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Review of meteorological research in Croatia
Survey of situation up to 1997

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This review of meteorological research is based on the published professional and scientific papers. Papers are divided into 19 main topics: books, measurements and data processing, solar energy, planetary boundary layer, ecological problems, climatological papers, research on wind and air humidity, traffic and agricultural meteorology, hail defense, biometeorology, air-sea interaction, atmospheric electricity, history of meteorology, research projects and other activities. For every group, main research problems and achieved results are outlined on the basis of selected papers, which are quoted in the list of references. This list does not include complete bibliography of meteorological papers published so far in Croatia. However, it was intended to include all authors with some of their papers in order to get insight into research they were involved with, and their contribution. The first meteorological papers commenced to appear in the middle of the nineteenth century but the greatest number of papers has been published in the last 50 years. This is in harmony with the development of meteorology as profession and of meteorological institutions: Geophysical institute »Andrija Mohorovičić« and Meteorological and Hydrological Service.

Keywords: meteorological research, Croatia, published papers.

We have been entrusted to produce an overview paper on the state of meteorology research in Croatia. With regard to the extent of the task and the limited space, we resolved to consider only the most important results of previous research. In doing so, we used available sources such as Zeljak's Meteorological Bibliography (1973, 1977), PMF records (B. Penzar 1986; I. Penzar 1996a), reports to IUGG (Poje, 1994) and listings of papers rendered at our disposal by individuals. It would be very worthwhile to produce an integral meteorological bibliography for the period 1976–1997, because only some of those papers are mentioned herein.

In order to facilitate examination of the extensive content, we partitioned this review according to main research domains and attempted to arrange

the particular papers accordingly. This was not always possible, because some research penetrates multiple domains. We apologize to authors if, according to their opinion, we did not succeed in doing it. Also we plead for understanding if the choice of papers was unfavorably accomplished.

1. Meteorological history studies

Numerous scientific and expert meteorological studies contain diverse historic data, yet we have only around thirty distinctive papers on the history of meteorology. The first historic outline on the state of meteorology in Croatia was presented by Šulek (1916), and the first list of meteorological stations was published by Mohorovičić (1902). B. Penzar and I. Penzar (1978a) wrote about the development of the station network in the 19th century, Katušin (1989, 1994) reported about the new network as well as about network devastation in the Homeland War and prior wars. Review of available meteorological data up to date was produced by Lukšić (1996).

Reviews of development of meteorology and climatology in Croatia may be found in the publications by Dadić (1991, 1994), Goldberg (1960), Hirc (1905), Klaić (1878), Mokrović (1943) and Maksić (1960, 1965). Meteorology at the Geophysical Institute is described in discussions by Goldberg (1951), Penzar et al. (1986), Penzar (1996a), Skoko and Mokrović (1982, 1996), Volarić et al. (1980), and at the Meteorological and Hydrological Service by Gelo (1979), Katušin et al. (1990), Pandžić (1998), Poje (1979) and others. Sijerković (1993) has collected a number of historical meteorological items in his book. Furthermore, endeavors of eminent experts have been exclusively scrutinized and presented at the scientific conferences dedicated to, for example, G. Bučić, A. Haračić, M. Lanosović, A. Mohorovičić, Gj. Pilar, so these may be found in the corresponding proceedings. Other sources of historic meteorological data may be found in the memory notes for the deceased. Among those, accounts that particularly stand out with their documented content are the ones for J. Goldberg, B. Kirigin, B. Makjanić, B. Maksić, F. Margetić, M. Šikić, S. Škreb and R. Vernić. Biography articles in domestic encyclopedia and lexicons are also supported by historic data, when treating Croatian geophysicists and meteorologists. The most exhaustive collection of old records on weather and other meteorological conditions in the Adriatic from antique times up to the middle of the 19th century is contained in the article by I. Penzar and B. Penzar (1997). A complete meteorological bibliography does not yet exist as does not a history of meteorology in Croatia.

2. Books, textbooks, *scripta*, popular editions

Books and booklets of meteorological content were published in Croatian language from the 19th century onwards. Among them the best known are »Weather« by Kučera, »Century Calendar« by Mikloušić and the textbook

»Science of Climatology« by Potočnjak, as well as popular editions like »Occurrences in Air« by Perkovac and »Weather Records« by Krempler. Nevertheless, booklets by Bakotić (1862) and Sinčić (1881), written for »teaching of common people« and also »for pupils of elementary schools«, remained unknown until now. In the first one of those, complete geophysics (seismology, oceanography, meteorology) is described, and in the other just atmospheric occurrences. Also, until recently, the marine meteorology textbook by Frane Visković (1836–1905) from Perast has been unknown. It was published in the Italian language in Trieste in 1876 under the title »Manuale nautico di Meteorologia« for use in nautical schools.

During the 20th century more than thirty books, textbooks, *scripta* and expert booklets were published. All of them are original, except for the translation of a foreign textbook by Nikolić (1983). Authors of those volumes are: Buljan and Zore (1963), Gelo (1994), Makjanić (1951, 1967a), Maksić (1950), Marki (1950), S. Mohorovičić (1943), Lisac (1996), Pavišić and Makjanić (1947), B. Penzar (1976), B. Penzar and Makjanić (1978, 1980), B. Penzar et al. (1996), I. Penzar (1977a), I. and B. Penzar (1984d, 1985), Randić (1952), Riboli-Mardešić (1936), Sijerković (1990, 1990a, 1991, 1993, 1996), Simović (1970, 1980, 1996), Skoko and Mokrović (1982, 1998), Šegota (1988), Tutiš (1997), Volarić and I. Penzar (1967). We emphasize the volume »Meteorology for Users« which is the effort of about twenty prominent meteorologists from both institutions.

3. Climatology

Since ancient times experience has taugth the man how useful it is to understand weather and climate in the region and in the adjacent provinces. Written records exist on that subject since before antique times. Among our regions the Adriatic zone was of the greatest interest due to the sailing routes. Therefore, Adriatic climate descriptions exist not only by foreign but also by domestic scientists, as for example by Kotruljević (15th century), Lučić (17th century), Lovrić (18th century) and Seljan (19th century). All such records were made on the basis of observation and experience. Since the middle of the 19th century, endorsement of climate studies with instrumental data measurement begins (Carara, 1846; Petter, 1857), and only in the last quarter of the 19th century the first climate reviews based exclusively on meteorological measurements are published (Haračić 1886; Mohorovičić 1889; Šega 1899). At the same time Austrian meteorologists studied extensively the climate of our regions, but this is not discussed here (Hann, 1879, 1886; Raulin, 1874).

More than 200 papers have been published in the field of climatology. There is almost no active meteorologist who did not publish a climatological paper. In addition to meteorologists, other experts also treat and use climato-

logical data – geographers, agronomists and forest experts, physicians and power engineers (Gavazzi-Franović, 1888; Gavazzi, 1893; Šegota, 1967; Tomić et al., 1995; Bertović, 1980; Trauner, 1961; Požar, 1988).

Papers on climatology may primarily be divided into those which treat the climate of particular locations or the climate of defined regions (also of countries and wider), and those that treat particular meteorological elements.

Up to the World War I climate presentations were compiled for ten places in Croatia: Bjelovar, Gospić, Hvar, Karlovac, Križevci, Mali Lošinj, Osijek, Pula, Vinkovci and Zagreb. These are not up to the level of contemporary work, neither in length of data series, nor by the count of items covered, and contain hardly any physical explanation of the facts established. Such papers were written by the observers themselves, who were usually high school teachers. To date, collected data of all meteorological stations in Croatia have been processed and published, and for many stations climate reviews have been produced. Notably many have been made for Adriatic locations, as for example for Dubrovnik (B. Penzar, 1989), Hvar (Makjanić and Volarić, 1979), Rab (Sliepčević, 1960), Cres and Lošinj (Pandžić et al., 1993), Zadar (Kraljev et al., 1995), Neretva Estuary (Filipčić, 1989), Rijeka and Split (B. Penzar, 1976), Vis (V. Vučetić and M. Vučetić 1995). In the interior of the country many sites have also their climate conditions published, as for example Zagreb (Mohorovičić, 1897; Goldberg, 1931; Kirigin, 1957a; B. Penzar, 1957, 1976; Makjanić et al., 1977; Lukšić, 1984; Gajić-Čapka and Čapka, 1985), Medvednica (Kirigin B., 1963), Sisak (Lisac and Heric-Nekić 1995), Virovitica (I. Penzar and Grisogono, 1986) Klenovnik (Kovačević, 1939), Osijek (B. Penzar, 1976b). In some papers, other geophysical data are described in addition to climate, as for example in the one for Prekodravlje (I. Penzar and B. Penzar, 1994). For the whole Adriatic region the climate was presented by Duplančić (1959) and Makjanić (1976), for the karst region by Maksić (1963), and Škreb et al. produced the »Climate of Croatia« in 1942. That is presently the sole domestic publication of such category. The climate atlas contains chosen maps with the distribution of meteorological elements in Croatia (Kirigin, 1977), and a comprehensive cartography presentation of climate even wider than Croatia is incorporated in the »SFRY Climate Atlas«, which was produced with the participation of numerous climatologists from Zagreb too.

Among the distinct climate elements, precipitation has been investigated most often in this country. Special attention has been given to it by Mohorovičić (1897) and Škreb (1912, 1929b, 1930), and Margetić (1942) in the »Climate of Croatia«. Particular features of the precipitation regime were studied by many other authors. We only mention the study on maximum daily amounts of precipitation linked to prevailing winds (Pleško, 1972; Zaninović, 1987), on position and causes of extremes in the yearly precipitation course in Croatia (B. Penzar and I. Penzar 1979/80, 1981), on the occurrence of muddy rain (Lisac, 1973), on the distribution of hail (Gajić-Čapka and Zaninović 1993a), on pollution of rainwater (Volarić et al., 1975), on the snow

cover (Kirigin, 1957, 1957a), on drought indices (B. Penzar, 1976a), and on variability of precipitation amounts papers of J. Juras (1994, 1997) are unavoidable. In addition to precipitation, there are many studies on the wind, but that is covered in another section of this paper. Further follow data on air temperature (Gačić, 1976; Kovačević, 1942; Milković, 1981; Sliepčević, 1959). Papers on atmospheric pressure were written by Filipčić (1991), Lončar et al. (1994a), Makjanić (1950), Obuljen (1942), B. Penzar (1977) and Volarić (1985), and on humidity by Gilić (1918, 1919).

Investigation on the climate fluctuations in Croatia were initiated by Goldberg (1953, 1954), and continued by Gajić-Čapka (1982, 1990, 1994) together with Zaninović (1993, 1995, 1996), Juras (1985), B. Penzar and I. Penzar together with Volarić (1967) and subsequently with Juras and Marki (1992). Studies on the same subject were performed by Šinik (1981b, 1985) together with Marki (1996), and Sijerković and Pandžić (1991). Recently a special world program was established for observation of the warming trend and weather and climate fluctuation. Croatian Meteorological and Hydrological Service participates in it too. The distribution of climate types in Croatia was elaborated already by Škreb and Goldberg (1942) in the »Climate of Croatia«. Later, other classifications were compiled, and the most recent one is by Volarić et al. (1994). With respect to climate fluctuations and available data, as well as to the station network density, particular classifications differ somewhat between one another. According to the latest study, there are 20 variants of the Koeppen's climate classification in Croatia.

Generally it can be noted that climate descriptions were initially based on simple statistical analyses of measured data, but with time climate analyses and treatment became more complex and reliable. In addition to that, investigations increasingly respect terrain features, global planetary circulation, synoptic weather surveys, as well as surface and upper air weather maps. Other dynamic approaches are applied to research (Pandžić and Kisegi, 1990; Pandžić et al., 1992; B. Penzar, 1974). The association of weather types with climate also has its place among such methods (Kovačević, 1940; B. Penzar, 1963), as well as human comfort feeling in various climates (B. Penzar, 1974a; Zaninović, 1990).

4. Meteorological instruments, measurements and basic data processing

Right from the start of the domestic service and network introduction, Croatian meteorology principals established strict inspection of the instrumentation and even stricter checking and verification of the measured data. They also critically accepted new statistical processing methods and reevaluated their physical justification for application in meteorology and geophysics in general. We find numerous proofs of that in observation manuals and discussions which were published in domestic and international periodi-

cals. Let us remember only the note by A. Mohorovičić to all observers in the year 1902 when the state government of Croatia and Slavonia entrusted him to manage the meteorological stations network. In that note he writes »...Whoever receives this moral duty to record something, let him either record it properly or not write at all. Better nothing than improper. …«

In order to ensure the validity of measured data Mohorovičić checked those himself, and also established an instrument inspection laboratory. He devoted particular attention to the perfection of barometers, so he calibrated them regularly. His successor Škreb published scientific and expert discourses for 20 years (from 1927 to 1947), in which he very critically judged the use of particular criteria, for example by Cornusch (Škreb, 1927), and of wind processing formulae Škreb (1927a), also on the vapour pressure mean (Škreb, 1929), the meanof other elements (Škreb, 1927b) or on the mean in general (Škreb, 1931, 1939). He also supplied the theoretical explanation of the principle of operation of the Sprung-Fuess barograph in 1932. Goldberg (1930) also discussed the climatological mean, as well as the heliograph errors due to its inferior sensitivity to weak morning and evening sunshine (Goldberg, 1933). Maksić (1949a) criticized the reliability of humidity measurements using the psychrometer. He gave a new contribution to the hygrograph theory in 1955 and the theory and implementation of psychrometric tables (Maksić, 1953a). Kirigin (1959) contributed to the reliability of precipitation measurement in the mountainous region. Poje (1987) reflects on remote research in meteorology. The practical methods for the critical inspection and objective analysis of data were also elaborated by Branković (1980).

It is interesting to note that already in the 16th century, within the zone of Croatia, doctor S. Santoro from Kopar, measured Bura gusts, and the temperature and humidity of air exhaled by patients in 1625. He produced the instruments for that purpose by himself.

Automatic meteorological stations are recently being deployed in our country too. Remote measurements have become irreplaceable. Storage of data on computer readable media, data processing and communication are crucial. Instead of publishing yearbooks Internet is used nowadays. Some electronic meteorological instrument were constructed as well.

5. Solar radiation, insolation and illumination

Research efforts in the solar influence domain appear relatively late because heliographic and actinometric measurements commenced significantly after other meteorological measurements.

J. Goldberg (1933a) initiated the study of sunshine duration. Untill now about fifteen papers have been published in this field of research. They deal with the characteristics of sunshine duration in particular locations and for the whole Croatian territory. Various probabilities have been established for

the duration and interruption of insolation (I. Penzar and B. Penzar, 1979, B. Penzar, 1980). Statistical functions of frequency distribution for the daily and monthly radiation values (I. Penzar and B. Penzar, 1984b), and the characteristics of U and J distributions (I. Penzar and B. Penzar 1986) were discussed. The cause of spring sunshine reduction in our climates has been clarified (I. Penzar and B. Penzar 1984c, B. Penzar and I. Penzar 1985,), as well as the insolation reduction in urban locations (Juras and Penzar, 1987). Empirical relations were derived for the stochastic link between the sunshine duration and cloudiness as well as insolation and global radiation (I. Penzar, 1959, 1961). An atlas of sunrise and sunset was produced, for the greater area of Croatia, and also the greatest possible sunshine duration values were calculated (I. Penzar, 1974). Actual insolation duration distributions based on measurements were also prepared (Poje et al., 1984; Vukov, 1972).

Croatian meteorologists have started to study solar radiation from the year 1959. Recently, other experts have joined the application of solar energy – for example physicists (N. Urli, P. Kulišić, J. Vuletin), power engineers (I. Kolin, A. Mihalić-Bogdanić, H. Požar), architects (Lj. Mišetić) and others. A total of 40 papers were published. Some of them contain descriptions of physical and meteorological conditions for the passage of solar energy through the atmosphere above Croatia (Barbaro et al., 1988; Lisac, 1967; I. Penzar, 1966). Others present extraterrestrial value (I. Penzar 1982), extinction of radiation in Rayleigh's and in the real atmosphere is discussed (I. Penzar and B. Penzar, 1984a; I. Penzar, 1977), and the spatial distribution of irradiated energy based on measurement and estimation (B. Penzar and I. Penzar 1960; Žibrat and Gajić-Čapka, 1986). Deterministic and statistical methods of local radiation process modeling were elaborated (I. Penzar and B. Penzar 1991), as well as separation methods of global radiation into the direct and diffuse component onto a plane inclined and oriented in any way (I. Penzar in B. Penzar et al., 1996), The daily amount of radiation onto the most probable radiation course during the day was discussed by Marki and Penzar (1994). The global radiation energy structure for certain energy thresholds has been examined (Penzar and Žic, 1987), as well as the portion of the photosynthetic active radiation (I. Penzar and. B. Penzar, 1984). All data on solar energy are prepared for practical use (Kulišić, 1991; B. Penzar et al., 1996).

Natural illumination has been investigated very inadequately so far. Results were published in only three papers. In the first of those (B. Penzar, 1967) variations of dispersed light measured during the total eclipse of the Sun are considered in order to attain the link between the illumination and the shaded part of the photosphere. In the study by Penzar and Marki (1992) a daily illumination course assessment method was elaborated for clear sky and the results of such an assessment are discussed. Also, a practical method was elaborated for daylight façade and windows illumination estimation,

which is used to establish geometric estimates of shades, lateral protrusions by the windows and canopies on walls for the protection from direct illumination of terraces, balconies and rooms at the time of the greatest daytime heat (Penzar and Marki, 1996).

6. Numerical modeling of atmospheric processes

The development of electronics has in recent decades led to the manufacture of fast and available computers, so their use reached full utilization also in the meteorological research, not only in processing and analysis of the numerous measured data, but also in development of mathematical models which use computers to give answers to many questions. Not all of our authors and all of their models produced so far are listed here. Some of them are mentioned in other parts of this review, for example in sections on the planetary boundary layer, the atmosphere-sea interaction or weather forecasting. Here, we only mention the work performed on modeling of flows (Makjanić, 1963, 1966; Ivančan-Picek, 1986; Mursch-Radlgruber and Kovačić, 1990; V. Vučetić and Bajić, 1994), of transport of polluting substances (Šinik et al., 1983), of numeric simulation of Adriatic cyclones (Brzović and Jurčec, 1997), of local climate modeling of temperature and cloudiness interaction (Šinik, 1992), of thermal comfort (Zaninović, 1983), of wind induced sea currents (Kuzmić and Orlić, 1985), of yearly uncertainty of the summer monsoon onset (Palmen et al., 1992) and others (Juras, 1989, 1990).

7. Analysis and forecasting of weather

We find primary scientific research of weather phenomena in the work by Mohorovičić on a tornado near Novska (1893) and on a whirl wind near Čazma (1898). In the period after the Second World War research of extreme meteorological phenomena included the occurrence of a spout (Poje, 1957; Tutiš and Sijerković, 1985; Ivančan-Picek et al., 1995) and also of very strong wind, primary Bura and Jugo. Meteorological and Hydrological Service publishes the results of research on extraordinary meteorological or hydrological situations within the area of Croatia regularly for the last 20 years in a special edition, where these situations are treated from various points of view – synoptical, climatological, bio-meteorological, ecological, agricultural, etc.

Although the application of air mass analysis has recently lost much in significance, it is worth to point out two papers from the years 1948 and 1952 by Vernić who determined the characteristics of air masses and their application in synoptic analysis. Maksić (1951) contributed his part to the theory and application of gradient wind and the types of gradient flows were also established (Lončar, 1980). Analysis of baric systems in the wider area surrounding our country was the object of research of a number of meteorolo-

gists (Čatlak and B. Penzar, 1977; Jurčec, 1980; Čapka, 1982; Bajić, 1982). The possibility of correlation of various weather states to definite weather types is shown already by Marki (1950), and then by Modrić (1958), B. Penzar (1963) and with the utilization of spectral analysis also by Šinik (1972). Based on the classification of weather types by D. Poje, which has a foundation in the ground level air pressure distribution above Croatia, and which is being performed by the Meteorological and Hydrological Service already for more than 30 years, a statistical analysis was produced of the 20-year weather type calendar for the interior of Croatia, resulting in grouping of these types into 5 categories: radiation, precipitation, wind and advection regime from SE and NW directions. These weather types were applied in ecology research. Ivančan-Picek (1982) investigated the dependence of the monthly mean air temperature in Zagreb on the macro-weather situation.

Croatian meteorologists devoted a great deal of attention to flow analysis and air flow simulation near ground: 11 papers have been published since the year 1981, of which we only mention the review of two numeric methods for the simulation of flow in orographically complex conditions, and which respect the influence of orography, friction and warming up (Bajić, 1993; Ivančan-Picek, 1986 and Ivančan-Picek and Tutiš, 1995). Tutiš (1992) examined wind lee waves and Grubišić (1997) studied a three-dimensional flow model behind an obstruction.

Meso-meteorological weather analyses above certain parts of Croatia were also subject of research by Croatian meteorologists (Gelo, 1985; Sijerković, 1981), particularly in association with a powerful development of meso-scale cyclones above the Adria (Tutiš et al., 1992). This analysis indicated that extensive quantities of precipitation are principally caused in processes of sub-synoptic scale which may not be detected by standard synoptic analyses. The influence of low and high pressure centers on the appearance of precipitation in our regions has been investigated also in relation to general circulation anomalies (Jurčec and Papišta, 1978; Pandžić et al., 1992).

Meteorologists in Croatia have been active in new numeric model development for weather forecasting already since the mid-seventies. This activity begins foremost with the production of a weather forecast model for a limited area (Jurčec et al., 1978), followed by a meso-meteorological precipitation forecast model in developed orography (Gelo, 1988). Glasnović (1983) builds a diagnostic isentropic model for the investigation of atmosphere's vertical structure, which is also applied in other countries and which opened a wide cooperation with meteorologists in Austria, Hungary and France. Bilinski (1948a) was the first to tackle the theoretical and practical problems of weather forecasting, and recently it was Branković (1990), who examined the influence of vertical resolution in a prognostic model for a limited region, proposed diverse methods of critical inspection and objective analysis of meteorological data, specifically of transformed isentropic coordinates, diagnosis of atmospheric general circulation and also weather outlook based on the

European Center For Medium Range Weather Forecast model. It is worth to add that Jurčec (1981) and Glasnović (1995) considered theoretical problems of energy transformation in the atmosphere.

Croatian meteorologists also treated methods of forecasting of particular meteorological elements: frost (I. Penzar, 1957), precipitation in Gorski Kotar (Poje, 1971), various methods of instability forecasting (Lončar, 1969), minimal temperature (Belamarić and Kisegi, 1981), very short-term air temperature forecasting (Čapka and Rebac, 1990) and objective snow-fall forecasting (Kisegi, 1981). Research also encompassed methods for weather forecast successibility (Sijerković and Kisegi, 1994) as well as the forecast of visibility at airports (Nikolić, 1985).

For the sake of completeness, we add that the renown pioneer of European and Croatian science Herman Dalmatin (around 1110 – Feb. 26, 1154), in his volume »Liber imbrium« (book of rains), provides general indications which may serve as a foundation for longer or shorter weather forecasts on rains and showers, for precipitation prediction throughout the year, and also mentions the influence of lunar phases on the weather. Herman puts forth general astrology rules on weather forecasting.

Since the early seventies meteorological satellites get an ever increasing role in regular and research aspects of weather forecasting. In our country problems associated with digital processing of satellite images were treated first by Lipovšćak (1984), and subsequently those on automatic cloud classification (Lipovšćak, 1989). Most recently, satellite images are used extensively for weather forecasting, and research is performed related to the analysis of frontogenesis and frontolysis with the help of a Q-vector combined with satellite pictures (Strelec et al., 1997).

8. Planetary layer and diffusion of air pollutants

Since the seventies of the 20th century, papers on processes in the planetary boundary layer are published more frequently. Related to those are studies of pollution substance spreading through that layer. Such research is important not only from the meteorological, but also from the ecological perspective.

In about fifty papers from that domain published so far, first investigations concern gases diffusion in various conditions (Grisogno, 1990, 1995; Lončar, 1978; Šinik, 1981a; Šinik and Lončar, 1987, 1990), occurrences of turbulence and heat transfer (Koračin et al., 1989; Grisogno et al., 1989), night cooling of the ground layer (Grisogno and Keislar, 1992), surface temperature inversions (Poje, 1971; Šinik and Lončar, 1990a), the stability in that layer (Cividini and Šinik, 1987; Lončar, 1974; Mann and Šinik, 1990). In addition wave drag decline with height (Grisogno, 1995; Grisogono et al., 1995), influence of topography on vertical wind profile (Jurčec and Bajić,

1985), and also on the mixing layer depth (Lončar and Šinik, 1984), and available potential energy (Šinik 1986) are investigated too.

In addition, analysis was performed of the air pollution by various substances (Lončar et al., 1985, 1994; Šinik and Lončar, 1992), of cumulative distribution of substance concentration (Grčić and Šinik, 1984), and of air pollution dependence on prevailing weather types (Lončar and Šinik, 1992). The Gaussian model is verified too (Lončar, 1988), and heavy gases diffusion in air model is refined (Koračin et al., 1985). Trajectories and dispersion of diverse substances ejected into the atmosphere during the Chernobyl disaster are also established (B. Penzar et al., 1987).

9. Eco-meteorology

Pollution of air and precipitation has been a research object of Croatian meteorologists for a long time. Even though first precipitation chemistry measurements were performed already in the fifties (Cindrić, 1960), significant air pollution research is pursued in Zagreb only since the seventies (Bolanča et al., 1974). The extended precipitation and air chemistry measurement station network in Croatia has facilitated the creation of a database for the assessment of the precipitation chemical composition situation, using which many studies have been done. Along with a general presentation of precipitation chemistry measurement results (Poje, 1986a; Klaić and Lisac, 1988, 1989), data were also analyzed as measured on Zavižan and in Zagreb (Bajsić 1982; Šoljić et al. 1991), on Mali Lošinj (Vidič et al., 1994), and along the motorway with respect to influence on quality of subterranean water (Vrhovac et al., 1986). Transport of sulfur dioxide to large distances in Croatia and Slovenia was also studied (Klaić, 1996), as well as the trajectory analysis methods (Bajić, 1997), and a ground level concentration calculation method (Šinik, 1981).

Changes in the ozonosphere have increased interest for the content of ozone also in the lower atmospheric layers: along with the »discovery« of old data on ozone in Zagreb from the end of the previous century (Lisac, 1991), measurements of tropospheric ozone in Croatia were analyzed too (Cvitaš et al., 1995).

10. Wind

Croatian meteorologists dedicated much time and effort to the research of wind. Basic facts on wind are included in the general review on wind and air pressure above Yugoslavia (B. Penzar, 1977), and additionally the characteristics of maximum wind velocities and wind persistence were determined above the territory of Croatia (Poje and Hrabak, 1982; Poje, 1985, 1992). Classical wind roses were also analyzed in a new way (Lisac, 1994). Local

winds in the Adriatic region and in the interior were also studied: sea breeze and Bura (Makjanić, 1959a), land and sea breeze on Brač, Mljet and Kornati (Lukšić, 1997), wind in Split (Stipanović and Brozinčević, 1927; Poje, 1981; Trošić, 1985) and Zagreb (Poje, 1982; Lisac, 1985; Jurčec, 1985), daily periodic winds in Senj (Lukšić, 1989), as well as Bura and Burin in Split (Poje, 1995). Detailed measurements of Bura were also performed on the bridge to the island Krk (Poje and Koračin, 1982; Poje, 1986).

With respect to the significance and proportions of the occurrence of storm winds Bura and Jugo on our Adriatic coast, it is not surprising that so far, most research ensued on theoretical and phenomenological characteristics of these winds (more than 25 papers). Here we can single only some of these papers. After the Bura vertical profile analysis in Split (Poje, 1962) and the work on the basic properties of Bura, Jugo and Etesia by Makjanić (1978) as well as results of the Adriatic Bura research by Japanese meteorologists and during the ALPEX period, the research focus shifts to theoretical interpretations of Bura occurrence, particularly with respect to objective determination of Bura's layer height and application of Smith's hydraulic theory to Bura in Adriatic (Jurčec and Glasnović, 1991). It has been shown that two-dimensional hydraulic theory, as one of strong surface level lee wind mechanisms, may partially explain the occurrence of gale force Bura in Adria. Three-dimensional analysis of cases with strong Bura in Adria, has indicated the necessity of considering wider area, as well as that differences in sustaining strong Bura in north and middle Adriatic exist for situations with strong NW upper winds and a shallow Bura layer (Vučetić, 1993). Understanding of statistical properties of Bura in Adriatic has been improved by results of Bajić (1989) and Brozović (1994). Stormy Jugo research by Jurčec et al. (1996) have shown that before strong Jugo begins, a meso-cyclone forms in northern Adriatic, which can not be discovered by usual synoptic analysis.

By introducing aerology measurements into Croatia in the mid-fifties, free atmosphere properties research became feasible. Very strong winds above our country and the influence of topography on the wind regime were examined (Poje, 1969, 1974), as well as lower troposphere structure based on measurements in Zagreb and Pula in the ALPEX period (Jurčec, 1986). Turbulence in clear air is most important for air traffic, so that phenomenon and its prediction prospects have been studied in our region too (Stanković, 1986).

Wind energy utilization prospects have been investigated for the whole Croatian territory and were found to be most favorable in the northern and central Adria (Poje and Cividini, 1988). Within the Middle-European initiative framework in meteorology, Croatian meteorologists investigated the wind energy potential for the Middle-European atlas in 9 selected locations according to the joint WASP program. The method applied in this program respects the station environment influence on wind measurement and is the basis of the »European wind atlas«. It has also been shown that in locations

with emphasized Bura, the adaptation to the customary Weibull's distribution, does not give realistic results to measured wind frequency data (Poje 1997).

11. Atmospheric moisture

There are only a few studies on atmospheric moisture research in our country. Those which pertain to measurement topics are discussed in the instrumentation section, those significant for climatology in the climate section; here we mention only those which consider moisture independent of other meteorological variables. Maksić (1953) studies synoptic situations with low humidity, Goldberg (1936) investigates theoretical requirements for water vapor condensation, and Maksić (1949) examines the reduced wet bulb temperature and its utilization.

12. Traffic meteorology

Although meteorological data are important for the safety of road, water and air traffic, there are still comparatively few scientific and expert studies on that topic. Among the authors which were so far engaged with it, let us mention Gelo (1994, 1996), Makjanić (1959), Stanković (1986), Gajić-Čapka and Zaninović (1991, 1994), Sijerković et al. (1992), Žibrat and Dvornik (1995) and Tutiš (1997). The work of Makjanić may serve as an example for what kind of climate data an airport study must contain, and discussions by Stanković give information on turbulence in clear air and its consequences for air traffic. Sijerković et al. debate meteorological traffic safety, Gajić-Čapka and Zaninović address meteorological assistance for highway design and minimum surface temperature forecasts, while Žibrat and Dvornik discuss the need for systematic weather monitoring for road traffic safety. Air traffic meteorology is treated in the *scripta* by Tutiš and a comprehensive meteorology discourse for all kinds of traffic is presented in books by Gelo. The safety of sea travel depends on weather conditions at the sea, primarily on winds. Numerous papers concerning that subject are mentioned in other chapters of this review as for example on climatology, naval meteorology, winds, analysis and forecasting of weather etc., so these should be looked up there.

13. Agricultural and forestry meteorology

At the agriculture and forestry faculties in Croatia, meteorology was lectured right from their establishment in the year 1860. The meteorological observatory commenced its operation in 1853. in the chambers of the Agricultural Society of Croatia and Slavonia at the address 18 Opatička Street in Zagreb. Cooperation between these professions has continued to this day. It

is evident in many ways, as for example in that meteorologists lecture at the Faculties of Agriculture, and within the organization of the Meteorological and Hydrological Service (DHMZ) there is an Agrometeorological department which controls its own station network and monitors weather influence on the flora. Such teamwork has generated numerous research studies on the part of meteorologists as well as on the part of agronomists.

In published papers soil temperature is considered by Butorac (1963), Kaučić (1985), I. Penzar (1971, 1978), snow cover by Kirigin (1957, 1957a) and Vukov (1964), frost and low temperature protection by Cindrić (1956), I. Penzar (1957), and Šikić (1956), weather conditions in some anomalous periods due to adverse consequences for vegetation by Capar and Kaučić (1984), Kaučić (1984) and Vajda (1947), precipitation conditions and dryness by Cindrić (1960), Gračanin (1950), I. Penzar and B. Penzar (1976, 1978). Related studies on erosion (Racz et al., 1993), irrigation (Romić et al., 1994) and evapotranspiration (M. Vučetić and V. Vučetić, 1994, 1996a) were also published. Relations between weather conditions and crop are explored too (Šikić, 1960). Influence of weather on particular plant development phases was studied by Pejić et al. (1997), and of climate on vegetation by Bertović (1975). Phenology attributes of particular regions are explored (M. Vučetić and V. Vučetić, 1992a, 1996) as well as agro-climate conditions (Bertović, 1974; Jugo, 1958; Maksić et al., 1968). A group of papers related to the danger and break out of forest fires were published by Dimitrov and Jurčec (1985) and M. Vučetić (1988, 1992). It should be emphasized that the Meteorological and Hydrological Service has organized a special service for fire hazard prognosis in the coastal region during the summer season, and for crop protection from hail in the lowlands region. Hail defense is active during the vegetation period.

14. Hail defense

Earliest organized hail defense in Croatia was pursued by bishop Vrhovac in the year 1824. by installing lightning rods into vineyards at Vugrovac near Zagreb, in order to facilitate discharge of electricity from storm clouds. According to contemporary belief it was considered that hail does not descend if the cloud is not electrically charged. It was however, not yet known at the time that generation of electric charges is a result of the freezing process in the cloud. By discovering artificial nuclei on which cloud droplets freeze and by refining methods of introducing such nuclei into a cloud using rockets, by generating ice-forming nuclei smoke from furnaces on the ground, and also by seeding from airplanes, a routine hail defense evolved in the world, and also in Croatia since the sixties.

Meteorologists who engage in hail defense report on their work and on related topics during various professional gatherings in the country and

abroad. Presentations of particular situations are offered, motion of storm clouds is described, as well as the influence of topography obstacles on cloud trajectories. Radar network is refined and active substances efficiency examined, as well as the Cb cloud structure. Authors of such expert studies are D. Bižić, D. Peti, Z. Gerber, B. Gelo, V. Horvat, I. Huzjak, T. Kovačić, F. Margetić, M. Matvijev, D. Nikolić, D. Počakal and others.

15. Biometeorology

Research of influence of weather conditions on human health and sensation started in Croatia in the late fifties when the first published paper by Dr. Trauner on health resorts and climate of those locations stems (Trauner, 1953, 1959) appeared. Already in the 16th century, physician and cosmographer A. Đurašević wrote about curing of patients born in the climate of Dubrovnik. Opinions exist that the 15th century physician Juraj Išpanić (Georgio Ispano) is the author of that manuscript. Since the mid-sixties, research of weather influence on certain illnesses starts at the Meteorological and Hydrological Service, in cooperation with physicians. Focus of research was initially on pulmonary embolia (Hančević et al., 1965), ulcus perforation (Hančević et al., 1972), and since the start of the eighties on dependence of *infarctus myocardi* and cerebrovascular insult on weather conditions (Pleško et al., 1983, 1983a, 1991). To that end, field research was pursued with larger groups of heart condition patients (Pleško and Grahovac, 1978; Pleško et al., 1991; Zaninović et al., 1992). Results were also published of research into weather factor dependence of suicide incidents and bronchial asthma in children (Pleško, 1985, 1994). Further research fields within human biometeorology, embraced primarily investigations related to the cooling index (V. Stipančić, 1968; B. Penzar, 1974a), and later since the early eighties, topics related to bioclimate characteristics (Zaninović, 1983), the biometeorological index of comfort sensation, for which wind speed was introduced as an innovation, and a new scale produced for that index. Presentations of bioclimate for some cities in Croatia were done using that scale as well as regular monthly reviews in the »Ekobilten« of DHMZ (Pleško et al., 1973; Pleško, 1983, 1985; Zaninović, 1992). Let us add that through medical professional publications, basic weather and climate factors were interpreted in relation to health (Pleško, 1981), tourism (Pleško, 1988), health tourism (Pleško, 1989, 1996) and in a broader sense to atmospheric stability significance as a biotropic factor (Pleško, 1992).

16. Atmosphere-sea interaction

The effect of the atmosphere on the Adriatic Sea was discussed in our country by Gačić et al. (1990), Kasumović (1958, 1959, 1961), Karabeg and

Orlić (1982), Kuzmić et al. (1985), Malčić and Orlić (1993), Orlić (1983, 1984, 1995), Orlić and Jeftić (1981), Orlić and Kuzmić (1985), Orlić and Pasarić (1994), Pasarić and Orlić (1992, 1997) and B. Penzar et al. (1980).

Our meteorologists also published papers on research at seas outside Adriatic (Enger and Grisogono, 1997; Palmen and Branković, 1989; Smedman et al., 1997).

Fair amount of discussion was also dedicated to the effect of the sea on the atmosphere, mostly regarding coastal air circulation, but that is referred to in the chapter on the wind.

17. Atmospheric thermodynamics

Papers on dynamic and thermal processes in the atmosphere are not separately defined. However, there are some which best fit this group by their content. Those are the ones describing thermodynamic properties of air masses (Vernić, 1952), dynamic instability in the troposphere (Labović, 1965), dynamic processes in Cb (Bilinski, 1948), and hydrodynamic effects on rotation of solid bodies in fluid (Kempni, 1941).

18. Atmospheric electricity

Investigation of the planetary electric field in Croatia is not systematically performed. Among the meteorologists, only B. Volarić engaged in that domain and published two papers. In the first she elaborated the lightning manifestations in Zagreb (B. Peko-Kačić, 1955), and in the other, variations of the Earth's electric field intensity during the total eclipse of the Sun on February 15, 1961 (Volarić, 1967).

19. Research within the framework of science-research projects

The organized science-research work was performed at the Geophysical Institute since the very beginning of fundamental and exact research of the atmosphere, litosphere and hydrosphere, astronomy and astrophysics, and also geodesy, and that means since 1964. There were numerous projects, as for example research of weather and climate, radiation balance, hygric conditions, physical structure and climate properties of winds in Adriatic, meteorology preconditions for solar energy usage, recent climate instabilities, interaction of the atmosphere and the sea, physical processes in the atmosphere and the sea, physical foundation of atmospheric processes in Croatia and alike. Individuals have also participated in other scientific endeavors either at the Institute, or in other institutions. The result of such research has become apparent in an increase of scientific paper production, in ever more frequent participation at domestic and international conferences, in publishing

of presented reports mostly »in extenso« within the related proceedings, as well as in establishing new professional ties and joining numerous interdisciplinary research assignments. Part of the financial support has been invested in acquiring of foreign professional periodicals, books and textbooks. Some funds have been spent on the new instrumental equipment, and for the maintenance of existing ones and for the replenishment of consumable material. Authors rewards were more than symbolic.

Scientific research in meteorology subjects has been pursued since the late sixties at the Meteorological and Hydrological Service, principally within the framework of science-research projects partially financed by the Science SIZ and Science Ministry. In the year 1968 a science-research unit was formed within the Institute, which was entered, at the beginning of the year 1970, into the institutions register of the former Republic Council For Scientific Work (since the year 1976 it is the Meteorology Research Center of the Hydrometeorological Institute). With the establishment of a postgraduate curriculum at the Geophysical Institute, conditions were created for further scientific education of meteorologists, so in the last 37 years the scientific grades Master of Science and Doctor of Physical Sciences were awarded to a significant number of meteorologists who were anxious to perform scientific work or develop their expertise in meteorology. Although State financing of scientific projects never was such as to provide a solid material base for operation or acquisition of suitable equipment for scientific research, the assembling of meteorologists into research teams nevertheless resulted in a large number of scientific papers of which some attained international significance.

In the interval 1972–1975 a total of three projects were funded (»Energy Balance of Ground Layer Atmosphere«, »Meteorology Forecast of Dry Periods«, »Hydrological Prognosis of Low Waters«). For the interval 1976–1980 we note five projects as follows: »Investigation of Weather and Climate above the Area of SR Croatia«, »Numeric Weather Forecasting«, »Space-Time Climate Variations«, »Wind Regime in SR Croatia«, »Distribution of Coarse-dispersed Particles«, and in the year interval 1981–1985 the following projects were active: »Research and Development of Solar Energy Utilization«, »Atmosphere and Air Pollution Exploration«, »Exploration, Utilization and Advancement of Adriatic Sea« (subproject »Weather And Climate Characteristics of the Adriatic Region«), »Emergence and Progression of Frequent Degenerative, Chronic and Tumor Diseases«. In the interval 1986–1990 the number of projects which involved meteorologists rose to seven, namely: »New Energy Sources« (subproject »Wind Energy«), »Geophysics« (project objective »Physical Foundations of Weather and Climate«), »People's Defense and Social Self-protection« (subproject »Meteorology and Hydrology Elementary Disasters«), »Environment Ecology Research and Environmental Protection« (subprojects »Exploration and Environmental Protection of the Continental Zone of SR Croatia« and »Exploration and Protection of Adriatic«),

»Research of Chronic and Degenerative Disease Ethiopathogenesis as well as Diagnostics and Cure Advancement« (task »Study of Meteorology Conditions Influence on Cerebrovascular Ailment Appearance«). In the new Croatian state in the years 1991–1995 meteorologists from the Institute participated in eight projects. They are: »Observation of Croatian Climate within Global Climate Change«, »Storms and Natural Catastrophes in Croatia«, »Exploration of Wind Energy Potential«, »Atmospheric Processes and Air Quality«, »Weather and Climate Influence on Human Health«, »Meteorological and Hydrological Adverse Weather Conditions«, »Mesometeorological Process Modeling », »Multi-lingual Geophysical Glossary«. In the most recent years (1996–1998) Institute's meteorologists are involved in the projects »Long Term Weather and Climate Forecasting at the Adriatic-Panonian Profile« and »Multi-lingual Meteorological Glossary«. We point out that a certain number of listed projects was carried out in cooperation with the scientists of the Geophysical Institute.

Although meteorologists in Croatia participated with their studies at numerous international conferences and symposia soon after the end of the Second World War, their participation should be singled out at the Conferences for Alpine and Carpathian Meteorology, one of which was hosted by Croatia. Exchange of scientific observations and discoveries in such gatherings has significantly contributed to the creation of numerous contacts with foreign meteorologists and the presentation of Croatian meteorology in the world.

Meteorologists in Croatia gave their contribution to the realization of large international projects of atmosphere research within the framework of the »International Geophysical Year« (1957–1958), »International Quiet Sun Year« (1964–1965), and the »Alpex« project in the year 1982, when numerous and very extensive supplemental measurements and investigations of the atmosphere were performed on Croatian territory. Croatian meteorologists participated also in the international project GARP/GATE in 1974, and the research of Bura in Adriatic which was conducted in the early seventies by Japanese meteorologists. We point out the international project »Bura in Adriatic« (years 1987–1989), and in the year interval 1991–1994 the project »Nature and Theory of Strong Stormy Buras«, both in cooperation with scientists from USA and Slovenia. Within the framework of cooperation on the project »Mid-European Meteorology Initiative«, participation ensues within the framework of the project »Wind and Wind Potential in Middle Europe«, where alongside Croatia, Austria, Czech Republic, Hungary, Slovakia and Slovenia also participate. Since the middle of the year 1995 Croatian meteorologists participate in the international project COST 75 which treats the application of radars in meteorology and their networking. In the project to develop meso-scale numerical models for weather forecasting »ALADIN«, which France launched in the year 1990, Croatia participates actively in addition to many European countries. Croatian meteorologists also cooperate in the Meso-scale Alpine Program »MAP«, in which all the Alpine zone countries,

Canada and USA take part, and whose goal is the solution of numerous problems linked to weather and climate in the mountainous regions of Middle Europe.

Respective project research results are published, as already mentioned, at many international conferences and congresses as well as in the scientific and professional periodicals. We have considered some of these papers in the review of particular meteorological categories, because detailed description of specific projects would cross the boundaries of this review. All studies on meteorological research which were published in the years 1947–1976 are listed in two »Meteorological Bibliographies of Yugoslavia«, and we hope that such a Croatian »Meteorological Bibliography« for the period after the year 1976, will be produced in foreseeable time.

20. Other publishing activities

In addition to the mentioned activities, the Meteorological and Hydrological Service regularly publishes, already through over 20 years, a special publication with a presentation of extraordinary meteorological and hydrological conditions in Croatia. Practically all structures of the Institute participate in its production, from Climatology, Agro-meteorology, Synoptics, Hydrology to Hail Defense. That publication presents case studies of specific unusual weather phenomena and gives expert explanations on causes that invoked the phenomenon. We find presentations of drought periods or the ones with excess rainfall, and also with too high or too low temperatures in particular years. Further, cases of summer thunderstorms with hail are described, of winter gale winds Bura and Jugo at the sea, of weather conditions during forest fires, of consequences of bad weather on crop and agriculture, on moisture in the ground, on water levels, on biometeorology effects and alike.

Except in the above-mentioned publication, meteorologists report on exceptional atmosphere occurrences also at scientific-professional gatherings as for example those on adverse weather conditions, on waters, on health and other (Sijerković, 1985; Čapka and Sijerković, 1995).

Further, measurement results were published in in-house publications of the Geophysical and Hydrometeorological Institutes. These are various yearbooks, reports, edited material for climate presentations, observation instructions, numerous studies and discourses, project descriptions and similar. Here, we shall refrain from presenting that material in detail.

Meteorologists published scientific and professional studies in the periodicals of the Geophysical Institute, and also of the Hydrometeorological Institute. The former were titled »Papers« and subsequently »Geofizika«, while the DHMZ periodicals were titled »Papers« then just »Discussions« and in the recently »Croatian Meteorological Journal«.

We add that meteorologists have written numerous articles on meteorology, climatology and meteorological instruments in encyclopedic and other reference editions of the Lexicographical Institute (LZ) and elsewhere. Here we denote the LZ General Encyclopedia, Encyclopedia of Yugoslavia, Nautical Encyclopedia, Technical Encyclopedia, Encyclopedia of Forestry, Encyclopedia of Agriculture, LZ General Lexicon, Croatian Lexicon, Croatian Biography Lexicon, Croatian Encyclopedia from 1939 to 1944, and the glossary »Our Homeland« 1943.

Concluding remarks

Although the meteorology in Croatia started to evolve in the middle of the nineteenth century, only a few individuals were engaged in research for the first hundred years. Among them Mohorovičić, Škreb and Goldberg hold pioneering places. After the beginning of the regular postgraduate study at the Faculty of Science, University of Zagreb, the number of researchers increased at both meteorological institutions *i.e.* at Geophysical Institute and at the State Hydrometeorological Institute. Their research encompass nearly all fields of meteorology, results are published primarily in domestic journals and in recent times more and more in the international journals and in numerous proceedings of scientific symposia. An ever increasing number of University textbooks as well as some professional meteorological books are being recently published. However, no complete bibliography of published meteorological papers after the year 1987 has been made.

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SAŽETAK

Osvrt na meteorološka istraživanja u Hrvatskoj do 1997.

Ivan Penzar i Dražen Poje

Pregled meteoroloških istraživanja izrađen je na osnovi objavljenih znanstvenih i stručnih radova. Tematski su radovi svrstani u 19 skupina: knjige, mjerenja i obrada podataka, sunčana energija, numeričko modeliranje, analiza i prognoza vremena, planetarni granični sloj, ekološka problematika, klimatološki radovi, istraživanje vjetra i vlage u zraku, prometna i poljoprivredna meteorologija, obrana od tuče, biometeorologija, međusobno djelovanje atmosfere i mora, atmosferski elektricitet, povijest meteorologije, istraživački projekti i ostale djelatnosti. Unutar svake skupine navode se glavni problemi istraživanja i postignuti rezultati na osnovi odabranih radova, koji se navode u popisu literature. Taj popis dakle ne sadrži cjelokupnu bibliografiju meteoroloških radova dosad objavljenih u Hrvatskoj. Ipak se nastojalo obuhvatiti sve autore s nekoliko njihovih djela, da se dobije uvid čime su se pojedinci bavili i koji je njihov doprinos. Vidljivo je da su prvi meteorološki radovi na hrvatskom počeli izlaziti sredinom 19. st., a najveći broj radova da je objavljen u posljednjih 50 godina. To se poklapa s razvojem struke i meteoroloških institucija: Geofizičkog zavoda Andrija Mohorovičić i Državnog hidrometeorološkog zavoda.

Ključne riječi: meteorološka istraživanja, Hrvatska, publikacije

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