



ASSESSMENT OF FUTURE HEAT EVENTS FOR THE CITY OF AUGSBURG BY MEANS OF A NORMAL VECTOR BASED ANALOG APPROACH

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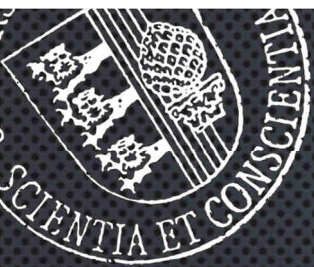


MOTIVATION



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- ANALYZING SYSTEM EVENTS IN MATTERS OF EXTREME HEAT AND ITS IMPACTS ON URBAN AGGLOMERATIONS
 - AUGSBURG
- DOWNSCALING OF LARGE-SCALE INFORMATION ON A POINT OBSERVATION BY MEANS OF WEATHER ANALOGS
 - SELECTION OF WEATHER ANALOGS IS BASED ON THE NORMAL VECTOR OF THE REGRESSION PLANE
- PROJECT THESE INFORMATION ON FUTURE PERIODS
 - USING DIFFERENT RCPs OF DIFFERENT GCMS
- USE PROJECTED TEMPERATURES FOR SPATIAL TEMPERATURE ASSESSMENTS OF THE TARGET AREA
 - CONSIDERING DIFFERENT ASPECTS OF BUILDING CHARACTERISTICS AND GREEN SPACE PROPORTION
- ASSESSMENTS OF THE FUTURE THERMAL LOAD DERIVED FROM THE SPATIAL TEMPERATURE DISTRIBUTION WITHIN THE TARGET AREA



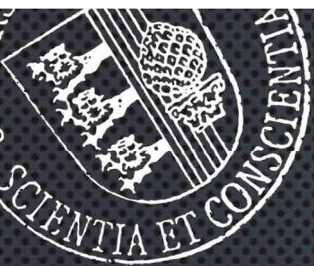
DATA



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PREDICTAND

- DATA FROM AUGSBURG-MÜHLHAUSEN WEATHER STATION (GERMAN WEATHER SERVICE, DWD)
- PERIOD 1979-2018
- ONLY MONTHS MAY TO SEPTEMBER WERE TAKEN INTO ACCOUNT
- EXTRACTING DIFFERENT DAILY TEMPERATURE DATA (2M ABOVE SURFACE)
 - TMIN
 - TMEAN
 - TMAX



DATA

PREDICTORS

- CIRCULATION OF THE ERA5 REANALYSIS DATA SET
 - GRIDDED DAILY DATA
 - $0.75^{\circ} \times 0.75^{\circ}$ RESOLUTION
 - AREA OF INTEREST: 0°E - 20°E & 40°N - 60°N
 - VARIABLES:
 - SEA LEVEL PRESSURE (SLP.0000)
 - GEOPOTENTIAL HEIGHTS (HGT.0850 & HGT.0700)
 - LAYER THICKNESS (HGT.0700-HGT.0850)
- TEMPERATURE OF THE ERA5 REANALYSIS DATA SET
 - GRIDDED 6H DATA
 - $0.75^{\circ} \times 0.75^{\circ}$ RESOLUTION
 - CENTER GRID BOX AND 8 NEAREST NEIGHBORS
 - EXTRACTED VARIABLES
 - TMIN, TMEAN & TMAX

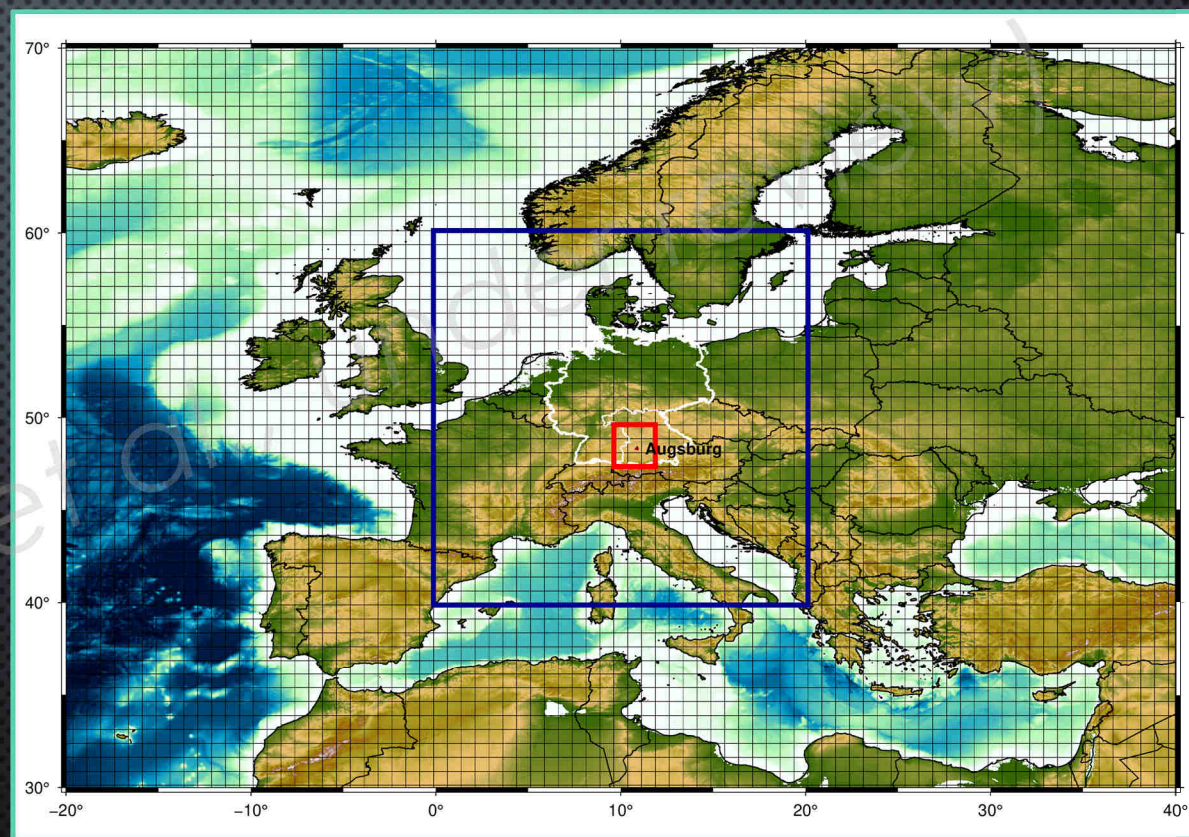
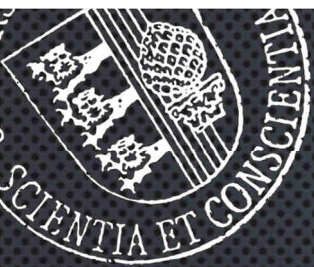


Fig. 1: Domains for circulation based predictor variables (blue) and for temperature variables (red). (Merkenschlager et al., under review)



DATA



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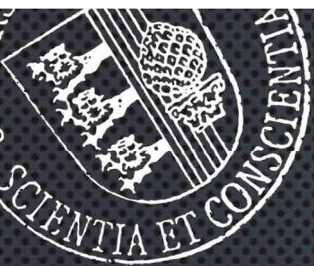
GENERALIZED CIRCULATION MODELS (GCMs)

- ACCESS1.0: 1 RUN
- CNRM-CM5: 1 RUN
- MPI-ESM-LR: 3 RUNS

REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs)

- HISTORICALS
- RCP4.5
- RCP8.5
- SAME VARIABLES AS CHOSEN FOR ERA5 (SLP, HGT.0850, HGT.0700, HGT.LT, TMIN, TMEAN, TMAX)
- DATA WERE RESTRICTED TO THE SAME TEMPORAL AND SPATIAL DOMAIN AS THE PREDICTORS OF ERA5





DATA



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PREPARATION

AUGSBURG-MÜHLHAUSEN

- TEMPERATURE DATA SETS WERE DETRENDED BY MEANS OF THE ANNUAL TEMPERATURE TRENDS

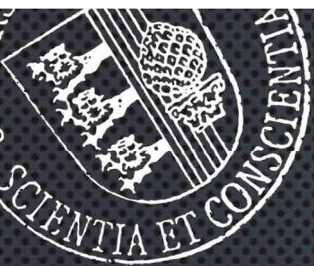
ERA5

- ALL DATA SETS WERE DETRENDED BY MEANS OF THE ANNUAL TEMPERATURE TRENDS

GCMs

- FOR VALIDATION ONLY THE PERIOD COMPRISED BY BOTH, ERA5 AND GCM, DATA SET WAS USED (1979-2005)
- FOR PROJECTIONS THE HISTORICAL PERIODS AND THE DIFFERENT RCPs WERE COMBINED (1979-2100)
- ALL DATA SETS WERE DETRENDED BY MEANS OF THE ANNUAL TEMPERATURE TRENDS
- THE MEANS OF ALL TIME SERIES WERE ADAPTED TO THE MEANS OF THE ERA5 DATA SET





METHODS

ANALOGS BASED ON NORMAL VECTOR (NVEC)

PRESELECTION:

- DAY OF INTEREST: JUNE, 5TH, 1980
- ± 15 DAYS OF THE DAY OF INTEREST (ORANGE PERIOD)
- DAYS SHOWING THE SAME EXCEEDANCES OF THE 90TH QUANTILE (TIMN, TMEAN, TMAX) LIKE THE DAY OF INTEREST (OVER=1, BELOW=0)
 - Q90 CALCULATED FOR EACH DAY OF THE TIME SERIES AND TEMPERATURE VARIABLE BY MEANS OF A 5-DAY MOVING WINDOW
 - E.G. (0 | 1 | 1) RED MARKED DAYS

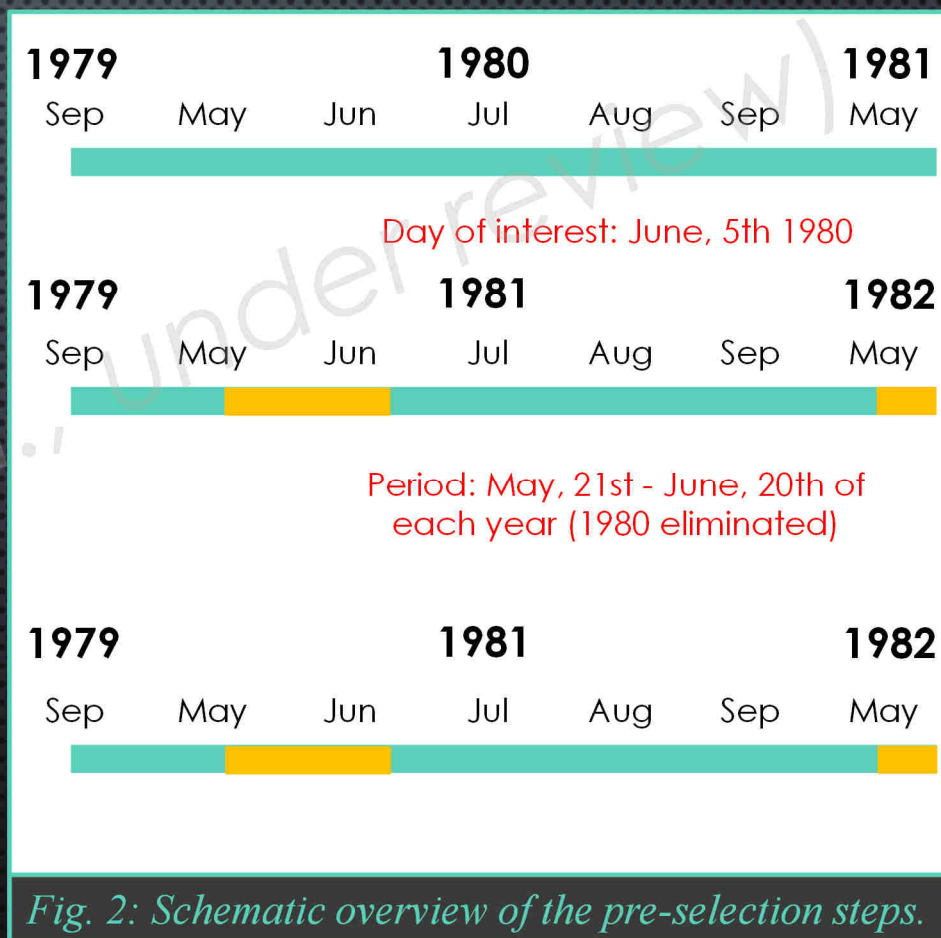


Fig. 2: Schematic overview of the pre-selection steps.

(Merkenschlager et al., under review)

ANALOGS BASED ON NORMAL VECTOR (NVEC)

FIRST LEVEL OF ANALOGY:

- CALCULATION OF THE REGRESSION PLAIN

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i$$

- CALCULATION OF THE NORMAL VECTOR

$$\vec{u} \times \vec{v} = \begin{pmatrix} u_2 \cdot v_3 - u_3 \cdot v_2 \\ u_3 \cdot v_1 - u_1 \cdot v_3 \\ u_1 \cdot v_2 - u_2 \cdot v_1 \end{pmatrix} = \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix} = \vec{n}$$

- CALCULATION OF POINTS IN AN ARTIFICIAL COORDINATE SYSTEM BY MEANS OF THE TWO SPANNED ANGLES OF THE NORMAL VECTOR AND THE MEAN OF THE STANDARDIZED PRESSURE FILEDS
- CALCULATION OF THE DISTANCE BETWEEN THE POINTS OF THE DAY OF INTEREST AND THE ANALOGS

→ DETERMINATION OF A SUBSAMPLE CONTAINING THESE 5% SHOWING THE LEAST ABSOLUTE DISTANCES BETWEEN THE POINTS

(Merkenschlager et al., under review)

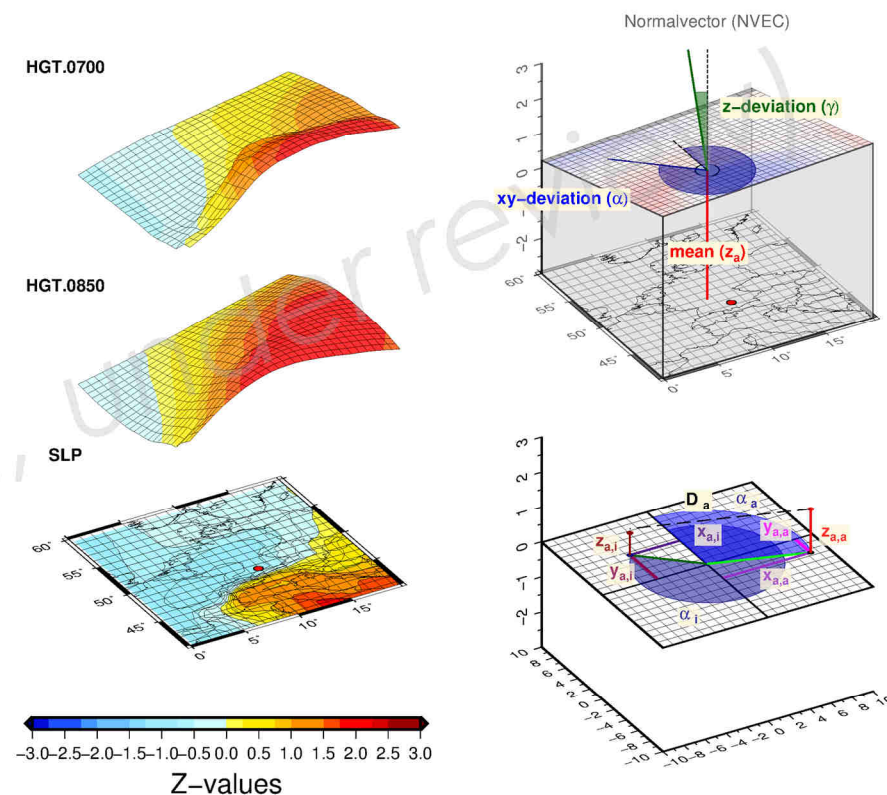
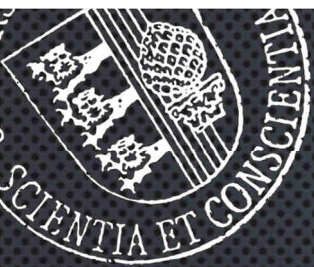


Fig. 3: Graphical overview for the analog methods based on the normal vector (right). The standardized values of the geopotential heights and the sea level pressure of the day of interest are depicted on the left.



METHODS

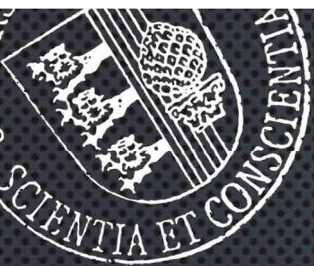


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ANALOGS BASED ON NORMAL VECTOR (NVEC)

SECOND LEVEL OF ANALOGY:

- ANALYSING THE TEMPERATURE FIELDS (TMIN, TMEAN, TMAX) OF THE REMAINING SUBSAMPLE
 - ROOT MEAN SQUARE ERROR (RMSE) AVERAGED OVER ALL ROWS AND COLUMNS
 - DAY WITH THE LEAST MEAN RMSE OVER ALL TEMPERATURE FIELDS REPRESENTS THE ANALOG
- ALL VARIABLES OF THE SELECTED DAY (AUGSBURG-MÜHLHAUSEN, ERA5) REPRESENT NOW THE DAY OF INTEREST WITHIN THE ANALOG TIME SERIES



METHODS



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ANALOGS BASED ON NORMAL VECTOR (NVEC)

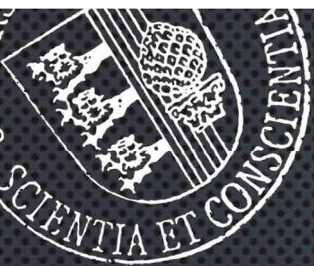
PROJECTIONS:

- FOR EACH DAY OF BOTH GCM TIME SERIES (VALIDATION AND PROJECTION PERIOD) AN ANALOG WAS DETERMINED
- THE ANALOGS REPRESENT CIRCULATION BASED VARIABLES OF ERA5 AND TEMPERATURE DATA FROM AUGSBURG-MÜHLHAUSEN
- THE REMOVED TRENDS OF EACH HISTORICAL PERIOD IOR RCP, RESPECTIVELY, IS SUBSEQUENTLY ADDED TO THE ANALOG TIME SERIES FOR EACH GCM
- IN THE FOLLOWING THE DIFFERENT ANALOG TIME SERIES ARE NAMED AFTER THE RESPECTIVE MODEL RUN OF THE GCMS

ANALYSIS:

- ABSOLUTE TEMPERATURES
- CIRCULATION
- EXCEEDANCE OF Q90
- DURATION AND NUMBER OF HEAT DAYS OR WAVES
 - HEAT DAY: AT LEAST TWO TEMPERATURE VARIABLES EXCEED Q90
 - HEAT WAVE: AT LEAST THREE CONSECUTIVE DAYS WERE MARKED AS HEAT DAY





RESULTS

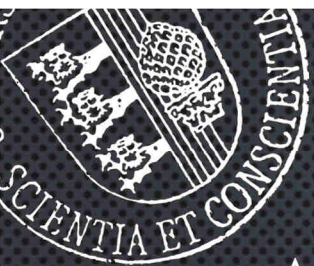


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HISTORICAL PERIOD

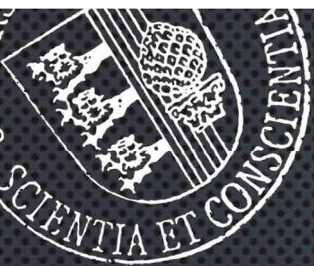
(MODEL VALIDATION)





CONCLUSIONS VALIDATION

- ALL ANALOG TIME SERIES, WITH THE EXCEPTION OF ERA5-ORIGINAL, EXHIBIT A MORE OR LESS DISTINCT WARM BIAS
- THE WARM BIAS IS MORE PRONOUNCED FOR TMIN AND LESS FOR TMAX
- OBSERVATIONS EXHIBIT THE LARGEST NUMBER OF DAYS EXCEEDING Q90 BUT A SIGNIFICANTLY LOWER NUMBER OF DAYS WHERE ALL TEMPERATURE VARIABLES EXCEED Q90 (1 | 1 | 1)
- THE NUMBER OF HEAT DAYS (I.E. AT LEAST TWO TEMPERATURE VARIABLES EXCEED Q90) IS OVERESTIMATED BY MEANS OF MOST ANALOG TIME SERIES (EXCEPT: CNRM-CM5)
- THE NUMBER OF HEAT WAVES IS ADEQUATELY REPRESENTED BY MEANS OF THE ANALOG TIME SERIES (EXCEPT: CNRM-CM5)
- IN GENERAL, THE SELECTED CIRCULATION PATTERNS OF THE ANALOG TIME SERIES REPRESENT THE CIRCULATION OF THE OBSERVATION ADEQUATELY
- DEVIATIONS COULD BE OBSERVED FOR DAYS EXCEEDING Q90
 - UNDERESTIMATION OF THE POSITIVE MODE OF PC-1
 - OVERESTIMATION OF THE POSITIVE MODE OF PC-2 AND NEGATIVE MODE OF PC-3



RESULTS



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FUTURE PERIODS BASED ON DIFFERENT RCPPs

(PROJECTIONS)





CONCLUSION FUTURE PERIODS

- UNDER CONSIDERATION OF RCP4.5 (RCP8.5) AROUND 50% (75%) OF THE DAYS IN THE PERIOD MAY-SEPTEMBER WILL EXCEED Q90 OF AT LEAST ONE TEMPERATURE VARIABLE IN THE END OF THE 21ST CENTURY
- OVER 40% (15%) OF THE DAYS WILL EVEN EXCEED ALL THREE Q90 VALUES AND OVER 60% (30%) ARE MARKED AS HEAT DAY UNDER CONSIDERATION OF RCP8.5 (RCP4.5)
- IN COMARISON TO THE REFERENCE PERIOD (1970-2000)
 - THE NUMBER OF ANNUAL HEAT EVENTS WILL BE 4-4.7 (RCP4.5-RCP8.5) TIMES HIGHER
 - THE MEAN DURATION WILL BE 2-4.2 TIMES LONGER
 - MAXIMUM DURATION OF HEAT WAVES WILL BE 3.3-8.1 TIMES LONGER
- UNDER CONSIDERATION OF ALL DAYS NO SIGNIFICANT CHANGES COULD BE OBSERVED FOR CIRCULATION PATTERNS
- UNDER CONSIDERATION OF DAYS EXCEEDING Q90 THE NUMBER OF DAYS ASSIGNED TO THE POSITIVE MODE OF PC-1 DECREASES WHEREAS THE NUMBER OF DAYS ASSIGNED TO THE POSITIVE MODE OF PC-2 INCREASES



SUMMARY



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- ON A REGIONAL SCALE THE NVEC ANALOG METHOD IS ABLE TO FIND APPROPRIATE ANALOGS FOR DIFFERENT VALIDATION PERIODS
- THE NVEC ANALOG METHOD IS ALSO AN APPROPRIATE METHOD FOR REGIONAL CLIMATE CHANGE STUDIES
- INDEPENDENT OF RCP, THE NUMBER OF HEAT WAVES WILL BE 4 TIMES HIGHER IN THE END OF THE 21TH CENTURY
- DIFFERENCES BETWEEN THE RCPS COULD BE OBSERVED WITH REGARDS TO MEAN AND MAXIMUM LENGTH OF THE HEAT WAVES
- BY MEANS OF THE ANALOG METHOD NO CLEAR SHIFT WITHIN THE LARGE-SCALE CIRCULATION COULD BE IDENTIFIED WHICH COULD BE RESPONSIBLE FOR THE DIFFERENT CHARACTERISTICS OF THE HEAT WAVES