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PRAĆENJE I OCJENA KLIME U 2021. GODINI  
CLIMATE MONITORING AND ASSESSMENT FOR 2021



DRŽAVNI HIDROMETEOROLOŠKI ZAVOD  
CROATIAN METEOROLOGICAL AND HYDROLOGICAL SERVICE

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## PREDGOVOR

Globalna srednja temperatura zraka za 2021. godinu bila je  $1.11 \pm 0.13^{\circ}\text{C}$  iznad prosjeka za predindustrijsko referentno razdoblje 1850. – 1900. što je svrstava između pete i sedme najtoplje godine na globalnoj razini (WMO, 2022). U analizi je korišteno šest skupova podataka i svi pokazuju da je posljednjih sedam godina, od 2015. do 2021., bilo sedam najtopljih godina od kada postoje mjerena. 2021. godina bila je manje topla od nekih posljednjih godina zbog utjecaja umjerenih pojava La Niña na početku i kraju godine. La Niña ima privremeni učinak hlađenja na globalnu srednju temperaturu zraka. Godina 2016. koja je započela tijekom snažnog El Niño (ekvatorijalno područje pozitivnih anomalija površinske temperature Tihog oceana) ostaje najtoplja godina od kada postoje mjerena u većini analiziranih skupova podataka.

Velika područja s ukupnim količinama oborine u 2021. godini iznadprosječnim u odnosu na referentno razdoblje 1951. – 2000., bila su: istočna Europa, jugoistočna Azija, tzv. Maritimni kontinent (između ostalih zemalja uključuje Indoneziju, Filipine i Papua Novu Gvineju, smještene između Indijskog i Tihog oceana, unutar tople oceanske regije poznate kao Tropski topli bazen), područja na sjeveru Južne Amerike i dijelovi jugoistoka Sjeverne Amerike. Velike regije s manjkom oborine u odnosu na spomenuto referentno razdoblje, uključivale su: jugozapadnu Aziju, Bliski istok, dijelove južne Afrike, južne Južne Amerike i područja u središnjoj Sjevernoj Americi. Dok su u dijelovima istočne Europe i oko Crnog mora pale neuobičajeno velike količine oborine, vrlo malo ih je bilo na području oko Sredozemnog mora. Zapadnu Europu su 2021. godine zadesile neke od najvećih zabilježenih poplava sredinom srpnja. Najviše je pogodeno područje zapadne Njemačke i istočne Belgije, gdje je u razdoblju 14. – 15. srpnja palo 100 – 150 mm oborine na već vodom zasićeno tlo, pa je to uzrokovalo poplave i klizišta. Hagen (Njemačka) izvijestio je o 241 mm oborine u 22 sata.

Površinska temperatura zraka na Arktiku rasla je barem dva puta brže od globalnog prosjeka od 1980-tih do danas, dok se u istom razdoblju smanjivao ledeni pokrivač Grenlanda, a temperatura permafrosta je rasla. Navedeno je imalo utjecaj ne samo na arktičke ekosustave nego i na globalne klimatske promjene preko različitih mehanizama povratne sprege.

Godina 2021. bila je vrlo topla na 24.3% teritorija Republike Hrvatske, topla na 74.4% teritorija, dok je samo 1.3% teritorija svrstano u kategoriju normalno. Oborinske prilike su bile normalne na 90.3% teritorija, dok je na 6.8% teritorija bilo sušno, a na 2.8% kišno.

Na području Hrvatske 2021. godinu obilježile su i ekstremne vremenske prilike. Prodor hladnog zraka preko sjeverne i središnje Europe uzrokovao je nagli pad temperature zraka početkom travnja 2021. godine. Na mnogim meteorološkim postajama kontinentalnog dijela Hrvatske 7. i 8. travnja 2021. zabilježen je vrlo hladan dan s minimalnom dnevnom temperaturom zraka nižom od  $0^{\circ}\text{C}$ . Na nekim postajama minimalna dnevna temperatura zraka bila je niža i od  $-13^{\circ}\text{C}$ . Bilo je svježe, ujutro sa slabim do umjerenim mrazom u unutrašnjosti i dijelu sjevernog Jadrana. U nekim voćnjacima štete na pojedinim kulturama poput trešnje, šljive i marelice bile su u rasponu od 90 do 100%. Ukupna šteta je procijenjena

## PREFACE

The global mean air temperature for 2021 was  $1.11 \pm 0.13^{\circ}\text{C}$  above the 1850 – 1900 average. The six data sets used in the analysis place 2021 between the fifth and seventh warmest year on record globally, and all six show that the most recent seven years, 2015 to 2021, were the seven warmest years on record (WMO, 2022). The year 2021 was less warm than some recent years due to the influence of moderate La Niña events at the start and end of the year. La Niña has a temporary cooling effect on the global mean temperature. The year 2016, which started during a strong El Niño (equatorial region of positive anomalies of the surface temperature of the Pacific Ocean), remains the warmest year on record in most of the analysed data sets.

In 2021, above-normal precipitation totals in relation to the reference period 1951 – 2000 was recorded in eastern Europe, southeast Asia, the Maritime Continent (including Indonesia, the Philippines, and Papua New Guinea, among other countries, and located between the Indian and Pacific Oceans, within the warm oceanic region known as the Tropical Warm Pool), parts of northern South America, and parts of south-eastern North America. In contrast, rainfall deficit in relation to the same reference period was observed in southwest Asia and the Middle East, parts of southern Africa, parts of southern South America, and areas in central North America. While unusually high totals were detected around the Black Sea and in parts of Eastern Europe, unusually low precipitation amounts fell around the Mediterranean Sea. In mid-July 2021 western Europe experienced some of its most severe flooding on record. The worst affected area was western Germany and eastern Belgium, where 100 to 150 mm fell over a wide area on 14 – 15 July over already saturated ground, causing flooding and landslides. Hagen (Germany) reported 241 mm of rainfall in 22 hours.

Since the mid-1980s, the Arctic surface air temperature has warmed at least twice as fast as the global average, while the Greenland ice cover has declined in the same period, and permafrost temperature has increased. This had large implications not only for Arctic ecosystems but also for the global climate through various feedbacks.

The year 2021 was very warm in 24.3% of the territory of the Republic of Croatia, warm in 74.4% of the territory, while only 1.3% of the territory was classified as normal. Precipitation conditions were normal in 90.3% of Croatian territory, while 6.8% experienced dry, and 2.8% experienced wet conditions.

Extreme weather events were also characteristic of the year 2021. An inflow of cold air over northern and central Europe caused a sudden drop in air temperatures in early April 2021. Many continental meteorological stations in Croatia registered a very cold day on 7 and 8 April 2021, with the minimum daily air temperature below  $0^{\circ}\text{C}$ , and as low as  $-13^{\circ}\text{C}$  in some stations. It was cool, with light to moderate frost in continental Croatia and parts of northern Adriatic in the morning. Damage to crops such as cherries, plums and apricots ranged between 90% and 100% in some orchards. Total damage was estimated to around 4 million kunas. Several counties declared a state of natural disaster. On the afternoon of 25 June 2021, Požega was hit by a strong thunderstorm that caused grave damage to property, mostly due to hail: in some locations, hailstones were estimated to be as large as an egg (up to 5 cm in diameter). Hailstones of this size point to a terminal fall velocity

na oko 4 milijuna kuna. Nekoliko županija proglašilo je prirodnu nepogodu zbog mraza. Područje Požege je 25. lipnja 2021. u poslijepodnevnim satima bilo pogodeno snažnim grmljavinskim nevremenom koje je uzrokovalo veliku materijalnu štetu, ponajviše zbog tuče koja je ponegdje bila i veličine jajeta (promjer do 5 cm). Zrnatе veličine upućuju na brzinu pada tuče oko 145 km/h. Oštećene su mnoge zgrade, voćnjaci i vrtovi, a akumulacija tuče na tlu bila je tolika da se led morao čistiti s prometnica. Grad i županija proglašili su prirodnu nepogodu. Snažno olujno nevrijeme praćeno jakom kišom izazvalo je bujične poplave u dijelu Slavonije i Baranje 17. i 18. srpnja 2021. Slična situacija bila je 17. srpnja i u drugim dijelovima Europe, posebice u Njemačkoj, Austriji, Belgiji i Luksemburgu gdje su se dogodile katastrofalne bujične poplave. Obilne količine oborine pale su 16. srpnja, a zatim je Osječko-baranjsku i Vukovarsko-srijemsku županiju 17. srpnja zahvatilo snažno olujno nevrijeme te je u kratkom vremenu palo preko 90 litara kiše po četvornom metru zbog čega su angažirane sve raspoložive službe spašavanja i zaštite od poplave. Velike količine kiše u Osijeku izazvale su zastoj tramvajskog prometa, oštetile su i velik broj prodajnih kućica na osječkoj tržnici kao i unutarnje prostore tržnice kojoj je uništen krov. Objavljeno je da štete za Vukovarsko-srijemsku županiju iznose oko 600 milijuna kuna. Na našičkom području poplavljeni su domovi i podrumi, cestama su tekli potoci vode, a u podvožnjacima su bili zarobljeni automobili. Dijelovi Našica ostali su bez struje. Izlili su se kanali, a na ceste je nanesen mulj, granje, kamenje i šljunak. Oštećene su brojne kuće, a stradali su i usjevi. Ukupna šteta procijenjena je na oko 1 milijun kuna. Na području Županije i Bošnjaka zbog obilne oborine poplavljene su ulice, kuće, okućnice, industrijski i trgovački objekti. Uništeni su i brojni usjevi. Istok Slavonije je 18. srpnja pogodila snažna tuča praćena olujnim vjetrom koji je uništilo gotovo sve parcele zasađene kukuruzom i sunčokretom. Rekordnu dnevnu količinu oborine zabilježila je postaja Županja (182.9 mm, 20. srpnja 2021.), što predstavlja najveću dnevnu količinu oborine otkad postoje mjerenja na toj postaji. Prvog kolovoza 2021. godine olujno nevrijeme je zahvatilo dio središnje Hrvatske, a najveće štete nastale su na Banovini i u Moslavini. Olujni vjetar je čupao i lomio stabla, nosio crijepl s krovova. Sa škole u Kutini odnesen je cijeli krov. Među oštećenim objektima našla se i crkva svetog Lovre u Petrinji. Oštećena je elektro mreža pa je bilo i nestanka struje. Štete je bilo na poljima i u voćnjacima. I u dijelovima Zagrebačke županije bilo je izvješća o srušenim stablima na cestama, te o oštećenim električnim stupovima i vodovima. Područje Osječko-baranjske županije također je zahvatilo nevrijeme koje je uzrokovalo poteškoće u prometu i prekide u opskrbi električnom energijom i štete na plastenicima. Olujnim nevremenom pogodjena je i Istra. U središnjoj Istri olujni vjetar rušio je stabla na automobile i kuće. U središnjem dijelu Istre, kod naselja Žužići, uočena je pjavica.

of about 145 km/h. Many buildings, orchards and gardens sustained damage. The accumulation of hail on the ground was so large that the ice had to be cleared from the roads. The town and county declared a state of natural disaster. A heavy rain caused flash floods in parts of Slavonia and Baranja on 17 and 18 July 2021. Other parts of Europe, particularly Germany, Austria, Belgium and Luxembourg, were also hit by catastrophic flash floods on 17 July. After heavy rain on 16 July, Osijek-Baranja and Vukovar-Srijem counties were hit by a severe weather on 17 July, with more than 90 litres of rain per square meter falling over a short time. All available emergency responders had to be dispatched to the area. Tram traffic in Osijek was halted due to heavy rain, and several booths were damaged at the farmers' market in Osijek, along with the interior of the market's main building, whose roof was torn off. Damage totalling to around 600 million kuna was reported in the Vukovar-Srijem County. Homes, basements and roads were flooded in Našice area, and cars were reported to have gotten stuck under flooded underpasses. Parts of Našice experienced a power outage. Canals overflowed, roads were contaminated by mud, tree branches, stones and gravel, and many houses and crops were damaged. The total damage was estimated to around 1 million kuna. Streets, houses, backyards, and industrial and commercial buildings were flooded in Županja and Bošnjaci area due to heavy rain, and there was serious crop damage in the area as well. A heavy hailstorm hit eastern Slavonia on 18 July, accompanied by strong wind that destroyed almost the entire maize and sunflower crops in the area. The climatological station Županja recorded the highest daily precipitation amount for July 2021 (182.9 mm, 20 July 2021), also the highest daily precipitation amount on record for mentioned station. Parts of central Croatia were hit by severe weather on 1 August 2021, with Banovina and Moslavina sustaining the worst damage. Trees were uprooted and broken, and tiles dislodged from roofs by strong wind. A school in Kutina lost its entire roof. The St. Lawrence Church in Petrinja sustained damage. The area experienced a power outage due to the wind blowing down utility poles. Fields and orchards sustained damage as well. There were reports of trees falling across roads, and damaged utility poles and cables, in the Zagreb County. The severe weather caused disruptions in traffic and in the power supply in the Osijek-Baranja County and destroyed a number of plastic greenhouses. Istria was hit by a severe weather, with strong wind bringing trees down on cars and houses in central Istria. A waterspout was spotted near the village of Žužići in central Istria.

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# SADRŽAJ

1.	Praćenje klime u Hrvatskoj .....	9
1.1	Kartografski prikaz mjesecnih, sezonskih i godišnjih klasa anomalija temperature zraka i količine oborine za 2021. godinu .....	12
1.2	Ocjena toplinskih i oborinskih prilika za 2021. godinu .....	21
1.3	Ekstremna klimatska razdoblja u 2021. godini .....	24
1.4	Rangovi temperature i oborine u 2021. godini .....	25
2.	Analiza srednjeg mjesecnog visinskega strujanja za Hrvatsku u 2021. godini .....	34
3.	Analiza rangova i trendova srednjih godišnjih temperatura zraka i godišnjih količina oborine za postaje Zagreb-Maksimir i Split-Marjan u 2021. godini .....	41
4.	Analiza dnevnih anomalija temperature zraka i količine oborine za postaje Zagreb-Maksimir i Split-Marjan u 2021. godini .....	44
5.	Izvanredni meteorološki događaji u Hrvatskoj u 2021. godini .....	47
5.1	Grmljavinsko nevrijeme u široj okolini grada Požege 25. lipnja 2021. ....	47
5.2	Poplava u Slavoniji u srpanju 2021. godine .....	55
5.3	Nevrijeme s olujnim vjetrom u središnjoj Hrvatskoj i Istri 1. kolovoza 2021. ....	61
6.	Ocjena klime na globalnoj ljestvici za 2021. godinu .....	65
6.1	Površinska temperatura zraka .....	65
6.2	Oborina .....	66
6.3	Koncentracije stakleničkih plinova .....	68
6.4	Pohrana topline u oceane i porast morske razine .....	69
6.5	Artik .....	69
6.6	Literatura .....	70

# TABLE OF CONTENTS

1.	Climate monitoring in Croatia .....	9
1.1	Maps of monthly, seasonal and annual anomaly classes of air temperature and precipitation amounts in 2021 .....	12
1.2	Assessment of climate anomalies in 2021.....	21
1.3	Extreme climate periods in 2021 .....	24
1.4	Temperature and precipitation ranks in 2021 .....	25
2.	Analysis of mean monthly upper-level flow regimes in Croatia in 2021 .....	34
3.	Analysis of mean annual air temperature and annual precipitation amount ranks and trends for Zagreb-Maksimir and Split-Marjan stations in 2021 .....	41
4.	Analysis of mean daily air temperature anomalies and precipitation amounts for Zagreb-Maksimir and Split-Marjan stations in 2021 .....	44
5.	Extraordinary meteorological events in Croatia in 2021 .....	47
5.1	Thunderstorm in the wider area of the town of Požega on 25 June 2021 .....	47
5.2	Flood in Slavonia in July 2021 .....	55
5.3	Severe weather in central Croatia and Istria on 1 August 2021 .....	61
6.	Climate assessment for the year 2021 on global scale .....	65
6.1	Surface air temperature .....	65
6.2	Precipitation .....	66
6.3	Greenhouse gases concentrations .....	68
6.4	Ocean heat content and sea level rise .....	68
6.5	The Arctic .....	69
6.6	References .....	70



## 1. PRAĆENJE KLIME U HRVATSKOJ

U okviru mreže meteoroloških postaja u Hrvatskoj djeluje sustav za praćenje klime temeljen na svakodnevnom prikupljanju klimatoloških podataka (termini 7, 14 i 21 sat) s 30 glavnih meteoroloških postaja (slika 1.1).

Operativni sustav praćenja klime u Hrvatskoj ima sljedeće komponente:

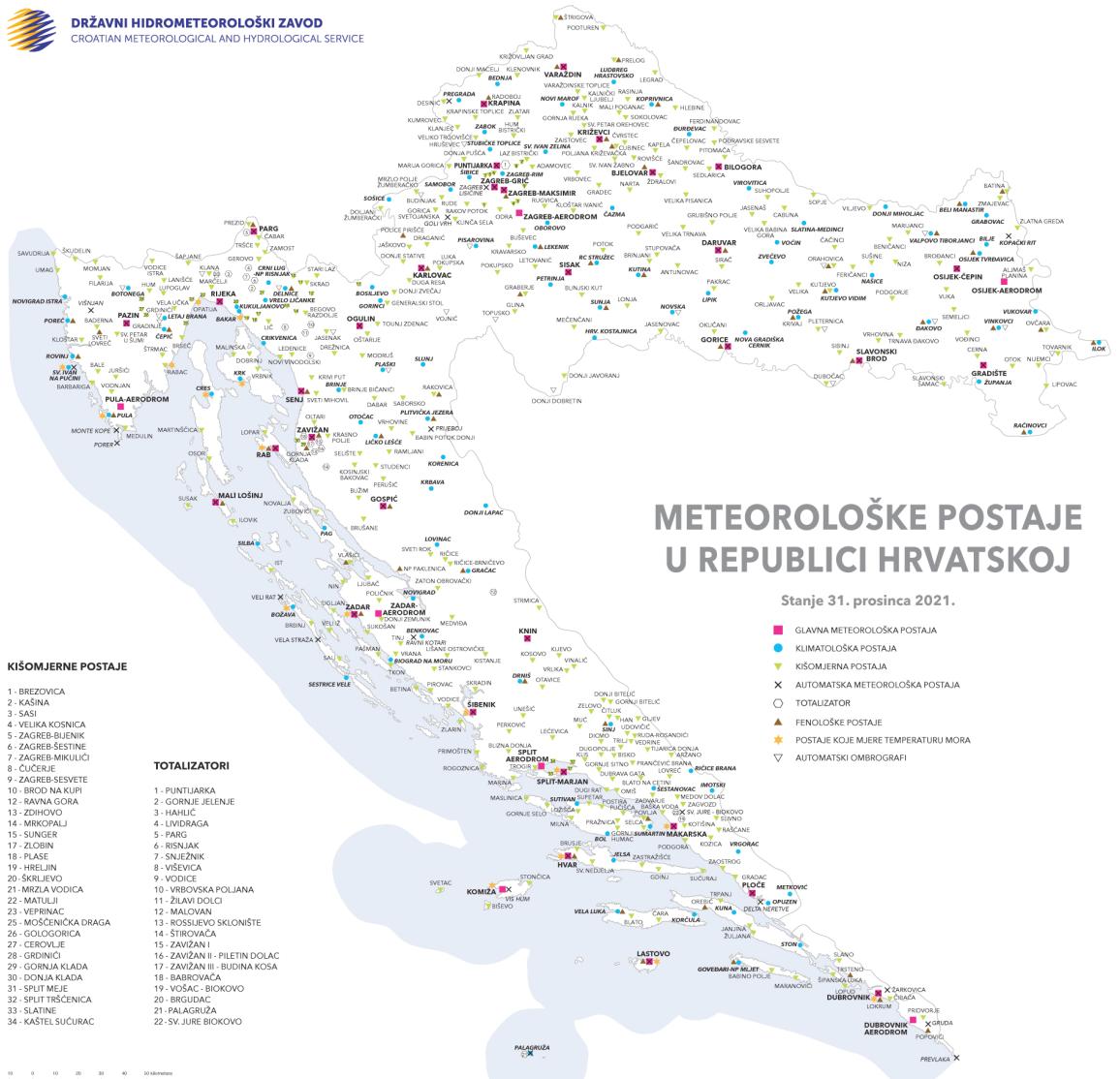
- meteorološka motrenja (opazanje i mjerjenja) na 30 glavnih meteoroloških postaja;
- dostava klimatoloških podataka pomoću HR-KLIMA izvješća svaki dan do 9 sati za klimatološke termine prethodnog dana;
- kontrola podataka u DHMZ-u;
- pohranjivanje podataka na računalnom sustavu DHMZ-a u obliku privremenih mjesecnih izvješća;
- mjesечne analize klimatoloških podataka s izradom ocjene za svaki mjesec usporedbom klimatoloških podataka dotičnog mjeseca s više-

## 1. CLIMATE MONITORING IN CROATIA

A climate monitoring system based on daily collection of climate data (observation times 7 am, 2 pm and 9 pm local time) from 30 main meteorological stations (Figure 1.1) is operational within the Meteorological Station Network of Croatia.

These are the components of the operational climate monitoring system in Croatia:

- meteorological observations at 30 main meteorological stations;
- climate data delivery via HR-KLIMA reports by 9 a.m. every day for climate observation hours or terms from the previous day;
- data quality control at the Meteorological and Hydrological Service of Croatia;
- data archiving in the computer system of the Meteorological and Hydrological Service of Croatia in the form of temporary monthly reports;



Slika 1.1 Mreža meteoroloških postaja u Hrvatskoj

Figure 1.1 Meteorological Station Network in Croatia

- godišnjim prosjekom za razdoblje 1981. – 2010. godina;
- ocjene klimatskih anomalija na razini godišnjih doba i godine kao cjeline;
  - redovito mjesечно, sezonsko i godišnje izvješćivanje javnosti, korisnika i stručnih krugova o ocjeni klime putem javnih glasila i stručnih biltena te internetske stranice DHMZ-a (<http://meteo.hr/klima.php>) i na službenom twitter profilu (@DHMZ\_HR).

Za klimatsku ocjenu koristi se klasifikacijska skala s granicama određenim prema vrijednostima 2., 9., 25., 75., 91. i 98. percentila dobivenih iz teorijskih razdioba koje na najbolji mogući način aproksimiraju osnovna obilježja svih podataka referentnog razdoblja (tablica 1.1).

Za ocjenu temperaturnih prilika korištena je aproksimacija podataka temperature normalnom razdiobom, a za ocjenu oborinskih prilika korištena je normalna razdioba drugim korijenom (Cindrić i sur. 2019). Na osnovi tako dobivenih razdioba moguće je svakoj izmjerenoj vrijednosti pridružiti odgovarajuću teorijsku kumulativnu čestinu ili percentil koji možemo interpretirati kao rang (ili redni broj mjesta) koji bi ta vrijednost imala u hipotetskom nizu od sto vrijednosti skupa koje ta razdioba opisuje. Pomoću percentila P može se procijeniti povratni period T (izražen u godinama) iz relacije:

$$T = 100 / P \quad \text{ako je } P < 50$$

$$T = 100 / (100 - P) \quad \text{ako je } P > 50$$

Primjerice, 98. percentil ukazuje na onu vrijednost koja je u višegodišnjem razdoblju premašena u 2% slučaja i može se očekivati prosječno jednom u 50 godina.

- monthly analysis of climate data with the evaluation of each month based on a comparison of climate data for the month in question with the multiannual average for the period 1981 – 2010;
- climate anomalies assessment on seasonal or annual basis;
- regular monthly, seasonal and annual reporting for the public, external users and the scientific community on climate assessment using media and professional newsletters as well as the website of the Meteorological and Hydrological Service (<http://meteo.hr/klima.php>) and official twitter account (@DHMZ\_HR).

A classification scale is used for climate assessment with the limits determined according to the following percentile values: 2<sup>nd</sup>, 9<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup>, 91<sup>st</sup> and 98<sup>th</sup> (Table 1.1).

They are obtained from theoretical distributions which best fit the reference period data: normal distribution for temperature and square-root-normal distribution for precipitation (Cindrić et al. 2019). For each measured value, the theoretical cumulative frequency and percentiles can be estimated. Percentile can be interpreted as a rank value in a hypothetical sequence of 100 data. According to percentile P, the return period (expressed in years) can be estimated from the expression:

$$T = 100 / P \quad \text{if } P < 50$$

$$T = 100 / (100 - P) \quad \text{if } P > 50$$

For example, 98<sup>th</sup> percentile is the value which is exceeded by 2% of the values and it is associated with a 50-year return value.

In addition to displaying percentiles at meteorological station locations, it is important to estimate values throughout the territory, even at locations where there are no measurements. Those values are calculated as a weight-

Tablica 1.1 Klasifikacija klimatskih anomalija u razrede (klase) prema razdiobi percentila.

Table 1.1 Climate anomaly classification according to percentile ranks and classification ratings.

Klase anomalija temperature zraka	Anomaly classes of air temperature	Percentili	Percentiles
ekstremno hladno	extremely cold	< 2	
vrlo hladno	very cold	2 – 9	
hladno	cold	9 – 25	
normalno	normal	25 – 75	
toplo	warm	75 – 91	
vrlo toplo	very warm	91 – 98	
ekstremno toplo	extremely warm	> 98	

Klase anomalija količine oborine	Anomaly classes of precipitation amount	Percentili	Percentiles
ekstremno sušno	extremely dry	< 2	
vrlo sušno	very dry	2 – 9	
sušno	dry	9 – 25	
normalno	normal	25 – 75	
kišno	wet	75 – 91	
vrlo kišno	very wet	91 – 98	
ekstremno kišno	extremely wet	> 98	

Pored prikaza percentila na lokacijama meteoroloških postaja važno je procijeniti vrijednosti na cijelom teritoriju, pa i na lokacijama na kojima nema mjerjenja. Procjena percentila na lokaciji na kojoj nema mjerjenja računa se kao otežani srednjak percentila okolnih postaja. Utjecaj percentila pojedine postaje definiran je težinskim faktorima, koji su u pravilu slabiji što je veća udaljenost mjerjenja od lokacije za koju se radi procjena. Kao i kod svake druge statističke metode, procjene mogu biti izvan raspona vrijednosti mjerjenja, što se понекad opaža na kartama, posebno kada je na pojedinoj postaji percentil vrlo blizu granične vrijednosti pojedine klase, a procjena može biti neznatno niža/viša čime ulazi u nižu/višu klasu. Karte su izrađene kao rasteri prostorne rezolucije 1 km. Nadopunjene su granicama županija (Državna geodetska uprava) i mjerilom.

Na kartama anomalija postaje su označene simbolom u boji klase anomalije kojoj pripada određena temperatura ili količina oborine. Pored simbola nalazi se ime postaje i dvije brojčane vrijednosti.

Gornji broj označava odstupanje meteorološkog elementa od višegodišnjeg prosjeka: za temperaturu zraka izraženo u Celzijevim stupnjevima ( $^{\circ}\text{C}$ ) te za količinu oborine u postotcima (%) višegodišnjeg prosjeka. Na primjer, unutar klase normalno mogu se pojaviti pozitivna ( $> 0^{\circ}\text{C}$ ) ili negativna ( $< 0^{\circ}\text{C}$ ) odstupanja temperature zraka od prosjeka ili odstupanja količine oborine iznad prosjeka ( $> 100\%$ ) ili ispod prosjeka ( $< 100\%$ ). Donji broj uz postaju na kartama označava percentil prema kojem se postaja svrstava u odgovarajuću klasu.

Rang neke meteorološke veličine je poredak te veličine u silaznom ili uzlaznom slijedu. Poredaju li se srednje temperature zraka uzlazno/silazno, dobivaju se rangovi počevši od najhladnjeg/najtoplijeg mjeseca/sezone/godine. Poredaju li se količine oborine uzlazno/silazno, dobivaju se rangovi od najsušnijeg/najvlažnijeg mjeseca/sezone/godine. Rang koji promatrana vrijednost ima u skupu svih višegodišnjih vrijednosti mjerjenja omogućuje uvid u to da li je ta vrijednost uobičajena ili predstavlja rijedak događaj. U Poglavlju 1 detaljno ćemo opisati rangove za one mjesecce/sezone za koje je na većini postaja neki od rangova manji ili jednak pet, odnosno promatrano razdoblje je među pet najhladnjih/najtoplijih ili po količini oborine među pet najsušnijih ili najvlažnijih u nizu podataka od 1981. godine do analizirane godine. Rangovi godišnjih temperatura zraka i količina oborine prikazuju se u ocjeni svake godine, počevši s 2021.

U Poglavlju 3 rangovi su analizirani za meteorološke postaje Zagreb-Maksimir i Split-Marjan za kompletну duljinu povijesnih nizova na tim postajama pa se mogu razlikovati od analize na kraćim vremenskim nizovima u Poglavlju 1.

Tamo su prikazane i dnevne temperature zraka analizirane godine, zajedno sa srednjim vrijednostima dnevnih temperatura zraka za razdoblje počevši od 1926. godine za Zagreb-Maksimir, odnosno 1948. za Split-Marjan do završno, godine koja prethodi godini analize. Ocjena izuzetnosti srednjih dnevnih temperatura zraka za svaki mjesec u godini temelji se na Chapman-ovom kriteriju uz pretpostavku da se srednje dnevne temperature zraka za pojedini datum pokoravaju Gauss-ovoj razdiobi (Penzar i Makjanić, 1980.). Prema Chapman-ovom kriteriju

je average of the percentiles from the surrounding stations. The influence of the percentile of an individual station is defined by weight factors, which are generally weaker the greater the measurement distance is from the location for which the assessment is being made. As with any other statistical method, estimates can be outside the range of measured values, which is sometimes observed on maps, especially when at one station the percentile is very close to the limit value of a particular class, and the estimate is slightly lower/higher so it enters a lower/higher class. The maps were made as rasters with a spatial resolution of 1 km. They are supplemented by county borders (State Geodetic Administration) and a scale bar.

Climate anomaly maps show locations of the stations where symbols are coloured according to anomaly category of the temperature or precipitation. Next to the symbol there is the name of the station and two numeric values.

The upper number describes the anomaly (deviation of the meteorological element from multiannual average), expressed in  $^{\circ}\text{C}$  for temperature and in percentages (%) of the multiannual average for precipitation amount. For example, the temperature anomalies belonging to normal category can be positive ( $> 0^{\circ}\text{C}$ ) or negative ( $< 0^{\circ}\text{C}$ ) and the precipitation amount anomalies can be above the long-term average ( $> 100\%$ ) or below the average ( $< 100\%$ ). The lower number in the maps for every station indicates the corresponding percentile.

The position of a meteorological parameter in a descending or ascending order is referred to as its rank. Ranks starting from the coldest/hottest month/season/year are obtained by arranging mean air temperatures in ascending/descending order. Ranks starting from the driest/wettest month/season/year are obtained by arranging precipitation amounts in ascending/descending order. Ranks allow us to estimate whether the measured value is a common or a rare event among the rest of the values in a long data series. In Chapter 1, we will describe in detail the ranks for months/seasons that have ranks lower than or equal to five in most stations, meaning that the period in question is among the five coldest/warmest or driest/wettest periods in the data series spanning the years from 1981 to the analyzed year. The ranks of annual air temperatures and precipitation amounts are shown in the assessment for each year, starting with 2021.

In Chapter 3, the ranks were analyzed for meteorological stations Zagreb-Maksimir and Split-Marjan over the complete length of historical series at the stations in question and may differ from the analysis performed on shorter time series in Chapter 1.

Chapter 3 includes a presentation of daily air temperatures for the analyzed year and mean daily air temperature values for the period starting with 1926 for Zagreb-Maksimir and 1948 for Split-Marjan, and ending with the year preceding the year of analysis.

The evaluation of exceptionality of mean daily air temperatures for every month of the year is based on the Chapman's criterion and on the assumption that the mean daily air temperature for individual dates follows a Gaussian distribution (Penzar and Makjanić, 1980). Chapman's criterion defines an exceptionally warm day as a day with a positive mean daily air temperature anomaly exceeding two standard deviations, and an exceptionally cold day as a day with a negative anomaly exceeding two standard de-

izvanredno toplim smatra se dan u kojem pozitivna anomalija srednje dnevne temperature zraka premaši dvije standardne devijacije, dok se izuzetno hladnim smatra dan u kojem negativna anomalija premaši dvije standardne devijacije. Vjerojatnost pojave izvanredno toplih odnosno izvanredno hladnih dana je oko 2%, to jest takvi događaji se pojavljuju u prosjeku dva puta u razdoblju od 100 godina.

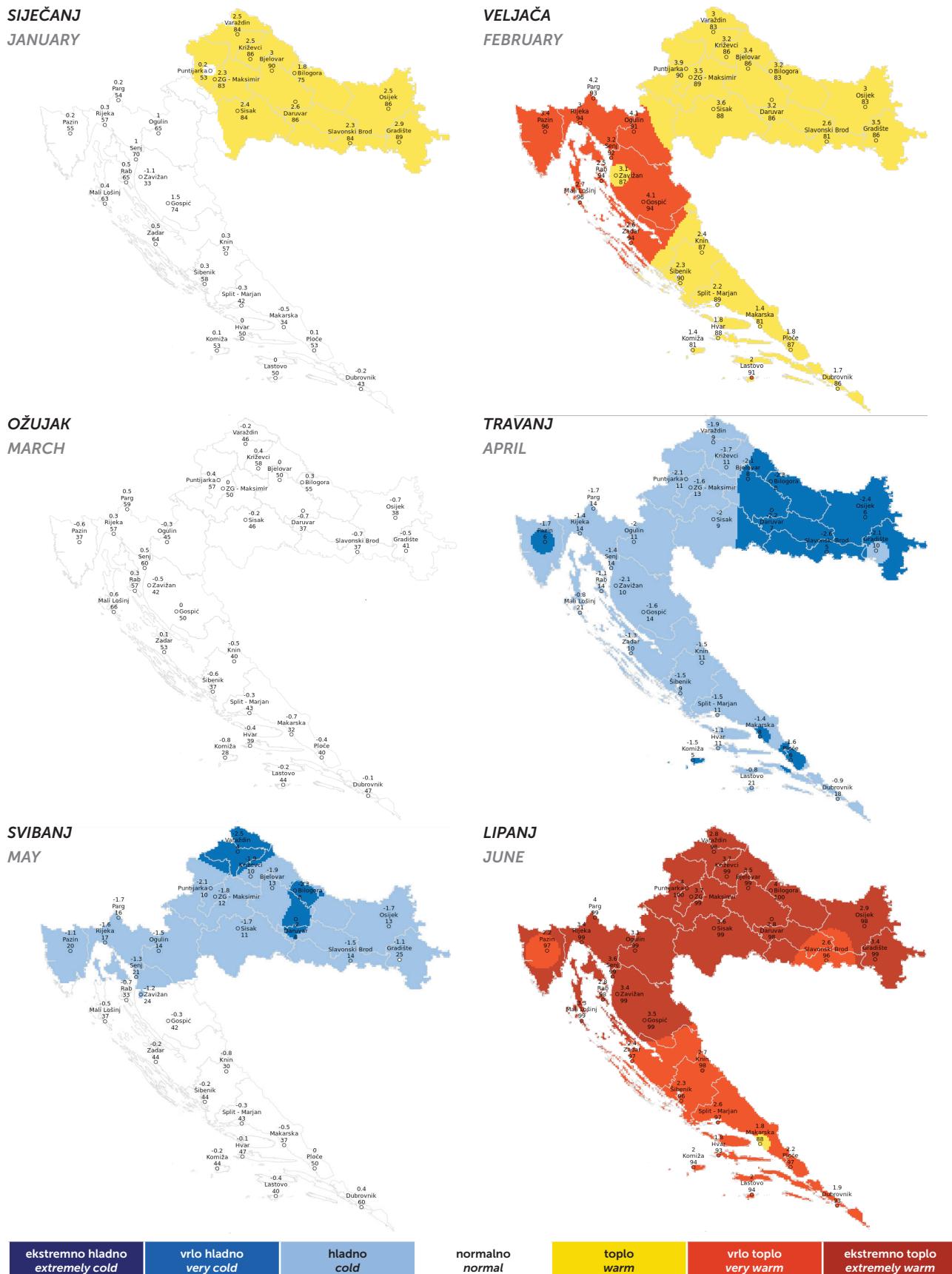
## **1.1 Kartografski prikaz mjesecnih, sezonskih i godišnjih klasa anomalija temperature zraka i količine oborine za 2021. godinu**

Mjesečne, sezonske i godišnje karte sadrže brojčane vrijednosti anomalija i percentila na meteorološkim postajama, dok su simboli na lokacijama meteoroloških postaja u boji koja odgovara klasi anomalije kojoj pripada izmjerena temperatura ili količina oborine. Anomalije temperature izražene su u °C, a anomalije količine oborine u postotcima višegodišnjeg prosjeka za odabranu referentno razdoblje 1981. — 2010. Na karti su bojama prikazane klase anomalija interpolirane prema vrijednostima klasa na meteorološkim postajama.

iations. Exceptionally warm and exceptionally cold days have a probability of occurrence of around 2%, meaning that they on average occur twice in 100 years.

### **1.1 Maps of monthly, seasonal and annual anomaly classes of air temperature and precipitation amounts in 2021**

The monthly, seasonal and annual maps show numerical values of the anomalies and percentiles at the stations, while the symbols at the locations are coloured according to the anomaly category of the measured temperature or precipitation. Temperature anomalies are in °C and precipitation amount anomalies are in percentage of the long-term average for the reference period 1981 — 2010. Colours on the maps show the interpolated anomaly categories according to the categories at the meteorological stations.

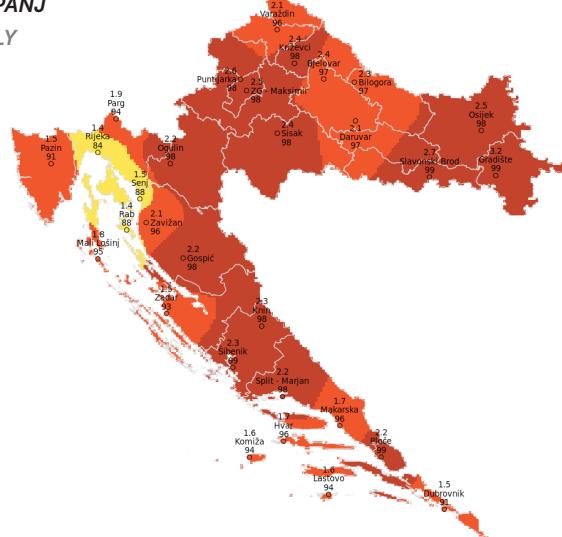


*Odstupanje srednje mjesecne temperature zraka (°C) od višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu*

*Monthly mean air temperature anomalies in Croatia, relative to the multiannual average for the period 1981 – 2010, for 2021*

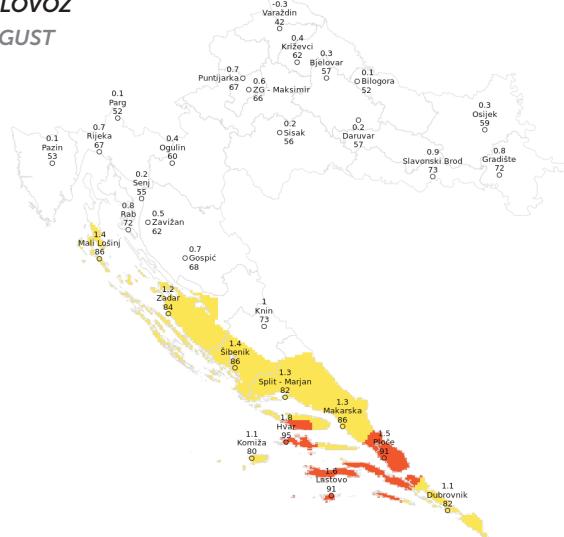
SRPANJ

JULY



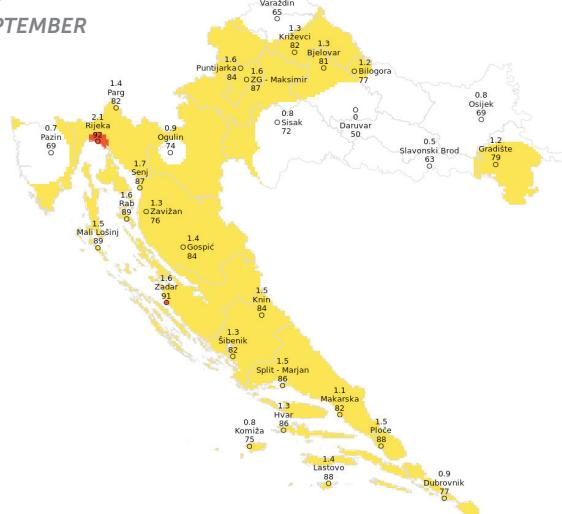
KOLOVOZ

AUGUST



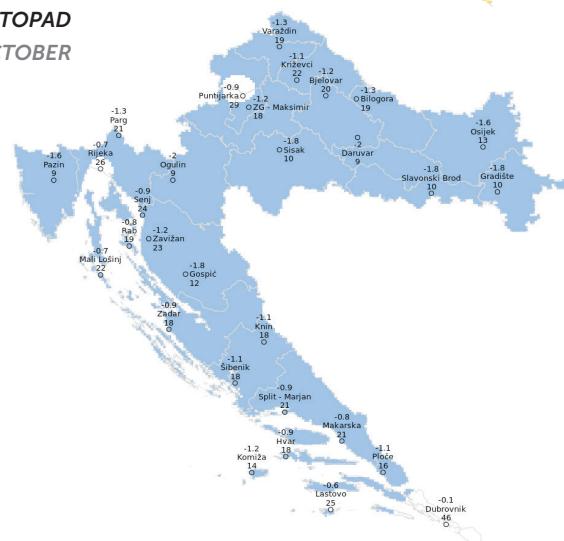
RUJAN

SEPTEMBER



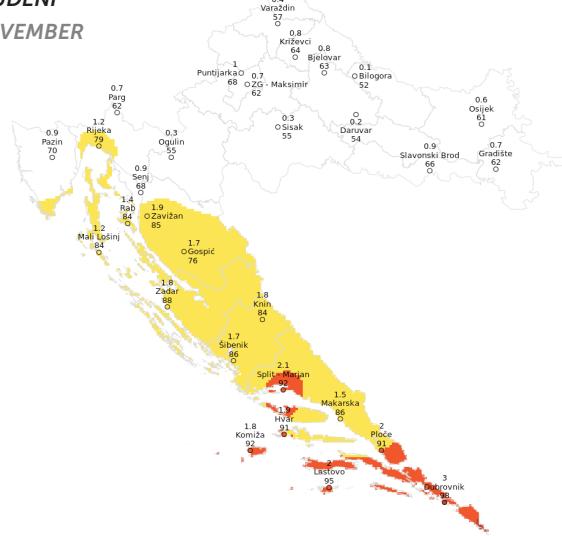
LISTOPAD

OCTOBER



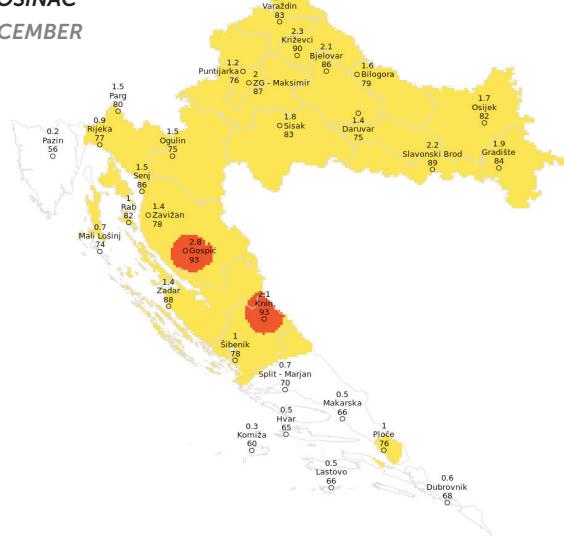
STUDENI

NOVEMBER



PROSINAC

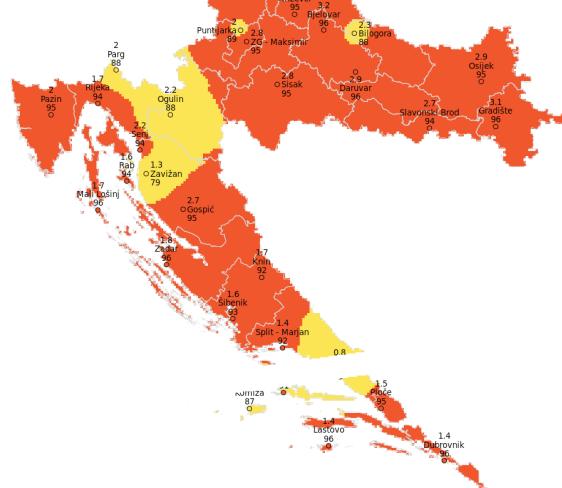
DECEMBER

ekstremno hladno  
extremely coldvrlo hladno  
very coldhladno  
coldnormalno  
normaltoplo  
warmvrlo toplo  
very warmekstremno toplo  
extremely warm

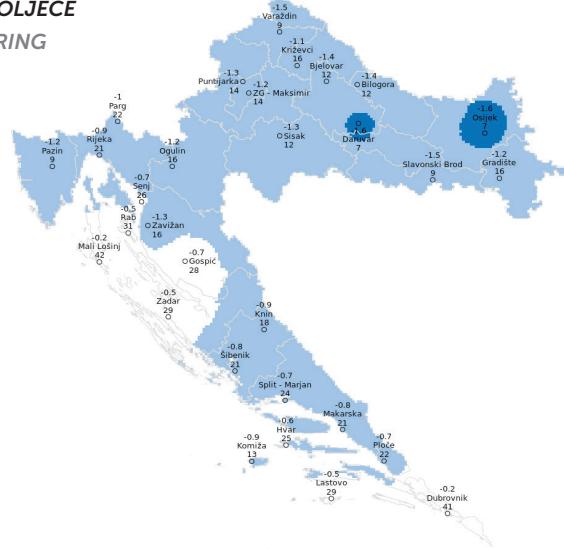
Odstupanje srednje mjesecne temperature zraka (°C) od višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu

Monthly mean air temperature anomalies in Croatia, relative to the multiannual average for the period 1981 – 2010, for 2021

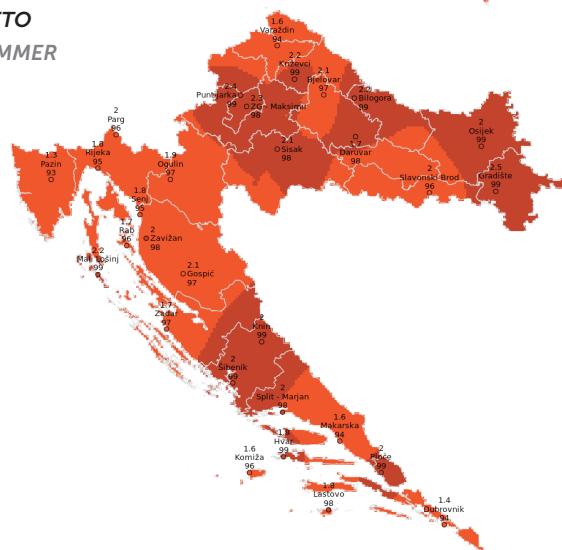
**ZIMA 2020./ 2021.**  
**WINTER 2020/2021**



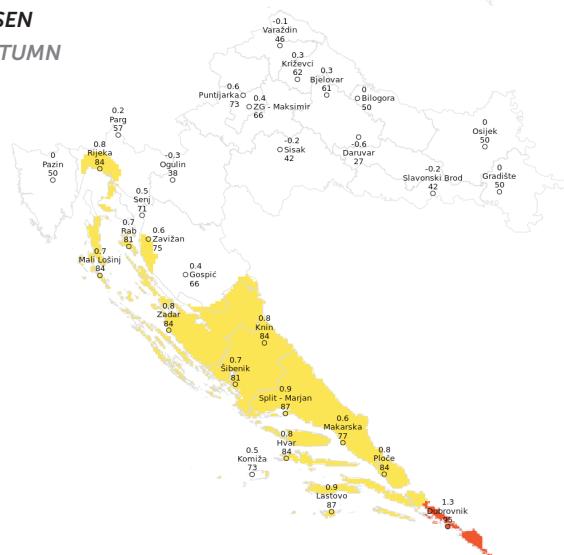
**PROLJEĆE**  
**SPRING**



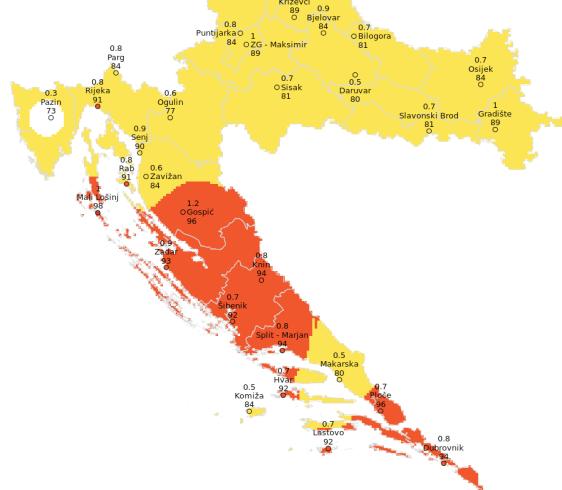
**LJETO**  
**SUMMER**



**JESEN**  
**AUTUMN**



**GODINA 2021.**  
**YEAR 2021**



normalno  
normal

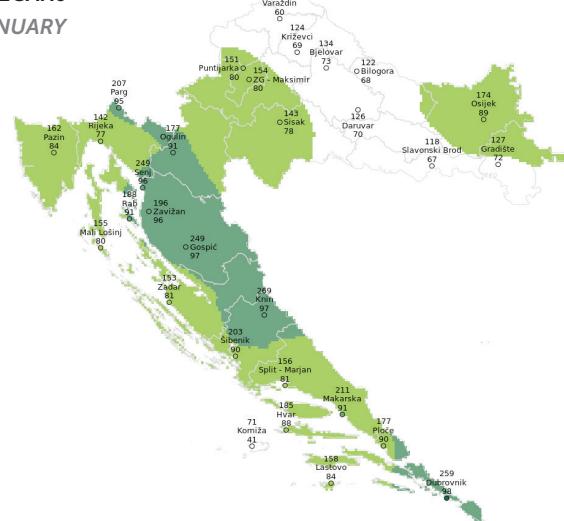
ekstremno hladno extremely cold	vrlo hladno very cold	hladno cold	toplo warm	vrlo toplo very warm	ekstremno toplo extremely warm
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Odstupanje srednje sezonske i godišnje temperature zraka ( $^{\circ}\text{C}$ ) od višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu

Mean seasonal and annual air temperature anomalies in Croatia, relative to the multiannual average for the period 1981 – 2010 for 2021

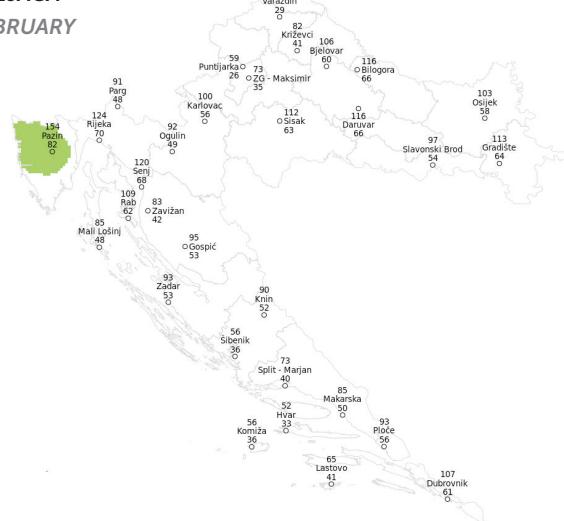
## SIJEĆANJ

JANUARY



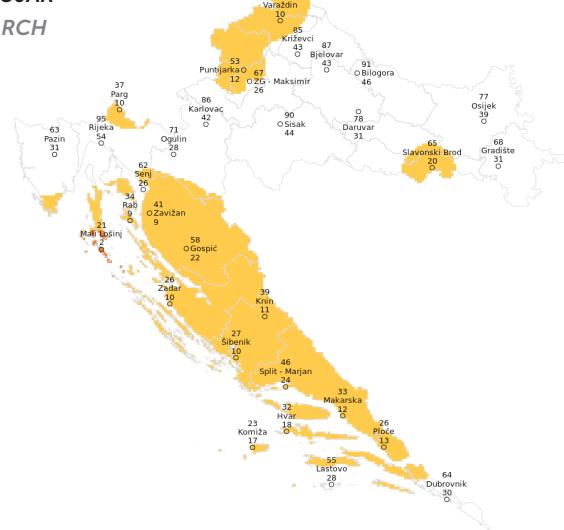
## VELJAČA

FEBRUARY



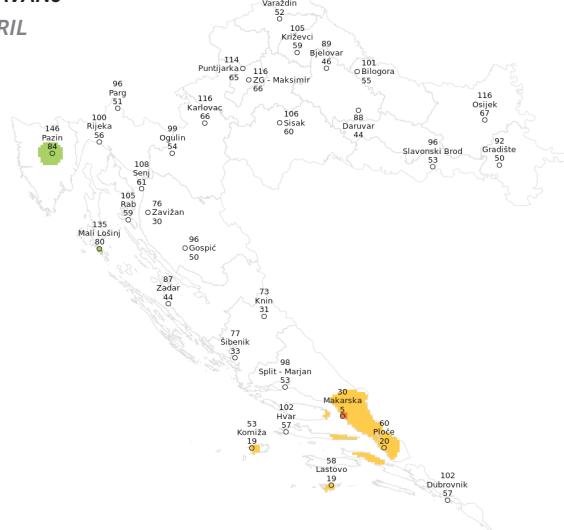
## OŽUJAK

MARCH



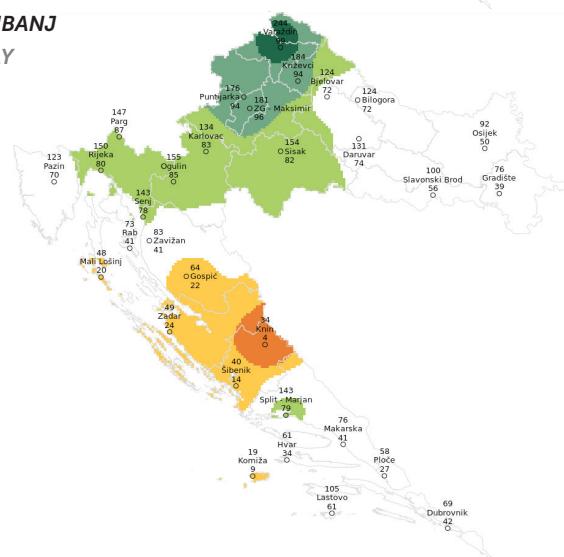
## TRAVANJ

APRIL



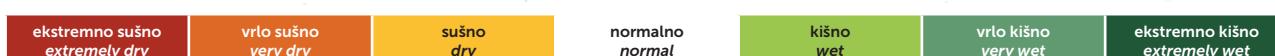
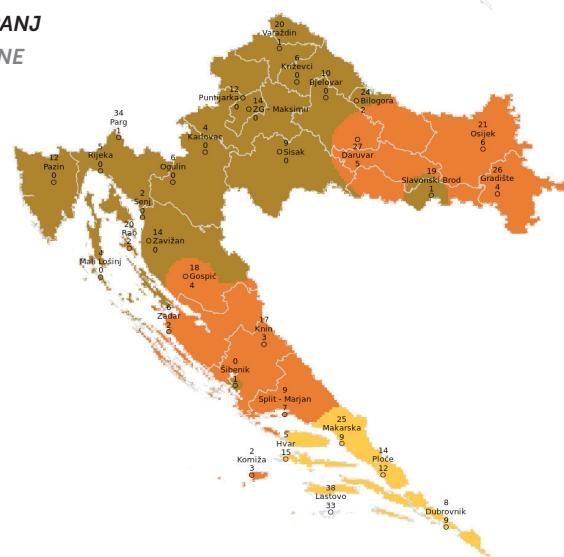
## SVIBANJ

MAY



## LIPANJ

JUNE

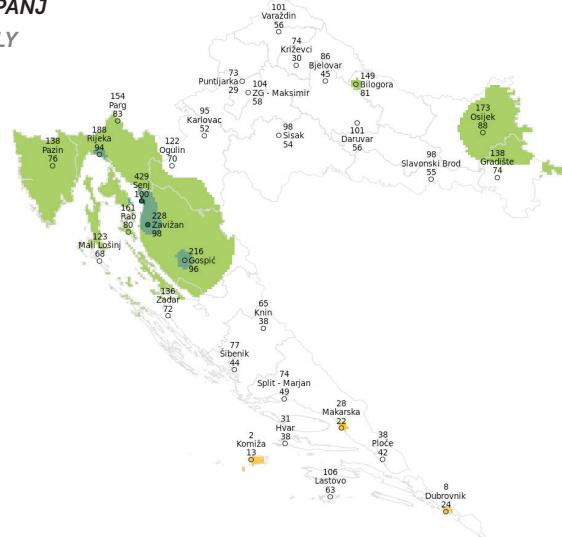


Mjesečne količine oborina, u postotcima višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu

Monthly precipitation amounts, in percentages of multiannual average for the period 1981 – 2010, in Croatia for 2021.

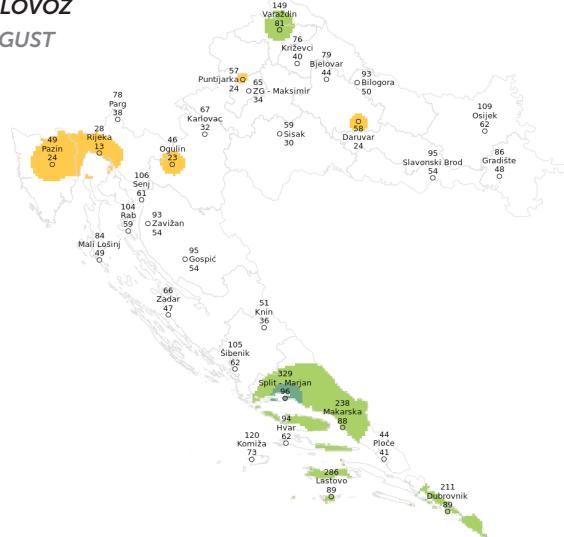
**SRPANJ**

JULY



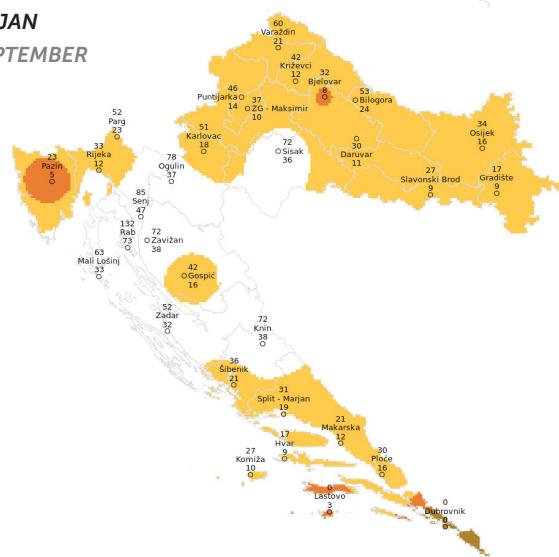
**KOLOVOZ**

AUGUST



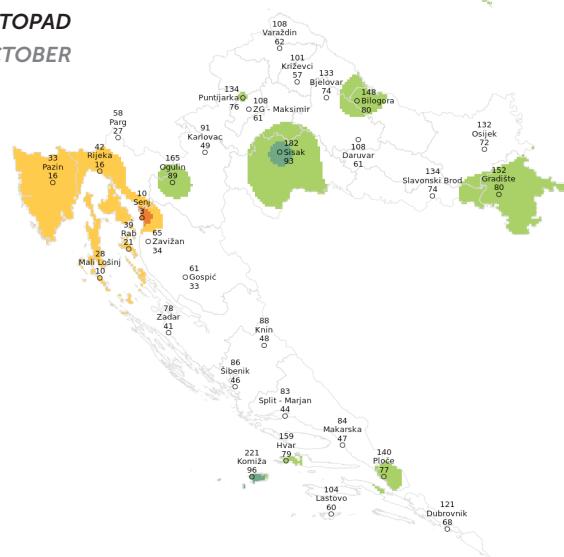
**RUJAN**

SEPTEMBER



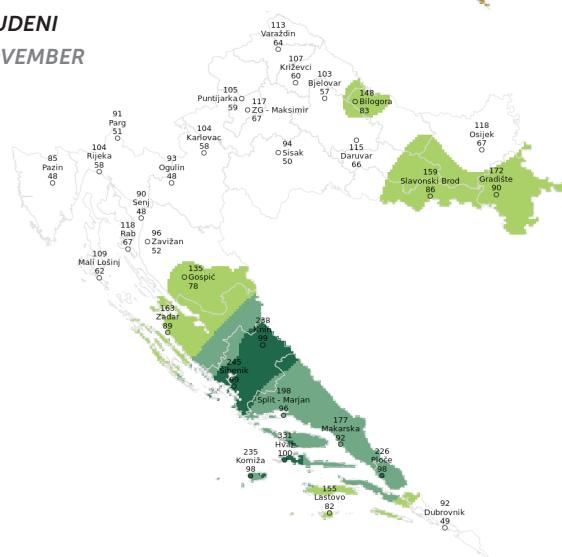
**LISTOPAD**

OCTOBER



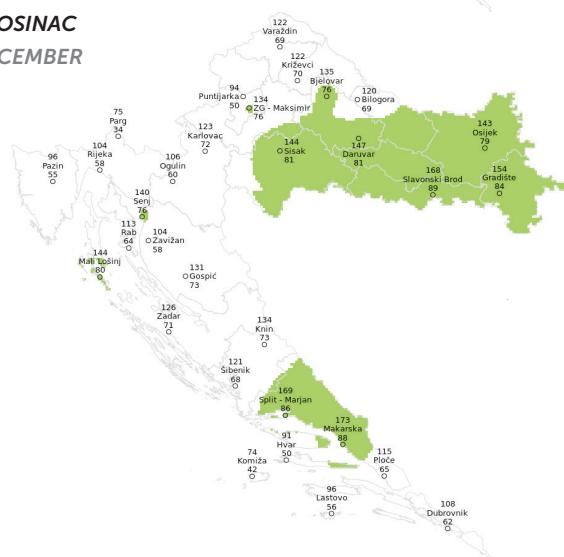
**STUDENI**

NOVEMBER



**PROSINAC**

DECEMBER



ekstremno sušno  
extremely dry

vrlo sušno  
very dry

sušno  
dry

normalno  
normal

kišno  
wet

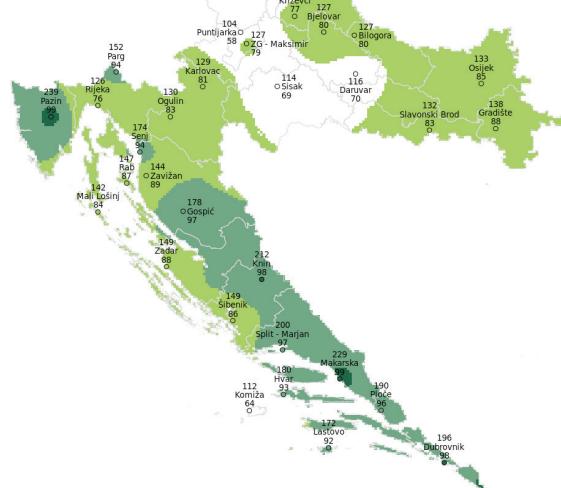
vrlo kišno  
very wet

ekstremno kišno  
extremely wet

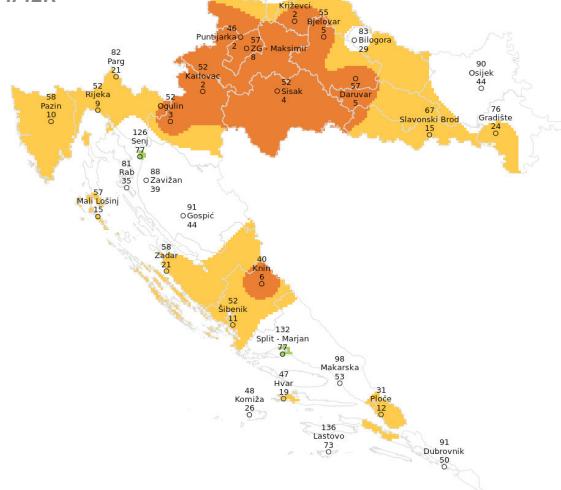
Mjesečne količine oborine, u postotcima višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu

Monthly precipitation amounts, in percentages of multiannual average for the period 1981 – 2010, in Croatia for 2021

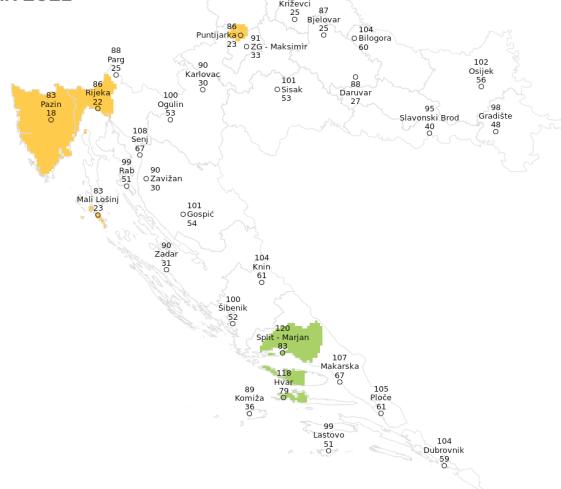
**ZIMA 2020./ 2021.**  
WINTER 2020/2021



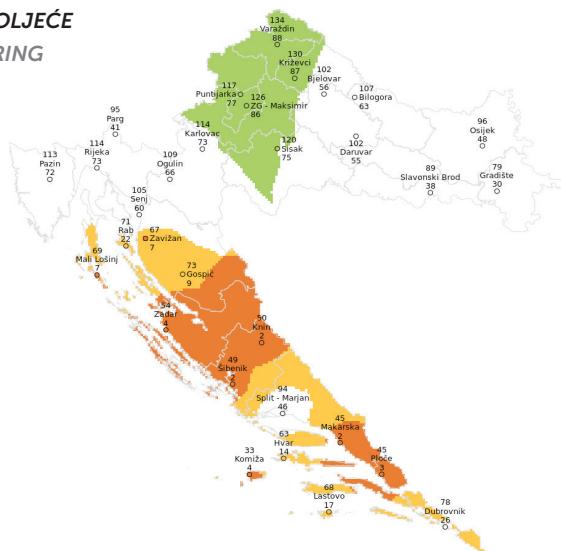
**LJETO**  
SUMMER



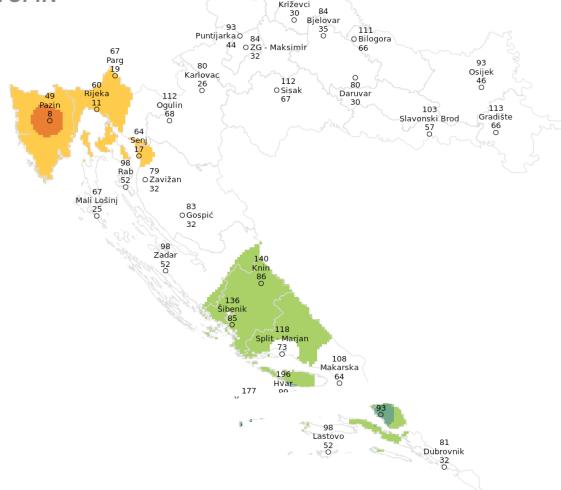
**GODINA 2021.**  
YEAR 2021



**PROLJEĆE**  
SPRING



**JESEN**  
AUTUMN



normalno  
normal

ekstremno sušno extremely dry	vrlo sušno very dry	sušno dry	normalno normal	kišno wet	vrlo kišno very wet	ekstremno kišno extremely wet
----------------------------------	------------------------	--------------	--------------------	--------------	------------------------	----------------------------------

Sezonske i godišnje količine oborine, u postotcima višegodišnjeg prosjeka za razdoblje 1981. – 2010. godina za Hrvatsku za 2021. godinu

Seasonal and annual precipitation amounts, in percentages of multiannual average for the period 1981 – 2010, in Croatia for 2021

Tablica 1.1.1 Odstupanja srednje mjesecne, sezonske i godisnje temperature zraka od višegodišnjeg prosjeka za razdoblje 1981. - 2010. i percentili.

Tablica 1.1.1 Monthly, seasonal and annual air temperatures anomalies, relative to the multiannual average for the period 1981 – 2010, and percentiles.

Postaja Station	Siječanj January	Veljača February	Ožujak March	Travanj April	Svibanj May	Lipanj June	Srpanj July	Kolovozaugust August	Rujan September	Listopad October	Studenovi November	Prosinac December	Zima Winter	Proleće Spring	Ljeto Summer	Jesen Autumn	Godina Year
Bilogora	1,8	3,2	0,3	-2,3	-2,3	4,0	2,3	0,1	1,2	-1,3	0,1	1,6	2,3	-1,4	2,2	0,0	0,7
	75	83	55	8	8	100	97	52	77	19	52	79	88	12	99	50	81
Bjelovar	3,0	3,4	0,0	-2,1	-1,9	3,6	2,4	0,3	1,3	-1,2	0,8	2,1	3,2	-1,4	2,1	0,3	0,9
	90	86	50	8	13	99	97	57	81	20	63	86	96	12	97	61	84
Daruvar	2,6	3,2	-0,7	-2,2	-2,0	2,8	2,1	0,1	0,0	-2,0	0,2	1,4	2,9	-1,6	1,7	-0,6	0,5
	86	86	37	7	8	98	97	53	50	9	54	75	96	7	98	27	80
Dubrovnik	-0,2	1,7	-0,1	-0,9	0,4	1,8	1,5	1,1	0,9	-0,1	3,0	0,6	1,4	-0,2	1,4	1,3	0,8
	43	86	47	18	60	92	91	82	77	46	98	68	96	41	94	95	94
Gospic	1,5	4,1	0,0	-1,6	-0,3	3,5	2,2	0,7	1,4	-1,8	1,7	2,8	2,7	-0,7	2,1	0,4	1,2
	74	94	50	14	42	99	98	68	84	12	76	93	95	28	97	66	96
Gradište	2,9	3,5	-0,5	-2,1	-1,2	3,4	3,2	0,8	1,2	-1,8	0,7	1,9	3,1	-1,2	2,5	0,0	1,0
	89	86	41	10	23	99	99	72	79	10	62	84	96	16	99	50	89
Hvar	0,0	1,8	-0,4	-1,1	-0,1	1,8	1,7	1,8	1,3	-0,9	1,9	0,5	1,2	-0,6	1,8	0,8	0,7
	50	88	39	11	47	93	96	95	86	18	91	65	91	25	99	84	92
Knin	0,3	2,4	-0,5	-1,5	-0,8	2,7	2,3	1,0	1,5	-1,1	1,8	2,1	1,7	-0,9	2,0	0,8	0,5
	57	87	40	11	30	98	98	73	84	18	84	93	92	18	99	84	84
Komiža	0,0	1,4	-0,8	-1,5	-0,2	2,0	1,6	1,1	0,8	-1,2	1,8	0,3	1,0	-0,9	1,6	0,4	1,0
	50	82	28	5	44	94	94	80	75	14	92	60	87	13	96	69	89
Križevci	2,5	3,2	0,4	-1,7	-1,9	3,7	2,4	0,4	1,3	-1,1	0,8	2,4	2,7	-1,1	2,2	0,3	0,7
	86	86	58	11	10	99	98	62	82	22	64	91	95	16	99	62	92
Lastovo	0,0	2,0	-0,2	-0,8	-0,4	2,0	1,6	1,6	1,4	-0,6	2,0	0,5	1,4	-0,5	1,8	0,9	0,5
	50	91	44	21	40	94	94	91	88	25	95	66	96	29	98	87	80
Makarska	-0,5	1,4	-0,7	-1,4	-0,4	1,8	1,7	1,3	1,1	-0,8	1,5	0,5	0,8	-0,8	1,6	0,6	1,0
	34	81	32	8	40	88	96	86	82	21	86	66	81	21	94	77	98
Mali Lošinj	0,4	2,7	0,6	-0,8	-0,5	3,3	1,8	1,4	1,5	-0,7	1,2	0,7	1,7	-0,2	2,2	0,7	0,6
	63	96	66	21	37	99	95	86	89	22	84	74	96	42	99	84	77
Ogulin	1,0	4,1	-0,3	-2,0	-1,5	3,1	2,2	0,4	0,9	-2,0	0,3	1,5	2,2	-1,2	1,9	-0,3	0,7
	65	91	45	11	14	99	98	60	74	9	55	75	88	16	97	38	84
Osijek	2,6	3,0	-0,7	-2,4	-1,7	2,9	2,6	0,3	0,8	-1,5	0,6	1,7	2,9	-1,6	2,0	0,0	0,8
	87	83	38	6	13	98	98	59	69	14	61	82	95	7	99	50	84
Parg	0,2	4,2	0,5	-1,7	-1,7	4,0	1,9	0,1	1,4	-1,3	0,7	1,5	2,0	-1,0	2,0	0,2	0,3
	54	93	59	14	16	99	94	52	82	21	62	80	88	22	96	57	73
Pazin	0,2	3,4	-0,6	-1,7	-1,1	2,2	1,5	0,1	0,7	-1,6	0,9	0,2	2,0	-1,2	1,3	0,0	0,7
	55	96	37	6	20	97	91	53	69	9	70	56	95	9	93	50	96
Ploče	0,1	1,8	-0,4	-1,6	0,0	2,2	2,2	1,5	1,5	-1,1	2,0	1,0	1,5	-0,7	2,0	0,8	0,8
	53	87	40	6	50	97	99	91	88	16	91	76	95	22	99	84	84
Puntijarka	0,2	3,9	0,4	-2,1	-2,1	4,0	2,6	0,7	1,6	-0,9	1,0	1,2	2,0	-1,3	2,4	0,6	0,8
	53	90	57	11	10	100	98	67	84	29	68	76	89	14	99	73	91
Rab	0,5	2,5	0,3	-1,1	-0,7	2,8	1,4	0,8	1,6	-0,8	1,4	1,0	1,6	-0,5	1,7	0,7	0,8
	65	94	57	14	33	98	88	72	89	19	84	82	94	31	96	81	91
Rijeka	0,3	3,0	0,3	-1,4	-1,6	3,4	1,4	0,7	2,1	-0,7	1,2	0,9	1,7	-0,9	1,8	0,8	0,9
	57	94	57	14	17	99	84	67	92	26	79	77	94	21	95	84	90
Senj	1,0	3,2	0,5	-1,4	-1,3	3,6	1,5	0,2	1,7	-0,9	0,9	1,5	2,2	-0,7	1,8	0,5	0,7
	70	92	60	14	21	99	88	55	87	24	68	86	94	26	95	71	92
Šibenik	0,3	2,3	-0,6	-1,5	-0,2	2,3	2,3	1,4	1,3	-1,1	1,7	1,0	1,6	-0,8	2,0	0,7	0,7
	58	90	37	9	44	96	99	86	82	18	86	78	93	21	99	81	81
Sisak	2,4	3,6	-0,4	-2,1	-1,7	3,6	2,4	0,2	0,8	-1,8	0,3	1,8	2,8	-1,3	2,1	-0,2	0,7
	84	88	42	8	11	99	98	56	72	10	55	83	95	12	98	42	81
Slavonski Brod	2,3	2,6	-0,7	-2,3	-1,5	2,6	2,7	0,9	0,5	-1,8	0,9	2,2	2,7	-1,5	2,0	-0,2	0,8
	84	81	37	8	14	96	99	73	63	10	66	89	94	9	96	42	94
Split-Marjan	-0,3	2,2	-0,3	-1,5	-0,3	2,6	2,2	1,3	1,5	-0,9	2,1	0,7	1,4	-0,7	2,0	0,9	0,6
	42	89	43	11	43	97	98	82	86	21	92	70	92	24	98	87	77
Varaždin	2,5	3,0	-0,2	-1,9	-2,5	2,9	2,1	-0,3	0,5	-1,3	0,4	1,7	2,5	-1,5	1,6	-0,1	0,9
	84	83	46	9	4	98	96	42	65	19	57	83	92	9	94	46	93
Zadar	0,5	2,6	0,1	-1,3	-0,2	2,4	1,5	1,2	1,6	-0,9	1,8	1,4	1,8	-0,5	1,7	0,8	1,0
	64	94	53	10	44	97	93	84	91	18	88	88	96	29	97	84	89
Zagreb-Maksimir	2,3	3,5	0,0	-1,6	-1,8	3,7	2,5	0,6	1,6	-1,2	0,7	2,0	2,8	-1,2	2,3	0,4	0,6
	83	89	50	13	12	99	98	66	87	18	62	87	95	14	98	66	84
Zavižan	-1,1	3,1	-0,5	-2,1	-1,2	3,4	2,1	0,5	1,3	-1,2	1,9	1,4	1,3	-1,3	2,0	0,6	0,6
	33	87	42	10	24	99	96	62	76	23	85	78	79	16	98	75	84,1

Tablica 1.1.2 Mjesečne, sezonske i godišnje količine oborine u postotcima višegodišnjeg prosjeka za razdoblje 1981. - 2010. i percentili.

Table 1.1.2 Monthly, seasonal and annual precipitation amounts, in percentages of multiannual average for the period 1981 – 2010 and percentiles

Postaja Station	Siječanj January	Veljača February	Ožujak March	Travanj April	Svibanj May	Lipanj June	Španj July	Kolovozaugust August	Rujan September	Listopad October	Studenji November	Prosincdecember December	Zima Winter	Proljeće Spring	Ljeto Summer	Jesen Autumn	Godina Year
Bilogora	121	116	91	101	124	24	149	93	53	148	148	120	127	107	83	111	104
	68	66	46	55	72	2	81	50	24	80	83	69	80	63	29	66	60
Bjelovar	134	107	87	89	124	10	87	79	32	133	103	135	127	102	55	84	87
	73	60	43	46	72	0	45	44	8	74	57	76	80	56	5	35	25
Daruvar	126	116	78	88	131	27	101	58	30	108	115	147	116	102	57	80	89
	70	66	31	44	74	5	56	24	11	61	66	81	70	55	5	30	27
Dubrovnik	259	107	64	102	69	8	8	211	0	121	92	109	195	78	91	81	104
	98	61	30	57	42	9	24	89	0	68	49	62	98	26	50	32	59
Gospic	249	95	58	96	64	18	216	95	42	61	135	131	178	73	91	83	101
	97	53	22	50	22	4	96	54	16	33	78	73	97	9	44	32	54
Gradište	127	113	68	93	76	25	138	86	17	152	172	154	138	79	76	113	98
	72	64	31	50	39	4	74	48	9	80	90	84	88	30	24	66	48
Hvar	185	52	33	102	61	5	31	94	17	159	331	91	180	63	47	197	118
	88	33	18	57	34	15	38	62	9	79	100	50	93	14	19	99	79
Karlovac	159	100	87	116	134	4	95	67	51	91	104	123	129	114	52	80	90
	82	56	42	66	83	0	52	32	18	49	58	72	81	73	2	26	30
Knin	270	90	39	74	34	17	65	51	72	88	238	134	212	50	40	140	104
	97	52	11	31	4	3	38	36	38	48	99	73	98	2	6	86	61
Komiža	71	56	23	53	19	1	2	121	27	215	235	74	112	33	48	176	89
	41	37	17	19	9	3	13	73	10	94	98	42	64	4	26	99	36
Križevci	124	82	85	105	184	6	74	76	42	101	107	122	123	130	50	81	87
	69	41	43	59	94	0	30	40	12	57	60	70	77	87	2	30	25
Lastovo	164	65	55	58	105	38	106	286	0	104	155	96	174	67	136	98	99
	85	41	28	19	61	33	63	89	3	60	82	56	93	17	73	52	51
Makarska	211	85	33	30	75	25	28	238	21	83	177	173	229	45	98	108	107
	91	50	12	5	40	9	22	88	12	47	92	88	99	2	53	63	67
Mali Lošinj	155	85	21	135	48	4	123	84	63	28	109	144	142	69	57	67	83
	80	48	2	80	20	0	68	49	33	10	62	80	84	7	15	25	23
Ogulin	177	92	71	99	155	6	122	46	78	165	93	106	130	109	52	112	100
	91	49	28	54	85	0	70	23	37	89	48	60	83	66	3	68	53
Osijek	174	103	77	116	92	21	173	109	34	133	118	143	133	96	90	93	102
	89	58	39	67	50	6	88	62	16	72	67	79	85	48	44	46	56
Parg	207	91	37	96	147	34	154	78	52	58	91	75	152	95	81	67	87
	95	48	10	51	87	1	83	38	23	27	51	34	94	41	21	19	25
Pazin	162	154	63	146	123	12	138	49	23	33	85	95	239	113	58	49	83
	84	82	31	84	70	0	76	24	5	16	48	55	99	72	10	8	18
Ploče	177	93	26	60	58	14	38	44	30	140	226	115	190	45	31	149	105
	90	56	13	20	27	12	42	41	16	77	98	65	96	3	12	93	61
Puntijarka	151	59	53	114	176	12	73	58	47	134	105	94	104	117	46	93	86
	80	26	12	65	94	0	29	25	14	76	59	50	58	77	2	44	23
Rab	188	109	34	105	73	21	161	104	132	39	117	113	147	71	81	98	99
	91	62	9	59	41	2	80	59	73	21	67	64	87	22	35	52	51
Rijeka	142	124	95	100	150	5	188	28	33	42	104	104	126	114	52	60	86
	77	70	54	56	80	0	94	13	12	16	58	58	76	73	9	11	22
Senj	249	120	62	108	143	2	429	106	85	9	90	140	174	105	126	64	108
	96	68	26	61	78	0	100	61	47	3	48	76	94	60	77	17	67
Šibenik	203	56	27	77	40	0	77	105	36	86	245	121	149	49	52	136	100
	90	36	10	33	14	1	44	62	21	46	99	68	86	2	11	85	52
Sisak	143	111	90	106	153	9	98	59	72	183	94	144	114	120	51	112	101
	78	63	44	60	82	0	54	30	36	93	50	81	69	75	4	67	53
Slavonski Brod	118	97	65	96	100	19	98	99	27	134	159	168	132	89	68	103	95
	67	54	20	53	56	1	55	56	9	74	86	89	83	38	16	57	40
Split-Marjan	156	73	46	98	143	9	73	329	31	83	198	169	200	94	132	118	120
	81	40	24	53	79	7	49	96	19	44	96	86	97	46	77	73	83
Varaždin	103	56	44	95	244	20	101	149	60	108	113	122	118	135	87	90	100
	60	29	10	52	99	1	56	81	21	62	64	69	70	88	37	40	52
Zadar	153	93	26	87	49	6	136	66	52	78	163	126	149	54	58	98	90
	81	53	10	44	24	2	72	47	32	41	89	71	88	4	21	52	31
Zagreb-Maksimir	154	73	67	115	181	14	104	65	37	108	117	134	127	126	57	84	91
	80	35	26	66	96	0	58	34	10	61	67	76	79	86	8	32	33
Zavižan	196	83	41	76	83	14	232	93	72	65	96	104	144	67	88	79	90
	96	42	9	30	41	0	98	54	38	34	52	58	89	7	39	32	30

## 1.2 Ocjena toplinskih i oborinskih prilika za 2021. godinu

Ocjena je napravljena na temelju kartografskog prikaza anomalija srednje mjesecne temperature zraka i mjesecne količine oborine definiranih u odnosu na višegodišnji prosjek 1981. – 2010. godina kao i kartografskih prikaza odgovarajućih sezonskih i godišnjih anomalija za navedene meteorološke elemente. Kvantitativna kartografska ocjena toplinskih i oborinskih prilika na području Hrvatske za 2021. godinu može se dopuniti sažetim opisom prikazanim u tablicama 1.2.1 do 1.2.4. U prvom stupcu tablica su klase odstupanja temperature zraka od standardnog višegodišnjeg prosjeka (tablice 1.2.1 za mjesec i 1.2.3 za sezone i godinu) kao i odgovarajuće klase količine oborine (tablice 1.2.2 za mjesec i 1.2.4 za sezone i godinu), a u ostalim kolonama je postotak u odnosu na ukupnu površinu Hrvatske za pojedinu klasu. U klasi normalno odstupanja mogu biti i pozitivna i negativna pa je u tablicama naveden broj postaja s pozitivnim anomalijama u klasi normalno (retci *pozitivno normalno*) i negativnim anomalijama u klasi normalno (retci *negativno normalno*).

Na području Hrvatske srednja godišnja temperatura zraka za 2021. godinu bila je iznad višegodišnjeg prosjeka (1981. – 2010.) na svim postajama koje su uključene u praćenje klime. Odstupanja srednje godišnje temperature zraka nalaze se u rasponu od 0,3°C (Pazin) do 1,2°C (Gospic).

Kategorizacija temperaturnih anomalija zasnovana na razdiobi percentila pokazuje da je središnja Istra bila u kategoriji normalno (1,3% teritorija), istočna, središnja i dio gorske Hrvatske, obala Istre, Kvarner s dijelom otoka, dio srednje Dalmacije i Korčula bili su u kategoriji toplo (74,4% teritorija) dok su dijelovi kvarnerskih otoka, dio gorske Hrvatske, sjeverna Dalmacija, dio srednje Dalmacije i južna Dalmacija izuzev Korčule bili u kategoriji vrlo toplo (24,3% teritorija) (tablica 1.2.2).

Analiza godišnjih količina oborine koje su izražene u postotcima višegodišnjeg prosjeka (1981. – 2010.) pokazuje da su u 2021. u Hrvatskoj količine oborine na većini analiziranih postaja bile oko višegodišnjeg prosjeka. Usporedba s navedenim višegodišnjim prosjekom pokazuje da se količine oborine za 2021. godinu nalaze u rasponu od 83% višegodišnjeg prosjeka u Pazinu (868,5 mm) i Malom Lošinju (770,7 mm) do 120% na postaji Split-Marjan (930,4 mm) (tablica 1.2.3).

Oborinske prilike u Hrvatskoj u 2021.godini bile su normalne na većem dijelu teritorija (90,3% teritorija). Sušno je bilo u okolini Puntitarke, na širem riječkom području, Istri i na Malom Lošinju (6,8% teritorija), a kišni su bili dijelovi srednje Dalmacije oko Splita, dijelovi Brača i Hvara (2,8% teritorija) (tablica 1.2.4).

## 1.2 Assessment of climate anomalies in 2021

The analysis is based on maps showing the anomalies of mean monthly air temperatures and monthly precipitation amounts, defined as the deviation from the 1981 – 2010 multiannual average, as well as the maps of the corresponding seasonal and annual anomalies for the meteorological elements in question. The quantitative cartographic assessment of temperature and precipitation climate anomalies in Croatia in 2021 is supplemented with the brief description in Tables 1.2.1 to 1.2.4. The first column of the tables shows the categories of air temperature anomalies in reference to the WMO standard multiannual average 1981 – 2010 (Tables 1.2.1 for months and 1.2.3 for seasons and year) as well as the corresponding precipitation amount anomaly categories (Tables 1.2.2 for months and 1.2.4 for seasons and year). The other columns show the percentage of the total Croatian territory for each category.

In the normal class, anomalies can be both positive and negative. The tables therefore show the number of stations with positive anomalies in the normal class (Pozitivno normalno PN rows) and negative anomalies in the normal class (Negativno normal NN rows).

The mean annual air temperature for 2021 was above the multiannual average (1981 – 2010) at all meteorological stations included in climate monitoring in Croatia. Mean annual air temperature anomalies fell within the range from 0.3°C (Pazin) to 1.2°C (Gospic).

According to the classification of temperature anomalies based on a percentile distribution, central Istria fell in the normal category (1.3% of the territory), eastern and central Croatia and parts of mountainous Croatia, Istrian coast, Kvarner and parts of its islands, and parts of central Dalmatia and Korčula fell in the warm category (74.4% of the territory), and parts of Kvarner islands, parts of mountainous Croatia, northern Dalmatia, parts of central Dalmatia and southern Dalmatia, except Korčula, fell in the very warm category (24.3% of the territory). (Table 1.2.2.)

An analysis of annual precipitation amounts in 2021, expressed as percentages of the 1981 – 2010 average, indicates that precipitation amounts in Croatia were around the average at most analysed stations. A comparison with the above multiannual average shows that the precipitation amounts for 2021 were in the range of between 83% of the multiannual average in Pazin (868.5 mm) and Mali Lošinj (770.7 mm) and 120% at the station Split-Marjan (9304 mm). (Table 1.2.3.)

Precipitation conditions in 2021 were normal in most of Croatia's territory (90.3%). The surroundings of Puntitarke, the wider Rijeka area, and Istria and Mali Lošinj fall in the dry category (6.8% of the territory), while parts of central Dalmatia around Split and parts of Brač and Hvar fall in the wet category (2.8% of the territory) (Table 1.2.4).

Tablica 1.2.1 Klase odstupanja srednjih mješevnih temperatura zraka u 2021. godini od višegodišnjeg prosjeka (1981. – 2010.) s udjelima površine u pojedinoj klasi u odnosu na ukupnu površinu Hrvatske (%).

Table 1.2.1 Mean monthly air temperature anomaly categories in 2021 relative to the multiannual average 1981 – 2010, with areas in each class compared to the total Croatian territory (%).

Klasa Category	SIJEČANJ JANUARY	VELJAČA FEBRUARY	OŽUJAK MARCH	TRAVANJ APRIL	SVIBANJ MAY	LIPANJ JUNE	SRPANJ JULY	KOLOVOZ AUGUST	RUJAN SEPTEMBER	LISTOPAD OCTOBER	STUDENI NOVEMBER	PROSINAC DECEMBER
ekstremno toplo <i>extremely warm</i>						70.9	14.4				0*	
vrlo toplo <i>very warm</i>		27.2				28.8	74.7	0.7	0.2		4.00	2.9
toplo <i>warm</i>	46.0	72.8				0.4	10.9	16.5	65.5		29.3	81.9
normalno <i>normal</i>	54.0		100		32.1			82.8	34.3	2.4	66.7	15.2
hladno <i>cold</i>				69.2	60.2					97.6		
vrlo hladno <i>very cold</i>				30.8	7.6							
ekstremno hladno <i>extremely cold</i>												
pozitivno normalno <i>positive normal</i>	16		12		2			19	7	0	15	8
negativno normalno <i>negative normal</i>	4		18		12			1	0	4	0	0

Tablica 1.2.2 Klase odstupanja mjesečne količine oborine u 2021. godini od višegodišnjeg prosjeka (1981. – 2010.) s udjelima površine u pojedinoj klasi u odnosu na ukupnu površinu Hrvatske (%).

Table 1.2.2 Monthly precipitation amount categories in 2021 relative to the multiannual average 1981 – 2010, with areas in each class compared to the total Croatian territory (%).

Klasa Category	SIJEČANJ JANUARY	VELJAČA FEBRUARY	OŽUJAK MARCH	TRAVANJ APRIL	SVIBANJ MAY	LIPANJ JUNE	SRPANJ JULY	KOLOVOZ AUGUST	RUJAN SEPTEMBER	LISTOPAD OCTOBER	STUDENI NOVEMBER	PROSINAC DECEMBER
ekstremno kišno <i>extremely wet</i>	0*				1.6		0.0*				4.9	
vrlo kišno <i>very wet</i>	21.0				8.8		1.4	0.5		0.7	11.9	
kišno <i>wet</i>	50.2	2.8		0.6	24.0		26.4	7.5		14.2	20.2	37.6
normalno <i>normal</i>	28.8	97.2	57.4	96.5	50.5	0.1	71.9	87.3	30.1	75.2	63.0	62.4
sušno <i>dry</i>			42.3	2.8	12.4	6.7	0.3	4.7	65.9	9.6		
vrlo sušno <i>very dry</i>			0.3	0.0*	2.7	40.6			3.3	0.2		
ekstremno sušno <i>extremely dry</i>						52.7			0.7			
pozitivno normalno <i>positive normal</i>	7	10	0	12	5	0	8	5	1	9	11	14
negativno normalno <i>negative normal</i>	1	20	15	13	9	1	11	16	7	9	7	6

Tablica 1.2.3 Klase odstupanja srednjih sezonskih i godišnje temperature zraka u 2021. godini od višegodišnjeg prosjeka (1981. – 2010.) s udjelima površine u pojedinoj klasi u odnosu na ukupnu površinu Hrvatske (%).

Table 1.2.3 Mean seasonal and annual air temperature anomaly categories in 2021 relative to the multiannual average 1981 – 2010, with areas in each class compared to the total Croatian territory (%).

Klasa Category	ZIMA WINTER	PROLJEĆE SPRING	LJETO SUMMER	JESEN AUTUMN	GODINA YEAR
ekstremno toplo <i>extremely warm</i>			41.8		
vrlo toplo <i>very warm</i>	83.1		58.2	0.8	24.3
toplo <i>warm</i>	16.9			24.7	74.4
normalno <i>normal</i>		9.9		74.5	1.3
hladno <i>cold</i>		87.1			
vrlo hladno <i>very cold</i>		3			
ekstremno hladno <i>extremely cold</i>					
pozitivno normalno <i>positive normal</i>		0		12	
negativno normalno <i>negative normal</i>		8		5	

Tablica 1.2.4 Klase odstupanja sezonskih i godišnje količine oborine u 2021. godini od višegodišnjeg prosjeka (1981. – 2010.) s udjelima površine u pojedinoj klasi u odnosu na ukupnu površinu Hrvatske (%).

Table 1.2.4 Seasonal and annual precipitation amount categories in 2021 relative to the multiannual average 1981 – 2010, with areas in each class compared to the total Croatian territory (%).

Klasa Category	ZIMA WINTER	PROLJEĆE SPRING	LJETO SUMMER	JESEN AUTUMN	GODINA YEAR
ekstremno kišno <i>extremely wet</i>	0.6			0.2	
vrlo kišno <i>very wet</i>	26.5			0.6	
kišno <i>wet</i>	51.2	16.1	0.2	11.6	2.8
normalno <i>normal</i>	21.6	55.1	36.1	78.9	90.3
sušno <i>dry</i>		13.3	37.1	7.6	6.8
vrlo sušno <i>very dry</i>		15.5	26.6	1	
ekstremno sušno <i>extremely dry</i>					
pozitivno normalno <i>positive normal</i>	5	8	1	7	11
negativno normalno <i>negative normal</i>	0	6	9	15	14

\* Zbog zaokruživanja na jednu decimalnu površinu koja je <=0.05% prikazana je kao 0.0\*.

Zbog zaokruživanja je moguće da suma površina klasa neznatno odstupa od 100%.

\* Due to rounding to one decimal place, an area of <= 0.05% is shown as 0.0 \*.

Due to rounding, slight deviation of the sum of the class areas from 100% is possible.

### 1.3 Ekstremna klimatska razdoblja u 2021. godini

Područja zahvaćena ekstremnim klasama temperaturnih i oborinskih anomalija koje mogu značajno utjecati na ljudе i različite gospodarske grane (energetika, poljoprivredа, turizam) izdvojena su u tablici 1.3.1 na mјesečnoj, sezonskoj i godišnjoj razini.

Tablica 1.3.1 Područja zahvaćena ekstremnim klimatskim prilikama u 2021. godini.

Table 1.3.1 Areas affected by extreme climate conditions in 2021

### 1.3 Extreme climate periods in 2021

Areas affected by extreme temperature and precipitation anomaly categories with potential significant impact on people and industries (energy, agriculture, tourism) are highlighted in Table 1.3.1 on a monthly, seasonal and annual scale.

Mjesečna razdoblja Monthly periods		
Ekstrem Extreme	Mjesec Month	Područje Region
ekstremno hladno extremely cold		niti jedno područje <i>no areas in this category</i>
ekstremno toplo extremely warm	lipanj June	istočna Hrvatska izuzev okoline Slavonskog Broda, središnja i gorska Hrvatska, obala Istre, Knin <i>Eastern Croatia, except the Slavonski Brod surrounding area, central and mountainous Croatia, coast of Istria, Knin</i>
	srpanj July	istok Hrvatske, veći dio središnje Hrvatske, Lika, južni Velebit, glavnina sjeverne Dalmacije, dijelovi srednje Dalmacije, Pelješac i Mljet <i>eastern Croatia, most of central Croatia, Lika, southern Velebit, most of northern Dalmatia, parts of central Dalmatia, Pelješac and Mljet</i>
	studeni November	Dubrovnik <i>Dubrovnik</i>
ekstremno sušno extremely dry	lipanj June	šira okolina Slavonskog Broda, središnja Hrvatska, gorska Hrvatska izuzev gospicкog područja, Istra, sjeverno Hrvatsko primorje, okolica Šibenika <i>wider Slavonski Brod surrounding area, central Croatia, mountainous Croatia, except the Gospic area, Istria, northern Croatian Littoral, Šibenik surrounding area</i>
	rujan September	dio Dubrovačkog primorja i Konavle <i>part of the Dubrovnik coastal area and Konavle</i>
ekstremno kišno extremely wet	siječanj January	Pazin <i>Pazin area</i>
	svibanj May	šire područje Varaždina i Zagreba <i>the wider areas of Varaždin and Zagreb</i>
	srpanj July	Senj i Zavižan <i>Senj and Zavižan</i>
	studeni November	šire šibensko područje sa zaleđem, dio otoka Hvara, Komiža i Ploče <i>wider Šibenik area, including hinterlands, part of the island of Hvar, Komiža and Ploče</i>

Godišnja doba Seasons		
Ekstrem Extreme	Mjesec Month	Područje Region
ekstremno hladno <i>extremely cold</i>		niti jedno područje <i>no areas in this category</i>
ekstremno toplo <i>extremely warm</i>	ljeto <i>summer</i>	dijelovi istočne i središnje Hrvatske, okolica Zavižana, Lošinj, dio sjeverne Dalmacije sa zaleđem, dio Brača i Hvara, šira okolica Ploče, središnji dio Pelješca, okolica Lastova <i>parts of eastern and central Croatia, Zavižan surrounding area, Lošinj, parts of northern Dalmatia, including hinterlands, parts of Brač and Hvar, wider Ploče surrounding area, central part of Pelješac, Lastovo surrounding area</i>
ekstremno sušno <i>extremely dry</i>		niti jedno područje <i>no areas in this category</i>
ekstremno kišno <i>extremely wet</i>	zima <i>winter</i>	okolica Pazina, okolica Knina, Makarske i Dubrovnika <i>Pazin surrounding area, Knin, Makarska and Dubrovnik surrounding areas</i>
	jesen <i>autumn</i>	okolica Hvara, Vis <i>Hvar surrounding area, Vis</i>

Godina 2021. Year 2021	
Ekstrem Extreme	Područje Region
ekstremno hladno <i>extremely cold</i>	niti jedno područje <i>no areas in this category</i>
ekstremno toplo <i>extremely warm</i>	niti jedno područje <i>no areas in this category</i>
ekstremno sušno <i>extremely dry</i>	niti jedno područje <i>no areas in this category</i>
ekstremno kišno <i>extremely wet</i>	niti jedno područje <i>no areas in this category</i>

## 1.4 Rangovi temperature i oborine u 2021. godini

Tijekom nekoliko mjeseci i ljeti 2021. godine su temperature zraka ili količine oborine bile među pet najtoplijih/najhladnijih, odnosno najsušnijih/najkišnijih na kon 1981. na većini postaja.

Travanj (tablica 1.4.1) je bio hladan i vrlo hladan na čitavom teritoriju Hrvatske s rangovima na svim postajama od drugog do petog najhladnjeg travnja u razdoblju 1981. – 2021. U tom razdoblju je na većini postaja najhladniji je bio travanj 1997.

## 1.4 Temperature and precipitation ranks in 2021

At most stations, air temperatures or precipitation amounts were among the five warmest/coldest or driest/wettest since 1981 during several months and the summer of 2021.

April (Table 1.4.1) was cold and very cold in the entire Croatian territory, ranking as the second to fifth coldest April in the period 1981 – 2021 at most stations. April 1997 was the coldest on most of the stations in the period in question.

Lipanj, srpanj i posljedično, ljetno, bili su među pet najtopljih na velikom broju postaja tijekom 2021. Lipanjske temperature (tablica 1.4.2) su na većini postaja bile među dvije do pet najtopljih, a samo na jednoj bio je to šesti najtoplji lipanj nakon 1981. Najtoplji lipanj u tom razdoblju bio je 2003., osim na Pargu, Puntijarki i Zavižanu na kojima je najtoplji bio lipanj 2019.

Srpanj (tablica 1.4.3) je bio prvi do peti najtoplji na svim, osim na dvije postaje, gdje je bio rangiran kao šesti i osmi najtoplji nakon 1981. Srpanj 2015. bio je najtoplji na većini postaja, a srpanj 2012. na deset njih. U Daruvru je srpanj 2021. bio je jednako topao kao do tada najtoplji srpanj 2012. i 2015., a u Varaždinu i Bjelovaru bio je jednako topao kao do tada najtoplji srpanj 2015.

Ljeto (tablica 1.4.4) je na većini postaja bilo treće do peto najtoplje nakon 1981., a na njih tri šesto najtoplje. Ljeto 2003. bilo je najtoplje nakon 1981. na svim osim na postajama Gradište, Osijek, Slavonski Brod i Zavižan gdje je najtoplje bilo ljeto 2012. U Dubrovniku su 2003. i 2012. ljetne temperature dosegle maksimum nakon 1981.

Na većini postaja je lipanj 2021. (tablica 1.4.5) bio najsušniji nakon 1981. što zajedno s vrlo visokim temperaturama svrstava lipanj 2021. na istaknuto mjesto po kombinaciji ova dva ekstrema. Na osam postaja lipanj 2021. bio je drugi do šesti najsušniji, a samo na Lastovu tek sedamnaesti, ne toliko iznenadjuće obzirom na količine oborine koje su tamo uobičajeno vrlo niske.

Rangovi srednjih godišnjih temperatura zraka (tablica 1.4.6) sortirani silazno su od petog do jedanaestog, što ih u promatranih 41 godinu smješta u toplu polovicu rangova analiziranog temperaturnog niza. Viši rangovi opaženi su za postaje koje su u ocjeni klime u prethodnim poglavljima ocijenjene kao vrlo tople.

Rangovi godišnjih količina oborine (tablica 1.4.7) ne mogu se smjestiti u jednu od kategorija, sušnu ili kišnu, tako da su u tablici prikazani sortirani uzlazno, za sušne rangove, i silazno za vlažne. Visoki rangovi sortirani uzlazno opaženi su za postaje koje su u prethodnim poglavljima ocijenjene kao sušne ili normalne na granici prema sušim. Visoki rangovi sortirani silazno opaženi su za Split-Marjan i Hvar koji su ocijenjeni kišnim u prethodnim poglavljima.

June, July and consequently the summer were among the warmest five at many stations in 2021. June temperatures (Table 1.4.2) were between two and five warmest at most stations, and sixth warmest in June after 1981 at only one station. The warmest June in the period was recorded in 2003, except in Parg and Puntijarka, where it was recorded in June 2019.

July (Table 1.4.3) was the first to fifth warmest at all but two stations, where it was ranked as the sixth and eighth warmest since 1981. July 2015 was the warmest at most stations, and July 2012 at ten stations. In Daruvar, July 2021 was as warm as the July of 2012 and 2015, which had held the record previously, and in Varaždin and Bjelovar, July 2021 was as warm as the July of 2015, which had held the record previously.

The summer of 2021 (Table 1.4.4) was the third to fifth warmest since 1981 at most stations, and the sixth warmest at three stations. The summer of 2003 was the warmest since 1981 at all stations but Gradište, Osijek, Slavonski Brod and Zavižan, where the summer of 2012 was the warmest. The highest summer temperatures in Dubrovnik since 1981 were recorded in 2003 and 2012.

At most stations, June 2021 (Table 1.4.5) was the driest since 1981. Considering the very high temperatures, June 2021 holds a prominent place due to the combination of these two extremes. At eight stations, June 2021 was the second to sixth driest, and only on Lastovo only the seventeenth, which is not so surprising, given the amount of precipitation that is usually very low there.

Mean annual air temperatures, sorted in a descending order (Table 1.4.6), rank from the fifth to the eleventh place, which places them in the warm half of the analysed temperature order ranks in the 41 years encompassed by the analysis. Higher ranks were observed at stations that were rated as very warm in the climate assessment in previous chapters.

Since the ranks of annual precipitation amounts (Table 1.4.7) cannot be categorized as either dry or wet, the table shows them in an ascending order for dry ranks, and in a descending order for wet ranks. In the ascending order high ranks were observed at stations that were rated as dry or normal bordering on dry in previous chapters. In the descending order, high ranks were observed for Split-Marjan and Hvar, which were rated as wet in previous chapters.

Tablica 1.4.1 Rangovi temperature zraka za HLADNI TRAVANJ 2021. Postaja, temperatura zraka ( $T$ ), odstupanje u odnosu na normalu 1981. – 2010. (Tanom), percentil temperature zraka (Tperc), rang niza sortiranog uzlazno (Rang hladni), godina s najhladnjim travnjem u razdoblju 1981. – 2021. (Najhladnija godina).

Table 1.4.1 Air temperature ranks for COLD APRIL 2021. Station, air temperature ( $T$ ), deviation from the normal 1981 – 2010 (Tanom), air temperature percentile (Tperc), rank of the series sorted in an ascending order (rank cold), year of the coldest April, 1981 – 2021 (Coldest year).

Postaja Station	$T$ $T$	Tanom Tanom	Tperc Tperc	Rang hladni Cold rank	Najhladnija godina Coldest year
Komiža	13,0	-1,5	5	2	1997
Ploče	12,5	-1,6	6	2	1997
Šibenik	12,2	-1,5	9	2	1997
Bilogora	8,9	-2,3	8	3	1997
Daruvar	9,0	-2,2	7	3	1997
Makarska	13,5	-1,4	8	3	1997
Osijek	9,4	-2,4	6	3	1997
Pazin	8,7	-1,7	6	3	1997
Rab	12,5	-1,1	14	3	1997
Rijeka	11,2	-1,4	14	3	1997
Senj	12,1	-1,4	14	3	1997
Split-Marjan	12,9	-1,5	11	3	1997
Bjelovar	9,6	-2,1	8	4	1997
Dubrovnik	13,4	-0,9	18	4	1997
Gospic	7,0	-1,6	14	4	1997
Gradište	10,0	-2,1	10	4	1997
Hvar	13,3	-1,1	11	4	1997
Knin	10,5	-1,5	11	4	1997
Križevci	9,1	-1,7	11	4	1997
Lastovo	12,5	-0,8	21	4	1997
Ogulin	8,2	-2,0	11	4	1982
Parg	4,8	-1,7	14	4	1982
Puntijarka	4,0	-2,1	11	4	1997
Sisak	9,7	-2,1	8	4	1997
Slavonski Brod	9,3	-2,3	8	4	1997
Varaždin	9,0	-1,9	9	4	1997
Zadar	12,1	-1,3	10	4	1997
Zagreb-Maksimir	9,8	-1,6	13	4	1997
Mali Lošinj	12,5	-0,8	21	5	1997
Zavižan	-0,2	-2,1	10	5	1997

Tablica 1.4.2 Rangovi temperature zraka za TOPLI LIPANJ 2021. Postaja, temperatura zraka ( $T$ ), odstupanje u odnosu na normalu 1981. – 2010. (Tanom), percentil temperature zraka (Tperc), rang niza sortiranog silazno (Rang topli), godina s najtopljim lipnjem u razdoblju 1981. – 2021. (Najtoplja godina).

Table 1.4.2 Air temperature ranks for WARM JUNE 2021. Station, air temperature ( $T$ ), deviation from normal 1981 – 2010 (Tanom), air temperature percentile (Tperc), rank of the series sorted in a descending order (Warm rank), year of the warmest June, 1981 – 2021 (Warmest year).

Postaja Station	$T$ $T$	Tanom Tanom	Tperc Tperc	Rang topli Warm rank	Najtoplja godina Warmest year
Bilogora	23,2	4,0	100	2	2003
Gradište	23,5	3,4	99	2	2003
Komiža	24,8	2,0	94	2	2003
Mali Lošinj	25,2	3,3	99	2	2003
Bjelovar	23,5	3,6	99	3	2003
Daruvar	22,2	2,8	98	3	2003
Gospic	20,5	3,5	99	3	2003
Križevci	22,5	3,7	99	3	2003
Ogulin	21,3	3,1	99	3	2003
Osijek	23,0	2,9	98	3	2003
Parg	18,7	4,0	99	3	2019
Puntijarka	18,0	4,0	100	3	2019
Rijeka	24,4	3,4	99	3	2003
Senj	25,7	3,6	99	3	2003
Sisak	23,5	3,6	99	3	2003
Slavonski Brod	22,4	2,6	96	3	2003
Varaždin	22,0	2,9	98	3	2003
Zadar	24,2	2,4	97	3	2003
Zagreb-Maksimir	23,3	3,7	99	3	2003
Zavižan	13,9	3,4	99	3	2019
Lastovo	23,8	2,0	94	4	2003
Rab	24,8	2,8	98	4	2003
Split-Marjan	26,0	2,6	97	4	2003
Šibenik	24,8	2,3	96	4	2003
Dubrovnik	24,4	1,8	92	5	2003
Hvar	24,6	1,8	93	5	2003
Knin	23,2	2,7	98	5	2003
Pazin	21,1	2,2	97	5	2003
Ploče	24,7	2,2	97	5	2003
Makarska	25,0	1,8	89	6	2003

Tablica 1.4.3 Rangovi temperature zraka za TOPLI SRPANJ 2021. Postaja, temperatura zraka ( $T$ ), odstupanje u odnosu na normalu 1981. – 2010. (Tanom), percentil temperature zraka (Tperc), rang niza sortiranog silazno (Rang topli), godina s najtoplijim srpnjem u razdoblju 1981. – 2021. (Najtoplja godina).

Table 1.4.3 Air temperature ranks for WARM JULY 2021. Station, air temperature ( $T$ ), deviation from normal 1981 – 2010 (Tanom), air temperature percentile (Tperc), rank of the series sorted in a descending order (Warm rank), year of the warmest July, 1981 – 2021 (Warmest year).

Postaja Station	$T$ $T$	Tanom Tanom	Tperc Tperc	Rang topli Warm rank	Najtoplja godina Warmest year
Bjelovar	24,2	2,4	97	1	2015;2021
Daruvar	23,4	2,1	97	1	2012;2015;2021
Varaždin	23,0	2,1	96	1	2015;2021
Bilogora	23,7	2,3	97	2	2015
Gradište	25,1	3,2	99	2	2012
Knin	25,8	2,3	98	2	2012
Komiža	27,4	1,6	95	2	2012;2015
Osijek	24,6	2,6	99	2	2012
Puntijarka	18,8	2,6	99	2	2015
Sisak	24,2	2,4	99	2	2015
Šibenik	27,8	2,3	99	2	2015
Gospic	21,6	2,2	98	3	2015
Hvar	27,4	1,7	96	3	2015
Križevci	23,0	2,4	99	3	2012
Lastovo	26,4	1,6	95	3	2015
Mali Lošinj	26,6	1,8	95	3	2015
Ogulin	22,4	2,2	98	3	2015
Ploče	27,6	2,2	99	3	2015
Slavonski Brod	24,4	2,7	99	3	2012
Split-Marjan	28,6	2,2	98	3	2015
Zadar	26,1	1,5	93	3	2015
Zagreb-Maksimir	24,0	2,5	98	3	2012
Zavižan	15,2	2,1	96	4	2015
Dubrovnik	26,7	1,5	91	5	2012
Makarska	28,0	1,7	96	5	2012
Parg	19,1	1,9	94	5	2015
Pazin	22,9	1,5	91	5	2015
Rab	26,5	1,4	88	5	2015
Senj	26,6	1,5	88	6	2015
Rijeka	25,4	1,4	84	8	2015

Tablica 1.4.4 Rangovi temperature zraka za TOPLO LJETO 2021. Postaja, temperatura zraka ( $T$ ), odstupanje u odnosu na normalu 1981. – 2010. (Tanom), percentil temperature zraka (Tperc), rang niza sortiranog silazno (Rang topli), godina s najtoplijim ljetom u razdoblju 1981. – 2021. (Najtoplja godina).

Table 1.4.4 Air temperature ranks for WARM SUMMER 2021. Station, air temperature ( $T$ ), deviation from normal 1981 – 2010 (Tanom), air temperature percentile (Tperc), rank of the series sorted in a descending order (Warm rank), year of the warmest summer, 1981 – 2021 (Warmest year).

Postaja Station	$T$ $T$	Tanom Tanom	Tperc Tperc	Rang topli Warm rank	Najtoplja godina Warmest year
Komiža	26,3	1,6	96	3	2003
Makarska	26,7	1,6	95	3	2003
Osijek	23,1	2,0	99	3	2012
Ploče	26,3	2,0	99	3	2003
Zagreb-Maksimir	22,9	2,3	98	3	2003
Daruvar	22,1	1,7	98	4	2003
Gradište	23,6	2,5	99	4	2012
Hvar	26,4	1,8	99	4	2003
Mali Lošinj	25,9	2,2	99	4	2003
Parg	18,2	2,0	97	4	2003
Sisak	23,0	2,1	98	4	2003
Split-Marjan	27,3	2,0	98	4	2003
Šibenik	26,3	2,0	99	4	2003
Bilogora	22,7	2,2	99	5	2003
Bjelovar	23,0	2,1	97	5	2003
Gospic	20,5	2,1	97	5	2003
Knin	24,3	2,0	99	5	2003
Križevci	21,9	2,2	99	5	2003
Lastovo	25,5	1,8	98	5	2003
Ogulin	21,2	1,9	97	5	2003
Pazin	21,6	1,3	93	5	2003
Puntijarka	17,8	2,4	99	5	2003
Rijeka	24,7	1,8	95	5	2003
Senj	25,8	1,8	95	5	2003
Slavonski Brod	22,9	2,0	97	5	2012
Varaždin	21,6	1,6	95	5	2003
Zadar	25,2	1,7	97	5	2003
Zavižan	14,2	2,0	98	5	2012
Dubrovnik	25,8	1,4	94	6	2003;2012
Rab	25,6	1,7	96	6	2003

Tablica 1.4.5 Rangovi količine oborine za SUHI LIPANJ 2021.. Postaja, količina oborine (R), odstupanje u odnosu na normalu 1981. – 2010. (Ranom), percentil količine oborine (Rperc), rang niza sortiranog uzlazno (Rang suhi), godina s najsušnjim lipnjem u razdoblju 1981. – 2021. (Najsušnija godina).

Table 1.4.5 Precipitation amount ranks for DRY JUNE 2021. Station, precipitation amount (R), deviation from normal 1981 – 2010 (Ranom), percentile of precipitation amount (Rperc), rank of the series sorted in an ascending order (Dry rank), year of the driest June, 1981 – 2021 (Driest year).

Postaja Station	R R	Ranom Ranom	Rperc Rperc	Rang suhi Dry rank	Najsušnja godina Driest year
Bilogora	20,5	-65,5	2	1	2021
Bjelovar	8,4	-80,0	0	1	2021
Daruvar	27,7	-76,4	5	1	2021
Gospic	16,3	-76,5	4	1	2005;2021
Gradište	21,7	-63,4	4	1	2021
Hvar	2,0	-40,1	15	1	2021
Karlovac	3,8	-104,1	0	1	2021
Komiža	0,6	-40,1	3	1	2021
Križevci	5,4	-83,6	0	1	2021
Mali Lošinj	2,3	-62,5	0	1	2021
Ogulin	8,2	-122,9	0	1	2021
Puntijarka	15,6	-116,1	0	1	2021
Rab	14,3	-55,3	2	1	2021
Rijeka	5,1	-103,4	0	1	2021
Senj	1,6	-85,6	0	1	2021
Sisak	8,8	-92,7	0	1	2021
Slavonski Brod	17,2	-71,3	1	1	2021
Split-Marjan	4,3	-44,3	7	1	2021
Šibenik	0,1	-54,0	1	1	2021
Varaždin	18,9	-77,2	1	1	2021
Zagreb-Maksimir	13,2	-84,2	0	1	2021
Zavižan	19,9	-120,8	0	1	2021
Pazin	11,0	-77,1	0	2	2006
Zadar	2,9	-45,9	2	2	2000
Dubrovnik	4,2	-46,2	9	3	2011
Osijek	18,4	-68,7	6	3	2000
Parg	49,6	-98,2	1	3	2019
Knin	13,2	-64,7	3	4	2019
Makarska	13,1	-39,6	9	4	2019
Ploče	7,1	-42,7	12	6	1982
Lastovo	13,1	-21,3	33	17	2019

Tablica 1.4.6 Rangovi temperature zraka za 2021. GODINU. Postaja, temperatura zraka ( $T$ ), odstupanje u odnosu na normalu 1981. – 2010. (Tanom), percentil temperature zraka (Tperc), rang niza sortiranog silazno (Rang topli), najtoplja godina tijekom razdoblja 1981. – 2021.

Table 1.4.6 Air temperature ranks for YEAR 2021. Station, air temperature ( $T$ ), deviation from normal 1981 – 2010 (Tanom), air temperature percentile (Tperc), rank of the series sorted in a descending order (Warm rank), the warmest year in the period 1981 – 2021.

Postaja Station	$T$ $T$	Tanom Tanom	Tperc Tperc	Rang topli Warm rank	Najtoplja godina Warmest year
Knin	14,0	0,8	95	5	2019
Mali Lošinj	16,6	1,0	98	5	2018
Ploče	16,3	0,7	96	5	2018
Šibenik	16,3	0,7	92	5	2018
Zadar	16,2	0,9	93	5	2018
Gospic	10,3	1,2	96	6	2019
Gradište	12,6	1,0	89	6	2019
Komiža	17,4	0,5	84	6	1994
Lastovo	16,6	0,7	92	6	2018
Makarska	17,4	0,5	80	6	2011;2018
Ogulin	11,0	0,6	77	6	2000;2014;2019
Rab	16,4	0,8	91	6	2018
Split-Marjan	17,2	0,8	95	6	2018
Zavižan	4,6	0,6	84	6	2014;2015;2019;2020
Bilogora	11,8	0,7	81	7	2019
Hvar	17,3	0,7	92	7	2018
Rijeka	15,0	0,8	91	7	2018
Sisak	12,1	0,7	81	7	2000;2014;2019
Zagreb-Maksimir	12,2	1,0	89	7	2018;2019
Dubrovnik	17,4	0,8	95	8	2018
Križevci	11,4	1,0	89	8	2014
Puntijarka	7,7	0,8	84	8	2019
Senj	16,0	0,9	90	8	2018
Slavonski Brod	11,9	0,7	81	8	2019
Bjelovar	12,1	0,9	84	9	2019
Daruvar	11,5	0,5	80	9	2019
Parg	8,4	0,8	84	9	2019
Osijek	12,0	0,7	84	10	2000;2019
Pazin	11,9	0,3	73	10	2014
Varaždin	11,2	0,6	77	11	2014

Tablica 1.4.7 Rangovi količine oborine za 2021. GODINU. Postaja, količina oborine (R), odstupanje u odnosu na normalu 1981. – 2010. (Ranom), percentil količine oborine (Rperc), rang niza sortiranog silazno / uzlazno (Rang kišni / Rang suhi), najkišnija / nasušnija godina tijekom razdoblja 1981. – 2021.

Table 1.4.7 Precipitation amount ranks for YEAR 2021. Station, precipitation amount (R), deviation from normal 1981 – 2010 (Ranom), percentile of precipitation amount (Rperc), rank of the series sorted in a descending/ascending order (Wet rank/Dry rank), Wettest/Driest year in the period 1981 – 2021.

Postaja Station	R R	Ranom Ranom	Rperc Rperc	Rang kišni Wet rank	Najkišnija godina Wettest year	Rang suhi Dry rank	Nasušnija godina Driest year
Križevci	691,5	-99,2	25	34	2014	8	2011
Parg	1586,3	-227,5	25	34	2014	8	2011
Puntijarka	1080,7	-172,2	23	34	2010	8	2011
Mali Lošinj	770,7	-156,6	23	33	2010	9	1983
Pazin	868,5	-175,2	18	33	2010	9	2015
Rijeka	1331,3	-217,3	22	32	2010	9	2003
Bjelovar	694,2	-100,7	25	32	2014	10	2011
Karlovac	959,5	-107,8	30	31	2014	11	2011
Daruvar	798,8	-103,6	27	30	2010	12	2011
Zavižan	1776,1	-196,9	30	30	2014	12	1983
Zadar	772,1	-81,9	31	29	2014	13	2011
Zagreb-Maksimir	772,2	-72,9	33	29	2014	13	2011
Komiža	638,0	-77,9	36	28	2014	14	1983
Slavonski Brod	729,6	-39,5	40	26	2005	16	2011
Varaždin	834,5	2,5	53	24	2014	18	2011
Lastovo	624,4	-7,8	51	23	2014	19	1983
Sisak	924,8	5,6	53	22	2014	20	2011
Šibenik	748,7	-1,3	52	20	2014	21	2011
Gospic	1367,7	12,7	54	20	2014	22	2011
Gradište	670,5	-15,1	49	20	2010	22	2000
Ogulin	1518,7	5,2	53	19	2014	23	1983
Rab	1080,9	-6,2	51	19	2014	23	2011
Ploče	1128,4	51,8	61	17	2010	24	1989
Bilogora	848,4	31,8	60	17	2014	25	2011
Dubrovnik	1101,0	40,4	59	17	2010	25	1991
Knin	1051,2	43,0	61	17	2014	25	1985
Osijek	697,8	14,6	56	16	2010	25	2000
Makarska	1080,6	72,1	67	16	2010	26	2011
Senj	1320,9	97,3	67	16	2013	26	2003
Hvar	835,1	128,5	79	9	2014	33	1983
Split-Marjan	930,4	154,3	83	9	2014	33	1989

## 2 ANALIZA SREDNJEĆNOG VISINSKOG STRUJANJA IZNAD HRVATSKE U 2021. GODINI

Srednja mjesecna visinska situacija sinoptičkih razmjera na izobarnoj plohi AT 500 hPa može pokazati prevladavajuće visinsko strujanje nad određenim predjelima tijekom mjeseca te se njezinom analizom mogu, u znatnoj mjeri, objasniti odstupanja od prosjeka mjesecnih vrijednosti pojedinih meteoroloških elemenata, primjerice srednje mjesecne prizemne temperature zraka, a najčešće i mjesecne količine oborine.

Stoga je učinjena meteorološka analiza 2021. godine pregledom srednjih mjesecnih situacija, odnosno strujanja nad širim područjem Europe i Sjevernog Atlantika.

U siječnju je nad našom zemljom srednje mjesecno strujanje na izobarnoj plohi AT 500 hPa bilo okarakterizirano dolinom koja se pružala od sjevera kontinenta sve do Sredozemlja, pa je u naše predjele prodirao razmjerno hladan i vlažan zrak (slika 2.1.a). Os visinske doline bila je upravo nad našim područjem. Izražen visinski greben pružao se nad istočnim Atlantikom sve do Grenlanda. Srednja mjesecna temperatura zraka je bila većinom malo viša od višegodišnjeg srednjaka (1981. – 2010.<sup>1</sup>). Odstupanja od prosjeka uglavnom nisu bila izražena. Mjesecna količina oborine je bila veća od prosjeka, mjestimice i znatno.

NAO indeks, pokazatelj oscilacije u prizemnom polju tlaka, odnosno advekcije zraka s Atlantika, u siječnju je bio negativan (tablica 2.1), što ukazuje na slabiji meridionalni gradijent tlaka te oslabljeno strujanje s Atlantika. Uz pritjecanje hladnjeg zraka sa sjevera pozitivno odstupanje temperature nije bilo izraženo, a višak oborine posljedica je pojačane ciklonalne aktivnosti u Sredozemlju.

<sup>1</sup> Vidi kartografski prikaz s detaljnijim opisom mjesecnih anomalija temperature zraka i količine oborine za 2021. godinu na području Hrvatske u poglavju 1.

## 2 ANALYSIS OF THE MEAN MONTHLY UPPER-LEVEL FLOW REGIME OVER CROATIA IN 2021

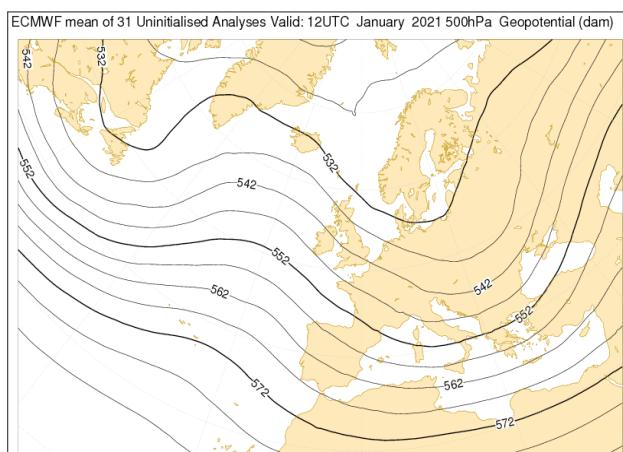
The mean monthly upper-level synoptic flow regime on the AT 500 hPa isobaric surface may show a prevalent upper-level flow over certain areas during the month. The deviations from the average monthly values for individual meteorological elements, such as the mean monthly low-level air temperatures, and even monthly precipitation amounts in most cases, can be explained by upper-level flow analysis.

A meteorological analysis of 2021 was therefore made by reviewing the mean monthly flow regimes over the wider area of Europe and the North Atlantic.

In January, the mean monthly flow over Croatia on the AT 500 hPa isobaric surface was characterized by a trough extending from the north of the continent to the Mediterranean, meaning that cold and humid air was penetrating our region (Figure 2.1.a). The axis of the upper-level trough was just above our region. A pronounced upper-level ridge extended over the eastern Atlantic, all the way to Greenland. The mean monthly air temperature was mostly higher than the multiannual mean (1981–2010<sup>1</sup>). Deviations from the average were not very pronounced. The monthly precipitation amount was higher than the average, in some places significantly.

The NAO (North Atlantic Oscillation) Index, an indicator of oscillation in the sea level pressure field, i.e., air advection from the Atlantic, was negative in January (Table 2.1), indicating a weaker meridional pressure gradient and weakened flow from the Atlantic. Thus, given the inflow of cold air from the north, there was no pronounced positive temperature anomaly, while the excess precipitation is the result of increased cyclonic activity in the Mediterranean.

<sup>1</sup> See the map with a more detailed description of the monthly air temperature and precipitation anomalies in 2021 in Croatia in Chapter 1.



Slika 2.1 Srednje mjesecne geopotencijalne visine iznad morske razine (dam) izobarne plohe 500 hPa (skraćeno: AT 500 hPa) za: a) siječanj (lijevo) i b) veljaču (desno) za 12 UTC (izvor: ECMWF).

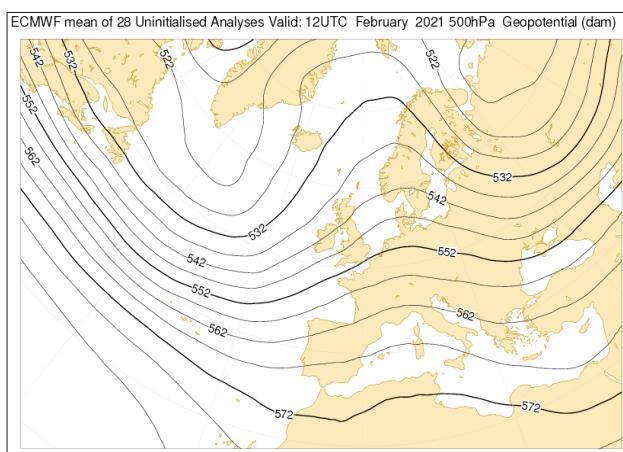


Figure 2.1 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) January (left) and b) February (right) for 12 UTC (source: ECMWF).

Tablica 2.1 Vrijednosti NAO\* (engl. North Atlantic Oscillation) indeksa u 2021. po mjesecima, izvor: <https://www.ncdc.noaa.gov/teleconnections/nao/>

Table 2.1 Monthly values of NAO\* (North Atlantic Oscillation) index in 2021, source: <https://www.ncdc.noaa.gov/teleconnections/nao/>

2021.	Siječanj January	Veljača February	Ožujak March	Travanj April	Svibanj May	Lipanj June
NAO index	-1,11	+0,14	+0,73	-1,43	-1,24	+0,77

2021.	Srpanj July	Kolovoz August	Rujan September	Listopad October	Studeni November	Prosinac December
NAO index	+0,03	-0,28	-0,21	-2,29	-0,18	+0,29

\* NAO indeks – indeks Sjeverno-atlantske oscilacija odnosi se na razliku u prizemnom tlaku između suptropskog područja visokog tlaka - Azorske anticklone i subpolarnog područja niskog tlaka - Islandske ciklone (razlika u prizemnom tlaku izmjerena na meteorološkoj postaji u Ponta Delgadi i Reykjaviku). Gradient tlaka između ta dva sustava određuje smjer i jačinu strujanja s Atlantika nad evropskim kopnjom. Prosječna pozicija i jačina Azorske anticklone i Islandske ciklone variraju iz mjeseca u mjesec, kroz sezone, odnosno iz godine u godinu i upravo ta varijacija određuje NAO indeks, odnosno njegov predznak. Pokazalo se da velika razlika u tlaku između ta dva sustava - izražena kao NAO+, za posljedicu ima jako zapadno strujanje te indirektno blage zime u srednjoj Europi. Također može biti povezan s pozitivnom anomalijom temperature iznad sjeverne Europe te ponekad negativnom anomalijom iznad južne Europe i Bliskog istoka. Što se oborine tiče, NAO+ je obično povezan s količinom većom od prosjeka iznad sjeverne Europe i Skandinavije te manjom oborinom iznad srednje i južne Europe. S druge strane, NAO– opisuje situaciju kada je gradient tlaka između ta dva sustava slabo izražen, odnosno strujanje s Atlantika je slabije, pa sjeverna Europa često može imati hladnu i suhu zimu, a putanje ciklona pomaknute su južnije. To za posljedicu može imati pojčanu ciklonalnu aktivnost u Sredozemlju uz više oborina na području južne Europe i sjeverne Afrike. Veza između NAO indeksa i prevladavajućeg tipa vremena izraženja je u hladnom dijelu godine.

\* NAO index - North Atlantic Oscillation index refers to the difference in mean sea level pressure between subtropical area of high pressure over the Azores and subpolar area of low pressure over Iceland. Air pressure gradient between these two systems determines the direction and the strength of air flow from the Atlantic to the European continent. The position and the strength of the high-pressure system over the Azores and low-pressure system over Iceland varies on the monthly, seasonal and annual basis and this variation determines the positive or negative sign of the NAO index. Large air pressure difference between these two systems expressed as NAO+ causes strong westerly flow and indirectly cooler summer seasons and mild winter seasons in Central Europe. Moreover, it can be connected to positive temperature anomaly over Northern Europe and sometimes negative temperature anomaly over Southern Europe and the Middle East. There is also the relationship between the NAO and precipitation; NAO+ usually causes greater than normal precipitation amount over Northern Europe and Scandinavia and precipitation deficit over Central and Southern Europe. On the other hand, NAO– describes a situation with lower air pressure gradients between these two pressure systems and consequently weaker air flow from the Atlantic. In such circumstances, in the northern part of Europe, winter seasons can be cold and dry. Low pressure system trajectories are moved to the south and this causes strong cyclonic activity in the Mediterranean with more precipitation in Southern Europe and in North Africa. NAO index and the prevailing weather regime link is more significant in the colder part of a year.

Nasuprot tome, u veljači je srednje mjesечно višinsko stanje ukazivalo na pritjecanje razmjerno toplog i vlagom siromašnog zraka pod utjecajem prednje strane grebena (slika 2.1.b). Os grebena se nalazila zapadnije od Hrvatske. Nad Atlantikom je bila dolina koja se pružala od Grenlanda prema jugu, a višinska dolina bila je istočno od Hrvatske. Srednja mjesечna temperatura zraka je bila viša, ponegdje i značajno od prosječne, dok je mješevna količina oborine bila manja ili oko prosjeka, samo mjestimice veća.

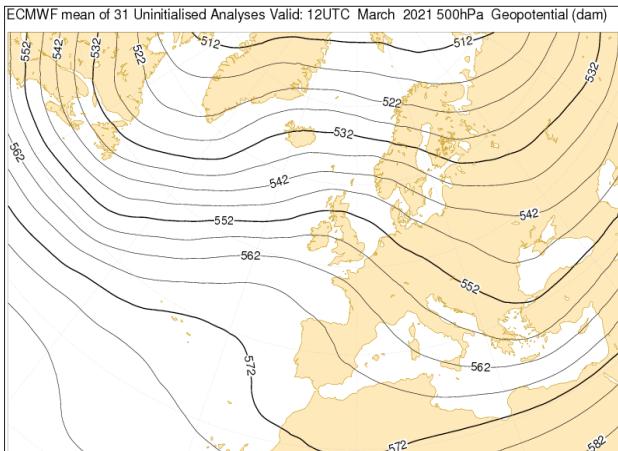
I u ožujku je nad našom zemljom na izobarnoj plohi AT 500 hPa bila prednja strana grebena (slika 2.2.a). No, za razliku od veljače, greben se u ožujku pružao s jugozapada Europe prema Sjevernom i Baltičkom moru, a nad istočnom Europom je bila dolina. Srednja mjesечna temperatura zraka u ožujku je bila uglavnom unutar višegodišnjeg prosjeka (1981. – 2010.). Mješevna količina oborine je bila većinom manja ili u nekim predjelima oko klimatološkog srednjaka.

S obzirom na to da je u veljači i ožujku u višim slojevima atmosfere iznad Hrvatske bila prednja strana

However, in February, the mean monthly upper-level flow indicated an influx of warm and dry air under the influence of the front of the ridge (Figure 2.1.b). The axis of the ridge was located west of Croatia. Above the Atlantic, a trough extended from Greenland to the south, and another upper-level trough was situated east of Croatia. The mean monthly air temperature was higher, somewhere even significantly higher than the average, while the monthly precipitation amount was lower than or close to the average, and higher only in some locations.

The front side of the ridge was located above Croatia on the AT 500 hPa isobaric surface again in March (Figure 2.2.a). However, unlike in February, in March the ridge extended from southwestern Europe to the North and Baltic Seas, while the trough was located over Eastern Europe. The mean monthly air temperature in March mostly fell within the multiannual average (1981 – 2010). The monthly precipitation amount was mostly lower, or in some areas around the climatological mean.

Given that the front of the upper-level ridge was located above Croatia in February and March, the NAO Index



Slika 2.2 Srednje mjesecne geopotencijalne visine iznad morske razine (dam) izobarne plohe 500 hPa (skraćeno: AT 500 hPa) za: a) ožujak (lijevo) i b) travanj (desno) za 12 UTC (izvor: ECMWF).

Figure 2.2 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) March (left) and b) April (right) for 12 UTC (source: ECMWF).

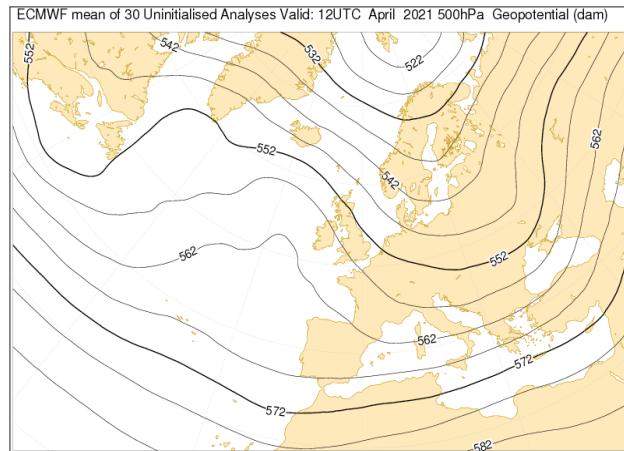
grebena, i NAO indeks za spomenuto razdoblje bio je pozitivan što pokazuje da su gradijenti prizemnog tlaka između Azorske anticiklone i Islandske ciklone bili izraženiji nego u siječnju, ali ne i ključni za transport vlage s Atlantika.

U travnju je prema srednjem mjesecnom stanju, odnosno strujanju nad područjem naše zemlje bila visinska dolina čija je os bila nad Hrvatskom (slika 2.2.b). Dolina se pružala sa sjevera kontinenta preko srednje Europe do Sredozemlja. Takva situacija ukazuje na prijeljeće razmjerno hladnog i vlažnog zraka. Greben je zahvaćao dio zapadne Europe i veći dio Atlantskog oceana. Srednja mjesecna temperatura zraka u travnju je bila posvuda niža od višegodišnjeg srednjaka. Mjesecna količina oborine je bila oko prosjeka ili malo veća, a u južnim predjelima manja od prosječne.

U svibnju je nad većim dijelom Europe, pa i nad našom zemljom bila visinska dolina čija je os bila zapadnije od Hrvatske (slika 2.3.a). To ukazuje na kruženje razmjerno hladnog i vlažnog zraka nad tim predjelima. Srednja mjesecna temperatura zraka je bila gotovo posvuda niža od klimatološkog srednjaka za svibanj, ponegdje i znatno niža. Količina oborine bila je nejednoliko raspoređena - bila je uglavnom veća, ponegdje i znatno veća od višegodišnjeg srednjaka, ali je isto tako, mjestimice bilo manje kiše od prosjeka.

U travnju i svibnju vrijednosti NAO indeksa bile su negativne što ukazuje na manje gradijente tlaka između Azorske anticiklone i Islandske ciklone, odnosno manje izražena strujanja. To je omogućavalo prodiranje i zadržavanje vlažnog i relativno hladnog zraka sa sjeverozapada do naših krajeva.

U lipnju je srednje mjesecno strujanje na AT 500 hPa nad našom zemljom bilo karakterizirano prednjom stranom grebena čija se os nalazila malo zapadnije od Hrvatske (slika 2.3.b). Dolina je bila nad najzapadnijim dijelovima kontinenta te na istoku. U lipnju je srednja mjesecna temperatura zraka bila zamjetno viša od prosjeka (1981. – 2010.), a mjesecna količina oborine je bila posvuda značajno manja od višegodišnjeg srednjaka.



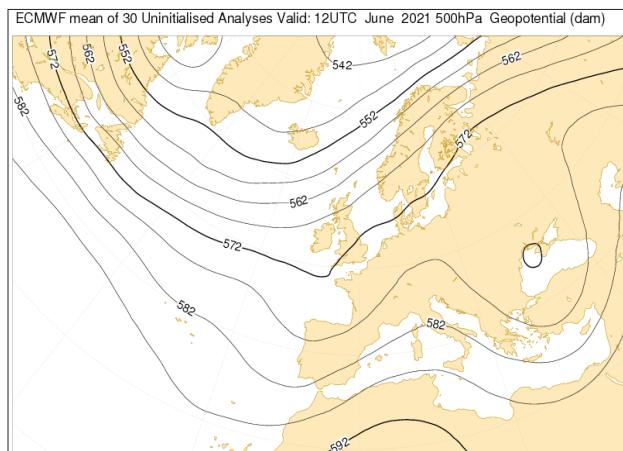
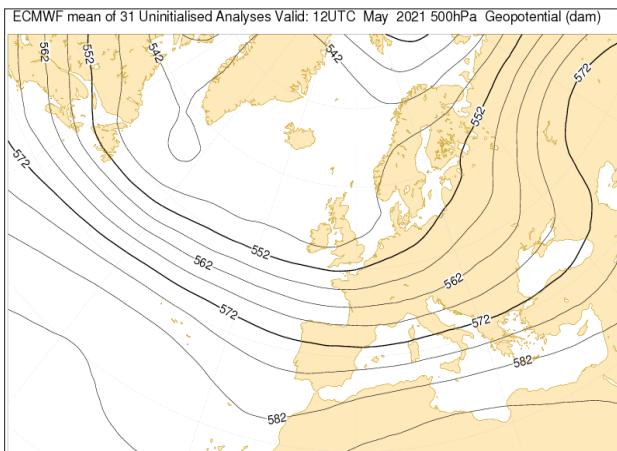
for the mentioned period was positive, which shows that the surface pressure gradients between the Azores High and the Icelandic Low were more pronounced than in January, but they were not crucial for the transfer of wet conditions from the Atlantic.

According to the average monthly flow, the axis of an upper-level trough was located above Croatia in April (Figure 2.2.b). The trough itself extended from the north of the continent through Central Europe to the Mediterranean. Such a situation is indicative of the influx of relatively cold and humid air. The ridge covered parts of Western Europe and most of the Atlantic Ocean. The mean monthly air temperature in April was lower than the multiannual mean. The monthly precipitation amount was around the average or slightly higher. Only the southern regions had below-average precipitation amounts.

In May, an upper-level trough whose axis lay to the west of Croatia was located over most of Europe, including Croatia (Figure 2.3.a). This indicates the circulation of relatively cold and humid air over these areas. The mean monthly air temperature was lower than the May climatological average almost everywhere, and in some places, it was significantly lower. The precipitation amount was unevenly distributed - it was mostly higher, and in some places significantly higher than the multiannual mean, but there were also some areas with below-average rainfall.

NAO Index values were negative in April and May, which is indicative of lower pressure gradients between the Azores High and the Icelandic Low, i.e., a less pronounced flow. This allowed the penetration and retention of moist and relatively cold air from the northwest to Croatia.

In June, the mean monthly flow at AT 500 hPa over Croatia was characterized by the front side of the ridge, whose axis was located slightly west of Croatia (Figure 2.3.b). The trough was located over the westernmost parts of the continent and to the east. In June, the mean monthly air temperature was significantly higher than the average (1981 – 2010), and the monthly precipitation amount was significantly lower than the multiannual average everywhere.



Slika 2.3 Srednje mjesečne geopotencijalne visine iznad morske razine (dam) izobarne plohe 500 hPa (skraćeno: AT 500 hPa) za: a) svibanj (lijevo) i b) lipanj (desno) za 12 UTC (izvor: ECMWF).

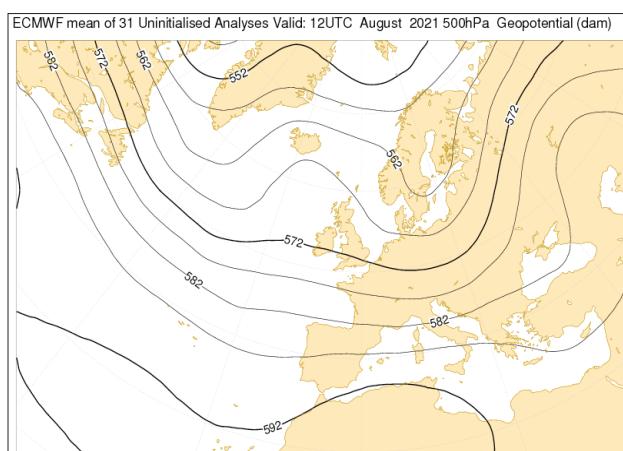
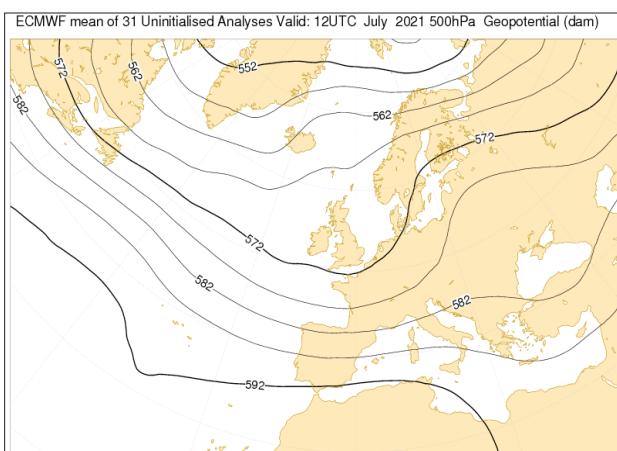
Figure 2.3 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) May (left) and b) June (right) for 12 UTC (source: ECMWF).

Iako NAO oscilacija značajnije utječe na vrijeme u Europi u zimskom dijelu godine, pozitivna vrijednost indeksa u lipnju odgovara situaciji s povećanim gradijentima u prizemnom polju tlaka te dotoku vlage s Atlantika uglavnom sjevernije od Hrvatske. Uz prevladavajući greben po visini i pri tlu je anticiklonalni greben, odnosno bezgradijentno anticiklonalno polje koje je omogućavalo zadržavanje toplog zraka iznad Hrvatske te sprječavalo prodiranje vlažnog zraka sa sjevera.

U srpnju se naša zemlja nalazila na stražnjoj strani grebena prema srednjem mjesečnom strujanju na AT 500 hPa (slika 2.4.a). Greben se pružao s juga preko Balkanskog poluotoka na sjeveroistok kontinenta. Visinska dolina se pružala od Sjevernog mora i zapadne Europe do Alpa. U srpnju je srednja mjesečna temperatura bila zamjetno viša od prosječne, dok je količina oborine bila vrlo nejednolikor raspoređena. U većem dijelu zemlje oborina je bila oko prosjeka, ali je bilo područja s većom

Although the NAO oscillation significantly affects the weather in Europe during the winter, the positive values of the index in June correspond to the situation of increased gradients of the sea level pressure field, and inflow of moisture from the Atlantic into the European continent, mostly north of Croatia. Along with the prevailing ridge in upper levels, a high-pressure ridge was present near the ground, or more precisely a non-gradient anticyclonic field that allowed the retention of warm air over Croatia and prevented the penetration of moist air from the north.

In July, our country was at the back of the ridge according to the mean monthly flow at AT 500 hPa (Figure 2.4.a). The ridge extended from the south across the Balkan Peninsula to the northeast of the continent. The upper-level trough extended from the North Sea and Western Europe to the Alps. The mean monthly temperature in July was noticeably higher than the average, while the amount of precipitation was very unevenly distributed. The amount of precipitation was around the average in most parts of the



Slika 2.4 Srednje mjesečne geopotencijalne visine iznad morske razine (dam) izobarne plohe 500 hPa (skraćeno: AT 500 hPa) za: a) srpanj (lijevo) i b) kolovoz (desno) za 12 UTC (izvor: ECMWF).

Figure 2.4 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) July (left) and b) August (right) for 12 UTC (source: ECMWF).

količinom kiše, ali i onih sa znatnim manjkom, posebice na jugu zemlje.

U kolovozu je na AT 500 hPa bio greben koji se pružao od sjeverne Afrike i zahvaćao Sredozemlje, a dolina od Sjevernog mora pružala se nad srednju Europu (slika 2.4.b). Naša zemlja je bila na južnom rubu doline. Srednja mjesecna temperatura zraka je u kolovozu bila najvećim dijelom malo viša od prosjeka. Međutim, ponegdje je pozitivno odstupanje srednje mjesecne temperature bilo izraženo, a količina oborine je, kao i u srpnju, bila nejednoliko raspoređena. U većem dijelu zemlje oborine je bilo oko višegodišnjeg srednjaka, ali je bilo područja s više, odnosno manje kiše od prosjeka.

Srednje mjesecno visinsko stanje je u rujnu nad našom zemljom karakterizirala prednja strana grebena koji je zahvaćao zapadnu Europu (slika 2.5.a). Nad istočnim dijelom kontinenta bila je duboka dolina. U takvima je okolnostima u rujnu srednja mjesecna temperatura zraka bila viša od srednjaka, a u najvećem dijelu zemlje oborine je bilo manje od prosjeka.

Od srpnja do rujna vrijednosti NAO indeksa bile su različitog predznaka i razmjerno male, što pokazuje da nije bilo prevladavajućeg utjecaja strujanja s Atlantika ili situacija s pojačanom ciklonalnom aktivnošću iznad Sredozemlja. S obzirom na to da je vrijeme u toplom dijelu godine uvelike određeno lokalnim čimbenicima kao što je raspodjela kopna i mora ili orografija, upravo su oni određivali vremenske prilike u spomenutom razdoblju.

U listopadu je nad našom zemljom bila dolina koja se od srednje Europe preko naše zemlje i Sredozemlja pružala do sjeverne Afrike (slika 2.5.b). Greben je bio nad jugozapadom kontinenta. Srednja mjesecna temperatura zraka u listopadu je bila niža od klimatološkog srednjaka. Mjesecna količina oborina je bila uglavnom oko prosječne ili veća, samo na sjevernom Jadranu manja.

Listopad je bio obilježen izraženom negativnom fazom Sjeverno-atlantske oscilacije. Pritom je, kao i u proljetnim mjesecima (travanj, svibanj) bio omogućen dotok relativno hladnog i vlagom razmjerno bogatog zraka sa zapada i sjeverozapada, odnosno s Atlantskog oceana.

country. However, there were areas with excessive rainfall, as well as areas with a significant deficit, especially in the south.

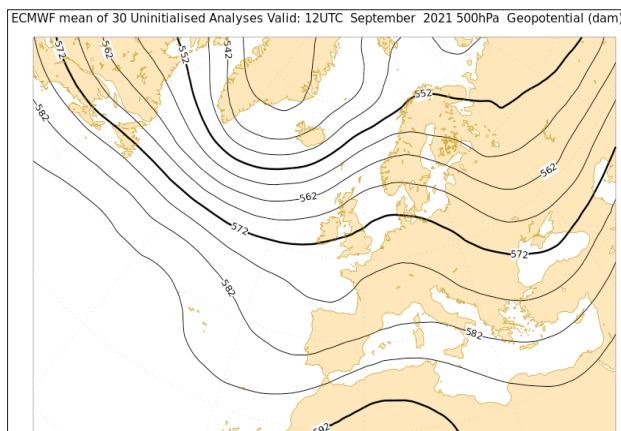
In August, there was a ridge extending from North Africa and affecting the Mediterranean at AT 500 hPa, and a trough extending from the North Sea over Central Europe (Figure 2.4.b). Our country was on the southern edge of the trough. The mean monthly air temperature in August was, in general, slightly higher than average. However, in some places the positive deviation of the mean monthly temperature was pronounced, and the amount of precipitation, like in July, was unevenly distributed. In most parts of the country, the precipitation amount was around the multianual mean, but there were areas that had rainfall higher or less than the average.

The mean monthly flow in September over Croatia characterized by the front side of the ridge that spanned Western Europe (Figure 2.5.a). A deep trough was located over the eastern part of the continent. In such circumstances, the average monthly air temperature in September was above the mean, and precipitation amounts were below-average in most of the country.

From July to September, NAO index values had different phases and were relatively low, indicating that there was no predominant impact of the flows from the Atlantic or situations of increased cyclonic activity over the Mediterranean. The weather in the warm part of the year is largely determined by local factors such as the distribution of land and sea, or orography. These factors defined the weather conditions in the period in question.

In October, a trough extended from Central Europe through the Mediterranean, including Croatia, to North Africa (Figure 2.5.b). The ridge was located over the southwest of the continent. The mean monthly air temperature in October was lower than the climatological mean. The monthly precipitation amount was mostly close to average or higher. North Adriatic was the only location that saw below-average precipitation.

October saw a pronounced negative phase of the North Atlantic Oscillation. Like in the spring (April, May),



Slika 2.5 Srednje mjesecne geopotencijalne visine iznad morske razine (dam) izobarene plohe 500 hPa (skraćeno: AT 500 hPa) za: a) rujan (lijevo) i b) listopad (desno) za 12 UTC (izvor: ECMWF).

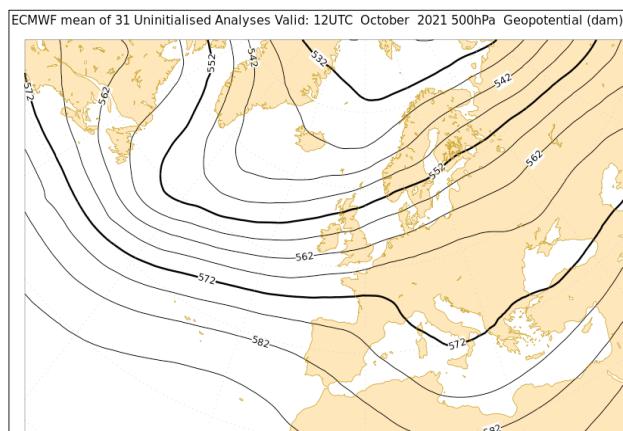
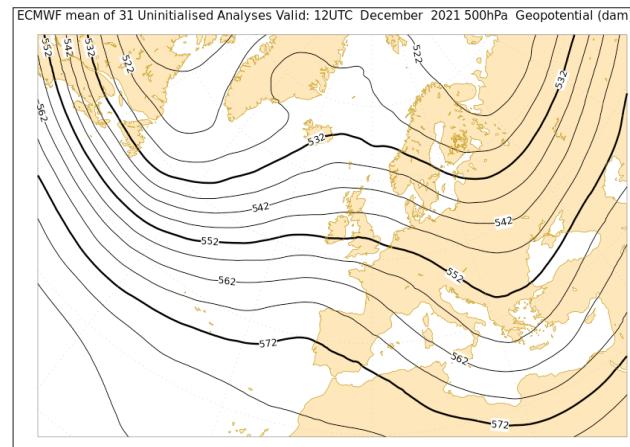
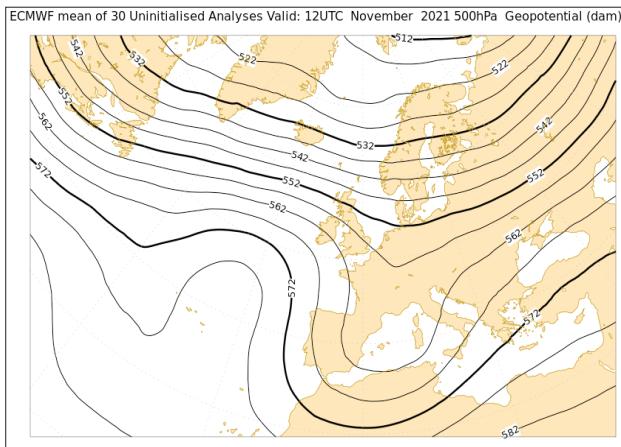


Figure 2.5 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) September (left) and b) October (right) for 12 UTC (source: ECMWF).



Slika 2.6 Srednje mjesечne geopotencijalne visine iznad morske razine (dam) izobarne plohe 500 hPa (skraćeno: AT 500 hPa) za: a) studeni (lijevo) i b) prosinac (desno) za 12 UTC (izvor: ECMWF).

Figure 2.6 Mean monthly geopotential height above sea level (dam) of the isobaric surface 500 hPa (abbreviated: AT 500 hPa) for: a) November (left) and b) December (right) for 12 UTC (source: ECMWF).

U studenom je na AT 500 hPa nad našom zemljom bila prednja strana doline, odnosno jugozapadno stanje ispred duboke doline zapadnije nad kontinentom (slika 6.a). Iznad Atlantskog oceana te iznad istoka Europe bio je greben. U studenom je srednja mjesечna temperatura zraka posvuda bila viša od prosjeka, osobito na jugu zemlje. Količina oborine je u najvećem dijelu zemlje bila veća od višegodišnjeg srednjaka ili najmanje oko njega.

U studenom je prevladavajući režim strujanja iznad Europe i dalje bila negativna faza Sjeverno-atlantske oscilacije (NAO–), ali manje izražena nego u listopadu. Naime, bio je omogućen dotok vlažnog zraka, ali uglavnom sa Sredozemlja zbog manjih meridionalnih gradijenata u polju tlaka, dok je situacija po visini omogućavala i dalje pritjecanje relativno toplog zraka u jugozapadnoj struji.

U prosincu je nad Hrvatskom bilo prednja strana grebena čija se os pružala od jugozapada prema sjeveru kontinenta (slika 2.6.b). Dolina je bila nad istočnim predjelima Europe. I u prosincu je srednja mjesечna temperatura zraka u cijeloj zemlji bila viša od prosjeka, a količina oborine bila je veća od prosječne uglavnom u istočnim i južnim krajevima Hrvatske.

Slabije izražena, ali pozitivna faza Sjeverno-atlantske oscilacije (NAO+) u prosincu prevladavala je uglavnom u prvom dijelu mjeseca, dok je u drugom dijelu dotok vlažnijeg zraka bio omogućen sa Sredozemlja uz slabije gradijente u polju tlaka, pa je i količina oborine na istoku i jugu bila veća od prosjeka.

## Zaključak

Tijekom 2021. godine iznad Hrvatske je na AT 500 hPa najčešće bila prednja strana grebena (veljača, ožujak, lipanj, rujan i prosinac). Osim u rujnu, u spomenutim mjesecima Sjeverno-atlantska oscilacija bila je u pozitivnoj fazi (NAO+) uz povremeno postojanje izraženih meridionalnih gradijenata u polju tlaka.

Zatim po učestalosti slijedi visinska dolina (siječanj, travanj, svibanj i listopad) čija je os uglavnom bila iznad Hrvatske, samo u svibnju nešto zapadnije. U tim je mjesecima vrijednost NAO indeksa bila negativna (NAO–),

this allowed the inflow of relatively cold and moist air from the west and northwest, i.e. from the Atlantic Ocean.

In November, the front of the trough, meaning the southwestern regime in front of the deep trough located toward the west of the continent, was at AT 500 hPa over Croatia (Figure 2.6.a). The ridge was located over the Atlantic Ocean and Eastern Europe. In November, the mean monthly air temperature was higher than the average everywhere, especially in the south of the country. In most parts of the country, the precipitation amount was higher than the multiannual mean, or at least close to it.

In November, the negative phase of the North Atlantic Oscillation (NAO–) was still the prevailing flow regime in upper levels over Europe, but it was less pronounced than in October. The inflow of moist air, predominantly from the Mediterranean, was made possible by the weaker meridional gradients in the pressure field, while the upper-level situation allowed the inflow of relatively warm air in the southwest flow.

In December, the front side of the ridge whose axis extended from the southwest to the north of the continent was located above Croatia (Figure 2.6.b). The trough, on the other hand, was located over the eastern parts of Europe. The mean monthly air temperature in December was higher than the average in the entire country, while the precipitation amount was higher than the average mainly in the eastern and southern parts of Croatia.

A less pronounced, but still positive phase of the North Atlantic Oscillation (NAO+) was mostly prevalent in the first half of December. Weaker gradients in the pressure field made the inflow of moist air from the Mediterranean possible in the second half. The average precipitation amount in the east and south was also higher than average.

## Conclusion

The front of the ridge was located over Croatia for most of 2021 (February, March, June, September, and December) at AT 500 hPa. With the exception of September, the North Atlantic Oscillation was in a positive phase (NAO

što znači da su bili prisutni manji gradijenti u polju tlaka između Azorske antiklone i Islandske ciklone, odnosno meridionalna strujanja su bila manje izražena. To je nad naše krajeve omogućavalo dotok i zadržavanje vlažnog i relativno hladnog zraka sa sjeverozapada.

U srpnju i kolovozu prevladavao je utjecaj grebena (osi ili stražnje strane). Vrijednosti NAO indeksa bile su male, pozitivne pa negativne, odnosno utjecaj Sjeverno-atlantske oscilacije na vremenske prilike u ljetnim mjesecima bio je manje izražen.

U studenom je srednje strujanje bilo jugozapadno što je rezultiralo pozitivnom anomalijom temperature i količine oborina s obzirom na prosjek. Sjeverno-atlantska oscilacija bila je u negativnoj fazi pa je bio omogućen dotok vlažnog zraka, ali uglavnom sa Sredozemlja zbog manjih meridionalnih gradijenata u polju tlaka.

+) in these months, with occasional pronounced meridional gradients in the pressure field.

Upper-level trough was the second most frequent phenomenon (January, April, May, and October), mostly with an axis located above Croatia. May was the only month when it was located slightly further to the west. In these months, NAO index value was negative (NAO-), which means that weaker gradients were present in the pressure field between the Azores High and the Icelandic Low, i.e. the meridional flows were less pronounced. This enabled the inflow and retention of moist and relatively cold air from the northwest over our region.

The influence of the ridge (axis or back) was prevalent in July and August. NAO index levels were low, first positive, and then negative, meaning that the impact of the North Atlantic Oscillation on the weather conditions in the summer months was less pronounced.

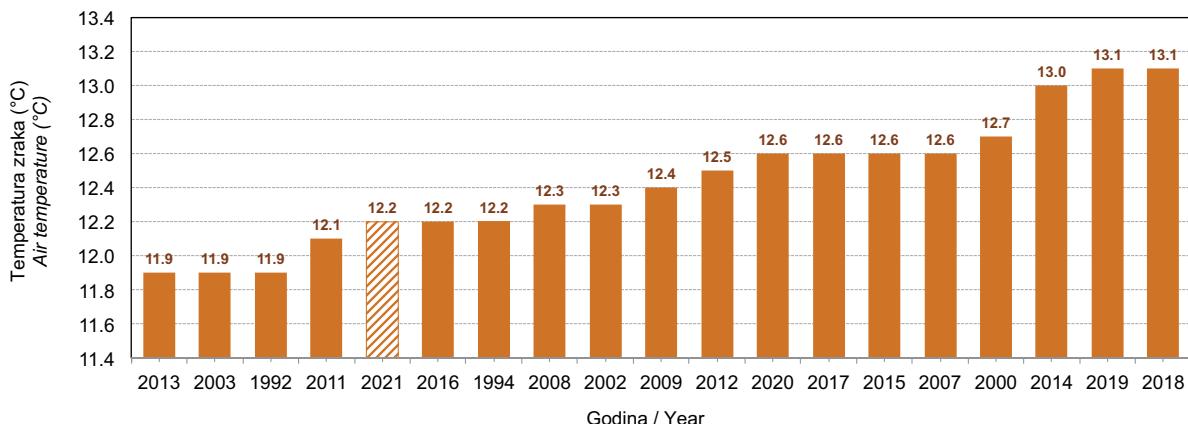
In November, the mean flow was southwesterly, resulting in a positive temperature and precipitation amount anomalies relative to the average. The North Atlantic Oscillation was in a negative phase, allowing the inflow of moist air, but mainly from the Mediterranean due to weaker meridional gradients in the pressure field.

### 3. ANALIZA RANGOVA I TREDOVA SREDNJIH GODIŠNJIH TEMPERATURA ZRAKA I GODIŠNJIH KOLIČINA OBORINE ZA POSTAJE ZAGREB-MAKSIMIR I SPLIT-MARJAN U 2021 GODINI

Za postaju Zagreb-Maksimir srednja godišnja temperatura zraka za 2021. godinu iznosi  $12.2^{\circ}\text{C}$ , zbog čega 2021. godina pripada osmoj skupini najtoplijih godina od početka meteoroloških motrenja na toj postaji (slika 3.1). Trend srednjih godišnjih temperatura zraka za Zagreb-Maksimir prikazan je na slici 3.2. Vidljiv je i daљe pozitivan trend srednje godišnje temperature zraka ( $0.2^{\circ}\text{C}/10 \text{ god}$ ) uz odgovarajuće međugodišnje varijacije. Primjetno je da je nakon sredine 80-tih godina prošlog stoljeća trend srednje godišnje temperature zraka znatno naglašeniji nego u prethodnom razdoblju što se

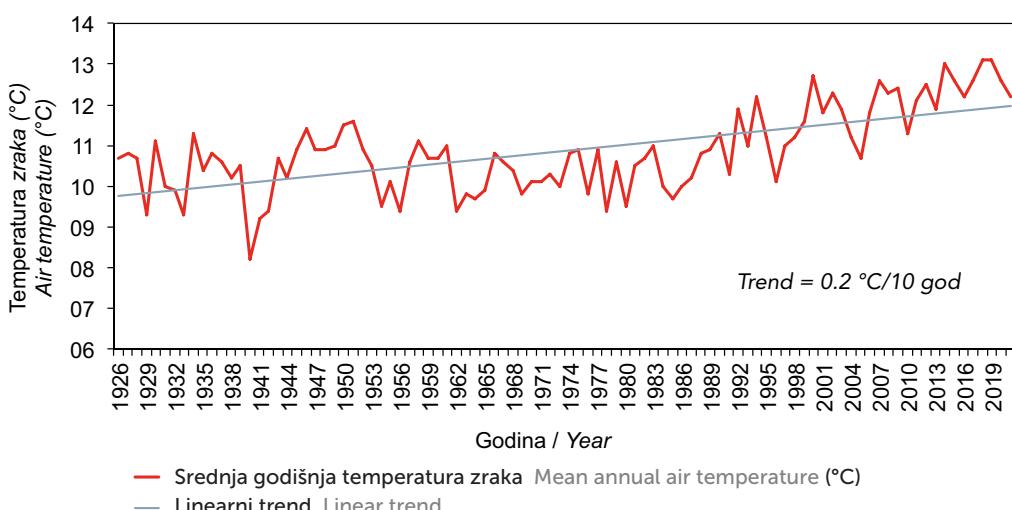
### 3 ANALYSIS OF MEAN ANNUAL AIR TEMPERATURE AND ANNUAL PRECIPITATION AMOUNT RANKS AND TRENDS FOR ZAGREB-MAKSIMIR AND SPLIT-MARJAN STATIONS IN 2021

A comparison of the average annual air temperatures for meteorological station Zagreb-Maksimir in the period (1926 – 2021) indicates that the year 2021 belongs to the 8th group of the warmest years on record (the average annual air temperature for Zagreb-Maksimir for the year 2021 is  $12.2^{\circ}\text{C}$ ) what is shown in Figure 3.1. The average annual air temperature trend for Zagreb-Maksimir is shown in Figure 3.2. The positive trend in average annual air temperature ( $0.2^{\circ}\text{C}/10 \text{ yrs}$ ) is apparent with certain inter-annual variations. It can be noticed that the secular average annual air temperature trend since mid 1980s became even



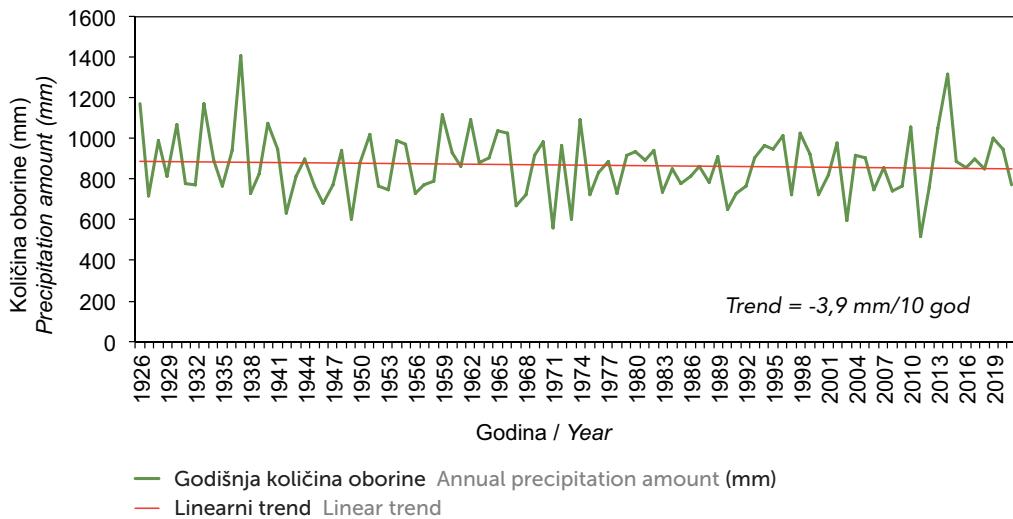
Slika 3.1 Deset skupina najtoplijih godina od početka meteoroloških motrenja (1926. – 2021.) za Zagreb-Maksimir

Figure 3.1 Ten groups of the warmest years on record (1926 – 2021) for Zagreb-Maksimir



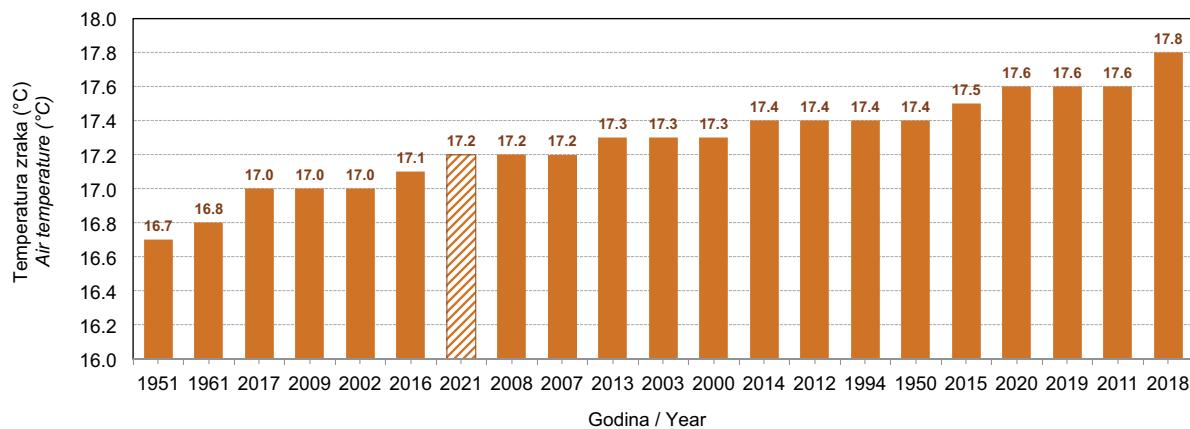
Slika 3.2 Srednje godišnje temperature zraka za Zagreb-Maksimir za razdoblje 1926. – 2021. godina

Figure 3.2 Mean annual air temperatures at Zagreb-Maksimir in the period 1926 – 2021



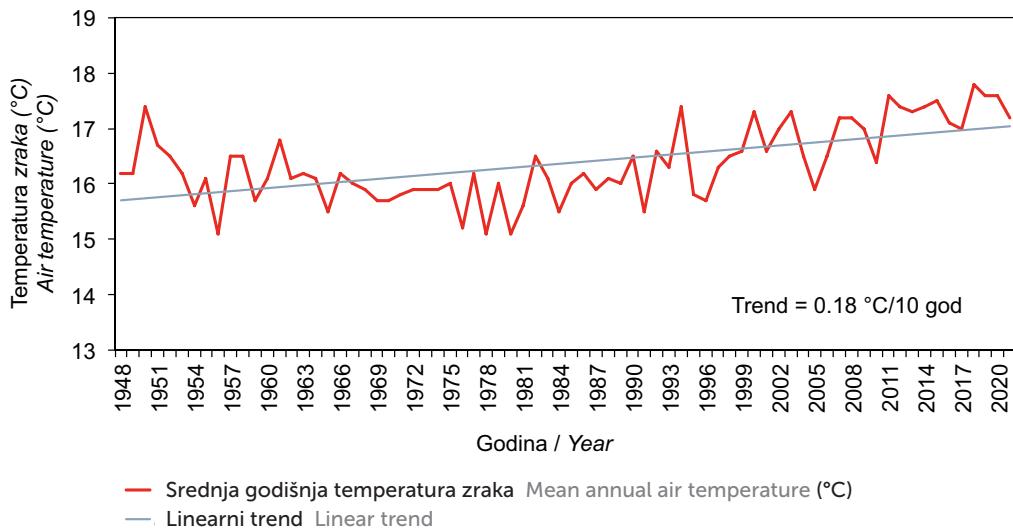
Slika 3.3 Godišnje količine oborine za Zagreb-Maksimir za razdoblje 1926. – 2021. godina

Figure 3.3 Annual precipitation amounts at Zagreb-Maksimir in the period 1926 – 2021



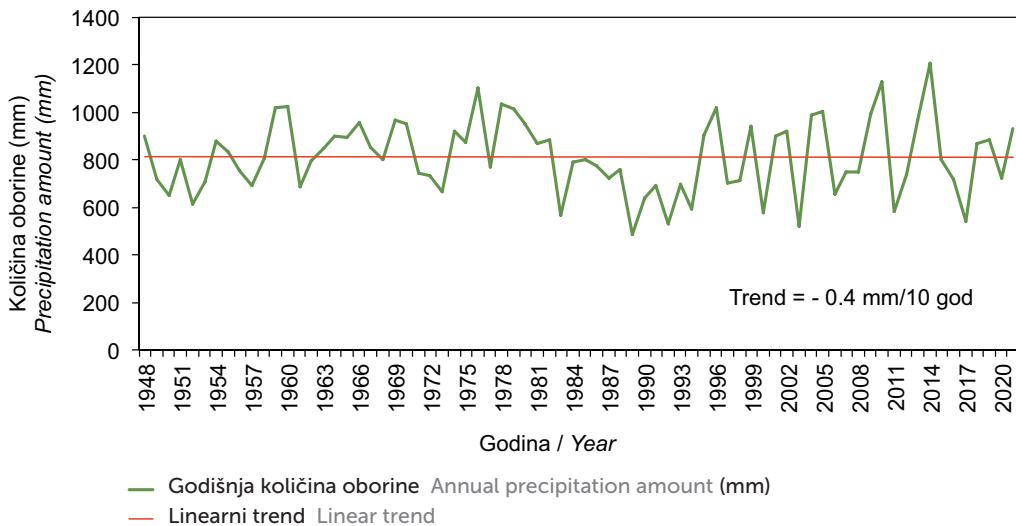
Slika 3.4 Deset skupina najtopljih godina od početka meteoroloških motrenja (1948. – 2021.) za postaju Split-Marjan

Figure 3.4 Ten groups of the warmest years on record (1948 – 2021) for Split-Marjan



Slika 3.5 Srednje godišnje temperature zraka za Split-Marjan za razdoblje 1948. – 2021. godina

Figure 3.5 Mean annual air temperatures at Split-Marjan station in the period 1948 – 2021



Slika 3.6 Godišnje količine oborine za Split-Marjan za razdoblje 1948. – 2021. godina

Figure 3.6 Annual precipitation amounts at Split-Marjan in the period 1948 – 2021

pripisuje globalnom zatopljenju, a kao posljedica djelovanja čovjeka. Za razliku od trenda srednjih godišnjih temperatura zraka trend godišnjih količina oborine za Zagreb-Maksimir ( $-3.9 \text{ mm}/10 \text{ god}$ ), prikazan na slici 3.3, nije signifikantan. I u ovom slučaju prisutne su znatne međugodišnje varijacije.

Za postaju Split-Marjan srednja godišnja temperatura zraka za 2021. godinu iznosi  $17.2^\circ\text{C}$  što je svrstava na šesto mjesto među skupinama najtopljih godina (slika 3.4). Moramo imati na umu da neke godine mogu imati istu vrijednost srednje godišnje temperature zraka i takve godine pripadaju istoj grupi. Zbog toga je točnije reći da 2021. godina pripada šestoj skupini najtopljih godina od kada postoji meteorološka mjerenja na toj postaji. Trend srednjih godišnjih temperatura zraka za Split-Marjan prikazan je na slici 3.5. Slično kao za Zagreb-Maksimir, prisutan je pozitivan trend srednje godišnje temperature zraka ( $0.18^\circ\text{C}/10 \text{ god}$ ) uz odgovarajuće međugodišnje varijacije. Nakon sredine 80-ih godina prošlog stoljeća trend srednje godišnje temperature zraka je naglašeniji nego u prethodnom razdoblju što se objašnjava globalnim zatopljenjem, a kao posljedica antropogenog utjecaja. Za razliku od trenda srednjih godišnjih temperatura zraka trend godišnjih količina oborine za Split-Marjan ( $-0.4 \text{ mm}/10 \text{ god}$ ), prikazan na slici 3.6, nije signifikantan.

more significant what is a consequence of human activities. Unlike the average annual air temperature trend for Zagreb-Maksimir station, the trend in annual precipitation amounts ( $-3.9 \text{ mm}/10 \text{ yrs}$ ), shown in Figure 3.3, is not significant. Certain inter-annual variation of precipitation amounts exist in this case as well.

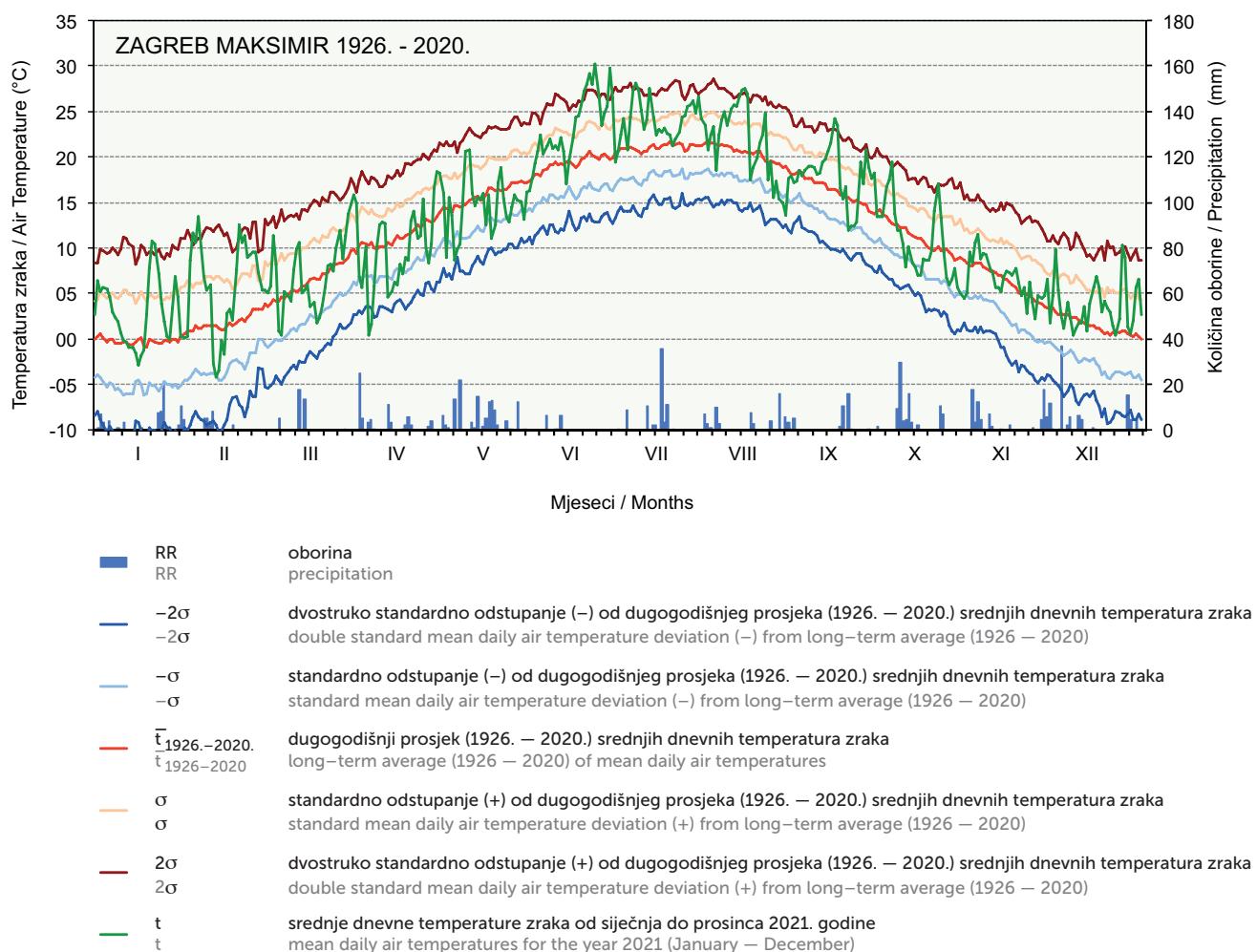
For Split-Marjan station the average annual air temperature for the year 2021 is  $17.2^\circ\text{C}$  what ranks 2021 as the 6<sup>th</sup> warmest year on record. We have to bear in mind that some years can have the same value of average annual air temperature and such years belong to the same group. It is the reason that is more correct to tell that 2021 belongs to the 6<sup>th</sup> group of the warmest year on record. The average annual air temperature trend for Split-Marjan is shown in Figure 3.5. Similar as for Zagreb-Maksimir station the positive trend in average annual air temperature ( $0.18^\circ\text{C}/10 \text{ yrs}$ ) is apparent with certain inter-annual variations. After mid 1980s of last century average annual air temperature trend is more apparent than before what is explained by global warming as a consequence of human activity. Unlike the average annual air temperature trend for Split-Marjan, the trend in annual precipitation amounts ( $-0.4 \text{ mm}/10 \text{ yrs}$ ), shown in Figure 3.6, is not significant.

#### 4. ANALIZA DNEVNIH ANOMALIJA TEMPERATURE ZRAKA I KOLIČINE OBORINE ZA POSTAJE ZAGREB-MAKSIMIR I SPLIT-MARJAN U 2021. GODINI

Prikazana analiza klimatskih anomalija u poglavljiju 1 daje općenitu ocjenu klime u Hrvatskoj za 2021. godinu. Detaljniji uvid od prikazanog može dati analiza vremenskih pojava na vremenskoj ljestvici koja nije unaprijed definirana, nego koja ovisi o duljini trajanja klimatskog odnosno vremenskog događaja. Na slici 4.1 prikazane su srednje dnevne temperature zraka u 2021. godini (zelena linija) u odnosu na dugogodišnji prosjek (1926. – 2020.) (crvena linija) i dnevne količine oborine za 2021. godinu (plavi stupići) na postaji Zagreb-Maksimir. Prevladavala su pozitivna odstupanja srednje dnevne temperature

#### 4 ANALYSIS OF MEAN DAILY AIR TEMPERATURE AND PRECIPITATION AMOUNTS FOR ZAGREB-MAKSIMIR AND SPLIT-MARJAN STATIONS IN 2021

The presented analysis of climate anomalies in Chapter 1 provides a general assessment of climate anomalies in Croatia for the year 2021. An analysis of weather events on a scale that is not predefined, but dependent on the duration of climate or weather events, can provide a more detailed insight than the above analysis. Figure 4.1 shows mean daily air temperature (green line) in comparison to the long-term average (1926 – 2020) (red line) and daily precipitation amounts for the year 2021 (blue bars) on Zagreb-Maksimir station. Positive anomalies prevailed during the year 2021 relative to the mentioned average.\*<sup>1</sup> In



Slika 4.1 Srednje dnevne temperature zraka za meteorološku postaju Zagreb-Maksimir u odnosu na dugogodišnji prosjek (1926. – 2020.)\*<sup>1</sup> i dnevne količine oborine za 2021. godinu.

Figure 4.1 Mean daily air temperatures for Zagreb-Maksimir station relative to the long-term average (1926 – 2020)\*<sup>1</sup> and daily precipitation amounts for the year 2021

\*<sup>1</sup> Meteorološki podaci za razdoblje 1926. – 1960. nisu prošli postupak kontrole kvalitete prema današnjim standardima.

\*<sup>1</sup> Meteorological data for the period 1926 – 1960 did not pass the quality control procedure according to present standards.

zraka u odnosu na navedeni dugogodišnji prosjek<sup>\*1</sup>. Na slici 4.2 prikazane su srednje dnevne temperature zraka za meteorološku postaju Split-Marjan u usporedbi s dugogodišnjim prosjekom (1948. – 2020.) i dnevne količine oborine za 2021. godinu.

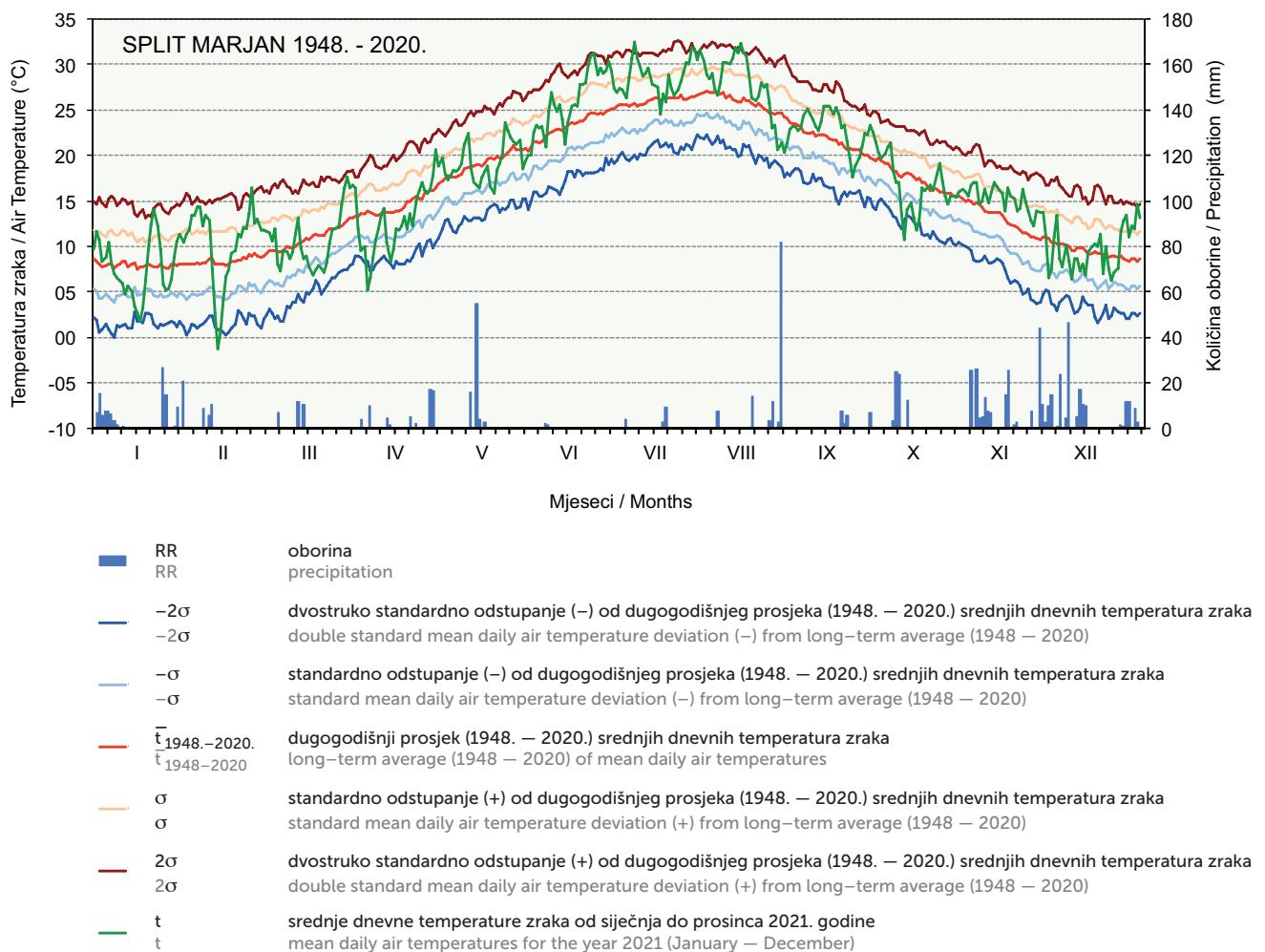
Prema Chapmanovom kriteriju izvanredno toplim smatra se dan u kojem pozitivna anomalija srednje dnevne temperature zraka premaši dvije standardne devijacije, dok se izuzetno hladnim smatra dan u kojem negativna anomalija premaši dvije standardne devijacije. Na slici 4.1 vidljivi su izvanredni dani tijekom 2021. godine za postaju Zagreb-Maksimir. Vizualnom ocjenom može se zaključiti da su prevladavala razdoblja s pozitivnim

Figure 4.2 are represented mean daily air temperatures for Split-Marjan station in comparison to the long-term average (1948 – 2020) and daily precipitation amount to the year 2021.

Chapman's criterion defines an exceptionally warm day as a day with a positive average daily air temperature anomaly exceeding two standard deviations, and an exceptionally cold day as a day with a negative anomaly exceeding two standard deviations. Figure 4.1 shows exceptionally warm and cold days registered in 2021 at meteorological station Zagreb-Maksimir. A visual assessment brings us to the conclusion that positive anomalies prevailed during the year 2021 which resulted in positive annual air temperature

\* Za razliku od prethodnih godina, u Prikazima 32 i 33 nisu analizirani dnevni podaci temperature zraka i dnevne količine oborine za glavnu meteorološku postaju Zagreb-Grič zbog prekida u radu nastalog nakon jakog potresa koji je pogodio Zagreb i šire zagrebačko područje 22. ožujka 2020. godine. U Prikazima 33 analiziraju se podaci s postaje Zagreb-Maksimir umjesto Zagreb-Griča.

\* Unlike the earlier editions, Reviews 32 and 33 do not analyse daily air temperature and daily precipitation amounts data for the main meteorological station Zagreb-Grič due to observing break after the strong earthquake that hit Zagreb and the wider Zagreb area on the 22 March 2020. Reviews 33 analyse data from the Zagreb-Maksimir station instead of the Zagreb-Grič station.



Slika 4.2 Srednje dnevne temperature zraka za meteorološku postaju Split-Marjan u odnosu na dugogodišnji prosjek (1948. – 2020.) i dnevne količine oborine za 2021. godinu.

Figure 4.2 Mean daily air temperatures for Split-Marjan station relative to the long-term average (1948 – 2020) and daily precipitation amounts for the year 2021

anomalijama srednje dnevne temperature zraka u odnosu na dugogodišnji prosjek što je rezultiralo pozitivnim godišnjim anomalijama prikazanim u poglavlju 1. Ipak, početkom travnja zabilježen je hladni val koji je prouzročio znatnu štetu u voćnjacima i vinogradima. Na slici 4.1 također su prikazane dnevne količine oborine za Zagreb-Maksimir u 2021. godini. Kao što je vidljivo iz poglavlja 1, zbroj dnevnih količina oborine za 2021. bio je blizak višegodišnjem prosjeku sa znatnijim manjkom oborine tijekom lipnja i rujna. Slika 4.2 prikazuje izvanredne dane tijekom 2021. godine za postaju Split-Marjan. Vizualnom ocjenom može se zaključiti da su prevladavale pozitivne anomalije srednje dnevne temperature zraka u odnosu na dugogodišnji prosjek (1948. – 2020.). Tijekom 2021. na postaji Split-Marjan zabilježeno je i nekoliko izvanredno hladnih dana tijekom veljače (2 dana), travnja (2 dana) i listopada (2 dana). Ukupna godišnja količina oborine bila je iznad prosjeka (poglavlje 1) uz naznaku da je u kolovozu maksimalna dnevna količina oborine iznosila 82 mm dok su sušni bili ožujak, lipanj te rujan.

anomalies shown in Chapter 1. However, at the beginning of April, a cold wave was recorded which caused considerable damage to orchards and vineyards. Figure 4.1 also shows daily precipitation amounts for Zagreb-Maksimir station in 2021. As can be confirmed from Chapter 1, the sum of daily precipitation amounts for 2021 was close to the multi-annual average with a more significant precipitation deficit during June and September. Figure 4.2 shows the exceptionally warm and dry days during 2021 for Split-Marjan station. A visual assessment also reveals that positive anomalies prevailed. During 2021 at Split-Marjan station several exceptionally cold days registered during February (2 days), April (2 days) and October (2 days). The total annual precipitation amount was above average (Chapter 1) with indication that the maximum daily precipitation amount of 82 mm measured in August, while dry periods were in March, June and September.

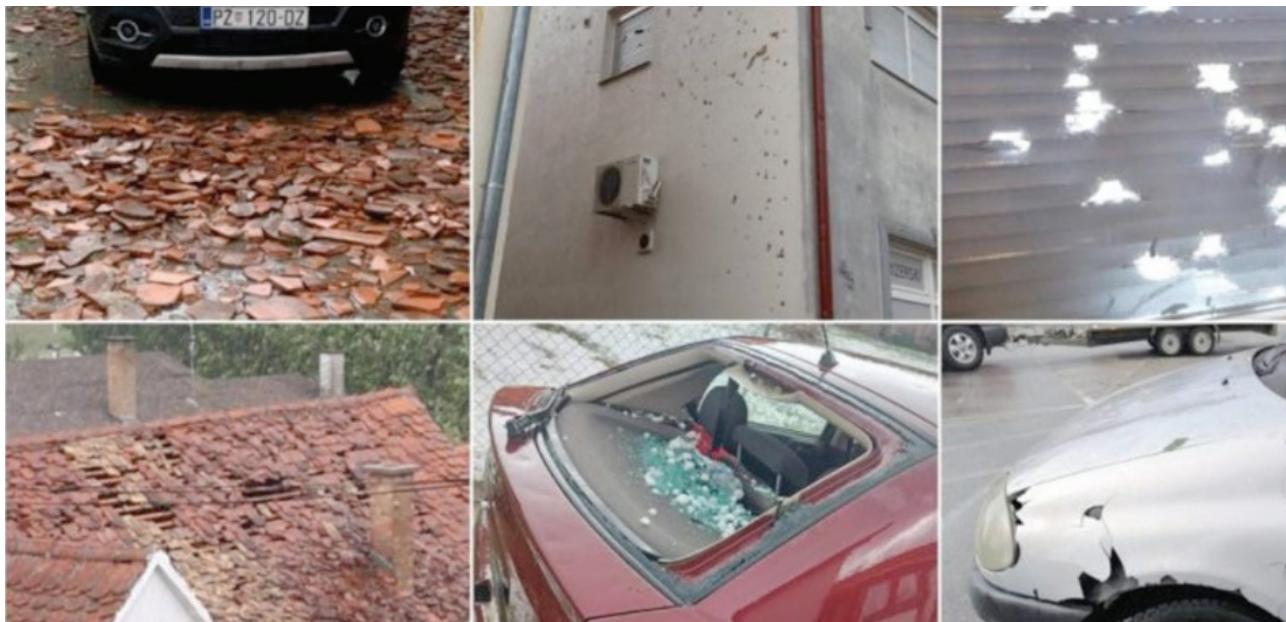
## 5. IZVANREDNI METEOROLOŠKI DOGAĐAJI U HRVATSKOJ U 2021 GODINI

### 5.1 Grmljavinsko nevrijeme u široj okolini grada Požege 25. lipnja 2021.

#### Uvod

Područje Požege je 25. lipnja 2021. u poslijepodnevnim satima bilo pogodeno snažnim grmljavinskim nevremenom koje je uzrokovalo veliku materijalnu štetu, ponajviše zbog tuče koja je ponegdje bila procijenjena i do veličine jajeta (promjer do 5 cm). Zrna te veličine upućuju na brzinu pada tuče oko 145 km/h.

Razmjeri nastale materijalne štete najbolje se vide na fotografijama s terena (slika 5.1.1), a akumulacija tuče na tlu bila je tolika da se led morao čistiti s prometnica.



**Slika 5.1.1** Velika zrna tuče, velike kinetičke energije, poput tanadi su uzrokovala štetu na fasadama, prozorima, krovovima, automobilima itd. Izvor: Internet; preuzeto s <https://www.tportal.hr/vijesti/clanak/nevrijeme-poharalo-dio-slavonije-jaka-tuca-u-pozegi-pleternici-slavonskom-brodu-20210625>

**Figure 5.1.1** Large hailstones having high kinetic energy hit facades, windows, roofs, cars, etc. like bullets, leaving destruction in their wake. Source: <https://www.tportal.hr/vijesti/clanak/nevrijeme-poharalo-dio-slavonije-jaka-tuca-u-pozegi-pleternici-slavonskom-brodu-20210625>

#### Sinoptička analiza

Dana 25. lipnja 2021. u jugozapadnoj visinskoj struci na prednjoj strani duboke doline koja se protezala od Skandinavije do zapadnog Sredozemlja (slika 5.1.2) nad Hrvatsku je pritjecao vlažan zrak. Tijekom dana, kako je dolina napredovala prema istoku (slika 5.1.3), uz pritjecanje vlage u višim slojevima, pristiže i svježiji zrak.

Izražena advekcija hladnjeg zraka, pogotovo u srednjoj troposferi, vidljiva je i u podacima tri uzastopna visinska radiosondažna mjerena s glavne meteorološke postaje Zagreb-Maksimir (tablica 5.1). Naime, u razdoblju od 00 UTC 25. 6. do 00 UTC 26. 6. 2021. tempe-

## 5. EXTRAORDINARY METEOROLOGICAL EVENTS IN CROATIA IN 2021

### 5.1 Thunderstorm in the wider area of the town of Požega on 25 June 2021

#### Introduction

On the afternoon of 25 June 2021, Požega town area was hit by a severe thunderstorm that caused significant material damage, mostly due to hail: in some locations, hailstones were estimated to be as large as an egg (up to 5 cm in diameter). Hailstones of this size point to a terminal fall velocity (fall speed) of about 145 km/h.

The extent of the material damage is best seen in photographs taken in the field (Figure 5.1.1). The accumulation of hail on the ground was so large that the ice had to be cleared from the roads.

#### Synoptic analysis

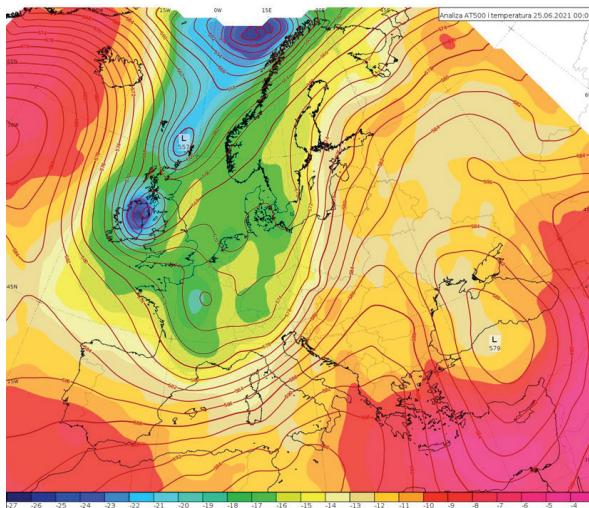
On 25 June 2021, moist air was advected over Croatia in the southwesterly upper-level flow, ahead of an advancing trough aloft that stretched from Scandinavia to western Mediterranean (Figure 5.1.2). In course of the day, as the trough moved eastwards (Figure 5.1.3), cooler air started to be advected as well.

The pronounced cold air advection, especially in the middle troposphere, is also evident from the data obtained by three consecutive upper-level radiosounding measurements performed at the main meteorological station Zagreb-Maksimir (Table 5.1). Between 00 UTC on 25 June and

Tablica 5.1 Temperatura zraka ( $^{\circ}\text{C}$ ) s radiosondažnih mjerena 25. lipnja 2021. u 00 i 12 UTC, 26. lipnja 2021. u 00 UTC na izobarnim ploham 500, 700, 850 i 925 hPa, te temperatura zraka na 2 metra visine (2m) iz SYNOP mjerena u Zagreb-Maksimiru.

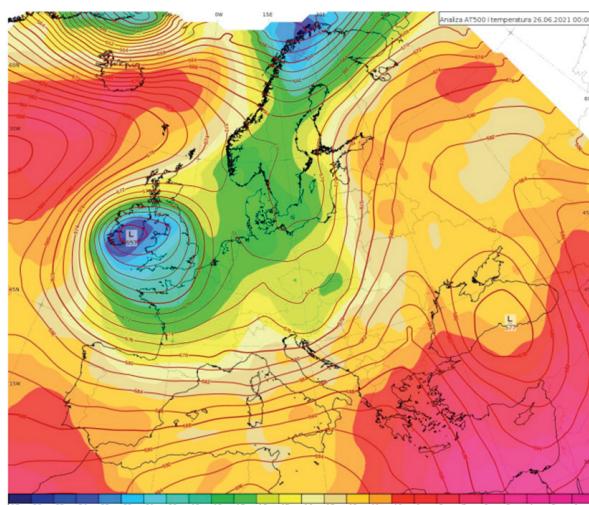
Table 5.1 Air temperature ( $^{\circ}\text{C}$ ) measured by radiosounding measurements on 25 June 2021 at 00 and 12 UTC and on 26 June at 00 UTC at the isobaric surfaces of 500, 700, 850 and 925 hPa. Two-meter air temperature (2m) from SYNOP measurements in Zagreb-Maksimir is shown as well.

Nivo / Level	25 June 2021, 00 UTC	25 June 2021, 12 UTC	26 June 2021, 00 UTC
500 hPa	-10.7	-13.3	-15.7
700 hPa	8.4	5.0	1.4
850 hPa	17.2	15.8	13.6
925 hPa	23.8	22.8	18.4
2 m	23.7	31.2	21.3



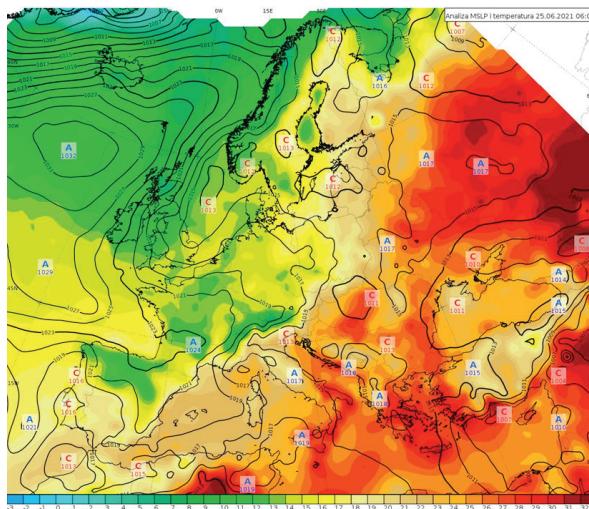
Slika 5.1.2 Sinoptička analiza geopotencijalne visine (gpdam) apsolutne topografije izobarne plohe 500 hPa, AT500 hPa, i temperaturu zraka ( $^{\circ}\text{C}$ ) na izobarnoj plohi 500 hPa, 25. lipnja 2021. u 00 UTC (2:00 sata po lokalnom vremenu).

Figure 5.1.2 Synoptic analysis of geopotential height (gpdam) of the isobaric surface 500 hPa, AT500 hPa, and air temperature ( $^{\circ}\text{C}$ ) at the isobaric surface 500 hPa, 25 June 2021 at 00 UTC (2:00 local time).



Slika 5.1.3 Sinoptička analiza geopotencijalne visine (gpdam) apsolutne topografije izobarne plohe 500 hPa, AT500 hPa, i temperaturu zraka ( $^{\circ}\text{C}$ ) na izobarnoj plohi 500 hPa, 26. lipnja 2021. u 00 UTC (2:00 sata po lokalnom vremenu).

Figure 5.1.3 Synoptic analysis of geopotential height (gpdam) of the isobaric surface 500 hPa, AT500 hPa, and air temperature ( $^{\circ}\text{C}$ ) at the isobaric surface 500 hPa, 26 June 2021 at 00 UTC (2:00 local time).



Slika 5.1.4 Sinoptička analiza tlaka zraka svedenog na razinu mora (hPa) i temperature zraka na 2 metra visine (°C), 25. lipnja 2021. u 06 UTC (8:00 sati po lokalnom vremenu).

Figure 5.1.4 Synoptic analysis of mean sea level (MSL) air pressure (hPa) and 2-meter air temperature (°C), 25 June 2021 at 06 UTC (8:00 local time).

ratura se na 500 hPa (otprilike 6 km visine) snizila za 5°C, a pad od 7°C u 24 sata izmjerena je na 700 hPa (otprilike malo iznad 3 km visine).

Prizemno se u jutarnjim satima 25. lipnja 2021. nad Hrvatskom nalazilo polje srednjeg tlaka zraka, a nad srednjom Europom bio je ogrank anticiklone s Atlantika, što je vidljivo na slici 5.1.4. Frontalni sustav, koji jasno razdvaja vrlo toplu zračnu masu na istoku i jugoistoku kontinenta od hladne na sjeverozapadu i zapadu, u prvom se dijelu dana još nalazio zapadnije od naših krajeva. U nastavku dana sjevernije se prema istoku premještala hladna fronta (nije prikazano).

### Mezoskalna analiza

Za nastanak snažne duboke mokre konvekcije, koja za posljedicu ima razvoj olujnih oblaka, tzv. kumulonimbusa potrebna su tri osnovna sastojka: vlaga u nižim slojevima, nestabilnost te mehanizam koji uzrokuje početno podizanje česti (Doswell, 2001, Doswell i sur., 1996). Uz navedene uvjete, da bi nastala organizirana konvekcija neophodano je i smicanje vjetra u sloju zraka 0 – 6 km koje većinom mora biti veće od 15 m/s (Doswell, 2001, Doswell i sur., 1996).

Svi gore navedeni i potrebni termodinamički i dinamički uvjeti, odnosno sastojci bili su prisutni na području Bosne i Hercegovine (BiH) te istočne Hrvatske u poslijepodnevnim satima 25. lipnja 2021. Tada je i započeo konvektivni razvoj oblaka, najprije na području BiH.

Neposredno prije pojave grmljavinskih nevremena u Hrvatskoj, u 14 sati po lokalnom vremenu (slika 5.1.5), nad kontinentalnom je Hrvatskom vrijeme bilo prevladavajuće sunčano uz većinom malo oblaka vertikalnog razvoja, vrste kumulus. U istočnoj Slavoniji i osobito slavonskom dijelu Posavine osmotreni su i visoki ledeni oblaci vrste cirrus i cirostratus. Zapravo su to već bili vrhovi olujnih oblaka vertikalnog razvoja, kumulonimbusa, koji su se počeli razvijati na području BiH. Izmjerena temperatura zraka u 14 sati je većinom bila viša od 30°C, a u Slavoniji i Baranji i od 32°C. Temperatura rosišta od

00 UTC on 26 June 2021, the temperature dropped 5°C at 500 hPa (at the altitude of about 6 km), and 7°C at 700 hPa (at the altitude slightly above 3 km).

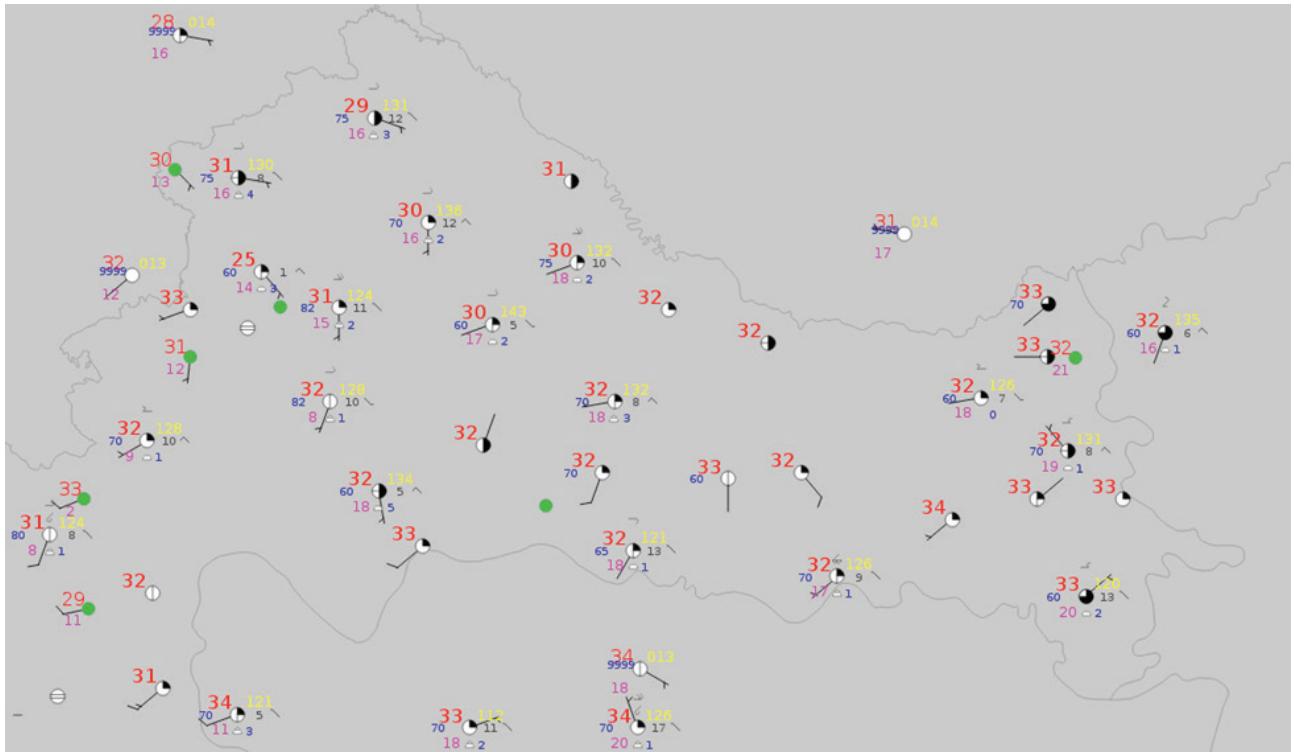
On the morning of 25 June 2021, a surface field of average air pressure was present over Croatia, and an anti-cyclonic ridge extended from the Atlantic in Central Europe (Figure 5.1.4). In the first part of the day, a frontal system, clearly separating the very warm air mass in the east and southeast of the continent from the cold air mass in the northwest and west, was still located west of Croatia. Later in the day, the cold front moved in the north towards the east (not shown).

### Mesoscale analysis

The formation of a strong deep moist convection, which results in the development of storm clouds, so-called cumulonimbus, requires three basic ingredients: moisture in the lower layers, instability, and sufficient lift that allows the consumption of existing instability (Doswell, 2001, Doswell et al., 1996). Organized storms require an additional ingredient - a deep layer (0–6km) wind shear, which in case of severe storms is usually larger than 15 m/s (Doswell, 2001, Doswell et al., 1996).

The said thermodynamic and dynamic conditions, i.e. ingredients were present in Bosnia and Herzegovina (BiH) and eastern Croatia in the afternoon of 25 June 2021 when the convective development began, first in BiH.

Just before the thunderstorms broke in Croatia, at 2:00 pm local time (Figure 5.1.5), weather over continental Croatia was mostly sunny, with some vertical growth clouds. In eastern Slavonia and especially the Slavonian part of Posavina, high ice clouds - cirrus and cirrostratus were observed. In fact, they had already formed the anvil of convective storm clouds that had started to develop in BiH. The measured air temperature at 2:00 pm was mostly higher than 30°C, and in Slavonia and Baranja it was higher than 32°C. Dew point temperatures of between 18 and 20°C indicate that low layer moisture in these areas was much higher than in central Croatia. The surface air pressure was



Slika 5.1.5 Prizemna sinoptička karta sa SYNOP podacima glavnih i nekih klimatoloških postaja u istočnoj i središnjoj Hrvatskoj i okolišu u 12 UTC (14:00 sati po lokalnom vremenu). Temperatura zraka na 2 metra visine prikazana je crveno, rosište na 2 metra ružičasto, tlak sveden na razinu mora žuto (oduzeta je tisuća), vidljivost je kodirana plavo, vjetar na 10 metara visine je prikazan kao zastavice, naoblaka kao osmine kruga, a prikazani su i simboli vrste oblaka i tendencije tlaka zraka.

Figure 5.1.5 Surface synoptic map with SYNOP data from the main and some climatological stations in eastern and central Croatia and its surroundings at 12 UTC (2:00 pm local time). Air temperature at 2 m height is shown in red, dew point temperature at 2 m in pink, air pressure reduced to sea level in yellow, visibility in blue, wind at 10 m height is shown in the form of wind barbs, the amount of cloud cover is estimated in eights, ranging from 0 oktas (completely clear sky) through to 8 oktas (completely overcast), and cloud type symbols and air pressure tendencies are shown as well.

18 do 20°C ukazuje na to da su ti krajeve imali mnogo više prizemne vlage od središnje Hrvatske. Prizemni tlak zraka bio je između 1012 i 1014 hPa s tendencijom laganog pada, a vjetar slab do umjeren, prevladavajuće jugozapadni i južni na području od interesa.

U jugozapadnom visinskom strujanju dio konvektivnih ćelija nastalih u BiH je jačao i gibao se prema sjeveroistoku te ušao na područje Srbije gdje su se pri tom razvili ekstremno jaki grmljavinski olujni oblaci. Za Hrvatsku važniji dio konvektivnih ćelija advektirao se u područje slavonske Posavine i doživio „eksplozivan“ razvoj te se zatim u jugozapadnoj i južnoj struci premještao preko zapadne Slavonije.

Iz visinskog radiosondažnog mjerjenja je procijenjena konvektivna raspoloživa potencijalna energija česti podignute s tla do razine slobodne konvekcije (SBCAPE) bila na području Zagreba oko 2700 J/kg (slika 5.1.6) što upućuje na veliku nestabilnost atmosfere tog dana. Za nastanak tuče je pogodno da je i nivo kondenzacije (LCL), odnosno visina baze oblaka na visinama između 1000 i 1500 m, što je također u ovoj situaciji bio slučaj jer je LCL bio na oko 1500 m.

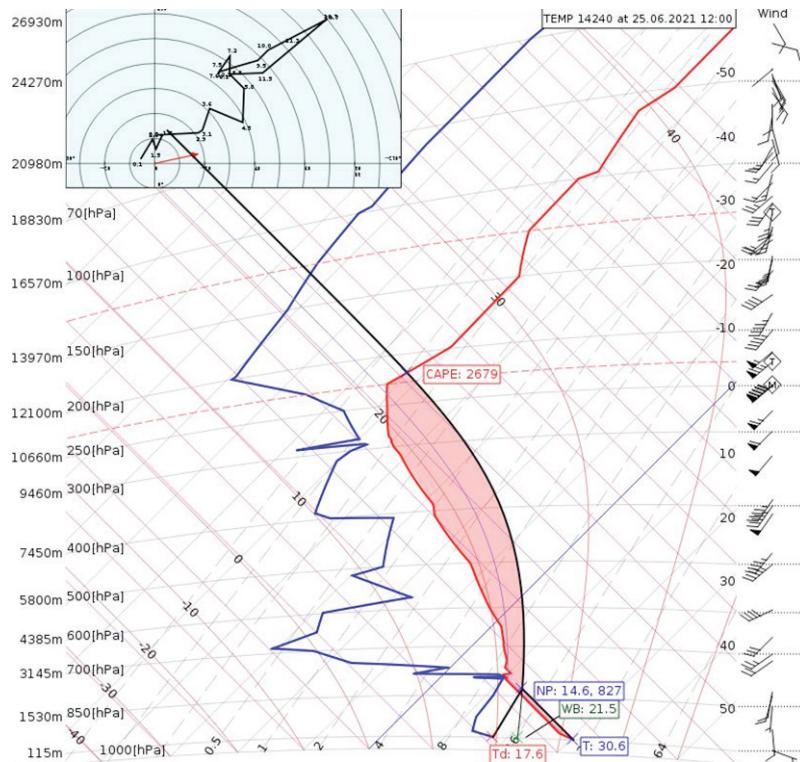
Smicanje vjetra u sloju 0–6 km bilo je procijenjeno na vrijednosti 20–25 m/s, što je pogodovalo nastanku organizirane konvekcije tipa superćelije u kojoj postoji rotacija uzlazne struje uzrokovana jakim smicanjem (ho-

between 1012 and 1014 hPa, with a slightly decreasing tendency, and the wind was light to moderate, predominantly southwestern and southern in the area in question.

In the southwesterly upper-level flow, a part of the convective cells that were formed in BiH strengthened, moved to the northeast, and entered Serbia, where extremely strong thunderstorm clouds developed. The convective cells that were more important for Croatia advected into the area of Slavonian Posavina and experienced "explosive" development, and then moved in the southwestern and southern flow across western Slavonia.

The estimated convective available potential energy of the air parcel raised from the ground to the level of free convection (SBCAPE) in the Zagreb area was about 2700 J/kg (Figure 5.1.6), which points to significant instability in the atmosphere on that day. For the hail formation is suitable that the lifting condensation level (LCL), i.e. the height of the cloud base is at altitudes between 1000 and 1500 m, which was also the case in this analyzed situation because the LCL was at about 1500 m.

Deep layer wind shear was estimated at 20–25 m/s, which favored the formation of a supercell storm. Supercell has rotating updraft, also known as a mesocyclone, caused by strong wind shear (the hodograph shows that there was no pronounced shear in wind direction, only in wind speed, in this case).



Slika 5.1.6 Visinsko radiosondažno mjerjenje (termodijagram) u Zagreb-Maksimiru, 25. lipnja 2021. u 12 UTC (14 sati po lokalnom vremenu). Crvena deblja linija je vertikalni profil temperature zraka, plava profil rosišta, a crna je termodinamička krivulja gibanja česti zraka koja bi se počela dizati od prizemnih slojeva s temperaturom oko  $31^{\circ}\text{C}$  i rosištem oko  $17.5^{\circ}\text{C}$  te dosegnula nivo kondenzacije (LCL) na visini oko  $830 \text{ hPa}$  što odgovara visini oko  $1500 \text{ m}$ . Osjenčana crvena površina predstavlja CAPE od  $2679 \text{ J/kg}$  (vrijednost CAPE-a se odnosi na dostupnu količinu potencijalne energije prilikom podizanja česti s tla). Vertikalni profil brzine i smjera vjetra prikazan je kao zastavice na desnoj strani termodijagrama. Promjena smjera i brzine vjetra s visinom prikazana je i kao hodograf u pravokutniku gore lijevo.

Figure 5.1.6 Skew T - log p thermodynamic diagram for Zagreb-Maksimir, 25 June 2021 at 12 UTC (2:00 pm local time). The thick red line represents the vertical air temperature profile, and the blue line represents the dew point temperature profile. The black line is the ascent curve of a parcel from the surface having an air temperature of about  $31^{\circ}\text{C}$  and a dew point temperature of about  $17.5^{\circ}\text{C}$  to lifting condensation level (LCL) at about  $830 \text{ hPa}$ , which corresponds to an altitude of about  $1500 \text{ m}$ . The shaded red surface represents a convective available potential energy (CAPE) of  $2679 \text{ J/kg}$ . The vertical wind profile is shown in the form of wind bars on the right side of the thermodynamic diagram. In the rectangle in the upper left corner the hodograph is also shown.

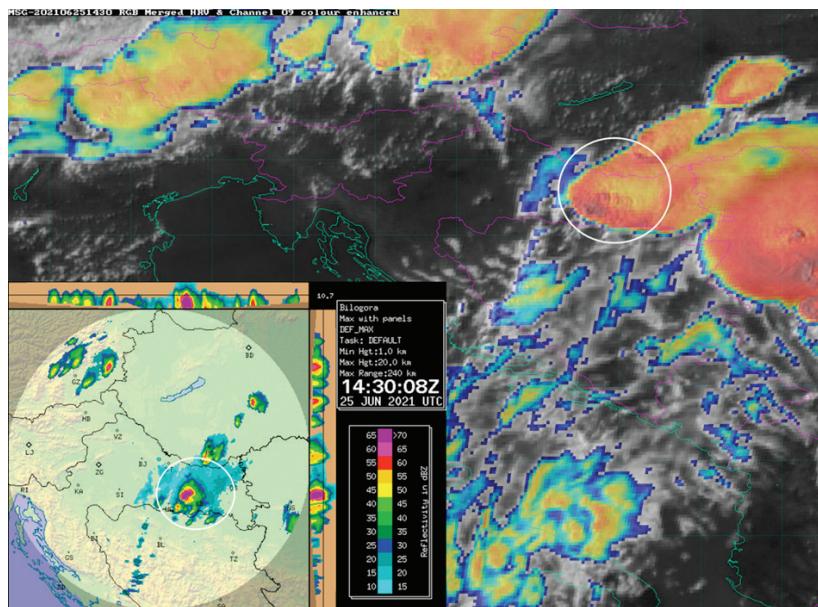
dograf pokazuje da u ovom slučaju nije bilo izraženog smicanja smjera vjetra, samo brzine vjetra).

Pritom treba imati na umu da su opisani termodinamički uvjeti u atmosferi, prije svega nestabilnost zbog povećane prizemne vlage, na području Slavonije bili još povoljniji za nastanak jakih grmljavinskih oluja nego na području Zagreba. Uvjeti u okolišu prema kojem se supercelijski oblak kretao također su bili povoljni za održavanje konvektivnih sustava, sudeći prema visinskom radiosondažnom mjerenu u Szegedu u Mađarskoj (nije prikazano).

Osim jačine grmljavinskog nevremena na području Požege (velika količina izbačenog leda i vrlo velika zrna tuče, te jak vjetar) uslijed za to opisanih povoljnih termodinamičkih uvjeta, interesantan je „eksplozivno“ brz rast olujnog oblaka i visina vrha olujnog oblaka koji je u fazi rasta i zreloj fazi probijao tropopauzu i dosezao visinu i do  $15 \text{ km}$ . Visoki vrhovi oblaka (eng. Overshooting tops) još su jedan od pokazatelja snage oluje (Bedka, 2011, Mikuš i Strelec Mahović, 2012), isto kao i hladni prstenovi (eng. Cold rings) koji se uočavaju na obojenim satelitskim slikama u infracrvenom kanalu  $10.8 \mu\text{m}$  (Dworak i

The described thermodynamic conditions in the atmosphere, especially instability and low-level moisture in the area of Slavonia, were even more favorable for the occurrence of strong thunderstorms than in the Zagreb area. According to radiosounding measurements in Szeged, Hungary (not shown), thermodynamic conditions were favorable along the entire supercell path, enabling the longevity of severe storm.

In addition to the severity of the thunderstorm in the Požega area (large amount of ejected ice and very large hailstones, as well as strong wind) due to the described favorable thermodynamic conditions, the "explosive" and rapid growth of storm clouds and the height of the storm cloud top were also very interesting. In the mature phase, the storm cloud top, known as the overshooting top, (OT), protruded through the tropopause into the lower stratosphere and reached the height of up to  $15 \text{ km}$ . OTs are an indicator of storm strength and severity (Bedka, 2011, Mikuš and Strelec Mahović, 2012) as are cold rings (Dworak et al., 2012, Brunner et al, 2007), observable in color enhanced satellite images in the  $10.8 \mu\text{m}$  infrared channel, where the colors show the temperature of storm cloud tops (Figure 5.1.7). Radar images reveal the state within the storm cloud,



**Slika 5.1.7** Superćelija u najsnažnijoj zreloj fazi nalazi se upravo nad Požegom i okolicom 25. lipnja 2021. u 14:30 UTC. Na satelitskoj slici vidi se vrh oblaka koji probija tropopazu kao tamnocrveno područje, te se pritom razvija veliki nakovanj na vrhu olujnog oblaka (eng. anvil). U njemu se uočava oblik hladnog prstena crvene boje unutar kojeg je manje hladno područje žućkaste boje. Radarska održajnost postoji do visine od 15 km, a unutar oblaka doseže vrijednosti veće od 65 dBZ što ukazuje na vrlo veliki tuču. Ujedno je tučnosno područje vrlo veliko.

*Figure 5.1.7 Color enhanced infrared 10.8 μm satellite image and radar image on 25 June 2021 at 14:30 UTC. The supercell in its strongest mature phase is located just above Požega and its surroundings. The satellite image shows the overshooting top as a dark red area, with a large anvil developing at the top of the storm cloud. A cold ring structure is observed in the anvil, with a less cold area of yellowish color inside. Radar reflectivity exists up to a height of 15 km, and reaches values higher than 65 dBZ in the clouds, which indicates very large hailstones. At the same time, the hail zone is very large.*

sur., 2012, Brunner i sur., 2007) gdje boje prikazuju temperaturu vrhova olujnih oblaka (slika 5.1.7). Radarske slike otkrivaju stanje unutar olujnog oblaka, prije svega prostorno-vremensku raspodjelu hidrometeora vezanih uz isti, ali i poziciju ulazne struje, visinu do koju dopiru hidrometeori, te smjer njihova kretanja. Radarske održajnosti veće od 50 dBZ ukazuju na mogućnost pojave tuče, a održajnosti 60 – 65 dBZ na tuču veličine 2.5 cm (Kumijan i sur. 2010) (slika 5.1.7).

### Prognoza i upozorenja

Dostupni analitički i prognostički materijali pokazali su vrlo nestabilnu atmosferu 25. lipnja 2021., pogotovo nad Slavonijom i južnije iznad BiH. Smicanje vjetra bilo je također dobro prognozirano. Neki modeli imali su slabiji ili nikakav signal za oborinu, što se tumači kao izostanak inicijacije konvektivnih procesa. No, korištenjem svog raspoloživog prognostičkog materijala (multi-modelski pristup), radnog iskustva te spoznaja o potrebnim uvjetima za razvoj konvekcije, koji su detaljno elaborirani u prethodnim poglavljima, prognostičari Sektora za vremenske i pomorske analize i prognoze izdali su pravovremena upozorenja na opasne vremenske pojave. Za područje istočne Hrvatske (u Meteoalarmu - regija Osijek) izdano je narančasto upozorenje za grmljavinsko nevrijeme (slika 5.1.8).

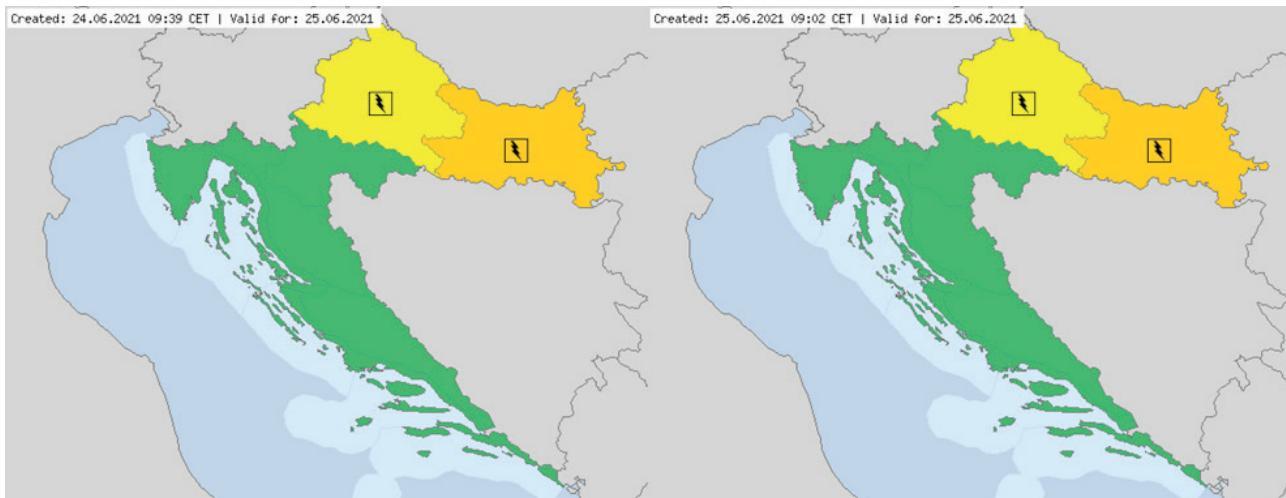
Štoviše, i dan ranije izdan je drugi stupanj, narančasto upozorenje za područje Slavonije uz prateći opis: "BUDITE SPREMNI na jača grmljavinska nevremena koja

primarily the spatio-temporal distribution of hydrometeors, the position of the updraft, the height that the hydrometeors reach, and the direction of their movement. Radar reflectivity higher than 50 dBZ indicates the possibility of hail, and reflectivity of between 60 and 65 dBZ indicates the possibility of hailstones measuring 2.5 cm in diameter (Kumijan et al., 2010) (Figure 5.1.7).

### Forecast and warnings

The available analytical and forecast materials showed a very unstable atmosphere on 25 June 2021, especially over Slavonia and further south over Bosnia and Herzegovina. Wind shear was also well predicted. Some models exhibited weak or no signal for precipitation, which is interpreted as the absence of initiation of convective processes. However, using all available prognostic material (multi-model approach), professional experience and knowledge of the conditions required for convection development, elaborated in detail in previous chapters, forecasters from the Weather and Marine Analysis and Forecasting Sector issued timely warnings about impending dangerous weather phenomena. An orange thunderstorm warning was issued for eastern Croatia (Osijek region in the Meteoalarm service) (Figure 5.1.8).

Moreover, an orange warning for Slavonia was issued the day before the event, with the accompanying description: "BE PREPARED for heavy thunderstorms that may cause heavy damage and protect yourself from lightning. Property damage and tree damage are possible. Local flash



Slika 5.1.8 Upozorenja za područje sjeverne Hrvatske za 25. lipnja 2021. izdana putem servisa Meteoalarm 24. lipnja 2021. (lijevo) i 25. lipnja 2021. (desno).

Figure 5.1.8 Alerts for northern Croatia for 25 June 2021 issued via the Meteoalarm service on 24 June 2021 (on the left) and 25 June 2021 (on the right).

*mogu prouzročiti veliku štetu i zaštitite se od munja. Moguća su oštećenja na imovini te na drveću. Moguće su lokalne bujične poplave, olujni udari vjetra i tuča. Mogući su prekidi u aktivnostima na otvorenom te u prometu.*"

Također, prema standardnom operativnom postupku, upozorenja su poslana i Ravnateljstvu civilne zaštite: "Žuto upozorenje na vrućinu, a na srednjem i južnom Jadranu narančasto. Upozorenje za grmljavinsko nevrijeme kasno poslijepodne i osobito navečer: Žuto u Međimurju, Hrvatskom zagorju i Podravini, narančasto u Slavoniji i Baranji."

Izraženje nevrijeme najavljeno je i u općoj prognozi dostupnoj na mrežnim stranicama DHMZ-a: "Pretežno sunčano, na jugu povremeno uz umjerenu i povećanu naoblaku. Uglavnom u unutrašnjosti mjestimice jak razvoj oblaka i pljuskovi s grmljavinom, osobito u istočnim i sjeverozapadnim predjelima. Ponegdje izraženije nevrijeme. Vjetar slab do umjeren jugozapadni, na Jadranu i sjeverozapadni, a u sjevernim područjima unutrašnjosti će okrenuti na sjeverni i sjeveroistočni. Najviša dnevna temperatura većinom između 29 i 34°C."

Neposredno prije nastanka nevremena nad Slavonijom dežurni prognostičari izdali su kratkoročno upozorenje (eng. Nowcast): "Zagreb, 25. 6. 2021. 16:20

#### KRATKOROČNO UPOZORENJE NA OPASNE VREMENSKE POJAVE ZA HRVATSKU

"U Slavoniji (najprije u Brodskoj Posavini i okolnom gorju) u narednim satima mjestimice jače grmljavinsko nevrijeme (obilni pljuskovi, moguće bujične poplave, tuča i olujni vjetar)."

#### Zaključak

Olujna nevremena ovakvih razmjera ponekad je teško prognozirati, točnije teško je predvidjeti točnu lokaciju gdje će nastati kao i precizirati vrijeme, no s velikom se vjerojatnošću mogu prognozirati uvjeti u kojima će nastati kao i opasnost koju mogu donijeti (olujni vje-

floods, gale force wind gusts and hail are possible. Interruptions in outdoor activities and in traffic are possible."

According to the standard operating procedure, warnings were also sent to the Civil Protection Directorate: "Yellow warning for heat, and orange warning in the central and southern Adriatic. Warnings for thunderstorms in the late afternoon and especially in the evening: yellow in Međimurje, Hrvatsko Zagorje and Podravina, orange in Slavonia and Baranja."

A severe thunderstorm was also announced in the general forecast available on the DHMZ's website: "Mostly sunny, with occasional moderate and increased cloudiness in the south. Local strong cloud development and thunder-showers, mostly in the inlands, especially in the eastern and northwestern regions. More severe thunderstorms locally. Light to moderate southwest wind, northwest wind in the Adriatic, turning to north and northeast in northern regions in the inland. Maximum daily temperature mostly between 29 and 34°C."

Just before the thunderstorm broke over Slavonia, the forecasters on duty issued a nowcast warning: "Zagreb, 25 June 2021, 16:20

#### SHORT-TERM WARNING OF DANGEROUS WEATHER PHENOMENA FOR CROATIA

*In Slavonia (starting in Posavina and the surrounding mountains) in the next few hours a severe thunderstorm is expected (heavy showers, possible flash floods, hail and gale force wind).*"

#### Conclusion

Severe thunderstorms of this extent are sometimes difficult to predict, namely, it is difficult to predict where and when exactly they will occur. However, conditions in which they will occur, and the dangerous weather phenomena they can cause (gale force wind, hail, tornadoes, heavy rain, etc.), can be predicted with a high degree of probability. Synoptic and then mesoscale conditions

tar, tuča, mogućnost tornada, obilna kiša i sl.). Sinoptički, potom i mezoskalni uvjeti sasvim su jasno upućivali na mogućnost izraženijeg grmljavinskog nevremena u poslijepodnevnim satima 25. 6. 2021. na području Slavonije zbog čega su i pravovremeno izdana upozorenja. Zbog parametara koji su osiguravali nastanak organizirane duboke konvekcije bilo je nedvojbeno da će lokalno biti pojava koje mogu izazvati veću štetu. Nažalost, šteta se i unatoč upozorenjima teško može sprječiti, no važno je u takvim situacijama informirati nadležne službe i javnost kako bi se izbjegle ljudske žrtve i čim više umanjila šteta prilagođavanjem planiranih aktivnosti. Presudnu pomoć pri izdavanju kratkoročnih upozorenja i obavješćivanja javnosti mogu pružiti moderni i napredni sustavi daljinskih mjerjenja (radarski i satelitski podaci te podaci o munjama) i guta mreža automatskih meteoroloških postaja jer pružaju pouzdan i pravovremen podatak o trenutnom stanju atmosfere. U tom smislu DHMZ sustavno radi na poboljšanju takvih podataka, primjerice kroz projekt METMONIC, kao i na educiranju svojih službenika.

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- clearly pointed to the possibility of a severe thunderstorm in Slavonia in the afternoon of 25 June 2021, and timely warnings were issued. Due to the thermodynamic parameters that resulted in the development of organized deep moist convection, there was no doubt that local high-damage events would occur. Unfortunately, despite the timely warnings, the damage is difficult to prevent, but it is very important to inform the relevant services and the public in such situations to avoid human casualties and minimize the damage as much as possible by adjusting the planned activities. State-of-the-art remote sensing systems (radars, satellite and lightning data) and a dense network of automatic weather stations are crucial in issuing Nowcast warnings and advising the public because they provide reliable and timely information on the current state of the atmosphere. In that regard, Croatian Meteorological and Hydrological Service (DHMZ) systematically works on improving such data, for example through the METMONIC project, as well as on the training of its employees.

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## 5.2 Poplava u Slavoniji u srpnju 2021. godine

U priopćenju objavljenom na <https://meteo.hr> 16. srpnja 2021., na većem području kontinentalne Hrvatske očekivane su značajnije količine oborine tijekom narednih 72 sata uslijed visinske ciklone bogate vlagom. Njavljene su količine oborine i više od 100 litara kiše po četvornom metru uz mogućnost bujičnih poplava.

### Sinoptička situacija

Razvoj sinoptičke situacije pokazao je da se Hrvatska nalazila u prizemnom polju izjednačenog i malo sniženog tlaka zraka, a 18. srpnja u poslijepodnevnim satima hladna fronta sa sjeverozapada Europe premještala se prema Hrvatskoj, dok se centar prizemne ciklone nalazio nad područjem Turske (slika 5.2.1). Kiša koja je pala u razdoblju od 16. do 20. srpnja 2021. nad središnjom i istočnom Hrvatskom posljedica je duboke visinske ciklone bogate vlagom (vidljive do visine 300 hPa) koja se prostirala iznad Hrvatske i Jadrana te se polako popunjava (slika 5.2.2).

Prema izvješću Službe za obranu od tuče, 18. srpnja 2021. godine poslije 13 UTC s jugoistoka su počeli pristizati olujni konvektivni oblaci. Od 14 UTC razvijala se konvekcija uz Dunav, a od 15 UTC nekoliko jakih oblaka kumulonimbusa (Cb) s jezgrama reflektivnosti do 60 dBZ nalazilo se na iločkom području, te oko Osijeka i Gradišta (slika 5.2.3) (Meteorološki i hidrološki bilten, 7/2021).

Radarski odrazi na kompozitu hrvatskih i slovenskih meteoroloških radara (slika 5.2.3), kao i satelitski produkti (slika 5.2.4) od 18. srpnja 2021. godine u 15 UTC otkrivaju pojavu jake konvekcije u istočnoj Slavoniji. Na "Sandwich" satelitskom produktu (slika 5.2.4b) također su vidljiva jaka uzlazna gibanja nad istočnim dijelom Slavonije. Boje na slici ukazuju na visinu konvektivnih oblaka, a označavaju temperature vrhova oblaka u intervalu od 240 do 200 K, pri čemu tamno plava boja ukazuje na

## 5.2 Flood in Slavonia in July 2021

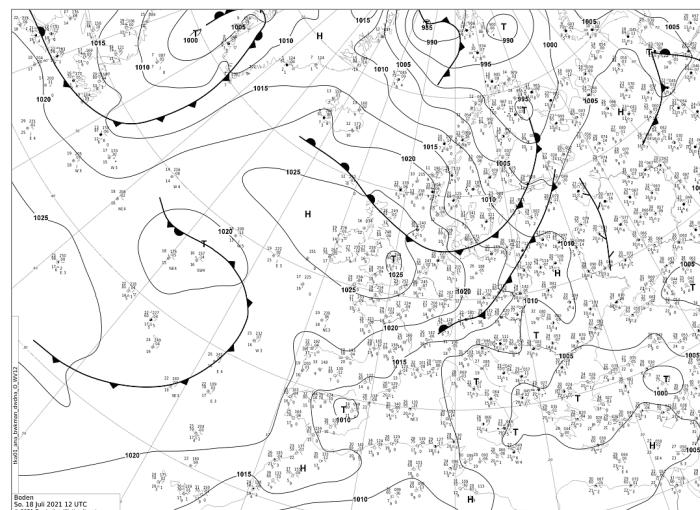
In a statement published on <https://meteo.hr> on 16 July 2021, significant precipitation amounts are expected in the larger area of continental Croatia during the next 72 hours due to the upper-level low rich in moisture. Precipitation amounts of more than 100 liters of rain per square meter have been announced, with the possibility of flash floods.

### Synoptic situation

The surface chart shows that Croatia was in a surface field of near-equalised and a bit lower air pressure, and in the afternoon of 18 July, a cold front from northwestern Europe moved toward Croatia, while the surface low pressure center was over Turkey (Figure 5.2.1). The rain that fell in the period 16 – 20 July 2021 over the central and eastern Croatia was the consequence of a deep, moisture-rich upper-level low (visible up to 300 hPa) that spread over Croatia and Adriatic Sea, which was slowly filling up (Figure 5.2.2).

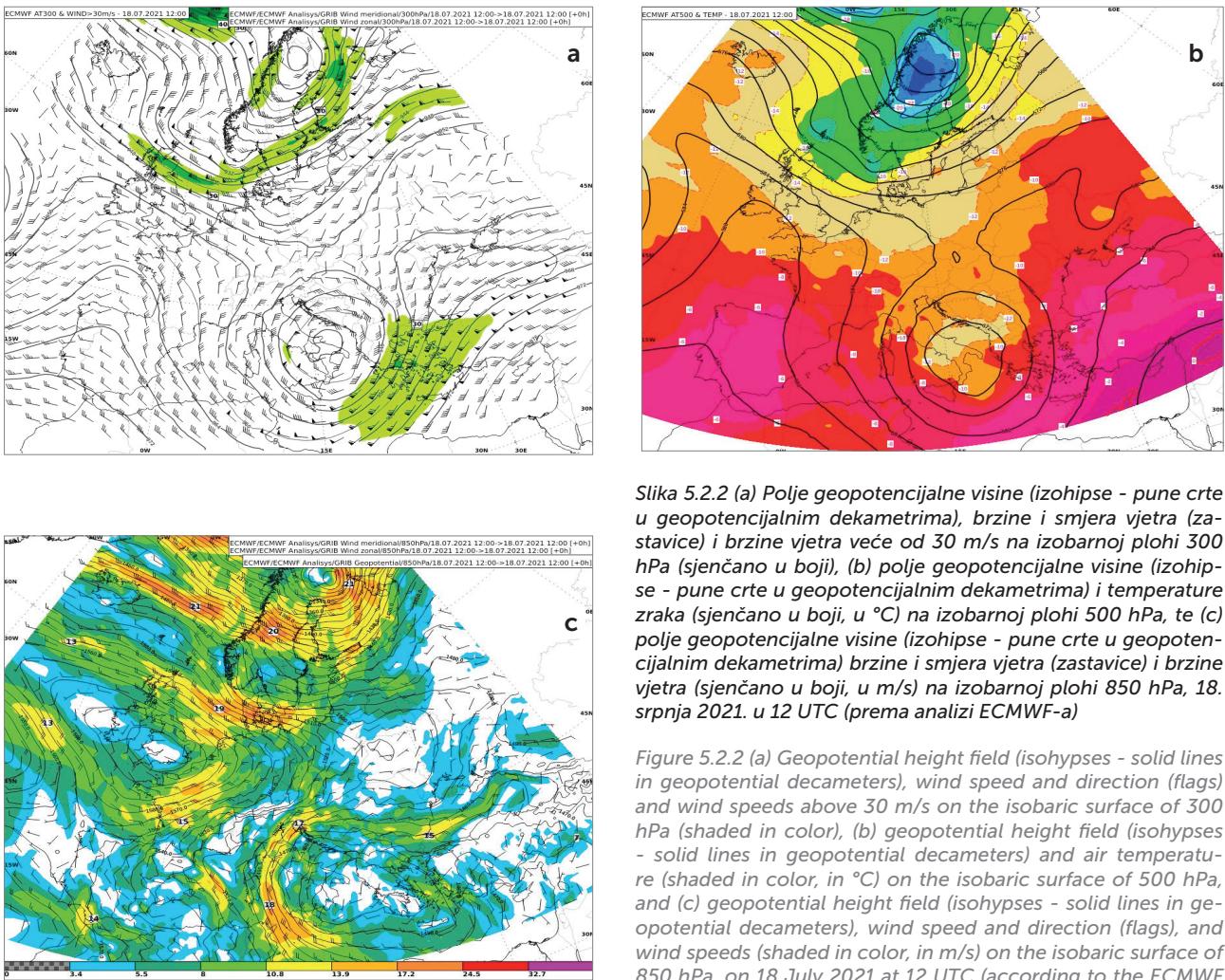
According to the report of the Hail Defence Service of the Croatian Meteorological and Hydrological Service, on 18 July 2021 after 13 UTC, there was convection coming from the southeast. From 14 UTC the convection developed along the Danube, and from 15 UTC several strong cumulonimbuses (Cb) with reflectivity cores up to 60 dBZ were located in the Ilok area, and around Osijek and Gradište (Figure 5.2.3) (Meteorološki i hidrološki bilten/Meteorological and Hydrological Bulletin, 7/2021).

The radar composite of the Croatian and Slovenian radar centres (Figure 5.2.3), as well as the satellite image (Figure 5.2.4) on 18 July 2021 at 15 UTC reveal the high convection in eastern Slavonia. On the so-called "Sandwich" product (Figure 5.2.4b) strong updraft is visible over the eastern part of Slavonia. The colours in the image point to the height of convective clouds, and the colours in the figure indicate cloud peak temperatures in the range of 240



Slika 5.2.1 Prizemna sinoptička situacija 18. srpnja 2021. godine u 1200 UTC (izvor: Njemačka meteorološka služba – DWD).

Figure 5.2.1 Surface synoptic situation on 18 July 2021 at 12 UTC (source: German Meteorological Service – DWD).



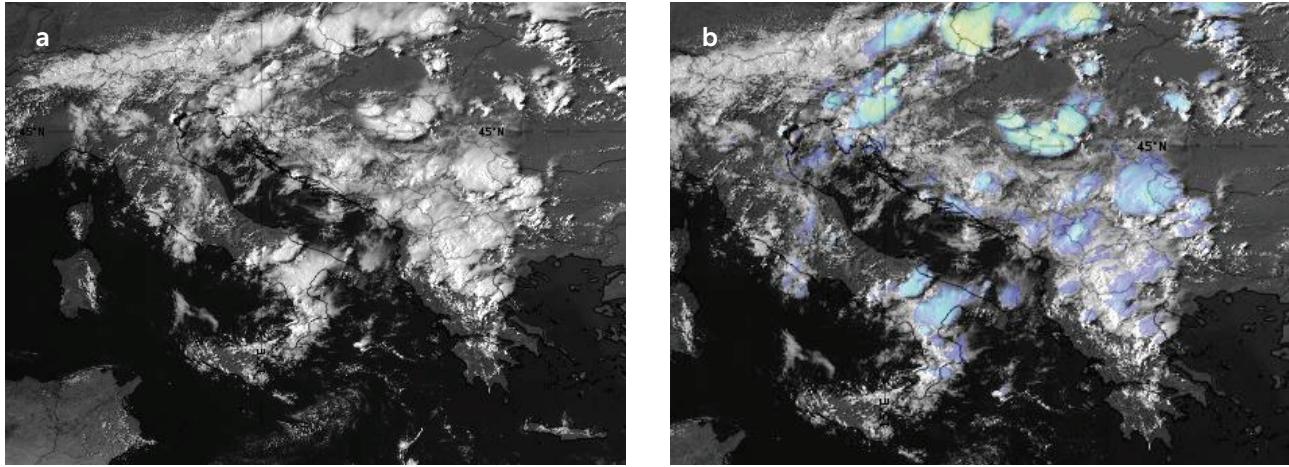
Slika 5.2.2 (a) Polje geopotencijalne visine (izohipse - pune crte u geopotencijalnim dekametrima), brzine i smjera vjetra (zastavice) i brzine vjetra veće od 30 m/s na izobarnoj plohi 300 hPa (sjenčano u boji), (b) polje geopotencijalne visine (izohipse - pune crte u geopotencijalnim dekametrima) i temperature zraka (sjenčano u boji, u °C) na izobarnoj plohi 500 hPa, te (c) polje geopotencijalne visine (izohipse - pune crte u geopotencijalnim dekametrima) brzine i smjera vjetra (zastavice) i brzine vjetra (sjenčano u boji, u m/s) na izobarnoj plohi 850 hPa, 18. srpnja 2021. u 12 UTC (prema analizi ECMWF-a)

Figure 5.2.2 (a) Geopotential height field (isohypes - solid lines in geopotential decameters), wind speed and direction (flags) and wind speeds above 30 m/s on the isobaric surface of 300 hPa (shaded in color), (b) geopotential height field (isohypes - solid lines in geopotential decameters) and air temperature (shaded in color, in °C) on the isobaric surface of 500 hPa, and (c) geopotential height field (isohypes - solid lines in geopotential decameters) brzine i smjera vjetra (zastavice) i brzine vjetra (sjenčano u boji, u m/s) na izobarnoj plohi 850 hPa, on 18 July 2021 at 12 UTC (according to the ECMWF analysis)



Slika 5.2.3 Segment radarskog kompozita hrvatskih i slovenskih meteoroloških radara, 18. srpnja 2021. godine u 15 UTC

Figure 5.2.3 Segment of radar composites from Croatian and Slovenian meteorological radars, 18 July 2021 at 15 UTC



Slika 5.2.4 (a) MSG Meteosat–10 slika visoke rezolucije u vidljivom dijelu spektra (eng. High Resolution Visible – HRV), te (b) "Sandwich" produkt kao kombinacija HRV satelitske snimke i infracrvene IR 10.8 μm satelitske slike gdje boje označavaju vrijednosti temperature vrhova oblaka, 18. srpnja 2021. u 15 UTC

Figure 5.2.4 (a) MSG Meteosat–10 High Resolution Visible (HRV) image, and (b) "Sandwich" product as a combination of HRV satellite image and infrared IR 10.8  $\mu\text{m}$  satellite image, where colors indicate values of cloud top temperatures, 18 July 2021 at 15 UTC

višu (manje hladnu, oko  $-30^\circ\text{C}$ ), a žuta na nižu temperaturu (hladniju, do oko  $-60^\circ\text{C}$ ) vrhova oblaka.

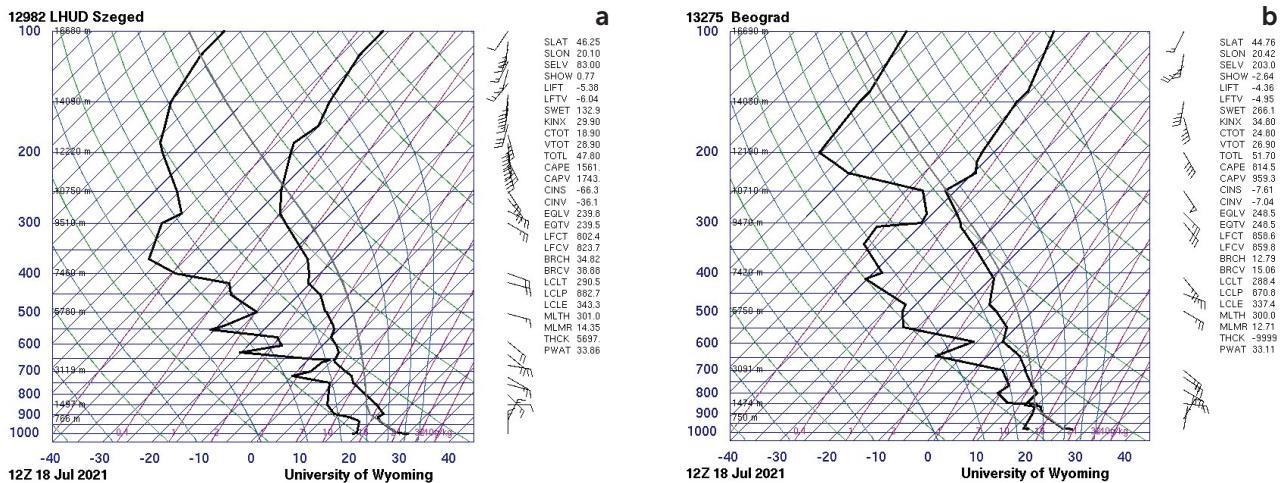
Slika 5.2.5 prikazuje radiosondaže najbližih radiosondažnih postaja Szeged u Mađarskoj i Beograd u Srbiji, te je prema konvektivnoj raspoloživoj potencijalnoj energiji (engl. convective available potential energy - CAPE) vidljiva izrazita nestabilnost atmosfere, posebno na postaji Szeged.

Prolaz prizemne hladne fronte uzrokovao je dodatnu nestabilnost atmosfere 18. srpnja 2021. godine i pojavu olujnih grmljavinskih nevremena s tučom u istočnom dijelu Slavonije, dok je cijekupna sinoptička situacija doveo do pojave obilnih oborina i bujičnih poplava u sjevernom i istočnom dijelu Hrvatske detaljnije opisanih u priopćenju objavljenom na <https://meteo.hr>.

to 200 K – where dark blue indicate higher temperature (less cold, around  $-30^\circ\text{C}$ ) and yellow lower temperature (colder, up to around  $-60^\circ\text{C}$ ) of cloud tops.

Figure 5.2.5 shows radiosoundings of the nearest radiosounding stations Szeged (Hungary) and Belgrade (Serbia). According to convective available potential energy (CAPE) the high instability is visible, particularly at Szeged station.

The passage of the cold front caused additional instability of the atmosphere on 18 July 2021 and the occurrence of thunderstorms with hail in the eastern part of Slavonia. The whole synoptic situation led to the heavy rain and flash floods in the northern and eastern parts of Croatia that are described in more details in the announcement issued on <https://meteo.hr>.



Slika 5.2.5 Sondaže meteoroloških postaja (a) Szeged (Mađarska) i (b) Beograd (Srbija) 18. srpnja 2021. godine u 12 UTC

Figure 5.2.5 Radiosoundings from meteorological stations (a) Szeged (Hungary) and (b) Belgrade (Serbia) on 18 July 2021 at 12 UTC

## Analiza oborine prema podacima meteoroloških postaja

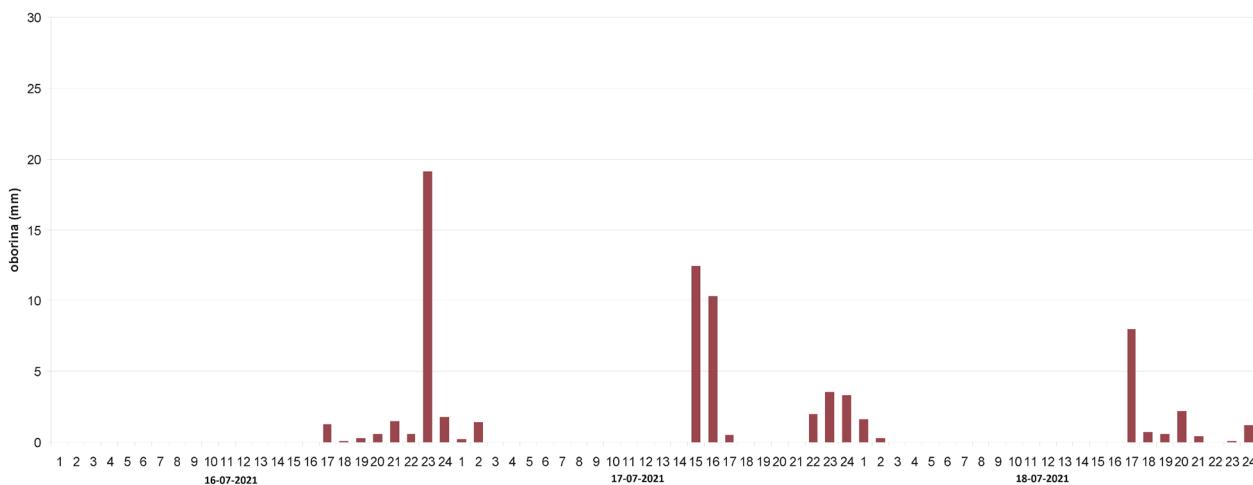
Slika 5.2.6 prikazuje satne vrijednosti količine oborine prema podacima s glavne meteorološke postaje (GMP) Osijek, a slika 5.2.7 maksimalnu satnu brzinu vjetra na GMP Osijek od 16. do 18. srpnja 2021. godine. Na GMP Osijek pale su velike količine oborine u kratkom vremenskom razdoblju, a vjetar je kratkotrajno 17. srpnja u 16 (SEV) bio olujne jačine.

U istočnom dijelu Slavonije u samo 5 dana na velikom broju postaja palo je preko 100 mm kiše, a najviše na klimatološkoj meteorološkoj postaji (KMP) Županja, 223.9 mm (slika 5.2.8a). Postaja Županja zabilježila je rekordnu dnevnu količinu oborine (182.9 mm) 20. srpnja 2021. (slika 5.2.8b), što predstavlja najveću dnevnu količinu oborine otkad postoje mjerena na toj postaji. Dotadašnja maksimalna dnevna količina oborine u srpnju iznosila je 58.9 mm (izmjereno 16. srpnja 2016.), a

## Precipitation analysis according to data from the meteorological stations

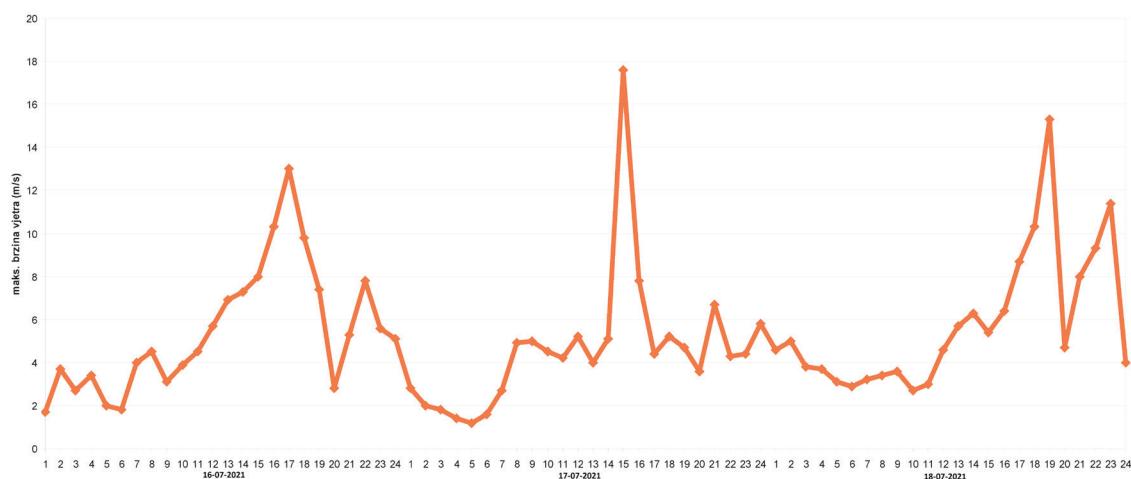
Figure 5.2.6 shows the hourly values of precipitation amount according to data from the main meteorological station Osijek, and Figure 5.2.7 the values of hourly maximum wind speed at the main meteorological station Osijek for the period 16–18 July 2021. High precipitation amounts fell at GMP Osijek in a short time period, and the wind was strong for a short time on 17 July at 4 pm (CET).

In the eastern part of Slavonia, in just 5 days, over 100 mm of rain fell at a large number of stations, and the most at the climatological meteorological station Županja, 223.9 mm (Figure 5.2.8 a). On 20 July the climatological station Županja recorded the highest daily precipitation amount (182.9 mm) for July 2021 (Figure 5.2.8 b), also the highest daily precipitation amount on record for mentioned station. The previous maximum daily precipitation amount in July was 58.9 mm (measured on 16 July 2016), and the



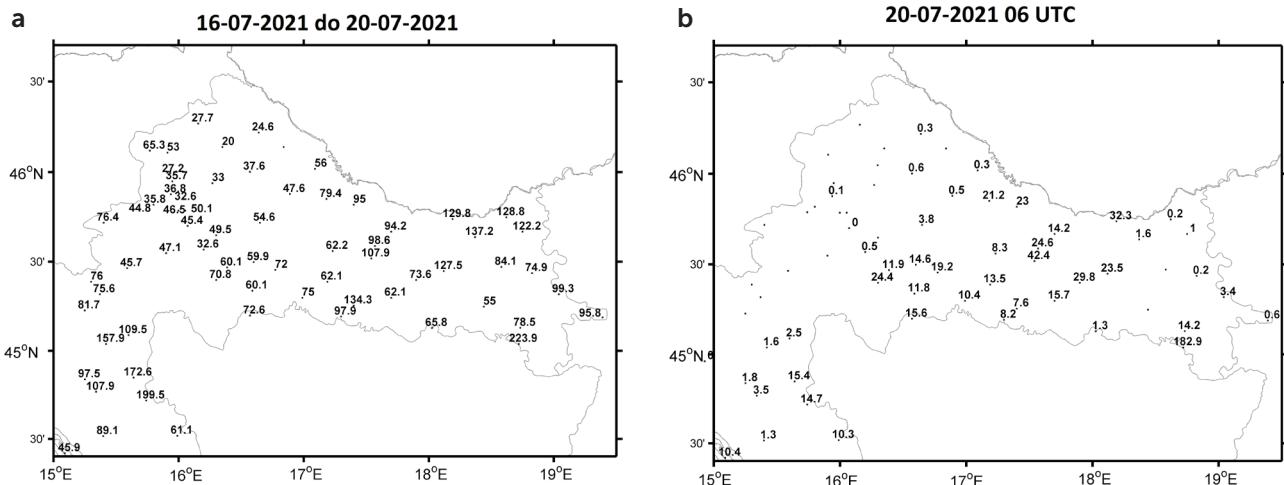
Slika 5.2.6 Satne vrijednosti količine oborine prema podacima glavne meteorološke postaje (GMP) Osijek od 16. do 18. srpnja 2021. godine

Figure 5.2.6 Hourly precipitation amounts based on data from the main meteorological station Osijek, 16–18 July 2021



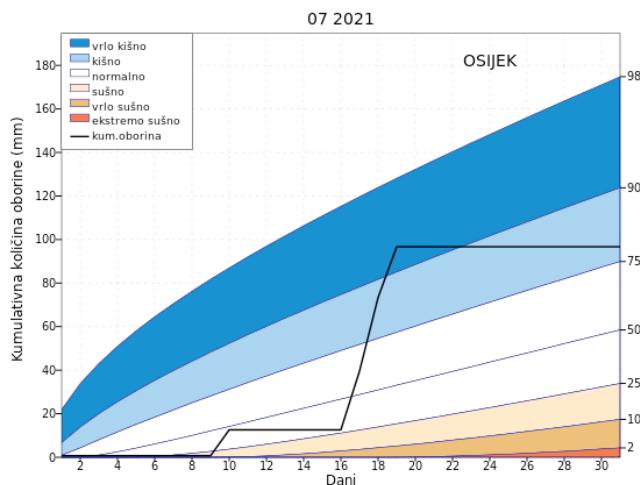
Slika 5.2.7 Satne maksimalne brzine vjetra (m/s) na GMP Osijek od 16. do 18. srpnja 2021. godine.

Figure 5.2.7 Hourly maximum wind speed values (m/s) at the main meteorological station Osijek, 16–18 July 2021



Slika 5.2.8 (a) Suma oborine od 16. do 20. srpnja 2021. godine, te (b) dnevne količine oborine 20. srpnja 2021. godine u 06 UTC na području središnjeg, sjevernog i istočnog dijela Hrvatske izmjerene na sinoptičkim i klimatološkim postajama

Figure 5.2.8 (a) Total precipitation amounts for the period 16–20 July 2021 and (b) daily precipitation amounts on 20 July 2021 at 06 UTC over central, northern, and eastern Croatia, measured at synoptic and climatological stations



Slika 5.2.9 Kumulativna količina oborine (mm) za srpanj 2021. i krivulje teorijskih percentila (2., 10., 25., 50., 75., 90. i 98.) za razdoblje 1961. – 2000. za Osijek

Figure 5.2.9 Cumulative precipitation amounts (mm) for July 2021 and theoretical percentile curves ( $2^{\text{nd}}$ ,  $10^{\text{th}}$ ,  $25^{\text{th}}$ ,  $50^{\text{th}}$ ,  $75^{\text{th}}$ ,  $90^{\text{th}}$  and  $98^{\text{th}}$ ) for the period 1961 – 2000 in Osijek

apsolutni dnevni maksimum izmjerен je 30. lipnja 2001. i iznosio 111.6 mm.

Kumulativna količina oborine za Osijek za srpanj pokazuje da je 18. srpnja kumulativna količina oborine bila između 90. i 98. percentila, odnosno u klasi vrlo kišno (slika 5.2.9).

Medijska izviešća

Prema medijskim izvješćima, ovo snažno olujno nevrijeme praćeno jakom kišom izazvalo je bujične poplave u dijelu Slavonije i Baranje 17. i 18. srpnja 2021. godine (slika 5.2.10). Slična situacija bila je i u drugim dijelovima Europe 17. srpnja, posebice u Njemačkoj, Austriji, Belgiji i Luksemburgu gdje se također događaju katastrofalne bujične poplave.

absolute daily maximum (111.6 mm) was measured on 30 June 2001 of 111.6 mm.

The cumulative precipitation amount for Osijek in July shows that on 18 July the cumulative precipitation-amount was between the 90<sup>th</sup> and 98<sup>th</sup> percentiles (Figure 5.2.9).

## Media reports

According to the media reports, a strong storm followed by heavy rain caused flash floods in parts of Slavonia and Baranja on 17 and 18 July 2021 (Figure 5.2.10). Other parts of Europe, particularly Germany, Austria, Belgium and Luxembourg, were also hit by catastrophic flash floods on 17 July.



Slika 5.2.10 Poplava u našičkom kraju 17. srpnja 2021. godine (<https://nasice.com/velike-poplave-na-nasickom-području/>)

Figure 5.2.10 Flood in Našice area, 17 July 2021 (<https://nasice.com/velike-poplave-na-nasickom-području/>)



Slika 5.2.11 Uništena polja suncokreta na području Iloka, 18. srpnja 2021. godine (<https://dnevnik.hr/galerija/vijesti/hrvatska/poljoprivrednici-na-istoku-hrvatske-zbrajaju-stete-nakon-jucerasnjeg-nevremena---659980.html/62125343/659980>)

Figure 5.2.11 Destroyed sunflower fields in the Ilok area, 18 July 2021 (<https://dnevnik.hr/galerija/vijesti/hrvatska/poljoprivrednici-na-istoku-hrvatske-zbrajaju-stete-nakon-jucerasnjeg-nevremena---659980.html/62125343/659980>)

Obilne količine oborine pale su 16. srpnja, a zatim je Osječko-baranjsku i Vukovarsko-srijemsku županiju 17. srpnja zahvatilo snažno olujno nevrijeme te je u kratkom vremenu palo preko 90 litara kiše po četvornom metru zbog čega su angažirane sve raspoložive službe spašavanja i zaštite od poplave. Velike količine kiše u Osijeku izazvale su zastoj tramvajskog prometa, oštetile su i velik broj prodajnih kućica na osječkoj tržnici kao i unutarnje prostore tržnice, a otkinuo se i krov zgrade. Objavljeno je da štete za Vukovarsko-srijemsku županiju iznose oko 600 milijuna kuna. Na našičkom području poplavljene su kuće, podrumi, cestama su tekli potoci vode, a u podvožnjacima su zaglavljeni automobili (slika 5.2.10). Dijelovi Našica ostali su bez struje. Izlili su se kanali, a na ceste je nanešen mulj, granje, kamenje i šljunak, te su brojne kuće oštećene. Stradali su i usjevi na njivama. Ukupne štete se procjenjuju na oko 1 milijun kuna. Na području Županje i Bošnjaka zbog obilne oborine poplavljene su ulice, kuće, okućnice, industrijski i trgovački objekti. Uništeni su i brojni usjevi.

Na području oko Iloka padala je i snažna tuča prćena olujnim vjetrom, što je uništilo polja kukuruza, sunčokreta i drugih poljoprivrednih kultura (slika 5.2.11).

After heavy rain on 16 July, Osijek-Baranja and Vukovar-Srijem counties were hit by a severe weather on 17 July, with more than 90 litres of rain per square meter falling over a short time. All available emergency responders had to be dispatched to the area. Tram traffic in Osijek was halted due to heavy rain, and several booths were damaged at the farmers' market in Osijek, along with the interior of the market's main building, whose roof was torn off. Damage totalling to around 600 million kuna was reported in the Vukovar-Srijem County. Homes, basements and roads were flooded in Našice area, and cars were reported to have gotten stuck under flooded underpasses (Figure 5.2.10). Parts of Našice experienced a power outage. Canals overflowed, roads were contaminated by mud, tree branches, stones and gravel, and many houses and crops were damaged. The total damage is estimated to around 1 million kuna. Streets, houses, backyards, and industrial and commercial buildings were flooded in Županja and Bošnjaci area due to heavy rain, and there was serious crop damage in the area as well.

In the Ilok area, a strong hailstorm followed by strong wind, which destroyed almost entire maize, sunflowers and other crops in the area (Figure 5.2.11).

### 5.3 Nevrijeme s olujnim vjetrom u središnjoj Hrvatskoj i Istri 1. kolovoza 2021.

Prvog kolovoza 2021. godine olujno nevrijeme je zahvatilo dio središnje Hrvatske, a najveće štete nastale su na Banovini i u Moslavini. Olujni vjetar je čupao i lomio stabla, nosio crijepe s krovova. S jedne škole u Kutini odnesen je cijeli krov. Među oštećenim objektima našla se i crkva svetog Lovre u Petrinji. Oštećena je elektro mreža pa je bilo i nestanka struje. Štete je bilo na poljima i u voćnjacima. I u dijelovima Zagrebačke županije bilo je izvješća o drveću koje je padalo na ceste, te o oštećenim električnim stupovima i kabelima. Područje Osječko-baranjske županije također je zahvatilo nevrijeme koje je uzrokovalo poteškoće u prometu i prekide u opskrbi električnom energijom, te je nosilo plastenike. Olujnim

### 5.3 Severe weather in central Croatia and Istria on 1 August 2021

Parts of central Croatia were hit by severe weather on 1 August 2021, with Banovina and Moslavina sustaining the worst damage. Trees were uprooted and broken, and tiles dislodged from roofs by wind. A school in Kutina lost its entire roof. The St. Lawrence Church in Petrinja was damaged as well. The area experienced a power outage due to the wind blowing down utility poles. Fields and orchards sustained damage. There were reports of trees falling across roads, and damaged utility poles and cables in the Zagreb County. The storm caused disruptions in traffic and in the power supply in the Osijek-Baranja County and destroyed several plastic greenhouses. Istria was hit by a storm too, with strong wind bringing down trees on cars and houses



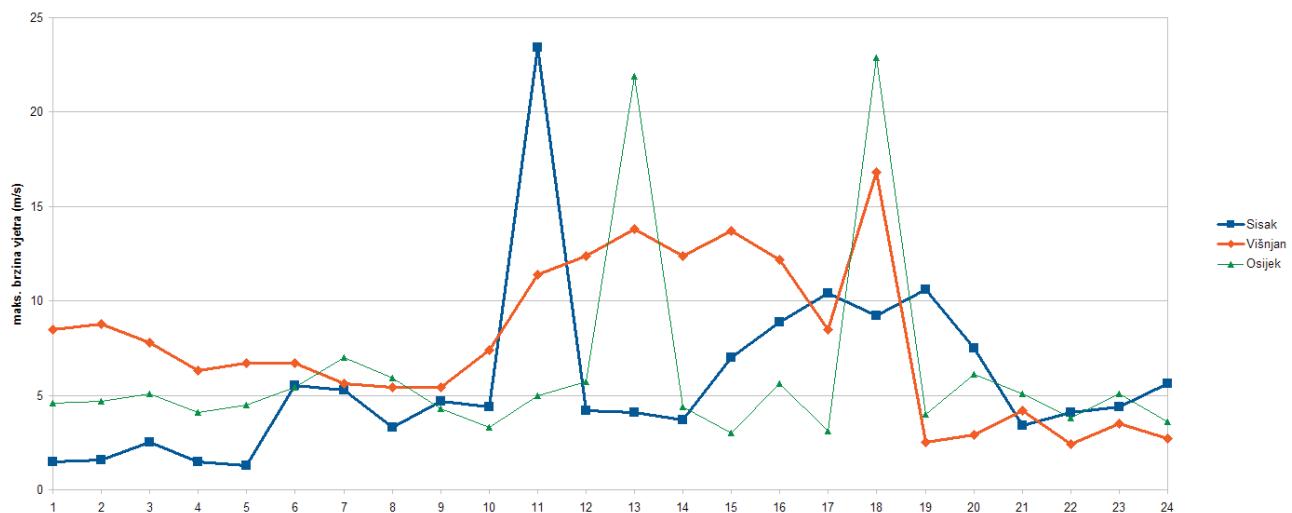
Slika 5.3.1 Posljedice olujnog nevremena u Sisku 1. kolovoza 2021. godine (<https://civilna-zastita.gov.hr/vijesti/nevrijeme-na-podrucju-vise-zupanija-4693/4693>; izvor: MUP)

Figure 5.3.1 The aftermaths of a severe weather in Sisak on 1 August 2021 (<https://civilna-zastita.gov.hr/vijesti/nevrijeme-na-podrucju-vise-zupanija-4693/4693>; source: MUP)



Slika 5.3.2 Pijavica u blizini sela Žužiči u središnjoj Istri 1. kolovoza 2021. godine (<https://www.meteoadriatic.net/tornado-u-istri-1-kolovoza-2021/>; Foto: Petar Radovan / Istramet)

Figure 5.3.2 A waterspout near the village of Žužiči in central Istria on 1 August 2021 (<https://www.meteoadriatic.net/tornado-u-istri-1-kolovoza-2021/>; Photo: Petar Radovan/Istramet)



Slika 5.3.3 Satne maksimalne brzina vjetra (m/s) na glavnim meteorološkim postajama (GMP) Sisak i Osijek, te automatske meteoroške postaje (AMP) Višnjan 1. kolovoza 2021. godine.

Figure 5.3.3 Values of hourly maximum wind speed (m/s) at the main meteorological stations Sisak and Osijek, and automatic meteorological station Višnjan on 1 August 2021

nevremenom pogodjena je i Istra. U središnjoj Istri olujni vjetar rušio je stabla na automobile i kuće. U središnjem dijelu Istre, kod naselja Žužići, uočena je pijavica. Slika 5.3.3 prikazuje satne maksimalne brzine vjetra na glavnim meteorološkim postajama (GMP) Sisak i Osijek, te na automatskoj meteorološkoj postaji (AMP) Višnjan 1. kolovoza 2021. godine. U Sisku je maksimalni dnevni udar vjetra u 10:41 h (SEV) iznosio 23.4 m/s, u Osijeku u 17:50 h (SEV) 22.9 m/s, te na AMP Višnjan u 17:35 h (SEV) 16.8 m/s.

Prizemno je nad područjem Hrvatske bilo polje snaženog tlaka zraka, a frontalni sustav sa sjeverozapadne Europe prelazio je preko Alpa, što je dovelo do stvaranja plitkog ciklonalnog središta nad sjevernim Jadranskim sredinom dana (slika 5.3.4). Hrvatska se nalazila na prednjoj strani visinske doline, a mlažna struja je prelazila preko sjevernog Jadrana i središnjeg dijela Hrvatske (slika 5.3.5a). Na 850 hPa bio je vidljiv uski lijevak doline s ciklonom koji je sredinom dana prelazio preko sjevernog Jadrana i sjevernog dijela Hrvatske (slika 5.3.5c).

Na satelitskim slikama (slika 5.3.6), pogotovo "Sandwich" produktu, vidljivi su jaki konvektivni razvoji nad sjevernim Jadranom, Gorskim kotarom i posebice Banovinom. Boje na slici 5.3.6 upućuju na visinu konvektivnih oblaka i označavaju temperature vrhova oblaka u intervalu od 240 do 200 K – pri čemu tamno plava boja ukazuje na višu temperaturu (oko  $-30^{\circ}\text{C}$ ) i niže vrhove oblaka, a žuta, odnosno narančasta na nižu temperaturu (do oko  $-60^{\circ}\text{C}$ ) i veću visinu vrhova oblaka.

Prema podacima s glavne meteorološke postaje (GMP) Zagreb-Maksimir konvektivna raspoloživa potencijalna energija (engl. Convective available potential energy - CAPE) je bila visoka (slika 5.3.7) što ukazuje na izrazito nestabilnu atmosferu koja u kombinaciji s jakim smicanjem vjetra po vertikali može dovesti do snažnih organiziranih konvektivnih procesa.

Sa slike 5.3.3 je vidljivo da je nagli skok maksimalne brzine vjetra na prikazanim postajama povezan s pojmom konvektivnih oluja, a u Višnjanu s olujnim nevreme-

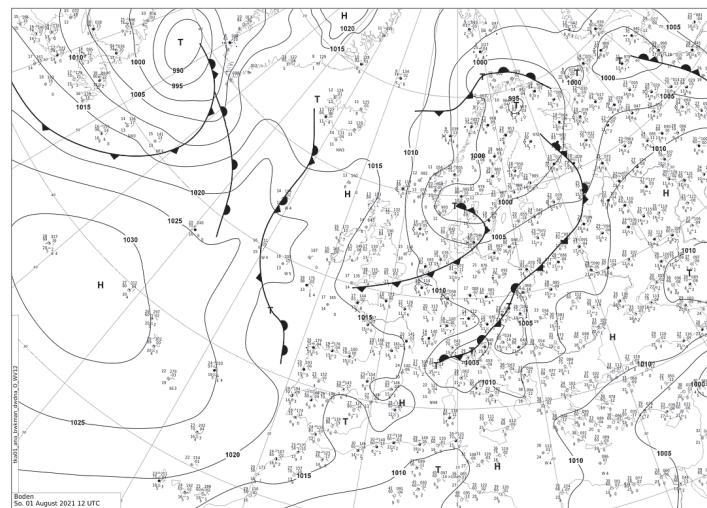
in central Istria. A waterspout was spotted near the village of Žužići in central Istria (Figure 5.3.2). Figure 5.3.3 shows the values of hourly maximum wind speeds at the main meteorological stations Sisak and Osijek, and the automatic meteorological station Višnjan on 1 August 2021. Maximum daily wind gust was 23.4 m/s at 10:41 (CET) in Sisak, 22.9 m/s at 17:50 (CET) in Osijek, and 16.8 m/s at 17:35 (CET) at the automatic meteorological station Višnjan.

The surface synoptic situation shows a field of low air pressure over Croatia. The frontal system crossed the Alps from northwestern Europe, causing the formation of a shallow cyclonic center over the northern Adriatic in the middle of the day (Figure 5.3.4). Croatia was on the frontal part of the upper level low, with the jet stream crossing the northern Adriatic and central part of Croatia (Figure 5.3.5 a). A narrow funnel-shaped trough was visible at the isobaric surface of 850 hPa, with a low crossing the northern Adriatic and northern Croatia in the middle of the day (Figure 5.3.5 c).

Satellite images (Figure 5.3.6), particularly the "Sandwich" product, show strong upward motions over the northern Adriatic, Gorski Kotar and Banovina in particular. Colors in Figure 5.3.6 indicate the height of convective clouds and cloud top temperatures in the range of 240 to 200 K – dark blue indicates a higher temperature (less cold – around  $-30^{\circ}\text{C}$ ), and yellow and orange indicate a lower cloud top temperature (colder, up to around  $-60^{\circ}\text{C}$ ) as well as the higher cloud top heights.

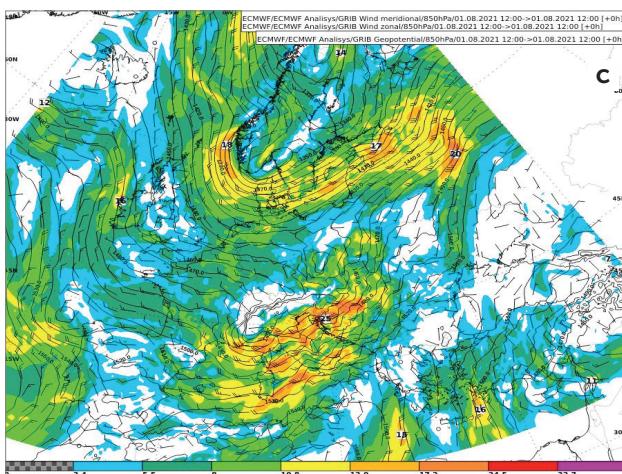
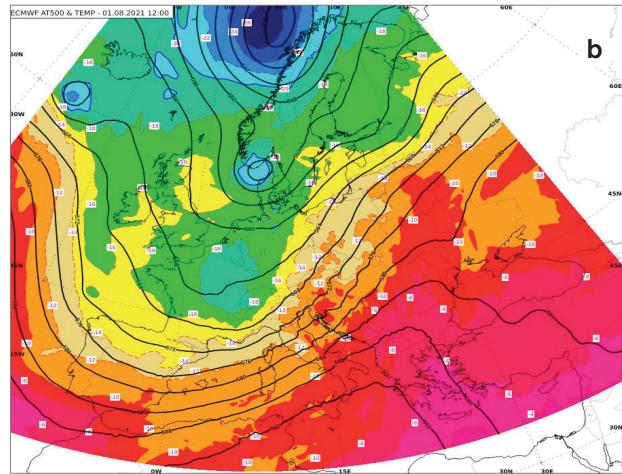
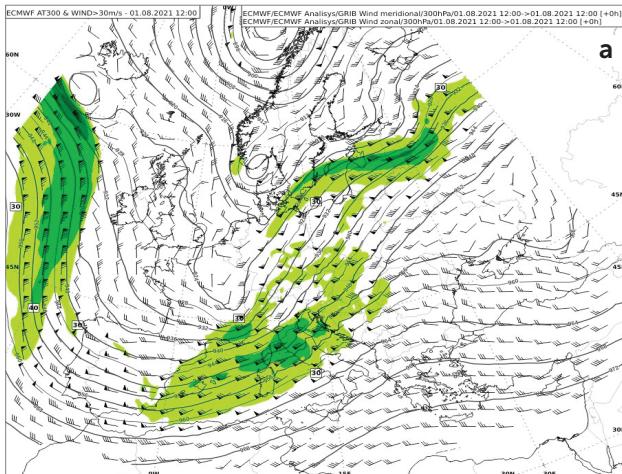
According to the data from the main meteorological station Zagreb-Maksimir, convective available potential energy (CAPE) was high (Figure 5.3.7), which indicates an extremely unstable atmosphere that can lead to strong and organized convective processes in combination with strong vertical wind shear.

Figure 5.3.3 shows a sudden jump in the maximum wind speed at all stations, which is associated with the occurrence of convective storms and the storm in Višnjan that resulted in the occurrence of a waterspout near the village of Žužići. The occurrence of the waterspout was influenced



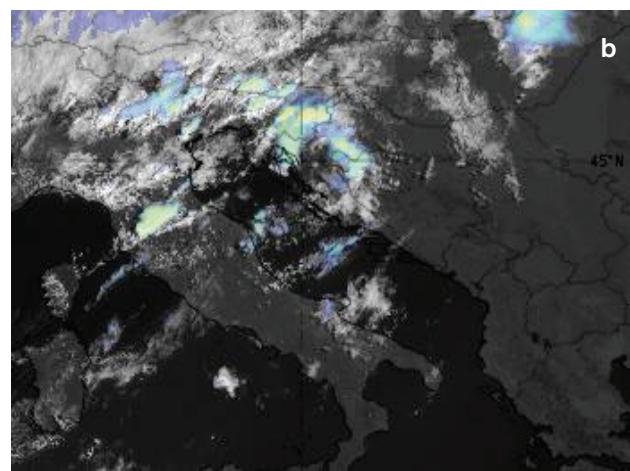
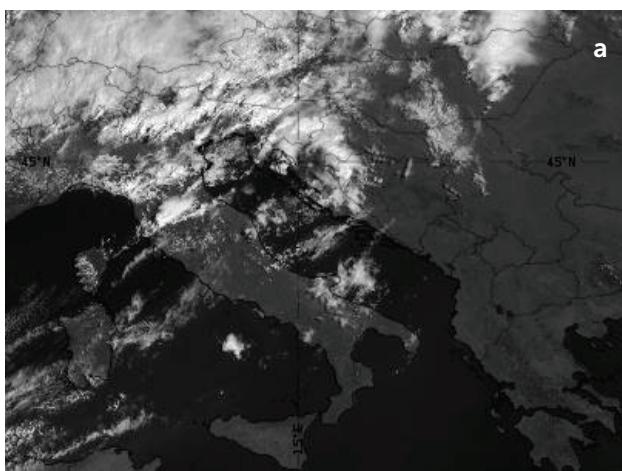
Slika 5.3.4 Prizemna sinoptička situacija 1. kolovoza u 12 UTC (izvor: Njemačka meteorološka služba – DWD)

Figure 5.3.4 Surface synoptic situation on 1 August 2021 at 12 UTC (source: German Meteorological Service, DWD)



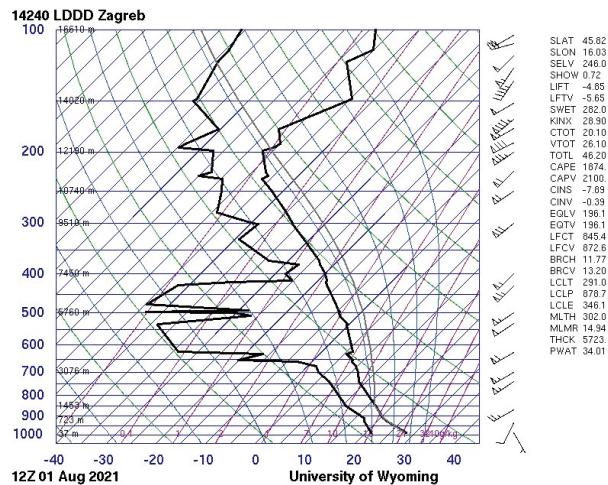
Slika 5.3.5 (a) Polje geopotencijalne visine (izohipse – pune crte u geopotencijalnim dekametrima), brzine i smjera vjetra (zastavice) i brzine vjetra veće od 30 m/s na izobarnoj plohi 300 hPa (sjenčano u boji), (b) polje geopotencijalne visine (izohipse – pune crte u geopotencijalnim dekametrima) i temperature zraka (sjenčano u boji u °C) na izobarnoj plohi 500 hPa, te (c) polje geopotencijalne visine (izohipse – pune crte u geopotencijalnim dekametrima), brzine i smjera vjetra (zastavice) i brzine vjetra (sjenčano u boji u m/s) na izobarnoj plohi 850 hPa, 1. kolovoza 2021. u 12 UTC

Figure 5.3.5 (a) Geopotential height field (isohypes - solid lines in geopotential decameters), wind speed and direction (flags) and wind speeds over 30 m/s on the isobaric surface of 300 hPa (shaded in color), (b) Geopotential height field (isohypes - solid lines in geopotential decameters) and air temperature (shaded in color in °C) on the isobaric surface of 500 hPa, and (c) Geopotential height field (isohypes - solid lines in geopotential decameters), wind speeds and directions (flags), and wind speeds (shaded in color in m/s) on the isobaric surface of 850 hPa, 1 August 2021 at 12 UTC



Slika 5.3.6 (a) Meteosat-10 slika visoke rezolucije u vidljivom dijelu spektra (eng. High Resolution Visible - HRV), te (b) "Sandwich" produkt kao kombinacija HRV satelitske slike i infracrvene IR 10.8 µm satelitske slike gdje boje označavaju vrijednosti temperature vrhova oblaka, 1. kolovoza 2021. u 09 UTC

Figure 5.3.6 (a) Meteosat-10 High Resolution Visible (HRV) image and (b) "Sandwich" product as a combination of HRV satellite image and infrared IR 10.8 µm satellite images, where colors indicate values of cloud top temperature, 1 August 2021 at 09 UTC



Slika 5.3.7 Sondaž glavne meteorološke postaje (GMP) Zagreb-Maksimir 1. kolovoza 2021. godine u 12 UTC

Figure 5.3.7 Radiosounding of the main meteorological station Zagreb-Maksimir on 1 August 2021 at 12 UTC

nom koje je rezultiralo pojavom pijavice kod sela Žužići. Na pojavu pijavice utjecali su povoljni termodinamički uvjeti u atmosferi - nestabilnost, jako smicanje vjetra u plitkom sloju atmosfere, te vrlo vjerojatno visoka temperatura mora. Primjerice, na obližnjoj automatskoj meteorološkoj postaji (AMP) Sv. Ivan na Pučini temperatura mora je iznosila 26.3°C.

by favorable thermodynamic conditions in the atmosphere - instability, strong wind shear in the shallow layer of the atmosphere, and very likely high sea temperature. For example, the sea temperature of 26.3°C was measured at the nearby automatic meteorological station Sv. Ivan na Pučini.

## 6. OCJENA KLIME NA GLOBALNOJ LJESTVICI ZA 2021. GODINU

U idućim poglavljima daje se sažeti pregled stanja klimatskog sustava i koncentracija stakleničkih plinova na globalnoj ljestvici objavljen u publikaciji Svjetske meteorološke organizacije "State of the Global Climate in 2021" (WMO, 2022).

### 6.1 Površinska temperatura zraka

Globalna srednja temperatura zraka za 2021. godinu bila je  $(1.11 \pm 0.13)^\circ\text{C}$  viša od prosjeka za predindustrijsko referentno razdoblje 1850. – 1900. (slika 6.1). Šest skupova podataka korištenih u analizi smještaju je između pete i sedme najtoplje godine na globalnoj razini, a svih šest skupova pokazuju da je posljednjih sedam godina, od 2015. do 2021., bilo sedam najtopljih zabilježenih godina.

2021. godina bila je manje topla od nekih posljednjih godina zbog utjecaja umjerenih pojava La Niña na početku i kraju godine, poznatih kao "dvostruko pojavljivanje" La Niña. La Niña ima privremeni učinak hlađenja na globalnu srednju temperaturu zraka. Osim slabe La Niña iz 2018., posljednji značajan događaj La Niña bio je 2011. godine. 2021. je oko 0.22 do 0.29°C toplija od 2011. Godina 2016., koja je započela tijekom snažnog El Niño (ekvatorijalno područje pozitivnih anomalija površinske temperature Tihog oceana), ostaje najtoplja godina zabilježena u većini analiziranih skupova podataka.

Prizemne temperature zraka u 2021. godini (slika 6.2) bile su iznad prosjeka za klimatsko razdoblje 1981. – 2010. u velikom dijelu Sjeverne Amerike i Grenlanda, sjeverne i tropске Afrike, Bliskog istoka i južne Azije. Područja s temperaturama ispod prosjeka uključivala su: dijelove sjeverne Azije, Australije, južne Afrike, sve-

## 6. CLIMATE ASSESSMENT FOR THE YEAR 2021 ON A GLOBAL SCALE

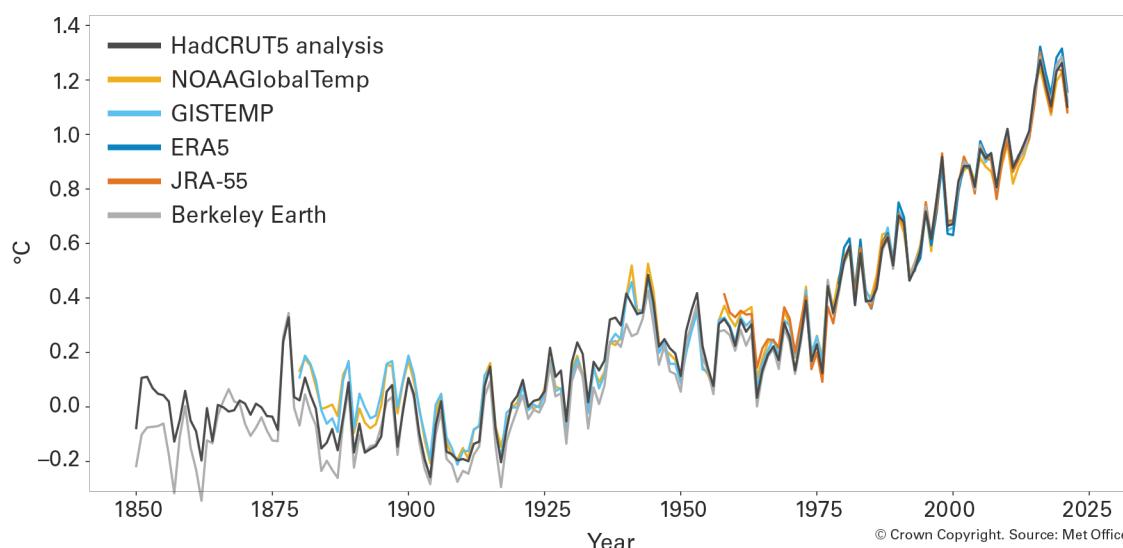
The following chapters provide a summary of the state of the climate system and greenhouse gas concentrations on a global scale, published in the World Meteorological Organization's publication "State of the Global Climate in 2021" (WMO, 2022).

### 6.1 Surface air temperature

The global mean air temperature for 2021 was  $(1.11 \pm 0.13)^\circ\text{C}$  above the 1850 – 1900 average (Figure 6.1). The six data sets used in the analysis place 2021 between the fifth and seventh warmest year on record globally, and all six data sets show that the most recent seven years, 2015 to 2021, were the seven warmest years on record.

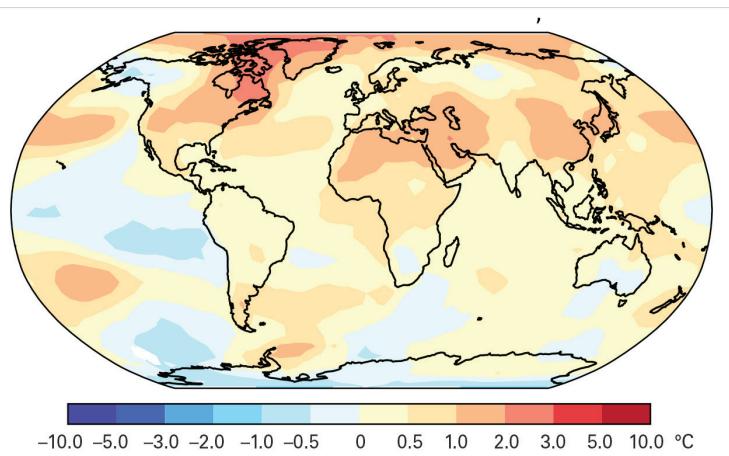
The year 2021 was less warm than some recent years due to the influence of moderate La Niña events at the start and end of the year, known as a "double-dip" La Niña. La Niña has a temporary cooling effect on the global mean temperature. Aside from the weak La Niña of 2018, the last significant La Niña event was in 2011. 2021 is around 0.22 to 0.29°C warmer than 2011. The year 2016, which started during a strong El Niño (equatorial region of positive anomalies of the surface temperature of the Pacific Ocean), remains the warmest year on record in most of the data sets surveyed.

Near surface air temperatures in 2021 (Figure 6.2) were above the 1981 – 2010 average across a broad swath of North America and Greenland, northern and tropical Africa, the Middle East and southern Asia. Areas with below average temperatures included parts of northern Asia, Australia, southern Africa, northwestern North America, and the southern central United States. The imprint of La Niña, with below-average temperatures, can clearly be seen in



Slika 6.1 Prosječna godišnja razlika temperature ( $^\circ\text{C}$ ) u odnosu na predindustrijske uvjete (1850. – 1900.) za šest skupova podataka o globalnoj temperaturi (1850. – 2021.). Izvor: Met Office, Ujedinjeno Kraljevstvo Velike Britanije i Sjeverne Irske.

Figure 6.1 Global annual mean temperature difference ( $^\circ\text{C}$ ) from pre-industrial conditions (1850 – 1900) for six global temperature data sets (1850 – 2021). Source: Met Office, United Kingdom of Great Britain and Northern Ireland.



**Slika 6.2 Temperaturne anomalije srednje godišnje površinske temperature zraka za 2021. u odnosu na srednjak razdoblja 1981. – 2010. Karta prikazuje srednje anomalije izračunate iz pet skupova podataka: HadCRUT5, ERA5, GISTEMP, NOAAGlobalTemp and Berkeley Earth. Izvor: Met Office, Ujedinjeno Kraljevstvo.**

*Figure 6.2 Near-surface temperature differences relative to the 1981 – 2010 average for 2021. The map shows the median anomaly calculated from five data sets: HadCRUT5, ERA5, GISTEMP, NOAAGlobalTemp and Berkeley Earth. Source: Met Office, United Kingdom.*

rozapada Sjeverne Amerike i južne dijelove središnjeg SAD-a. Učinak La Niña uz temperaturu ispod prosjeka jasno se može vidjeti u tropskom Pacifiku. Hladniji uvjeti u južnoj Africi, Indiji i istočnoj Australiji karakteristični su za La Niña. Područje hladnije od prosjeka u sjevernoj Aziji u 2021., imalo je iznimno visoke temperature u 2020. godini. To je dijelom povezano s različitim fazama arktičkih oscilacija početkom 2020. (jako pozitivna) i početkom 2021. godine (jako negativna), koje su imale utjecaj na prosjek cijele godine.

## 6.2 Oborina

U usporedbi s temperaturom zraka, oborinu karakterizira veća prostorna i vremenska varijabilnost.

Velika područja s ukupnim količinama oborine u 2021. godini iznadprosječnim u odnosu na referentno razdoblje 1951. – 2000., bila su: istočna Europa, jugoistočna Azija, tzv. Maritimni kontinent (između ostalih zemalja uključuje Indoneziju, Filipine i Papuu Novu Gvineju, smještene između Indijskog i Tihog oceana, unutar tople oceanske regije poznate kao Tropski topli bazen), područja na sjeveru Južne Amerike i dijelovi jugoistočne Sjeverne Amerike (slika 6.3). Velike regije s manjom oborinom u odnosu na spomenuto referentno razdoblje, uključivale su: jugozapadnu Aziju, Bliski istok, dijelove južne Afrike, jug Južne Amerike i područja u središnjoj Sjevernoj Americi.

Dok su u dijelovima istočne Europe i oko Crnog mora pale neuobičajeno velike količine oborine, neuobičajeno male pale su oko Sredozemnog mora. Zapadnu Europu su 2021. godine zadesile neke od najvećih zabilježenih poplava sredinom srpnja. Najviše je pogodeno područje zapadne Njemačke i istočne Belgije, gdje je u razdoblju 14. – 15. srpnja pao 100 - 150 mm oborine na već vodom zasićeno tlo, pa je to uzrokovalo poplave i klizišta. Hagen (Njemačka) izvjestio je o 241 mm oborine u 22 sata. Poplave su pogodile i dijelove Hrvatske (poglavlje 5.2).

the tropical Pacific. Cooler conditions in southern Africa, India, and eastern Australia are characteristic of La Niña. The cooler-than-average area in northern Asia in 2021 stands in contrast to 2020, which saw exceptionally high temperatures in the region. This is partly associated with the different phases of the Arctic Oscillation in early 2020 (strongly positive) and early 2021 (strongly negative), which had an imprint on the average for the whole year.

## 6.2 Precipitation

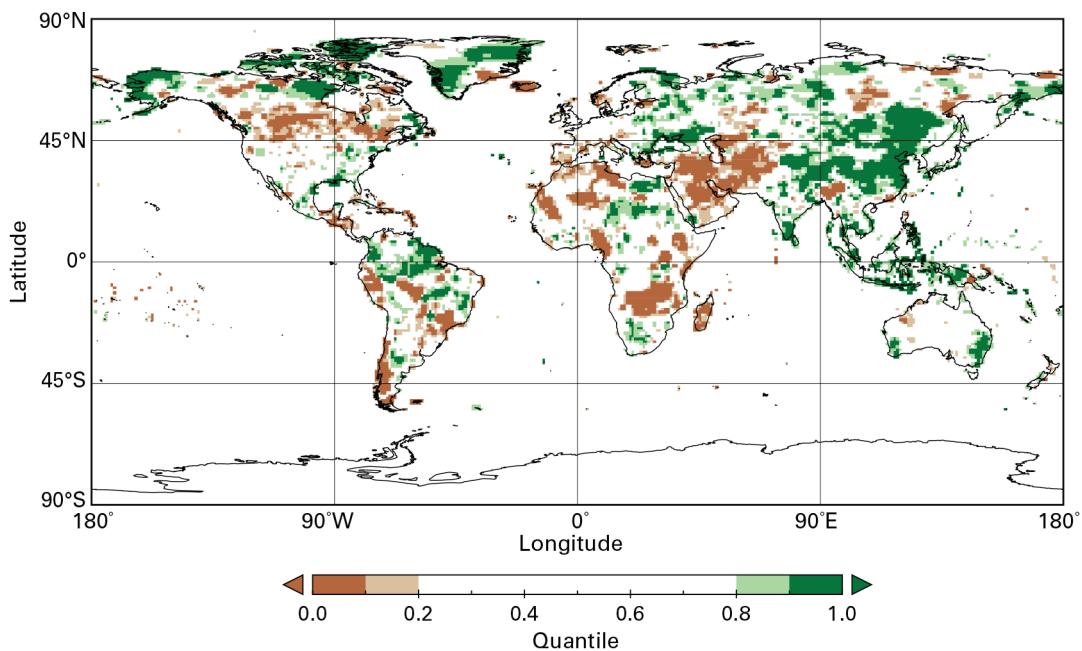
Compared to air temperature, precipitation is characterized by greater spatial and temporal variability.

In 2021, the following large regions had above-normal precipitation totals, relative to the chosen climatology period (1951 – 2000): Eastern Europe, South-east Asia, the Maritime Continent, areas of northern South America, and parts of Southeastern North America (Figure 6.3). Large regions with a rainfall deficit included South-west Asia and the Middle East, parts of Southern Africa, parts of southern South America, and areas in Central North America.

While unusually high totals were detected around the Black Sea and in parts of Eastern Europe, unusually low precipitation amounts fell around the Mediterranean Sea. Western Europe experienced some of its most severe flooding on record in mid-July. The worst affected area was western Germany and eastern Belgium, where 100 to 150 mm fell over a wide area on 14-15 July over already saturated ground, causing flooding and landslides. Hagen (Germany) reported 241 mm of rainfall in 22 hours. Parts of Croatia were also flooded (Chapter 5.2).

Extreme rainfall hit Henan Province of China from 17 to 21 July. The city of Zhengzhou on 20 July received 201.9 mm of rainfall in one hour (a Chinese national record), 382 mm in 6 hours, and 720 mm for the event as a whole, more than its annual average.

La Niña events are often – but not always – characterised by shifting patterns of rainfall. In some regions the pattern of precipitation anomalies was typical of those as-



Slika 6.3 Ukupna količina oborine u 2021., izražena kao percentil referentnog razdoblja 1951. – 2010., za područja najsuših 20% (smeđe) i najkišovitijih 20% (zeleno) godina tijekom referentnog razdoblja, s tamnjim nijansama smeđe i zelene koje redom označavaju najsuših i najvlažnijih 10% godina. Izvor: Globalni klimatološki centar za oborine (GPCC), Deutscher Wetterdienst, Njemačka.

Figure 6.3 Total precipitation in 2021, expressed as a percentile of the 1951 – 2010 reference period, for areas in the driest 20% (brown) and wettest 20% (green) of years during the reference period, with darker shades of brown and green indicating the driest and wettest 10%, respectively. Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst, Germany.

Ekstremne količine oborine u 2021. godini zabilježene su u kineskoj provinciji Henan od 17. do 21. srpnja. U gradu Zhengzhou je 20. srpnja pao 201.9 mm oborine u samo jednom satu (kineski nacionalni rekord), 382 mm tijekom 6 sati, a ukupno u pet dana 720 mm, što je više od tamošnje prosječne godišnje količine.

Događaji La Niňa često su - ali ne uvijek - obilježeni pomicanjem padanja glavnine oborine od uobičajenih područja. U nekim područjima su 2021. godine anomalije oborine ostale tipične za one povezane s La Niňom na početak godine, pa je tako npr. Maritimni kontinent (klimatološki važno područje otoka i mora između kopna jugoistočne Azije i Australije te između Indijskog i Tihog oceana) bio vlažniji od prosjeka, a sušniji uvjeti od uobičajenih bili su u Patagoniji. Također, La Niňa je uobičajeno povezana sa sušnjim uvjetima od normalnih u istočnoj Africi. Kenija, Etiopija i Somalia iskusile su uzastopne sezone oborine ispod prosjeka krajem 2020., početkom 2021. i krajem 2021., što je dovelo do suše u regiji.

Negativni dipol Indijskog oceana (IOD) razvio se tijekom srpnja 2021. i vratio se na neutralan do kraja godine. Ovo je označilo prvi negativni IOD od 2016. U kombinaciji s La Niňom, ova je faza pridonijela vlažnim uvjetima u većem dijelu Australije u kasnu australsku zimu i proljeće. Jugozapad Zapadne Australije izvijestio je o najvećim srpanjskim ukupnim oborinama od 1996., kao i mnoga mjesta u Južnoj Australiji. Australija kao cjelina zabilježila je svoje desete najkišovitije proljeće u svojim 122 godine dugim mjerljivima, a država Novi Južni Wales zabilježila je svoje četvrto najkišovitije proljeće. Studeni je bio najkišovitiji studeni otkako se bilježe podaci i za Novi Južni Wales i za Australiju u cjelini. Na suprot tome, negativan IOD, u kombinaciji s La Niňom,

sociated with La Niňa conditions at the beginning of the year: wetter than average conditions over the Maritime Continent (the climatologically important region of islands and seas between mainland South-east Asia and Australia and between the Indian and Pacific Oceans), and drier than usual conditions in Patagonia. In addition, La Niňa is associated with drier-than-normal conditions in East Africa. Kenya, Ethiopia and Somalia experienced consecutive below-average rainfall seasons in late 2020, early 2021 and late 2021, which led to drought in the region.

A negative Indian ocean dipole (IOD) developed during July 2021 and returned to neutral by the end of the year. This marked the first negative IOD since 2016. In combination with La Niňa, this phase contributed to wet conditions in much of Australia in the late austral winter and spring. South-west Western Australia reported its highest July rainfall totals since 1996, as did many locations in South Australia. Australia as a whole observed its tenth wettest spring in its 122-year record, with the state of New South Wales observing its fourth wettest. November was the wettest November since records began for both New South Wales and Australia as a whole. Conversely, the negative IOD, in combination with La Niňa, likely contributed to the extreme dry conditions in Eastern Africa.

Over North America, above-average rainfall totals were observed in Alaska and the north of Canada, and in the southeast of the United States and parts of the Caribbean. Between these two wetter than-average bands was a swath of unusually dry conditions extending across the width of the continent. The 20 months from January 2020 to August 2021 were the driest on record for the southwestern United States, more than 10% below the previous record.

vjerojatno je pridonio ekstremno sušnim uvjetima u istočnoj Africi.

U Sjevernoj Americi, na Aljasci i sjevernom dijelu Kanade, kao i na jugoistoku SAD-a i dijelovima Kariba, zabilježene su iznadprosječne količine oborine. Između ova dva pojasa vlažnija od prosjeka, mnoga područja s neobično suhim uvjetima protezala su se cijelom širinom kontinenta. Na jugozapadu SAD-a je od siječnja 2020. do kolovoza 2021. trajalo razdoblje dvadeset rekordno najsušnjih mjeseci, sušnijih za više od 10% od prijašnjeg rekorda.

Dugotrajna razdoblja s natprosječnim količinama oborine uzrokovala su značajne i dugotrajne poplave u prvoj polovici 2021. godine, u sjevernim područjima Južne Amerike, osobito na sjevernom slijevu Amazone. Rijeka Negro u Manausu (Brazil) dosegnula je rekordni vodostaj.

S druge strane, suša je drugu godinu za redom znatno pogodila velike dijelove suptropske Južne Amerike. Godišnja količina oborine znatno ispod prosjeka zabilježena je u velikom dijelu južnog Brazila, Paragvaju, Urugvaju i sjevernoj Argentini.

### 6.3 Koncentracije stakleničkih plinova

Atmosferske koncentracije stakleničkih plinova rezultat su bilance između emisija koje nastaju ljudskim aktivnostima i prirodnih izvora te pohrane stakleničkih plinova u biosferu i oceane. Porast koncentracije stakleničkih plinova zbog ljudskog djelovanja glavni je pokretač klimatskih promjena od sredine 20. stoljeća. Koncentracije stakleničkih plinova za globalnu ljestviku izračunavaju se iz pojedinačnih mjerjenja programa WMO-a GAW (Global Atmospheric Watch) i partnerskih opažačkih mreža.

U 2020. godini je globalni prosjek koncentracije ugljičnog dioksida ( $\text{CO}_2$ ) dosegao novi rekord od 413.2 ppm (WMO, 2021). Povećanje globalnog prosjeka koncentracije  $\text{CO}_2$  se nastavilo u 2021. godini.

Persistent above-average rainfall in the first half of 2021 in parts of northern South America, particularly the northern Amazon basin, led to significant and long-lived flooding in the region. The Rio Negro at Manaus (Brazil) reached its highest level on record.

Significant drought affected much of subtropical South America for the second successive year. Rainfall was well below average over much of southern Brazil, Paraguay, Uruguay and northern Argentina.

### 6.3 Greenhouse gases concentrations

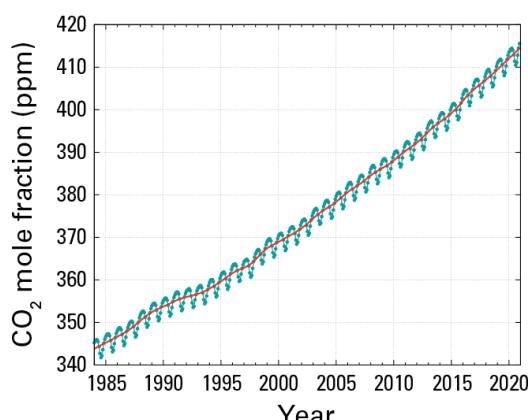
Atmospheric concentrations of greenhouse gases reflect a balance between emissions from human activities and natural sources and sinks in the biosphere and oceans. Increasing levels of concentration of greenhouse gases in the atmosphere due to human activities have been the major driver of climate change since the mid-twentieth century. Global average concentrations in the atmosphere are calculated from in situ observations made at multiple sites in the Global Atmospheric Watch Programme implemented by the WMO and its partner observation networks.

In 2020, greenhouse gas concentrations reached new highs. Levels of carbon dioxide ( $\text{CO}_2$ ) were 413.2 parts per million (ppm). The increase has continued in 2021.

### 6.4 Ocean heat content and sea level rise

Increasing human emissions of  $\text{CO}_2$  and other greenhouse gases cause a positive radiative imbalance at the top of the atmosphere – the Earth Energy Imbalance (EEI) – leading to an accumulation of energy in the form of heat in the Earth system, which is driving global warming. Around 90% of this accumulated heat in the Earth system is stored in the ocean.

Consequently, global mean sea level changes primarily result from ocean warming via thermal expansion of sea water and land ice melt. Between 1993, when global satellite sea level monitoring began, and 2022, the average



Slika 6.4 Prosjek koncentracije  $\text{CO}_2$  u globalnim razmjerima u ppm (parts per million) od 1984. do 2020. godine. Crvena linija je prosječna mjesečna molna frakcija bez sezonskih varijacija; plave točke i linija prikazuju mjesečne prosjekе.

Figure 6.4 Global average of  $\text{CO}_2$  concentration in ppm (parts per million) from 1984 to 2020. The red line is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line show the monthly averages.

## 6.4 Pohrana topline u oceane i porast morske razine

Porast emisija CO<sub>2</sub> i drugih stakleničkih plinova u atmosferi zbog ljudske aktivnosti uzrokuju pozitivnu radijacijsku bilancu na vrhu atmosfere (engl. Earth Energy Imbalance - EEI). To dovodi do rasta količine topline u Zemljiniom sustavu i tako do globalnog zatopljenja. Oko 90% te topline se pohranjuje u oceanima.

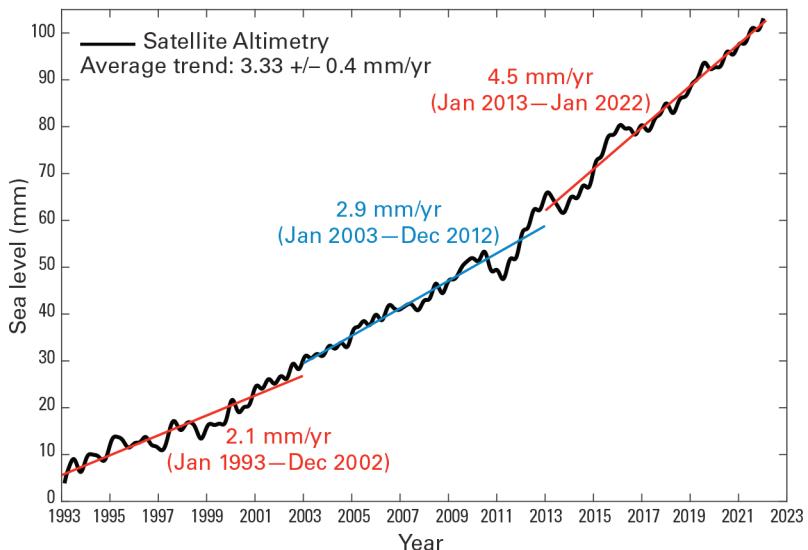
Posljedično, globalne promjene srednje razine mora primarno su rezultat zagrijavanja oceana i toplinskog širenja morske vode, te otapanja leda na kopnu. Od 1993. godine, od kada počinje globalno satelitsko praćenje morske razine, pa do 2022. godine, prosječan porast je 3.33 mm/god, dok je zadnjih godina sve brži zbog ubrzaniog topljenja ledenjaka i ledenog pokrivača (slika 6.5). U razdoblju od 2013. do 2021. godine morska razina prosječno je rasla 4.5 mm/god, odnosno dva puta brže nego u prvom desetljeću satelitskog mjerjenja morske razine kada je iznosila 2.1 mm/god.

increase has been 3.3 mm / year, while in recent years it has been accelerating due to the accelerated melting of glaciers and ice sheets (Figure 6.5). In the period 2013 – 2021, sea levels rose on average 4.5 mm / year, i.e. twice as fast as in the first decade of satellite sea level measurements (2.1 mm / year).

## 6.5 The Arctic

Since the mid-1980s, Arctic surface air temperature has warmed at least twice as fast as the global average, while the Greenland ice cover has declined over the same period, and permafrost temperature has increased. This has had large implications not only for Arctic ecosystems, but also for the global climate through various feedbacks.

The AO was negative during the Northern Hemisphere 2020/2021 winter and, seasonally, was the most negative on record since winter 2009/2010. The Arctic Oscillation is a large-scale atmospheric phenomenon that affects weather



Slika 6.5 Globalna promjena srednje razine mora od siječnja 1993. do siječnja 2022. (crna krivulja) na temelju satelitske altimetrije visoke preciznosti. Obojene ravne linije predstavljaju prosječni linearni trend u tri uzastopna vremenska razdoblja (od siječnja 1993. do prosinca 2002.; od siječnja 2003. do prosinca 2012.; od siječnja 2013. do siječnja 2022.). Izvor: AVISO altimetry (<https://www.aviso.altimetry.fr>).

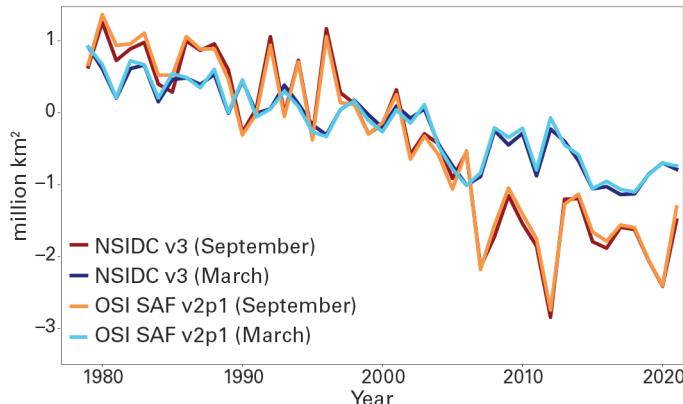
Figure 6.5 Global mean sea level evolution from January 1993 to January 2022 (black curve) based on high-precision satellite altimetry. The coloured straight lines represent the average linear trend over three successive time spans (January 1993 to December 2002; January 2003 to December 2012; January 2013 to January 2022). Source: AVISO altimetry (<https://www.aviso.altimetry.fr>).

## 6.5 Arktik

Površinska temperatura zraka na Arktiku rasla je barem dva puta brže od globalnog prosjeka od 1980-tih do danas, dok se u istom razdoblju smanjivao ledeni pokrivač Grenlanda, a temperatura permafrosta je rasla. To je utjecalo ne samo na arktičke ekosustave nego i na globalne klimatske promjene preko različitih mehanizma povratne sprege.

Tijekom zime 2020./2021. na sjevernoj polutci arktička oscilacija bila je negativna, i to najnegativnija zabilježena od zime 2009./2010. Arktička oscilacija je atmosferski fenomen velikih razmjera koji utječe na vrijeme diljem sjeverne hemisfere. Pozitivnu fazu karakteri-

throughout the Northern Hemisphere. The positive phase is characterized by lower-than-average air pressure over the Arctic and higher-than-average pressure over the northern Pacific and Atlantic Oceans. While the positive phase of the Arctic Oscillation is characterized by a jet stream parallel to latitude lines, which keeps cold Arctic air further north than average, the negative phase of the Arctic Oscillation is associated with a more meandering jet stream. By curving toward lower latitudes, cold arctic air spreads southward into the midlatitudes where the jet stream weakens. During the Northern Hemisphere 2020/2021 winter, the jet stream swept down over North America, contributing to its coldest February for the continent since 1994. However, the same wavy jet stream also contributed to extreme warmth



*Slika 6.6 Razlika u veličini morskog leda u odnosu na prosjek 1981. – 2010. na Arktiku za mjesec s najvećim ledenim pokrovom (ožujak) i minimalnim ledenim pokrovom (rujan). Izvor: Podaci iz EUMETSAT OSI SAF v2p1 i Nacionalnog centra za podatke o snijegu i ledu (NSIDC) v3 (Fetterer et al., 2017).*

*Figure 6.6 Sea-ice extent difference from the 1981 – 2010 average in the Arctic for the months with maximum ice cover (March) and minimum ice cover (September). Source: Data from EUMETSAT OSI SAF v2p1 and National Snow and Ice Data Centre (NSIDC) v3 (Fetterer et al., 2017)*

rizira tlak zraka niži od prosjeka iznad Arktika i tlak viši od prosjeka iznad sjevernog dijela Tihog i Atlantskog oceana. Dok pozitivnu fazu arktičke oscilacije karakterizira mlazna struja paralelna s linijama zemljopisne širine, koja zadržava hladan arktički zrak sjevernije od prosjeka, negativna faza arktičke oscilacije je povezana s krvudavljom mlaznom strujom. Krvudanjem prema nižim geografskim širinama, hladni arktički zrak se širi prema jugu u srednje geografske širine gdje mlazna struja slablji. Mlazna struja koja se tijekom zime 2020./2021 pružala Sjevernom Amerikom pridonijela je najhladnijoj veljači od 1994. godine, ali i ekstremnoj toplini u veljači u dijelovima sjeverne i istočne Azije. Negativna zimska faza arktičke oscilacije također je povezana i s umjerenijim gubitkom morskog leda na Arktiku u ljetu 2021. Početkom ljeta 2021. područje topljenja ledenog pokrivača Grenlanda bilo je blizu dugogodišnjeg prosjeka. No, temperature i otjecanje otopljene vode bili su znatno iznad normalnih u kolovozu, kao rezultat velikog prodora toplog, vlažnog zraka sredinom kolovoza. Dana 14. kolovoza na postaji Summit, najvišoj točki ledenog pokrivača Grenlanda (3216 m), zabilježeno je padanje kiše nekoliko sati, a temperatura zraka bila je iznad nule oko devet sati. To je prvi puta u povijesti mjerena da je kiša zabilježena na Summitu i treći puta u posljednjih devet godina da je na Summitu bilo otapanja leda. Zapisi iz ledene jezgre ukazuju da se u 20. stoljeću dogodio samo jedan takav događaj otapanja. Minimalna površina arktičkog morskog leda u 2021. godini zabilježena je 16. rujna i bila je 12. najniža do sada utvrđena i ujedno najveći godišnji minimum leda od 2014. godine.

Gubitak mase sjevernoameričkih ledenjaka ubrzao se tijekom posljednja dva desetljeća, gotovo se udvostručivši u razdoblju 2015. – 2019. u odnosu na 2000. – 2004. Iznimno topli i suho ljetu 2021. godine na zapadu Sjeverne Amerike uzrokovalo je veliko otapanje planinskih ledenjaka.

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in parts of northern and eastern Asia in February. The negative winter phase of the Arctic Oscillation has also been linked to more moderate Arctic sea ice loss the following summer. The Greenland Ice Sheet melt extent was close to the long-term average through the early summer. However, temperatures and meltwater runoff were well above normal in August 2021 as a result of a major incursion of warm, humid air in mid-August. On August 14, rain was observed for several hours at Summit Station, the highest point on the Greenland Ice Sheet (3216 m), and air temperatures remained above freezing for about nine hours. There is no previous report of rainfall at Summit. It marks the third time in the last nine years that the Summit has experienced melting conditions. Ice core records indicate that only one such melt event occurred in the 20th century. The minimum extent of Arctic sea ice for 2021, reached on 16 September, was the 12th lowest extent on record and the highest minimum since 2014.

Mass loss from North American glaciers accelerated over the last two decades, nearly doubling for the period 2015 – 2019 compared to 2000 – 2004. An exceptionally warm, dry summer in 2021 in western North America took a brutal toll on the region's mountain glaciers.

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