipitation, relative air humidity and snow cover characteristics was provided by correlation methods. The significant rise of potential evapotranspiration and dropping trends of precipitation, relative air humidity, soil moisture and snow cover characteristics after 1-2°C warming, especially in southern part of Slovakia, follows from the results.

**Keyword** : climate change, water balance, snow cover

### TIME SERIES OF AREAL PRECIPITATION AND LAND SURFACE EVAPORATION AS COMPONENTS OF WATER BALANCE

*Kasperek, L., Krejcová, K., Water Research Institute T.G.M., Prague, Czech Republic*

As tool for analysis of hydrological and meteorological data in their interactions was developed simple water balance model. The model uses monthly averages of areal precipitation, areal mean temperature and estimation of potential evapotranspiration as inputs and generates monthly data of stream flow and areal evapotranspiration. The results of analysis of areal long time series from different climate conditions

as components of water balance are discussed. Time variability, seasonality and main factors influencing areal evapotranspiration studied.

**Keyword** : area, evapotranspiration, water balance model

#### **WATER BALANCE OF THE UPPER RIVER BASIN OF BODVA RIVER**

*M. Kupco, P. Nejedlik, P. Stastny, Slovak Hydrometeorological Institute, Kosice*

Upper river basin of Bodva river is located in an mountainous region. There is an adequate rainfall supply, which attains 630 up to 850 mm. and surpasses the potential evapotranspiration in average of 30 up to 250 mm. From the 50-ies the river discharges are having a decreasing trend, whole this tendency increased during 80-ies and some parts of river channel completely dried up. According to the general evaluation the climatological drought - rainfall deficiency and the actual evapotranspiration - are not a sufficient explanation for an excessive hydrological drought.

**Keywords** : drought, discharge, evapotranspiration

#### **VERTICAL HYDROLOGICAL BALANCE IN ZIHAREC FOR THE PERIOD OF 1961-1990**

*Petrovidc, P., Water Research Institute Bratislava, Slovakia*

Research station of WRI in Zinharec was based in 1954 and a regular vertical hydrological elements study started in 1955. Subsequently the observation program was enlarged from free water evaporation study of complex research using 4 types of most common Slovak soils in weighting and compensating lysimeters, in last 4 depth of groundwater level is used. Two different plants chosen from local crop rotation system are used in the report some results of observation from the representative period 1961-1990 are given. Experimental data have been used from testing the vertical hydrological balance model and results of vertical balance simulation are shown.

**Keywords** : hydrological balance, lysimeters, modelling

#### **STEPWISE LOGISTIC DYNAMIC-STATISTIC INTERPRETATION FORECAST MODEL FOR N-W PACIFIC TYPHOON RAIN GUSH USING NWP PRODUCTS**

*Lue, Chun-Lien Chem, Shun-Hua, Naajing Institute of Meteorology, 210044 Naajing, Jisages, PR China*

Well known techniques using Regression Estimation for Event of Probability (REEP), Multivariate Discriminant Analysis (MDA) and Multiple Linear Regression (MLR) have been widely used in Precipitation. They are strictly applicable only



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when the underlying variables are jointly normal. But Logistic Discriminant Analysis (LDA) results from assuming that the variables are not only multivariate normally distributed but also independent or dichotomous, or some continuous and some polychotomous.

The MR has been the most widely applied method in Statistical Interpretation of Numerical Weather Prediction (SINWP). And REEP, MDA and MLR have been introduced in the WMO training workshop on the SINWP products in 1991.

We have established a Stepwise Logistic Dynamic-Statistic Forecast Model for N-W Pacific typhoon rain gush in terms of NWP products, that have been forward selected and backward eliminated at each step in the LDA.

**Keywords** : precipitation, discrimination, variables, selection

### AN EVOLUTION OF WATER BALANCE OF THE SELECTED BASINS IN SLOVAKIA

*Majercakova, O.-Skoda, P.*

*SHMI, Jeseniova 17, 833 15 Bratislava*

The water balance in the time step of one year for 5 selected basins in Slovakia is analysed. Three basic components of water balance equation (precipitation, runoff and evaporation) are discussed. The areal precipitation totals are calculated by the method of double weighted mean. The runoff is measured in the outlet sections. The evaporation is assessed as a balance value of a difference between the precipitation and the runoff. The evaporation is calculated for the uncorrected and corrected precipitation. Separately there is given the change of the particular balance components for the various time periods and their linear trend.

**Keywords** : water balance, changes, corrected precipitation

### A FORECASTING MODEL OF VECTOR SIMILARITY IN PHASE SPACE FOR FLOOD AND DROUGHT IN CHINA

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Most previous forecasting models dealt only the mean precipitation in a region or the rainfall for a representative station and the spatial distribution of precipitation was omitted. In this paper the Chebyshev expansion at irregular grids proposed by Zhou et al. is used to describe the distribution of rainfall.

To represent well the characteristics of temporal and spatial distribution of precipitation, 30 days total precipitation is get apart 10 days for every station, then the chart of 30 days moving total precipitation is constructed.

Zhou proposed a new forecasting model of vector similarity in phase space. This method is used in this paper to predict the distribution of precipitation over Huanghe-Huaihe-Haihe Plains in China.

Using the data of ten days rainfall at 23 stations over Huanghe-Huaihe-Haihe Plains from Jan. 1959 to Feb. 1992 we get the forecast of rainfall from May 1992 to Feb. 1993.

**Keywords** : drought/flood forecasting model in phase, space

**MONTHLY, SEASONAL AND ANNUAL PRECIPITATIONS, EVAPORATION AND WATER BALANCE AT THE OBSERVING SITE OF THE SWISS METEOROLOGICAL INSTITUTE IN ZURICH FROM 1901 TO 1990**

*Brandil, J., 1993; Swiss Meteorological Institute, Zurich*

A method to find, classify and expound very quickly past and present weather types is discussed. Especially, it allows to detect select amounts of precipitation, evaporation, sunshine duration, relative humidity as well as wet or dry season. Evaporation is calculated with the formula of Primoult which matches evaporation measured with a Wild evaporimeter.

**Keywords** : climate, natural variability, drought

**DEW, ATMOSPHERIC WELLS AND THEIR WATER PRODUCTION IN MEDITERRANEAN CLIMATES**

*Gloda, A. (Orstom, BP 5045, F-34032 Montpellier), Beysens, M. (SPEC. CEA Saclay, F-91191 Gif-sur-Yvette), Acasta Baladon, A.N. (WMO Emeritus. P<sup>o</sup> Canalejas, 57/61, 7a, E-37001 Salamanca)*

An antique supply channel network without any spring was discovered above Feodoslya in Crimea (previously Theodosia, a colony founded by the Greeks in -600 B.C.) almost at the beginning of the XXth century. The discovery of huge stone heaps at the network head led the engineer Zibold to think that it was possible to rebuild a natural water condenser, called on atmospheric well, to collect the dew. Works were stopped by the Soviet Revolution. L. Chaptal in Montpellier (France) made further trails using a small pyramid (3 x 3 x 2.32 m). The construction (12 m high and 12 m in diameter) was built in the early thirties by A. Knapen in Trans-en-Provence (Finance). It never produced high quantities of water but it is now unique worldwide and hence restored.



**THE INFLUENCE OF PRECIPITATION CORRECTION ON THE BALANCE OF  
SURFACE WATER POLLUTION**

*Mendel, O., Pekarova, P.*

*Institute of Hydrology SAS, Bratislava, SR*

The atmospheric nitrogen significantly influences the nitrate pollution of surface water. To balance the mass of the nitrates in the basin, it is necessary to determine the total mass of the atmospheric nitrogen as accurate as possible. The precipitation totals obtained are not exact due to some systematic errors of the measurements. These errors carry over to the basin pollutant balance equations. In this contribution, a method for calculation of the nitrate mass contained in precipitation is proposed, and an influence of corrections of annual precipitation totals on basin nitrate balance is determined.

**Keywords** : precipitation correction, surface water pollution, nitrate balance

**FOG COLLECTORS IN TROPICAL AREAS : A REVIEW**

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Studies on fog precipitations have followed three different approaches ; (i) to measure precipitations with ad hoc apparatus; (ii) to harvest fog in nets to catch this water resource in arid areas; (iii) to study the natural collectors, such as trees, and the cloud forest ecology.

(i) Aside of UCN experiments in Chile, the most often seen apparatus are gauze cylinders, i.e. fog-catchers on raingauges (South Africa, Cope Verde Is., Canary Is.).

(ii) Nowadays two layers of mesh rubbing together capture droplets to drink for villages, such as El Tofo in Chile, with help from CONAF and Environment Canada, and, In Peru where SENAMHI and Estratus s.r.l. cooperate.

(iii) On Cape Verde Is., In Oman, and on Canary Is., Farmers and breeders put traditionally cisterns under agaves or frees of differents species (olive tree, laurel, juniper tree) to collect water dropping off the leaves in periods of fog.

**Keywords** : aridity, Chile, Cope Verde Is, Canary Is.

### **FEATURES OF TROPICAL CONVECTION IN THE SAHEL**

*Ben Mohamed, A.,<sup>(1)</sup> Sauvageol, H.,<sup>(2)</sup> Lebel, T.<sup>(1)</sup>*

*(1) ORSTOM, Missing au Niger*

*(2) Laboratoire d'Aerologie, CRA Copmpistrous*

This paper deals with tropical convection in the sahelian zone and its relation with observed precipitation during the monsoon rainy season.

It focuses on the aerological conditions associated with the formation and development of the convective cells and squall lines in this region, the dynamic characteristics of the precipitating systems and features of large scale precipitation fields over Niger. Emphasis is put on prediction of occurrence of convective systems based on regional observational data and those available from European Forecasting Centers.

**Keywords :** convective cells, squall lines, prediction

### **CLOUD AND FOG-WATER DEPOSITION AS HYDROLOGICAL AND CHEMICAL INPUTS**

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Coniferous spruce forest of the mountainous part of the Sumava Mts. (South Bohemia) are subject to significant deposition of water and chemicals via cloud droplet impaction. This paper discusses the methods for determining amounts of cloud-water deposition. This deposition has been estimated by a micrometeorological method. Water inputs from clouds are about 7% of the vertical precipitations here. From 1988 to 1992 impaction of droplets on toflon strands of the specially constructed active collector provided a total 73 samples of cloud-water. Collected samples were analysed for pH, conductivity and major ions. Enrichment factors for cloud vs rain varied from 2 to 25 in this region.

**Keywords :** cloud-water deposition, pollution

### **A METHOD FOR A RELIABLE ESTIMATION OF THE WET DEPOSITION**

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In the F.R.G. numerous but heterogeneous and inconsistent wet deposition data are available. Therefore presently no reliable areal estimation of the pollutant input to soil - which is very important for the observation of critical loads - can be obtained.



## Frontier Areas of Research in Hydrometeorology

The project presented in this paper was designed to develop a method for a more accurate estimation of the wet deposition. This is done by using information about the temporal variation of the concentrations of trace substances in precipitation during a rain event and its dependency on genesis of the rain, on orographic conditions and on local influences. From these information the pollutant loads of different types of rain will be parameterized.

In a second step a model will be developed which includes the parameterization mentioned before and which were precipitation statistics as input data. Such very detailed statistics can be obtained from the German Weather Service. For the validation of the model the data of homogeneous deposition monitoring networks will be used.

Beside these investigations additional measurements will be made with rain collectors inside and outside forests. Those measurements will lead to a better understanding of the deposition processes inside a forest and can be used for a more reliable estimation of the deposition under such conditions.

The paper will present the methodology of the precipitation investigations and statistical methods used for modelling as well as first results of measurements and modelling.

**Keywords :** Networks, optimization, interpolation, areal, regional estimation, wet deposition, critical loads

### TEMPORAL AND AREAL VARIABILITY OF ACID DEPOSITION IN THE BASIN DURING WINTER SEASON

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In order to obtain more information on the temporal and spatial variation of snow cover and on the role of different hydrologic condition during winter on stream water chemistry the detailed investigation was undertaken at the Bystrianka basin (10 year observation). For comparison the measured values had been used. The paper presented spatial and temporal variability of pH, SO<sub>4</sub>, NO<sub>3</sub> in obtain for both accumulation and snowmelt period.

**Keywords :** pH, sulphates, nitrates, accumulation, snowmelt, variability

**PRECIPITATION CHEMISTRY AND WET DEPOSITION AT THE TERRITORY OF SLOVAKIA**

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The results of acidity and chemical composition of precipitation at the territory of Slovakia are presented. Significant decrease of precipitation acidity as well as sulphate and nitrate concentration were observed. Wet deposition of sulphate and nitrate at the whole territory of Slovakia remarkable exceed recommended critical loads (95 %). Reasonable good agreement was observed between model calculated and observed data. The errors of wet deposition of principal components in precipitation are discussed.

**Keywords** : wet deposition, precipitation, chemistry, acidity

**TIME SERIES ANALYSIS OF SNOWMELT RUNOFF AND ATMOSPHERIC FACTORS INCLUDING PRECIPITATION**

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The object of this study is investigated the characteristics of snowmelt runoff by spectral analysis. In spectral analysis, power spectrum, cross spectrum, coherence and phase of snowmelt runoff, precipitation, wind speed, air temperature and inflow in reservoir are calculated.

Main conclusions are as follows.

1. The precipitation may be of white noise.
2. The relation between heat flux and snowmelt volume for the low frequency domain is nearly linear.
3. The runoff component of snowfall is divided into two components -a shorter period which ends within about 20 days and a longer period which lasts 20 days or more.
4. The lag time of snowmelt runoff is about 15 days to 20 days.

**Keywords** : spectral, analysis, wind, speed, heat, flux

**CORRELATION BETWEEN THE DENSITY OF THE SNOW COVER AND THE METEOROLOGICAL PARAMETERS**

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The density of the snow cover is the main parameter of the snow cover which occurs in the calculation of the water stock accumulated in snow. By using



the gravimetric measurements of the snow at the measuring stations for the evaporation at the snow surface, in correlation with the meteorological parameters, estimation functions have been found for the density of the snow cover in terms of the air temperature or the saturation deficit. By introducing in the correlation an implicit parameter of the snow cover dynamics, the correlations exceeded the value of 0.8. The estimations will be used for the transformation of the snow cover depth into the water equivalent in the mountain areas.

**Keywords** : snow, accuracy

#### **DEPENDENCE OF CHANGE OF SNOW DEPTH OF SNOWFALLS AT BRZEGI DOLINE**

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Snowfalls at Brzegi Dolne (438 m a.s.l., the Bieszczady Nts. -Carpathians) appear in 61 days a year (on the average). Snowfalls and depth of snow are measured at the morning observation terms. The analysis of changes of snow depth from day to day (only for days with snow falls) gives, in about half of cases snow depth increases, in 13% of cases snowcover occurs without any change of its depth, in 24% of cases there is not snowcover in the both morning terms. If increase of snow depth is > 10 cm from day to day, then frequency of 24 hours total precipitation more than 5 mm equalled 81% (increase > 15 cm - frequency 93%). The number of days with snowcover at Brzegi Dolne is 93 a year and the sum of daily snow depth is 1678 cm a year (on the average).

**Keywords** : 24 hours changes, Carpathians

#### **CHANGES IN THE SNOW COVER DURATION IN BOHEMIA SINCE THE TWENTIES**

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Author proposes an objective method of the determination of the beginning and the end of the period with the prevailing occurrence of the snow cover. The method enables the core of the period of snow cover occurrence (which can include days without snow cover, too, but only as an inferior component) and the periods before and after the core (when the snow cover can occur but the time without it prevails). The many years trends of the snow cover duration characteristics were analysed. The results are discussed with regard to simultaneous climatic changes.

**Keywords** : snow cover, changes in snow cover, duration, climatic change, detection

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