Meteorological research in Croatia, 1991–1994

Report to the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics

During the period 1991–1994 meteorological research has been mainly accomplished by the following institutions: Andrija Mohorovičić Geophysical Institute, Faculty of Science, University of Zagreb; Meteorological and Hydrological Service, Headquarters Zagreb; Marine Centre of the Meteorological and Hydrological Service, Split.

Main research activities were organized within the framework of 19 research projects, 4 of which are of the international character (one with NSF-USA, two with UNEP, and one with NOAA-USA). Altogether, 13 PhD's, 21 MSc's and 14 Bsc's were involved in research. Scientific projects are mainly sponsored by Croatian Ministry of Science and Technology.

Most of observational data in meteorology was supplied by the Meteorological and Hydrological Service, which operates large network of meteorological stations in Croatia. The network steadily increased since the World War II until the start of Serbian aggression against Croatia in 1991. It should be pointed out that out of 566 stations existing at the end of the year 1990 (38 of these were principal synoptic stations, 97 climatological stations and 395 precipitation stations) Serbian aggressors damaged or occupied 30.4%. Some of the stations at the border of the free territory (and at the same time in the area of war activities) have been forced to move several times and at several stations regular observations have been made under imminent life danger. Due to war activities pilot-balloon observations in Split and Slavonski Brod were suspended although radiosounding observations at the observatory Zagreb–Maksimir were regularly performed. The airport station at Osijek–Klisa has been occupied and the stations at airports of Zadar and Dubrovnik had suspended their observations for many months. Due to interruption of telecommunications the contribution of meteorological data into international exchange network was also severely hampered. Detailed report on this matter is given in a paper by Katušin (1994).

Most of research projects are a continuation of studies which started 5 or even 10 years ago. Pandžić and Trninić (1991b, 1992b) used the principal component analysis to resolve the connection between the Kupa river flow and the parameters of macro-circulation. Pandžić et al. (1992a) analysed the influence of the low and high pressure centres on precipitation with the same method.

As a part of research project »*Croatian climate monitoring within the global climatic change*« several investigations were made. Pandžić and Sijerković (1991a) described the greenhouse effect and its influence on climatic change. Šinik (1992a) examined the long-term average temperature data of Zagreb–Grič observatory and constructed a deterministic climatic model which describes dependence of climatic temperature changes on cloudiness. Lončar and Šinik (1993) investigated some features of annual air pressure course at the representative stations in Croatia and found the significant pressure drop in second decade of February which is nearly of the same magnitude in all Croatia. Penzar I. et al. (1992c) presented results of long term meteorological observations and measurements, carried out at the Zagreb–Grič Observatory for the period of 129 years. Climate data published there include those on: global solar radiation, air temperature, humidity, atmospheric pressure, wind, sunshine duration, rainfall, cloudiness, observations of other forms of precipitation and other phenomena. Penzar B. et al. (1992a) described the climatic fluctuations recorded in Zagreb between 1862 and 1990: a rise in temperature is most obvious during the heating season. The lowest temperatures took place at the end of the 19th century. In the second and third quarter of the 20th century most clouds were observed. The climatic fluctuations in October were most apparent on several climatic elements. According to the analysis of Juras J. and Juras V. (1992) temperature normals for the 1961–1990 period approach more closely the mean values for the entire period of observations in Zagreb than any other standard normals. It is shown that the often advocated advantage of short period (5 or 10 years) normals as a more reliable basis for future value estimation, has no justification. In another paper Juras J. (1993) examined various methods for internal consistency of meteorological observations. He found that the Maronna-Yohat test can be used for detection of possible systematic errors in observations by means of the time series of the mean values of various correlated meteorological elements measured at the same station. The same author in another paper (Juras J., 1994) deals with various transformations commonly employed in order to obtain near normal distribution of precipitation data. It was shown that the square-root normal and the cube-root-normal are very similar to compound Poisson-exponential and the gamma distributions, respectively. The long-term precipitation data of the Zagreb–Grič Observatory were analysed also by Gajić-Čapka (1992b) who showed not only the stationarity of the precipitation amounts time series but also a generally decreasing, statistically not significant trend over the entire period (1862–1990). The annual and warm half-year precipitation spectra can be fitted by Markov »red noise« continuum and the cold half-year precipitation series by that of »white noise«. Quasi-periodic oscillations appear in two spectra ranges: short (2–6 years) and medium (16–43 years). Pandžić et al. (1993) analyse possible climatic conditions on the islands Cres and Lošinj in the northern Adriatic with respect to

the global climatic changes. A higher increase in annual temperature (up to 5°C) is expected by the end of the 21st century. No significant change in annual precipitation is anticipated. The climate characteristics of precipitation in different parts of Croatia were investigated by Gajić-Čapka (1992a, 1992b, 1993b, 1994). In the first paper the maximum precipitation amounts for different time intervals were analysed using the Jenkinson method, in the second one the stationarity in time series, in the third one the periodicity of the secular annual precipitation in different climate regions of Croatia and finally in the fourth one the periodicity of annual precipitation in various climate regions of Croatia was addressed. A decreasing trend is generally present over the entire interval, but is statistically significant only in the continental lowland. The annual precipitation variance spectra show the quasi-periodic oscillations in two spectral ranges: short (2.2 and 4.7 years) and medium (25.0 and 33.3 years).

Meteorologists in former Yugoslavia have for a long time been considering whether it would be justified to change the »classical« observation times at 07, 14 and 21 LMT to main synoptic observation times at 06, 12 and 18 UTC. Lukšić (1991) explains the main reasons why the climatological observation times were retained.

In the past four years considerable attention was paid to the research of bura[1] and jugo[2] winds on the Adriatic. The recent major stride in our knowledge of the bura phenomenon has been made possible by the data set collected during the field experiment in the ALPEX Special Observation Period (SOP) with extended surface and upper air measurements, and particularly by the first aerial observations of this phenomenon. Jurčec and Glasnović (1991) applied Smith's internal hydraulic theory to some special cases of Adriatic bura during the ALPEX SOP. Their conclusion is that in the case of 15 April 1982 neither inversion nor critical level are of importance for the bura occurrence, but the low-level wave breaking due to a weak flow in the upstream region. They found that for the case of the strongest SOP bura on 6 March 1982, hydraulic theory offered much better results. Bajić (1991a) also applied the generalised hydraulic theory to selected strong bura cases in Northern Adriatic and investigated data on aerial analysis of the severe bura cases (Bajić, 1992). The generalised hydraulic model sensitivity to the input data was also investigated by Vučetić V. and Bajić (1994). Statistical analysis of severe Adriatic bora cases has also been made by Vučetić V. (1991b), and in another paper (Vučetić V., 1993) it was concluded that the application of two-dimensional hydraulic theory could not fully explain the bura phenomenon. On the basis of time series of three-hourly average pressure drag vectors

[1] *Bura* is a Croatian name for katabatic wind bora.

[2] *Jugo* is a Croatian name for south-easterly wind in the Adriatic, in other parts of the Mediterranean known as scirocco.

Ivančan-Picek and Tutiš (1991) and Tutiš and Ivančan-Picek (1991) outlined the method of drag estimation for period in which no microbarographic data are available. The pressure drag maxima during SOP are always related to the bura periods and the magnitudes of the drag values indicate that during these events there is a major sink of atmospheric momentum over the Dinaric Alpine region. Brzović and Benković (1994) elaborated the statistical characteristics of the severe bora winds in the period of 1987–1993 at selected stations on the eastern Adriatic coast. Visković (1991) described the synoptic situation during the storm bura at Split. Statistical characteristics of jugo storm at Split have been elaborated by Vukičević (1991). Britvić (1991) applied the mesometeorological model for rainfall forecasting in the area of the Middle Adriatic.

Another area of research in Croatia covers the boundary layer of the atmosphere and the problems related to the air pollution. Cvitan (1991) elaborated a wind model based on the Monin-Obukhov theory for operational use over the flat terrain in Northern Croatia. Local functions were derived for each stability class and satisfactory wind speed profile simulation was achieved. The applicability of the several methods of estimation of the wind profile to the 925 hPa pressure level winds has been discussed by Klaić and Cvitan (1993b). The same authors elaborated also an amelioration of Petterssen's method of trajectory calculation (1993a). Šinik and Lončar (1992b) showed that the basic local air pollution is not only dependent on seasonal variation of the SO_2 emission but also on the characteristic seasonal variability of predominant weather types. The background air pollution was also investigated in dependence of prevailing weather types (Lončar and Šinik, 1992). Šinik et al. (1994) developed a model of the local basic air pollution, which enables its determination using series of simultaneous data of wind velocity and air pollution concentration. The model has been tested on the data from Croatia, Hungary, USA and Slovenia. Grčić (1993) proposed a method for deriving the vertical turbulent flux of light, chemically inert pollutant from meteorological and urban parameters that are easily available. The method has been applied to a range of possible urban characteristics and it came out that the influence of surface roughness upon pollutant turbulent vertical fluxes is predominated in all stabilities. The application of Venkatram's model for internal boundary layer height evaluation was given in the paper by Britvić (1993). This model has been applied to the Istrian peninsula and tested by radiosounding data in Pula. In a statistical analysis of surface and elevated inversions and mixing heights over Zagreb region based on 5-year data, Lončar (1991) found that the annual frequency of all night inversions is 90% and of all day inversions about 65%. During all seasons the surface inversions most frequently reach the height of about 100 m. Grisogono and Keislar (1992) proposed a model based on a modified diffusion equation by which a radiative destabilisation of the nocturnal stable atmospheric

boundary layer over homogeneous desert can be predicted. In another paper Grisogono et al. (1993) present an integral expression for the mountain wave drag associated with linearized, hydrostatic flow over two infinitely long, bell-shaped ridges. Grisogono (1994a) also performed an analytical study of dissipation of wave drag in the atmospheric boundary layer and in another paper (Grisogono, 1994b) described the effect of curvature on the critical Richardson number. Tutiš (1992) found a special analytical solution for trapped lee waves and Smith and Grubišić (1993) reported on the aerial observations of Hawaii's wake. The paper by Glasnović (1994) gives a detailed review of the methodology to compute vertical cross sections in time and space based on the Polynomial Hydrostatic Adjustment Technique (PHAT). Special attention was paid to the interpretation of the meteorological phenomena in the cross sections and particularly to the comparison of differences in their visualisation in both potential temperature and geometrical height coordinates.

Having in mind that air pollution transport and dispersion and other atmospheric processes depend largely on the general synoptic situation, the weather types defined by Poje were used to assess the dependence of mesocirculation on the measured concentrations of sulphur dioxide and precipitation acidity in the area of island Lošinj in the Northern Adriatic (Bajić et al., 1994, Vidič et al., 1994). Weather types are being determined at the Meteorological and Hydrological Service at Zagreb regularly since 1970, and Lončar and Bajić (1994) statistically analysed them for the inland of Croatia. In addition to ordinary statistical characteristics for occurrence and duration of weather types for the year, seasons and months, the authors also in their paper present decadal values and the transition of one weather type into another. Mann (1991) investigated the causes of weather prediction failure on June 22, 1990 and found that the barotropic wind shear had governed the movement of cyclones.

Wind field simulation (Bajić, 1993) based on a simple, one level model has been used at several locations for practical applications of designing industrial objects. An observational study of wind characteristics in a small valley is presented in a paper by Bajić (1991b). Detailed analysis of the relation between the wind speeds at 10 and 50 m above ground, as well as of the gust factors and roughness, is outlined in a paper by Cividini (1994). The Wieringa method for estimation of local roughnes from data taken at one measurement level is not acceptable in complex terrain conditions. Wind persistence in the eastern part of the Adriatic Sea and inland of Croatia has been analysed by Poje (1992), in continuation of his earlier work which dealt with wind persistence regardless of wind direction. In this paper three dominant winds of the Adriatic area: bura, jugo and etesian winds, were analysed. With respect to the potential utilisation of wind, the most promising areas regarding wind persistence are the Velebit Channel in the Northern Adriatic and the exposed

islands in the Southern Adriatic. Zelenko and Lisac (1994) described an approximation of the occurrence probability of wind direction classes by means of mixture distribution consisting of several component distributions.

Although the measurements of solar radiation in Croatia are recently very limited, the research on different aspects of it continued. Penzar I. and Penzar B. (1991) determined hourly values of the global solar irradiation in clear sky as a function of solar elevation. The estimation was performed on the 15^{th} of every month for latitudes 41° to 46° N also including the influence of clouded sky.

A 12-year record of surface ozone data collected by means of the Schönbein's method in Zagreb between 1889 and 1900 is analysed in a paper by Lisac and Grubišić (1991). A comparison of old ozone measurements shows an increase of volume fractions from 36 to 67 ppb for daytime and from 30 to 56 ppb for night-time. A recent stratospheric ozone intrusion over Zagreb was described and analysed by Lisac et al. (1993). On February 6, 1990, at 1045 UTC the ozone volume fractions in Zagreb suddenly rose from 2 ppb to 100 ppb and remained at unusually high values for another five hours. From a long-term data of fallout ^{137}Cs which has been investigated in Zagreb since 1965 Franić (1992) deduced an exponential decline of radioactivity level till 1986 when the nuclear accident in Chernobyl occurred and high radioactivity levels were detected again. The results of the analysis of long-term measurements of ^{90}Sr radioactivity in the wet fallout in the Zagreb area are presented in another paper of the same author (Franić, 1994).

At the Meteorological and Hydrological Service of Croatia the extraordinary meteorological and hydrological events are recorded and analysed for many years. For the last 17 years each year a monograph (Trninić, 1994) on this topic has been published. In this publication many articles deal with different aspect of meteorology, hydrology, agrometeorology and biometeorology in relation to the extraordinary weather events, thermal comfort, acid rain, hail suppression, forest fires, dry spells, high waters and floods. The influence of extreme weather conditions on energy systems was discussed by Čapka (1992a, 1992b) who presented the case of extensive rainfall on 3 to 4 July 1989 in which atmospheric conditions caused rainfall amounts corresponding to return period greater than 100 years. Synoptic and theoretical aspects of rare or extreme weather events were addressed by other researchers. Tutiš et al. (1992) submitted a case study of a late snowstorm in south-western Croatia in May 1991 which was caused by processes of a subsynoptic scale. Vučetić M. (1992) analysed the weather and climatic conditions on the island of Hvar during the prolonged forest fire in July 1990. On the basis of mean surface distribution and AT 500 hPa constructed from 15 severe bura storms in Split, Jurčec and Visković (1994) indicate the mesoscale cyclone in the Southern Adriatic to have the main downstream influence on bura intensity. Two bura types are separately analysed: »dark bura« with

clouds and rain and »clear bura« with cloudless sky. In the paper by Gajić-Čapka and Zaninović (1993a) the empirical and theoretical distributions and a trend analysis of days with hail and thunderstorms at three locations in Northern Croatia during the 40-year period were analysed. Medvedović (1993) describes the pluviothermal climate favourableness indices for the forest vegetation that presume that the most favourable climate condition dominates in those areas where the biocoenoses members are the most numerous. The development stages of perennial trees as well as stages of honey bees at Đurđevac and Bjelovar were analysed by Vučetić V. (1991a) ten years before and ten years after the marsh gas station began to operate. Vučetić V. (1994) outlined the analysis of temperature sums for different thresholds in mountainous regions of Croatia. The appearance of the northern lights in Dalmatia on November 1991 has been described by Miljak (1991).

In cooperation with physicians, the research in biometeorology has been conducted for many years. Main topic of research was the correlation of psychosis and suicide attempts with meteorological factors (Pleško et al., 1991a) and the correlation between meteorological factors and blood coagulation (Pleško et al., 1991b). In the first paper the authors stated that the suicidal attempts and psychoses increase significantly if the cloudy period lasts for at least three days and in the second one that a significant correlation exists only between air temperature and both prothrombine and thrombine time. Limits of warm and cold bioclimatic stress in different climatic regions were determined by Zaninović (1992a) by means of combined biometeorological index, based on temperature, wind velocity and humidity. Zaninović et al. (1992b) investigated also the changes in coagulability in a group of patients with cerebrovascular symptoms in different weather situations and concluded that the most significant changes were manifested during the passage of a cold front and during the cold spell caused by it. Influence of meteorological factors on occurrence of myocardial infarct in Dalmatia was explored by Mirić et al. (1992). The occurrence of sino-bronchial syndrome in children in dependence on weather conditions in Zagreb has been elaborated by Pleško et al. (1994). In another paper Vucelić et al. (1993) discussed the influence of atmospheric conditions on the frequency of bleeding from the peptic ulcer.

Different aspects of applications of meteorology are described and discussed in several papers. Gelo (1992a, 1992b, 1993) outlined various meteorological services in aviation, maritime navigation and surface transport. Trošić (1992) elaborated a simulation model for exploring and adapting the potential benefits of meteorological information in traffic. Dimitrov (1993a) described the role of the Meteorological and Hydrological Service of Croatia in the forest protection organisation and in another article (Dimitrov, 1993b) the weather conditions and forest fires in the coastal area of Croatia during 1992. The same author considers also the influence of climate on wood drying in the open (Dimitrov, 1993c).

In the last several years a large number of meteorologists in Croatia have been working on the multilingual glossary of meteorological and hydrological terms. Main emphasis is put on defining the Croatian terms for many words used in meteorology and hydrology wherever is that suitable and justifiable (Penzar, 1992).

At the end of this review it should be pointed out that between 1991 and 1994 Croatian meteorologists remained active despite the war: they published about 140 papers, took part in several domestic and foreign scientific symposia and workshops where they presented many reports and contributions (these are not reviewed here). Besides this four MSc theses and one DSc thesis have been defended. In his thesis Branković (1992) discussed the results obtained from a set of 30-day integrations made with the ECMWF model over a period of two years. He studied the impact of spectral horizontal resolution and of model changes on the model systematic errors, and forecast skill in the extended range. In her thesis Grčić (1991) developed a two-layer model (DSM) of urban pollution which describes temporal variations of pollutant concentrations. Vučetić V. (1992) in her thesis analysed the vertical atmospheric structure during severe bura in the period 1959–1963 on the basis of radiosounding data in Split, Zagreb and Belgrade. The causes of 15 severe bura cases in Split were studied in the thesis of Visković (1992) as well as the accompanying macro, meso and local scale processes and their mutual interactions. Finally, Zaninović (1994) in her thesis investigates the bioclimatic conditions in Croatia using the combined biometeorological index TWH which contains 9 thermal comfort classes, ranging from »extremely cold« to »extremely hot«.

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Dražen Poje