Homogeneity of long-term traditional circulation types series – problems and challenges

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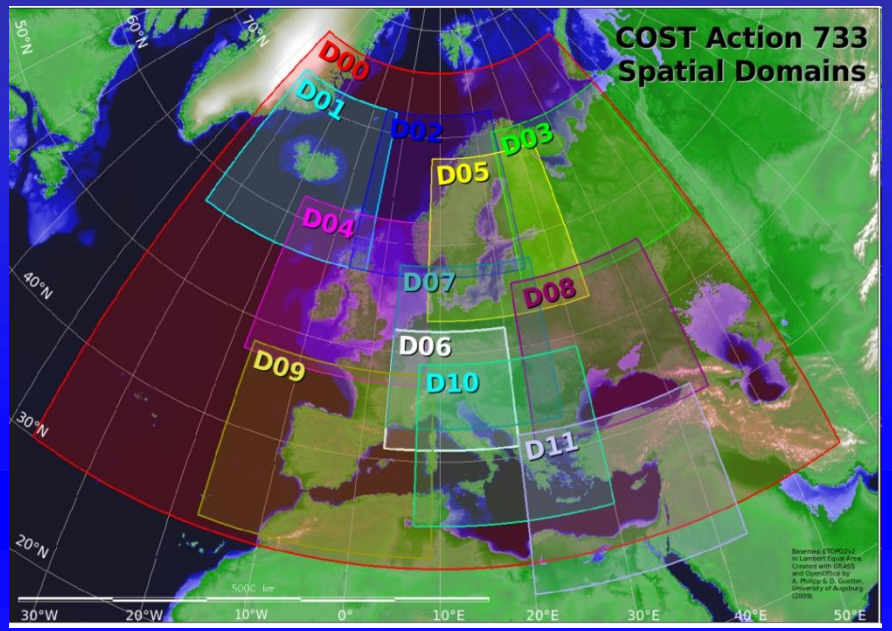
COST 733 „Harmonisation and Applications of Weather Types Classifications for European Regions”

„There is, for a wide range of environmental applications a need for information that, in an easy way, describes the current weather (situation)”



- **Weather type**

Simple, discrete characterisation of the current atmospheric conditions on the nominal scale.

- **Circulation type**

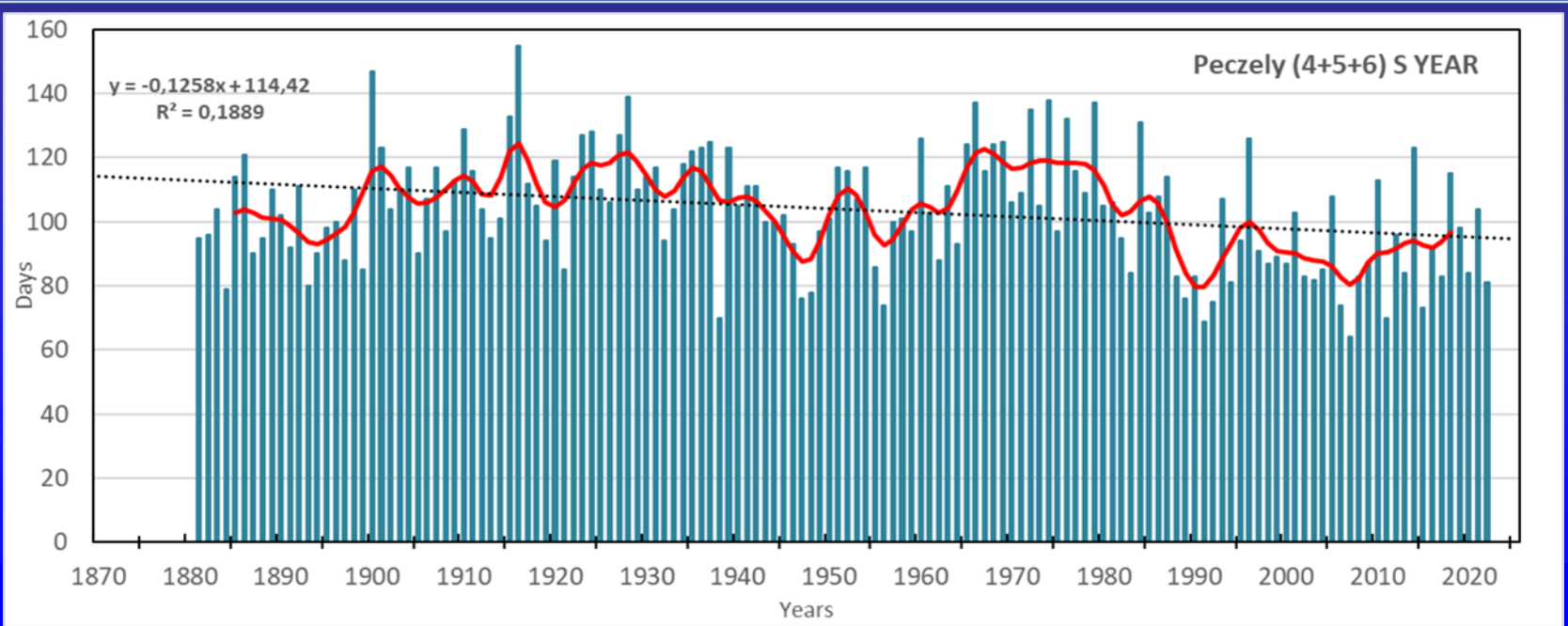
Discrete characterisation of the current atmospheric circulation conditions on the nominal scale excluding other parameters than those describing the circulation state.

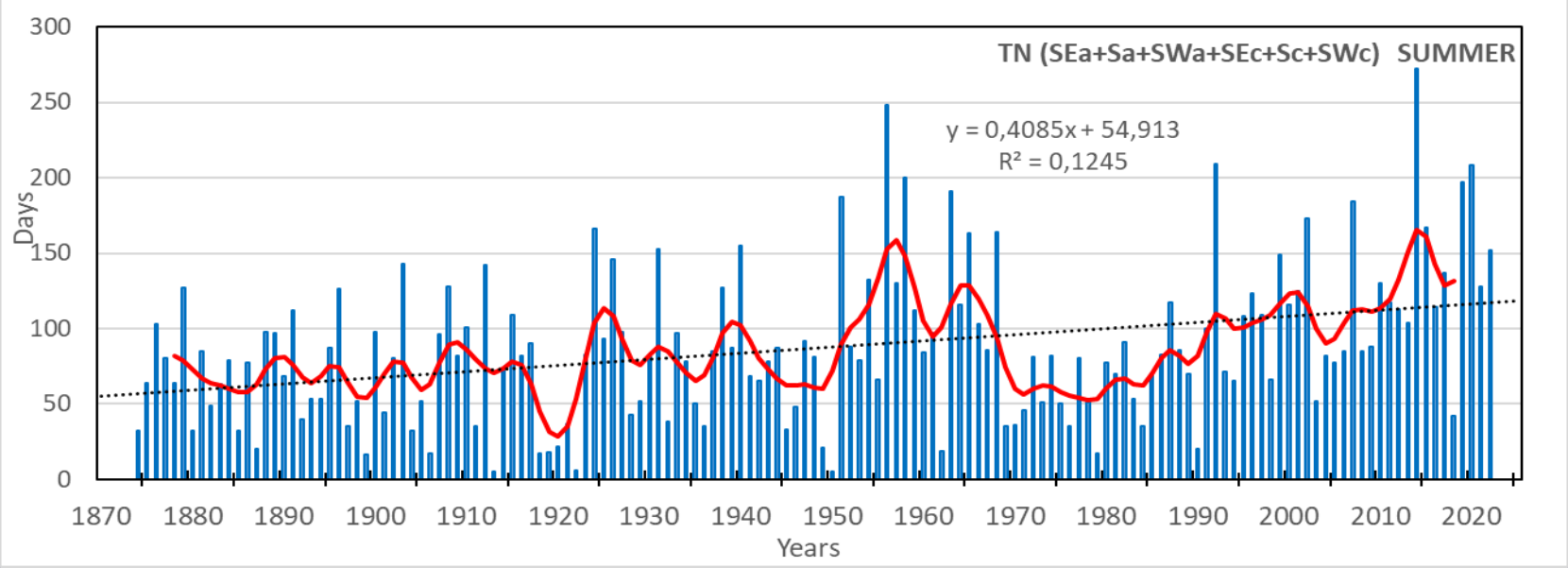
Huth R., Beck Ch., Philipp A., Demuzere M., Ustrnul Z., Cahynová M., Kyselý J., Tveito O.E., 2008, Classifications of atmospheric circulation patterns: recent advances and applications, Annals of the New York Academy of Sciences, Vol. 1146, pp. 105-152

Circulation types (CT) / synoptic situations (synoptic types, map patterns)

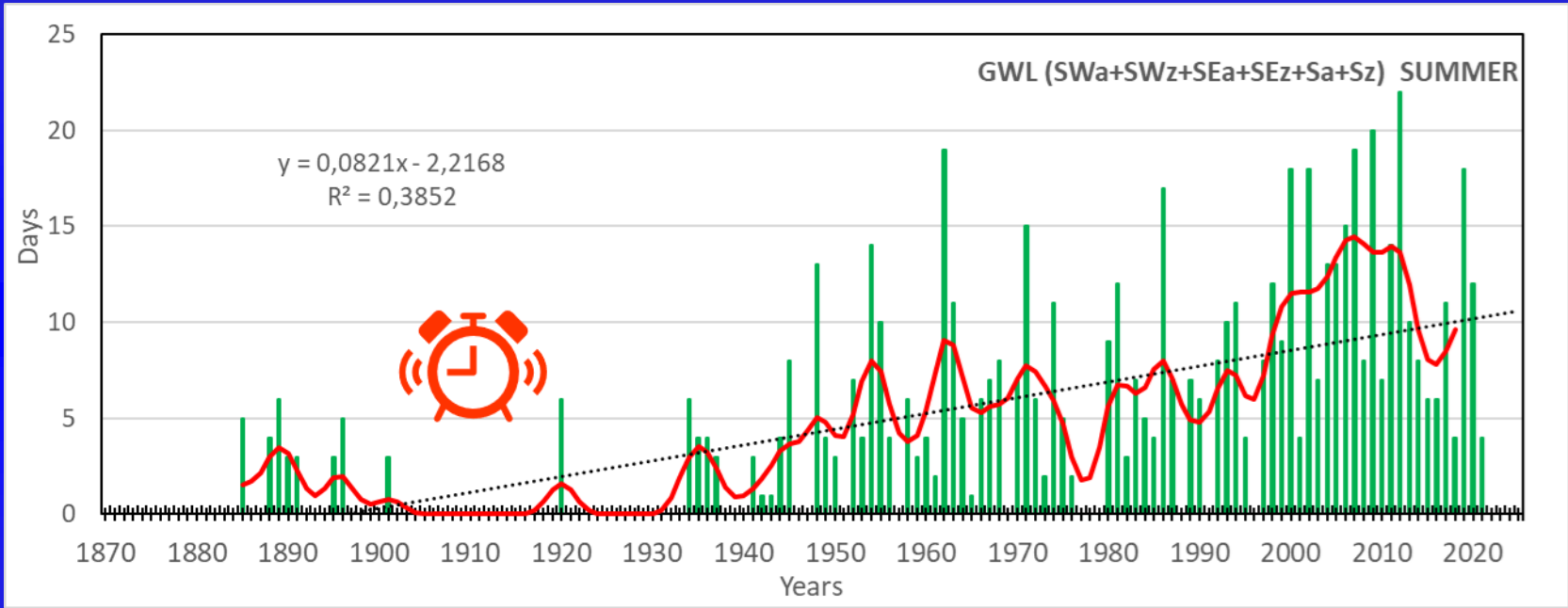
B. Yarnal (1993) distinguishes 7 classification methods used in modern climatology:

- ***Manual synoptic types***
- *Correlation-based map patterns*
- *Eigenvector-based synoptic types*
- *Eigenvector-based map patterns*
- *Eigenvector-based regionalizations*
- *Compositing*
- *Circulation indices*
- *Specification*
- *Other ('hybrid')*





Summer (JJA) southerely circulation days (southern sector); PECZ + TN



Summer (JJA) southerely circulation days (southern sector); GWL

CT and HOMOGENEITY

According to many studies, also thanks to COST733 Action, there has been significant progress in the modern distinguishing of circulation types, **traditional manual methods are still used**. This applies especially to climatological analyzes where long series are highly desirable.

The available CT calendars are therefore very valuable, but careful analysis suggests that they may contain inhomogeneities. It is hardly surprising, since they were based on manual analyzes of many old synoptic maps.

INHOMOGENEITY SOURCES

Due to the above, the basic material for determining CT had limitations such as:

- ✓ Different availability of maps for a given day (e.g. 1-4)
- ✓ Different scale and spatial resolution and accuracy
- ✓ Different substantive quality of the maps, including the course of the isobars themselves

Other: e.g. **GWL:** SLP level and 500 hPa?

- ✓ The available calendars were constructed:
  - by various authors,
  - with different experience (and also variable over time)
  - taking into account other subjective feelings (sensations), e.g. related to the occurrence of various weather events

Assumptions?!?

As previosly mentioned no wonder that currently analyzing various CTs and confronting them with maps, one often can have dilemmas and doubts.

Therefore, we propose a method (tool) to detect (INDICATE!) potential inhomogeneities in such CT series using machine learning.

After many analyses, we chose the method of convolutional networks (CNN) as the most useful.

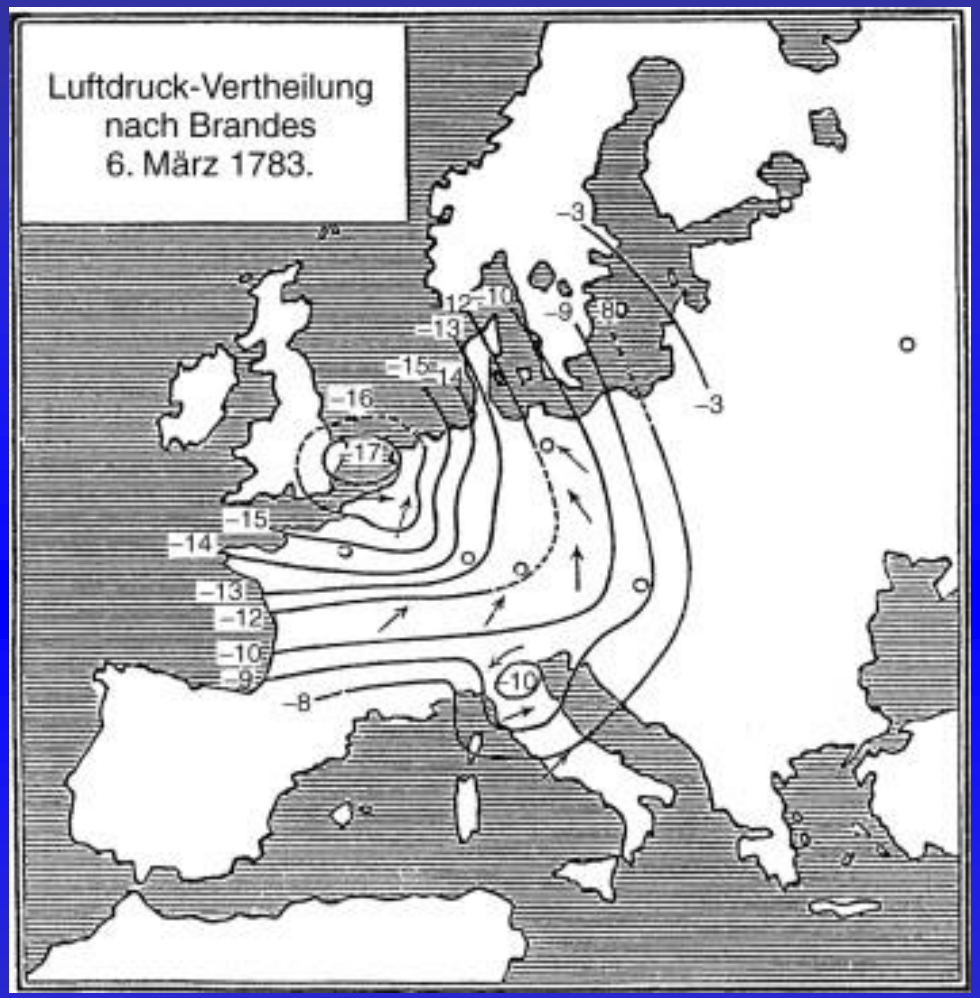
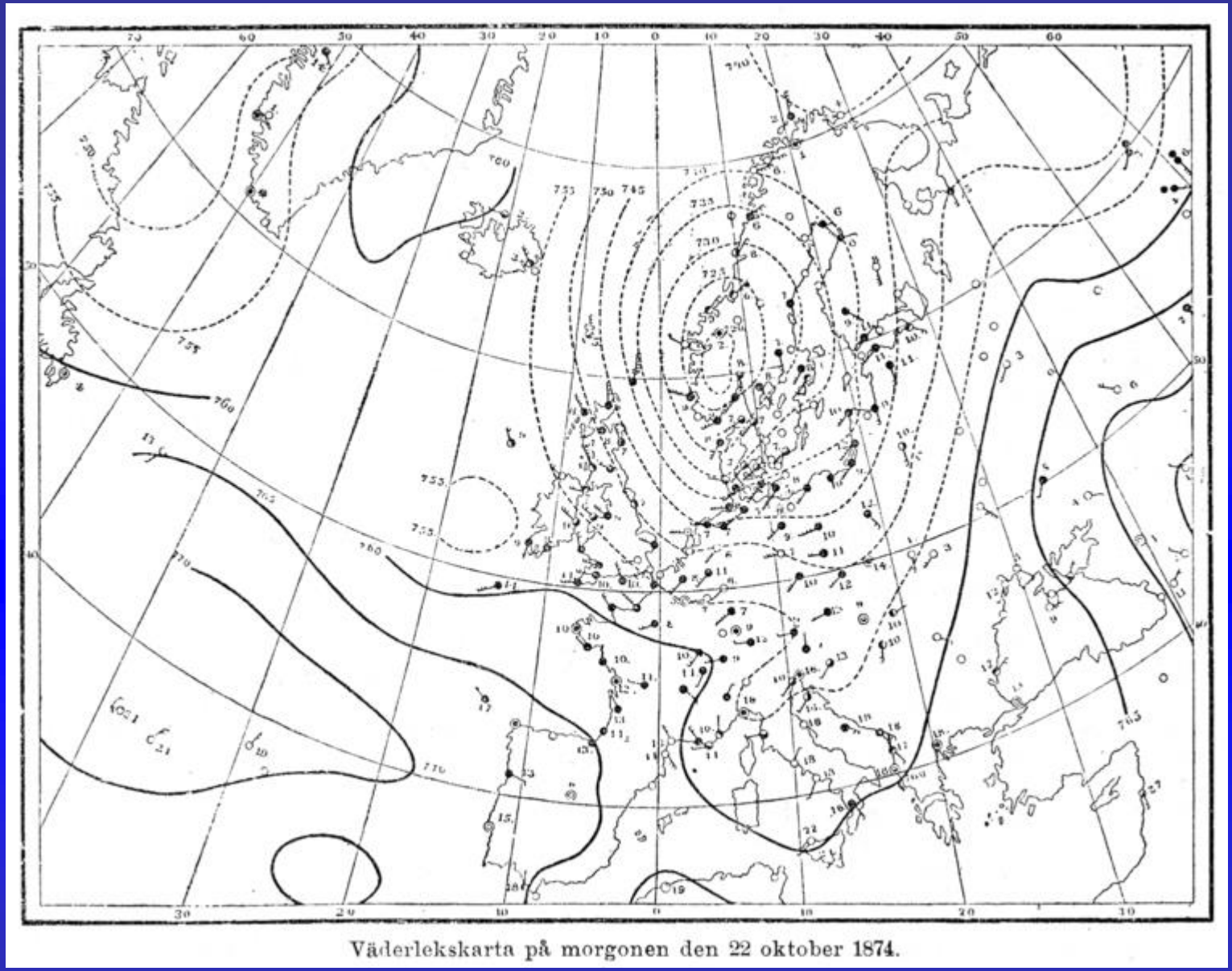
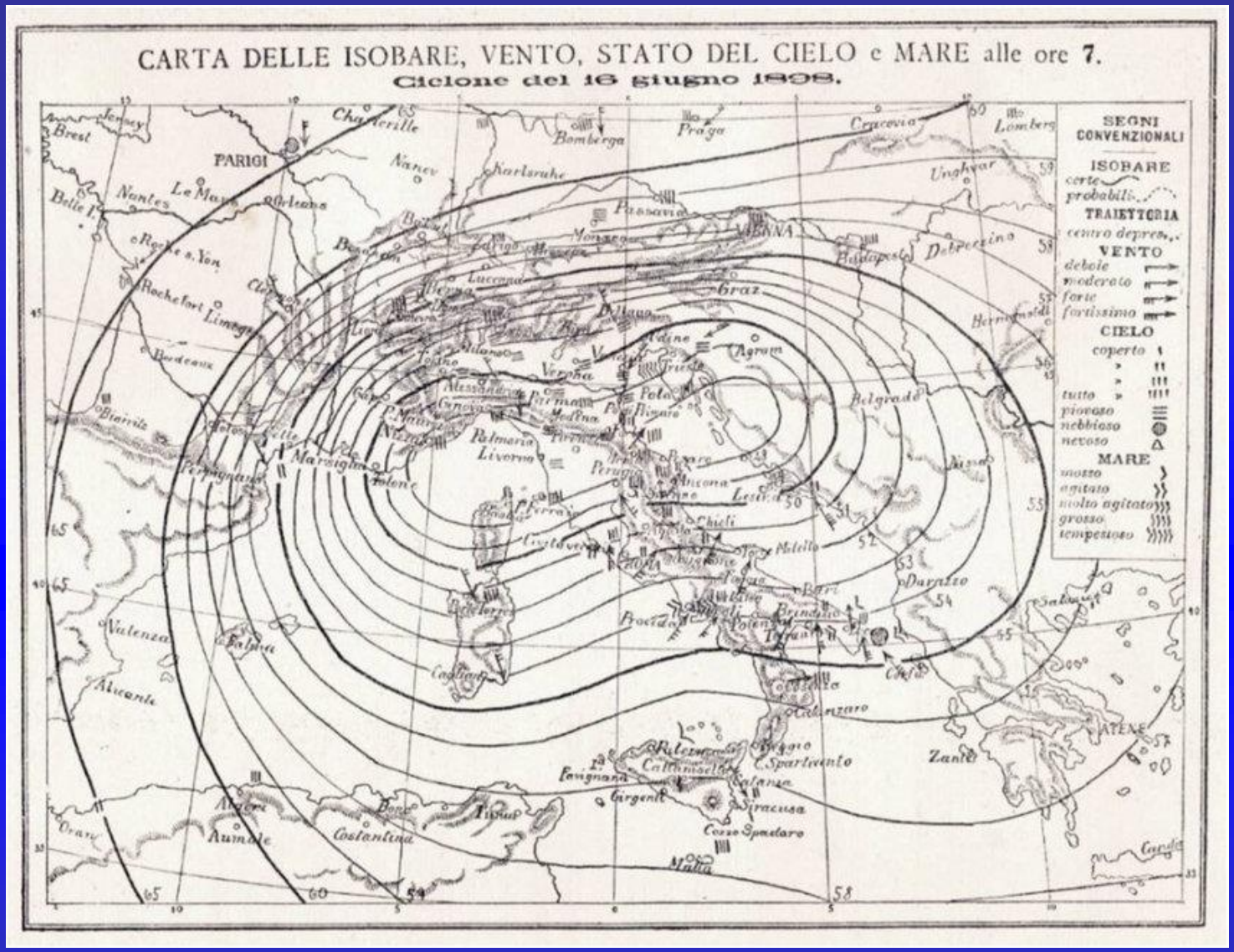


Chart by Brandes
6 March 1783

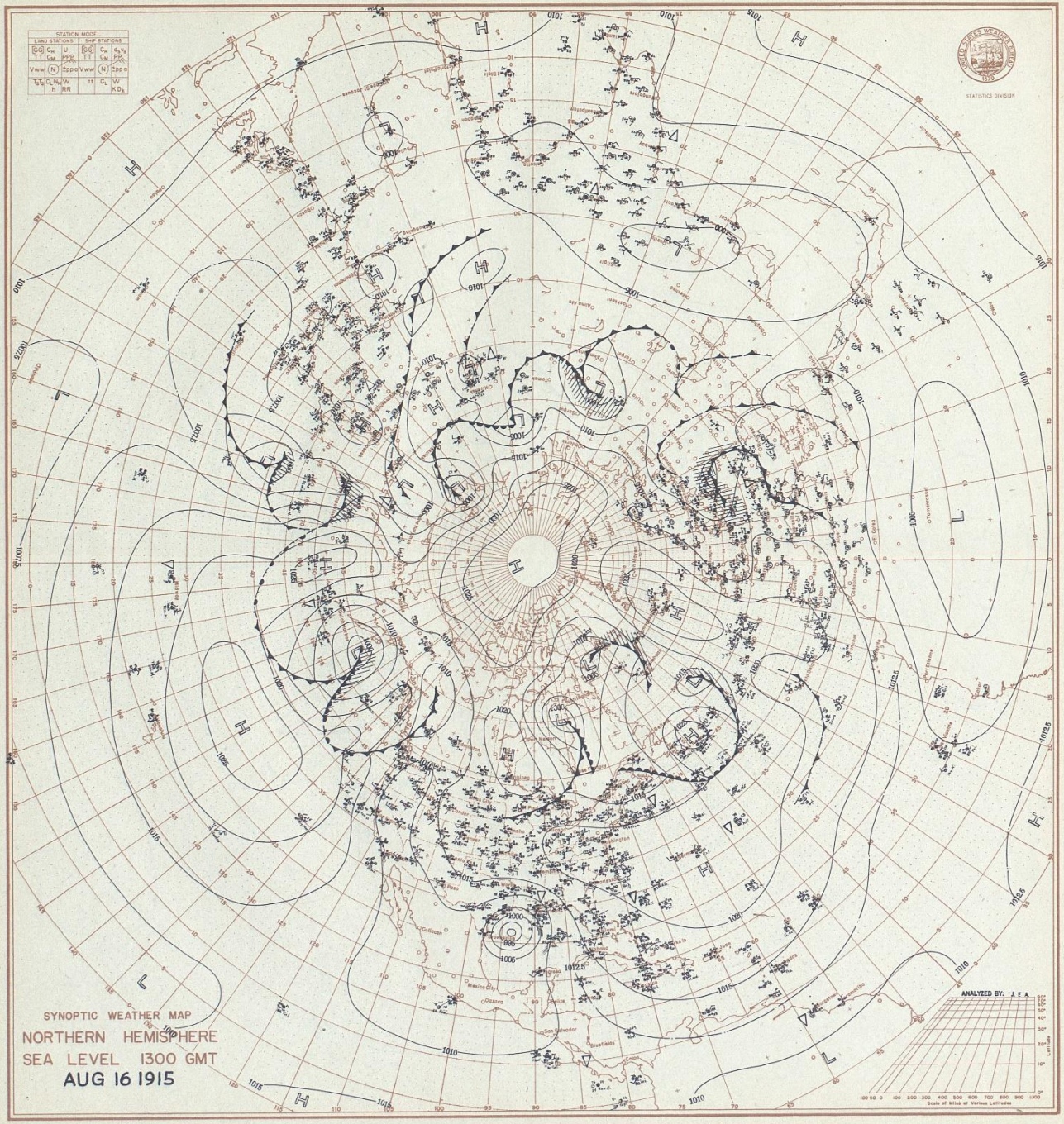


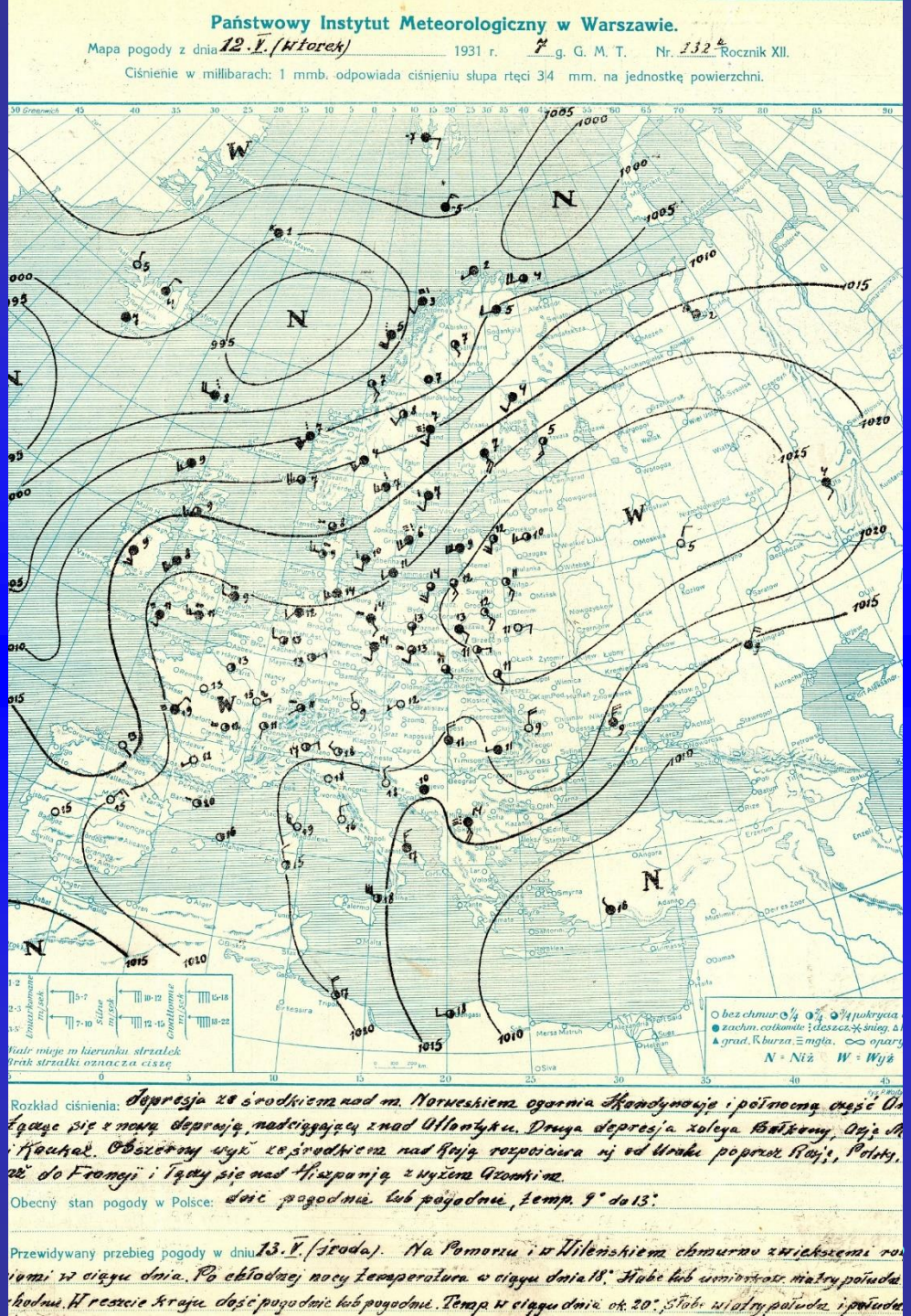
Väderlekskarta på morgonen den 22 oktober 1874.

Norwegian map, 22 October 1874 (morning)



Italian map, 16 June 1898


STATION MODEL
LAND STATIONS
SHIP STATIONS
STATISTICS DIVISION
SYNOPTIC WEATHER MAP
NORTHERN HEMISPHERE
SEA LEVEL 1300 GMT
AUG 16 1915
ANALYZED BY: J. F. A.
Scale of Miles at Various Latitudes



Polish synoptic map

12 May 1931, 07 UTC

Polish 'climatic' map, 12 May 1931

Państwowy Instytut Meteorologiczny w Warszawie

Mapa klimatologiczna z dn. 12 V. (wtorek) 1931 r. Nr. 131

Miejsce obserwacji	Temperatura: 7 rano	max. wczoraj	min. z nocy	zachmurzenie	opady	pokrywa śnieżna	Kierunek i szybkość wiatru	UWAGI
Puck	12	11	4	2	0		JSE2	
Gdynia	11	12	7	3	0		SSE6	
Chojnice	10	17	-1	4	0		JSE4	
Bydgoszcz	10	17	5	3	0		JSE2	
Toruń	11	17	7	3	0		JSE4	
Poznań	10	16	7	3	0		JSE2	
Zbąszyń	13	18	9	4	0		S2	
Leszno	12	18	4	0	0		N4	
Ostrów	10	17	4	3	0		E4	
Kalisz	9	17	6	2	0		JSE3	
Sokolniki	12	18	3	2	0		SE4	
Łódź	10	16	3	4	0		ESE2	
Skierniewice	11	17	3	1	0		SE4	
Płock	10	17	6	3	0		E4	
Mława	9	15	6	3	0		JSE4	
Warszawa	9	17	3	3	0		SE4	
Częstochowa	12	17	5	0	0		NE1	
Kielce	10	16	4	1	0		ENE2	
Tarnów	8	19	2	0	0		E1	
Kraków	9	17	3	0	0		Cisa	
Cieszyn	9	18	4	1	0		Cisa	
Katowice	11	18	4	0	0		JSE1	
Zakopane	5	13	-2	1	0		ENE4	
Hala Gąsien.	5	5	1	0	0		NNW1	
Morskie Oko	-2	6	-3	0	0		Cisa	
Krynica	4	13	-0	0	0		Cisa	
Tom. Lub.	8	14	2	0	0		E2	
Lublin	9	15	5	0	0		NE2	
Dęblin	10	16	2	3	0		ENE2	
Brześć n/B	8	14	2	0	0		ESE2	
Białowieża	8	14	-2	0	0		Cisa	
Białystok	9	14	2	1	0		JE6	
Czerw. Bór	9	15	1	2	0		SE4	
Domaczewo	10	15	5	0	0		JE6	
Grodno	9	13	1	1	0		JSE4	
Pohulanka	8	12	7	1	0		N2	
Królewszcz.	2	10	2	1	0		ESE1	
Wilno	2	12	1	1	0		JSE4	
Radoszkowice	5	13	-3	0	0		ESE1	
Lida	7	12	1	0	0		ENE2	
Prohobycze	6	15	2	=3	sl.		ESE1	
Leśna	8	14	-1	0	0		Cisa	
Nowogródek	11	18	4	1	0		E2	
Pińsk	10	15	5	0	0		E4	
Sarny	9	15	1	0	0		NE1	
Łuck	9	15	5	0	0		ESE6	
Przemyśl	8	15	2	1	0		Cisa	
Lwów	10	14	5	1	0		SE4	
Tarnopol	8	15	6	3	0		E2	
Kołomyja	10	14	6	2	3		SE4	
Zaleszczyki	10	15	7	2	6		NW4	

Stan pogody:

W dniu dzisiejszym ran
kiem w całej Polsce uż
myrała się piękna s
neczna pogoda o nieco
większem zachmurze
niu na Pomorzu i w
Kopolsce. Temp. o godz.
7ª wynosiła od 5 do 8
w Wileńskiem i na Podl
lu, a od 8 do 12 w po
zostałych okolicach K
lekkie nocne przymro
ki wystąpiły na Pomo
rzu w okolicach Chojn
miejscami w Wileńskiem
i na Podlasiu oraz w gó
rach. Drobne opady
z doby ubiegłej notowano jedynie na Pom
i tylko w okolicach Za
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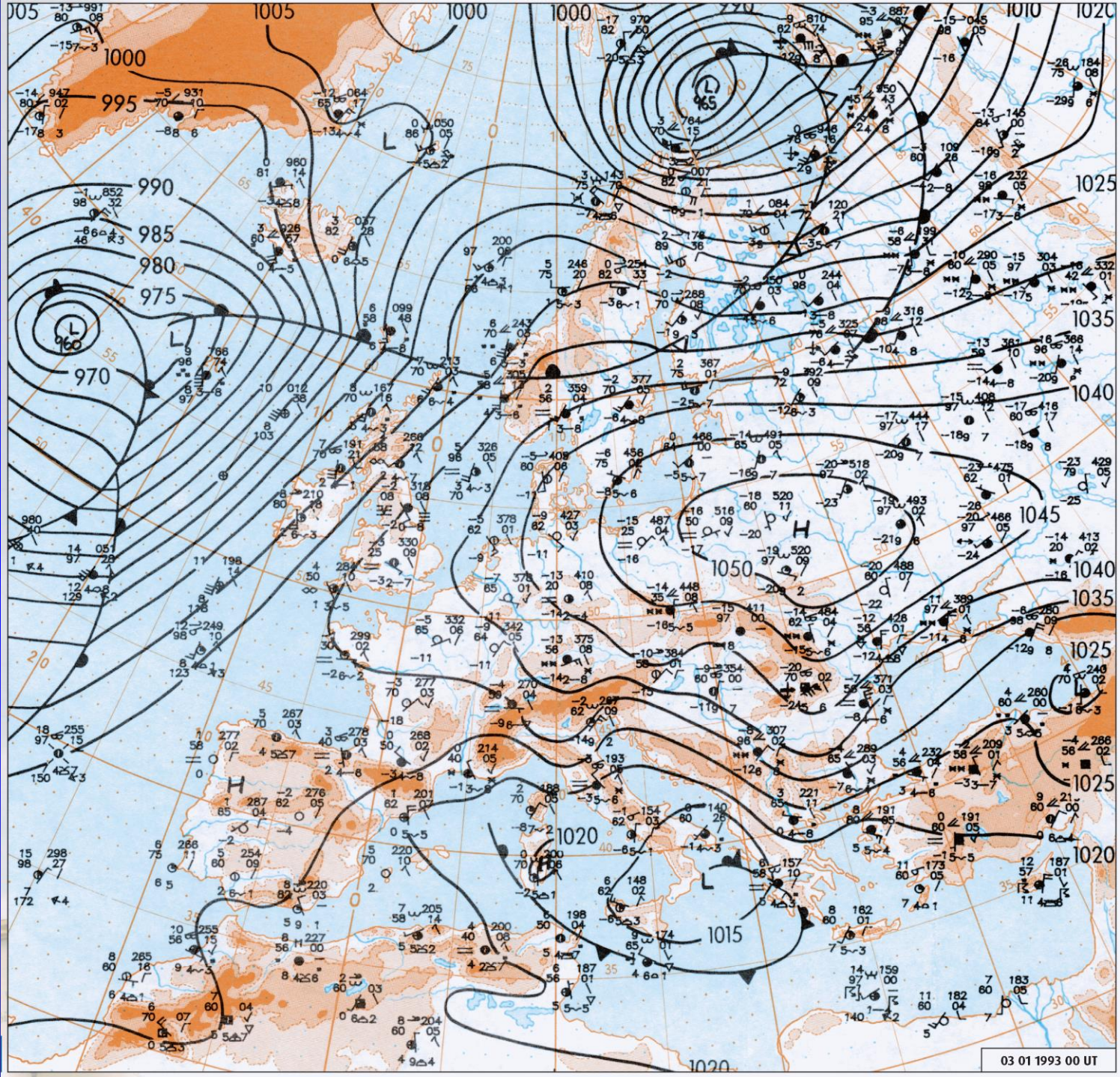
one 5 mm.



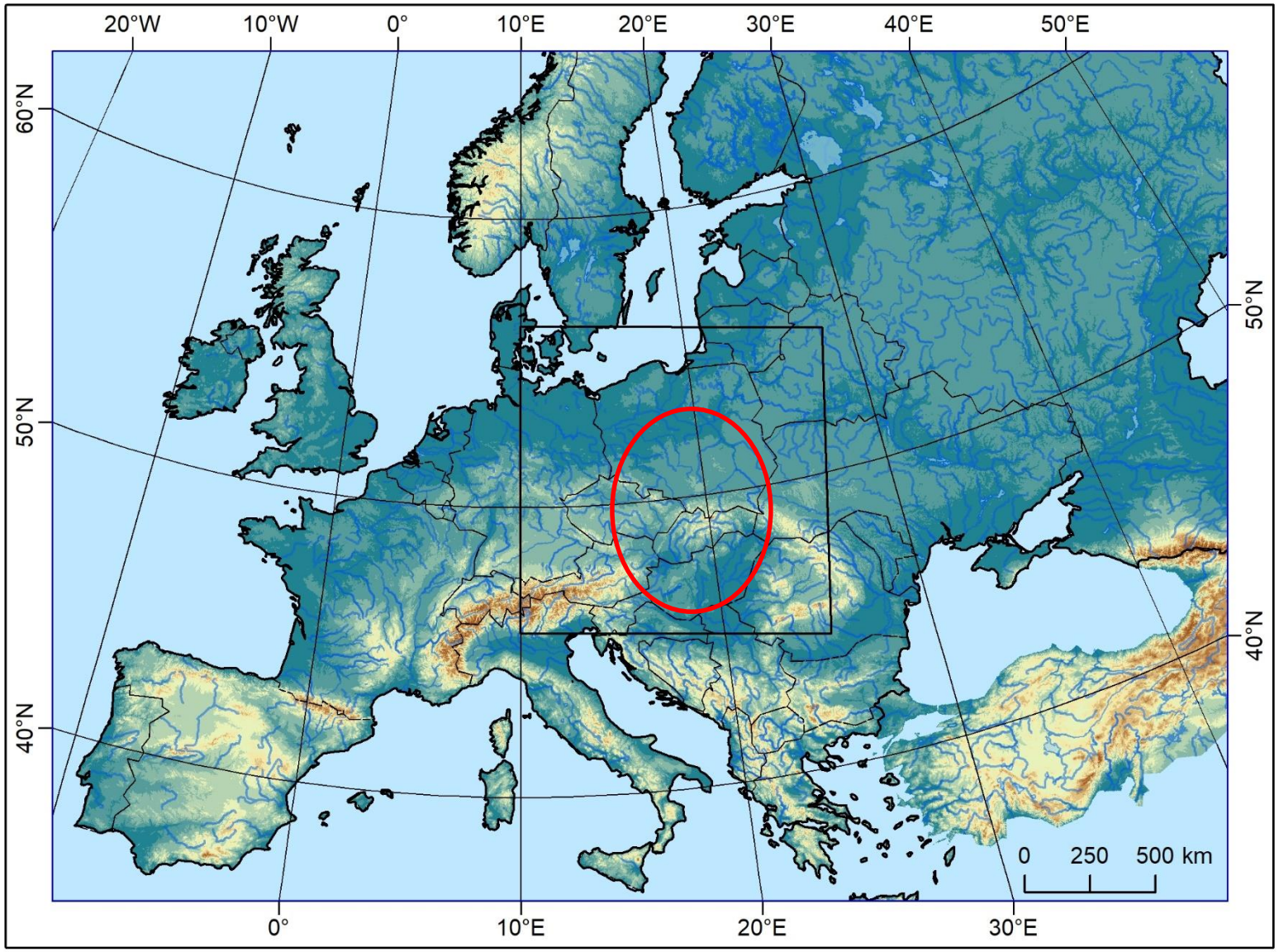
DWD
synoptic map

3 January 1993
00 UTC

An attempt to detect nonhomogeneity in traditional (manual) classifications of circulation types

- taking into account currently available data and methods of analyses

(on the example of particular classifications for Central Europe)


20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°N
50°N
40°N
0
250
500 km

Main data input:
calendars of CT available for Central Europe!

Availability of the mentioned classifications:

- **Grosswetterlagen** – since 1881
- **Peczely** – since 1881
- **Niedźwiedź** – since 1873

150 years! ☺

Classifications of circulation types (CT) - and main features

Grosswetterlagen (Hess i Brezowsky 1952, Baur 1947, Gerstengarbe i Werner 1993); GWL (29+1)

Peczely (1957) + Károssy; PECZ (13)

Niedźwiedź (1981); TN (20+1)

1.	Wa	zachodnia, antycyklonalna Anticyclonic westerly
2.	Wz	zachodnia, cyklonalna Cyclonic westerly
3.	Ws	zachodnia, przesunięta ku południowi South-shifted cyclonic westerly
4.	Ww	zachodnia, brzeżna na skraju blokującego wyżu rosyjskiego Maritime westerly (block Eastern Europe)
5.	SWa	południowo-zachodnia, antycyklonalna Anticyclonic south-westerly
6.	SWz	południowo-zachodnia, cyklonalna Cyclonic south-westerly
7.	NWa	północno-zachodnia, antycyklonalna Anticyclonic north-westerly
8.	NWz	północno-zachodnia, cyklonalna Cyclonic north-westerly
9.	HM	wyż nad Europą Środkową High over Central Europe
10.	BM	klin (wał) wyżowy nad Europą Środkową Zonal ridge across Central Europe
11.	TM	niż nad Europą Środkową Low over Central Europe
12.	Na	północna, antycyklonalna Anticyclonic northerly
13.	Nz	północna, cyklonalna Cyclonic northerly
14.	HNa	wyż nad Morzem Północnym-Islandią, antycyklonalna Norwegian Sea-Iceland high, cyclonic
15.	HNz	wyż nad Morzem Północnym-Islandią, cyklonalna Norwegian Sea-Iceland high, cyclonic
16.	HB	wyż nad Wyspami Brytyjskimi High over British Isles
17.	TrM	bruzda nad Europą Środkową Trough over Central Europe
18.	NEa	północno-wschodnia, antycyklonalna Anticyclonic, north-easterly
19.	NEz	północno-wschodnia, cyklonalna Cyclonic, north-easterly
20.	HFa	wyż nad Fennoskandią, antycyklonalna Fennoscandian high, anticyclonic
21.	HFz	wyż nad Fennoskandią, cyklonalna Fennoscandian high, cyclonic
22.	HNFa	wyż nad Morzem Północnym-Fennoskandią, antycyklonalna Norwegian Sea-Fennoscandian high, anticyclonic
23.	HNFz	wyż nad Morzem Północnym-Fennoskandią, cyklonalna Norwegian Sea-Fennoscandian high, cyclonic
24.	SEa	południowo-wschodnia, antycyklonalna Anticyclonic south-easterly
25.	SEz	południowo-wschodnia, cyklonalna Cyclonic south-easterly
26.	Sa	południowa, antycyklonalna Anticyclonic southerly
27.	Sz	południowa, cyklonalna Cyclonic southerly
28.	TB	niż nad Wyspami Brytyjskimi Low over British Islands
29.	TrW	bruzda nad Europą Zachodnią Trough over Western Europe
30.	U	sytuacja nieokreślona lub przejściowa Unclassified or transitional

Grosswetterlagen (GWL)

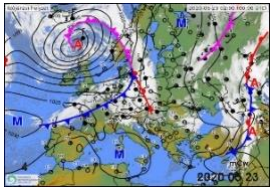
Niedźwiedź (TN)

Budapest, 9 - 11 May 2023

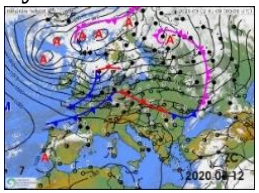
1.	Na	północna antycyklonalna Northerly anticyclonic
2.	NEa	północno-wschodnia antycyklonalna North-easterly anticyclonic
3.	Ea	wschodnia antycyklonalna Easterly anticyclonic
4.	SEa	południowo-wschodnia antycyklonalna South-easterly anticyclonic
5.	Sa	południowa antycyklonalna Southerly anticyclonic
6.	SWa	południowo-zachodnia antycyklonalna South-westerly anticyclonic
7.	Wa	zachodnia antycyklonalna Westerly anticyclonic
8.	NWa	północno-zachodnia antycyklonalna North-westerly anticyclonic
9.	Ca	centralna antycyklonalna, centrum wyżu Central anticyclone situation, high center
10.	Ka	klin antycyklonalny lub wał wyżowy Anticyclonic wedge or ridge of high pressure
11.	Nc	północna cyklonalna Northerly cyclonic
12.	NEc	północno-wschodnia cyklonalna North-easterly cyclonic
13.	Ec	wschodnia cyklonalna Easterly cyclonic
14.	SEc	południowo-wschodnia cyklonalna South-easterly cyclonic
15.	Sc	południowa cyklonalna Southerly cyclonic
16.	SWc	południowo-zachodnia cyklonalna South-westerly cyclonic
17.	Wc	zachodnia cyklonalna Westerly cyclonic
18.	NWc	północno-zachodnia cyklonalna North-westerly cyclonic
19.	Cc	centralna cyklonalna, centrum niżu Central cyclonic, center of low
20.	Bc	bruzda cyklonalna Through of the low pressure
21.	X	nieokreślona lub siodło baryczne Unclassified situation or pressure col

Peczely (PECZ)

C1 Atlantic Cyclones

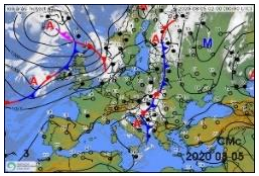

mCw (2020.06.23.)

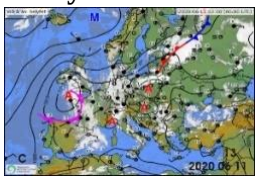

mCc (2020.04.14.)


zC (2020.03.12.)

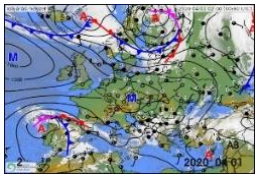
C2 Mediterranean Cyclones

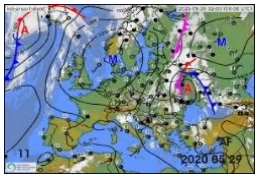

CMw (2020.05.11.)

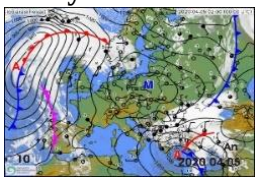

CMc (2020.08.05.)


C (2020.06.11.)

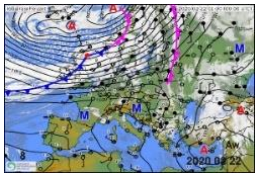
A1 Northward Anticyclones

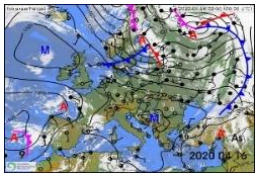

AB (2020.04.01.)

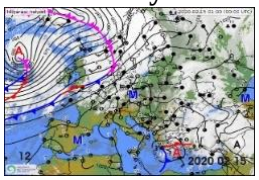

AF (2020.05.29.)

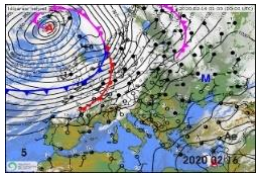

An (2020.04.05.)

A2 Central and Southward Anticyclones


Aw (2020.02.22.)

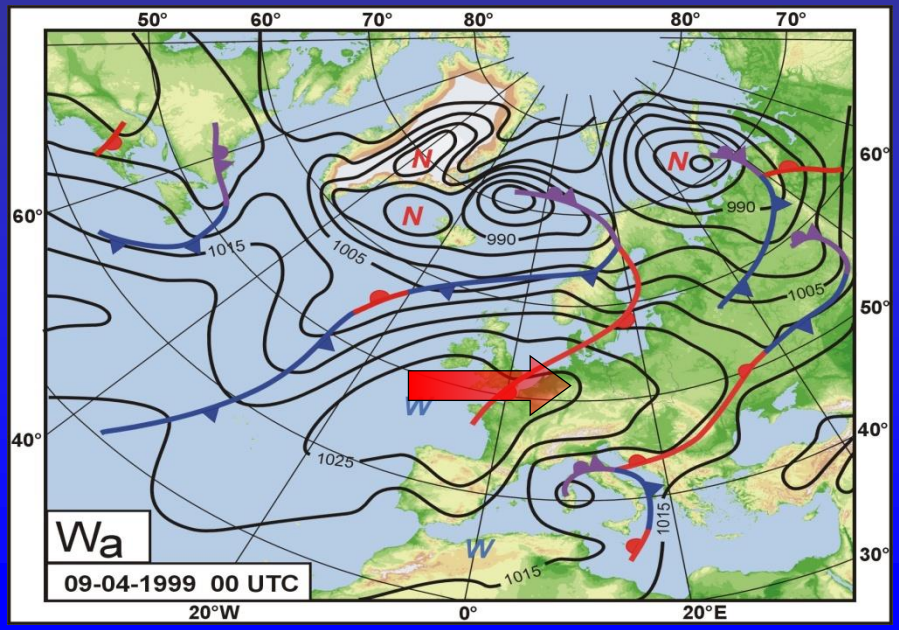

As (2020.04.16.)

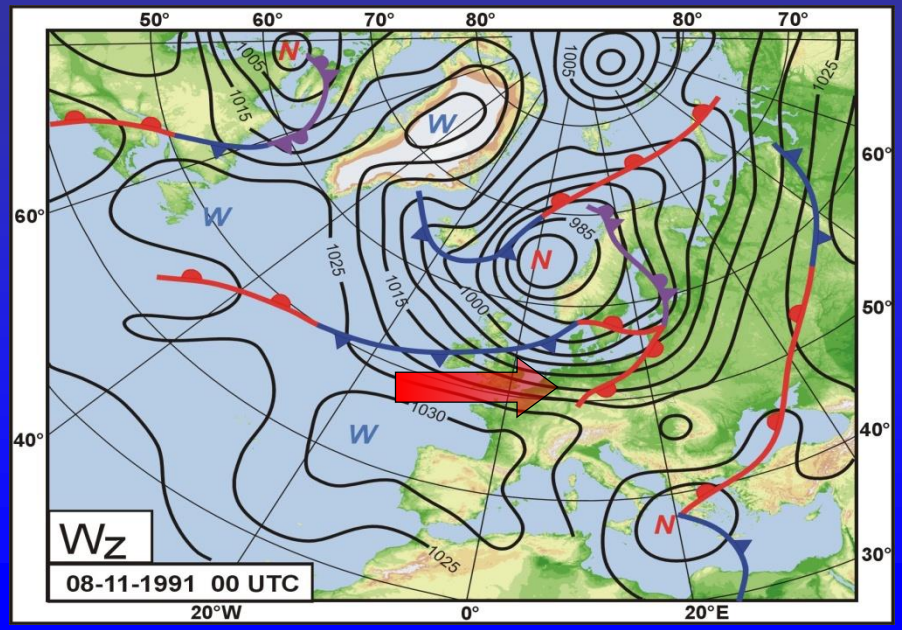

A (2020.02.15.)

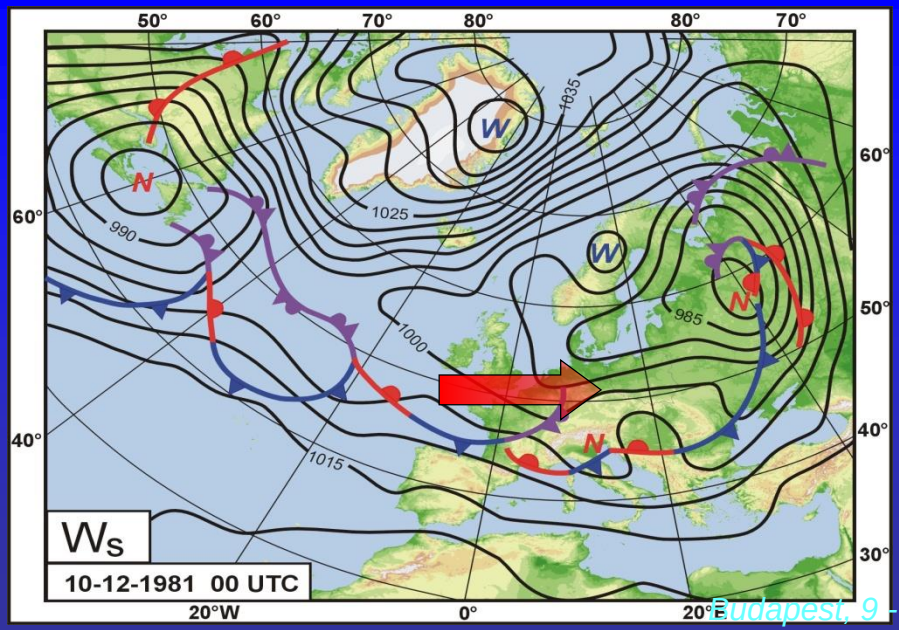

Ae (2020.02.16.)

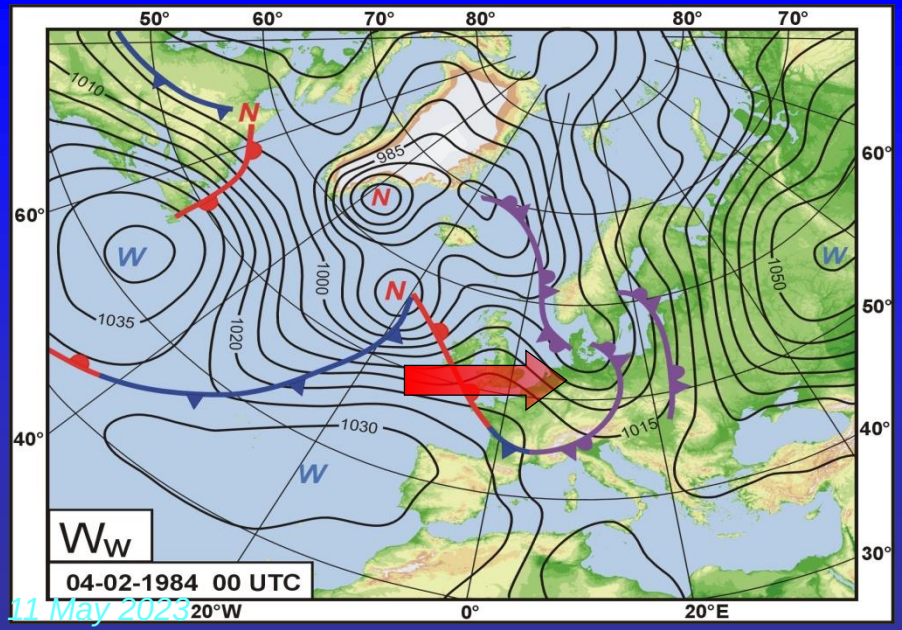
(MIKA J., KÁROSSY C., LAKATOS L., 2023)

Westerly circulation (acc. to GWL)



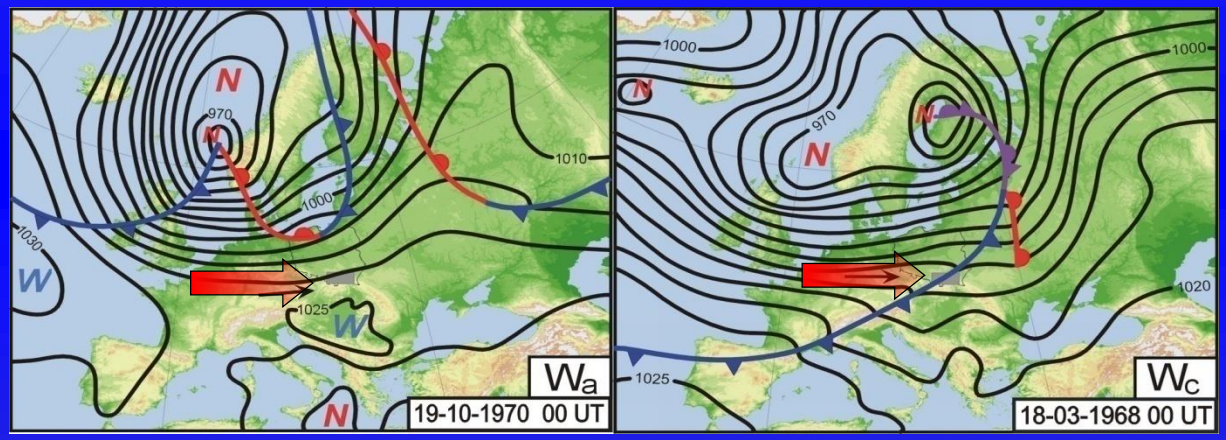






Westerly circulation (acc. to TN)

NIEDŹWIEDŹ



ERA5

- Surface level + levels: SLP/1000, 925, 850, 700, 500 hPa

2 variables (sea level pressure, geopotential height)

+ some other elements for individual studies of some cases *(e.g. air temperature, divergence, relative humidity, specific humidity, cloudiness, u & v wind components, etc.)*

⟶ **For the domain** 45-60°N, 5-30°E

- 6000 grid points, i.e. ca. 4 mln values for each term (every 6 hrs),
- data every 0.25°

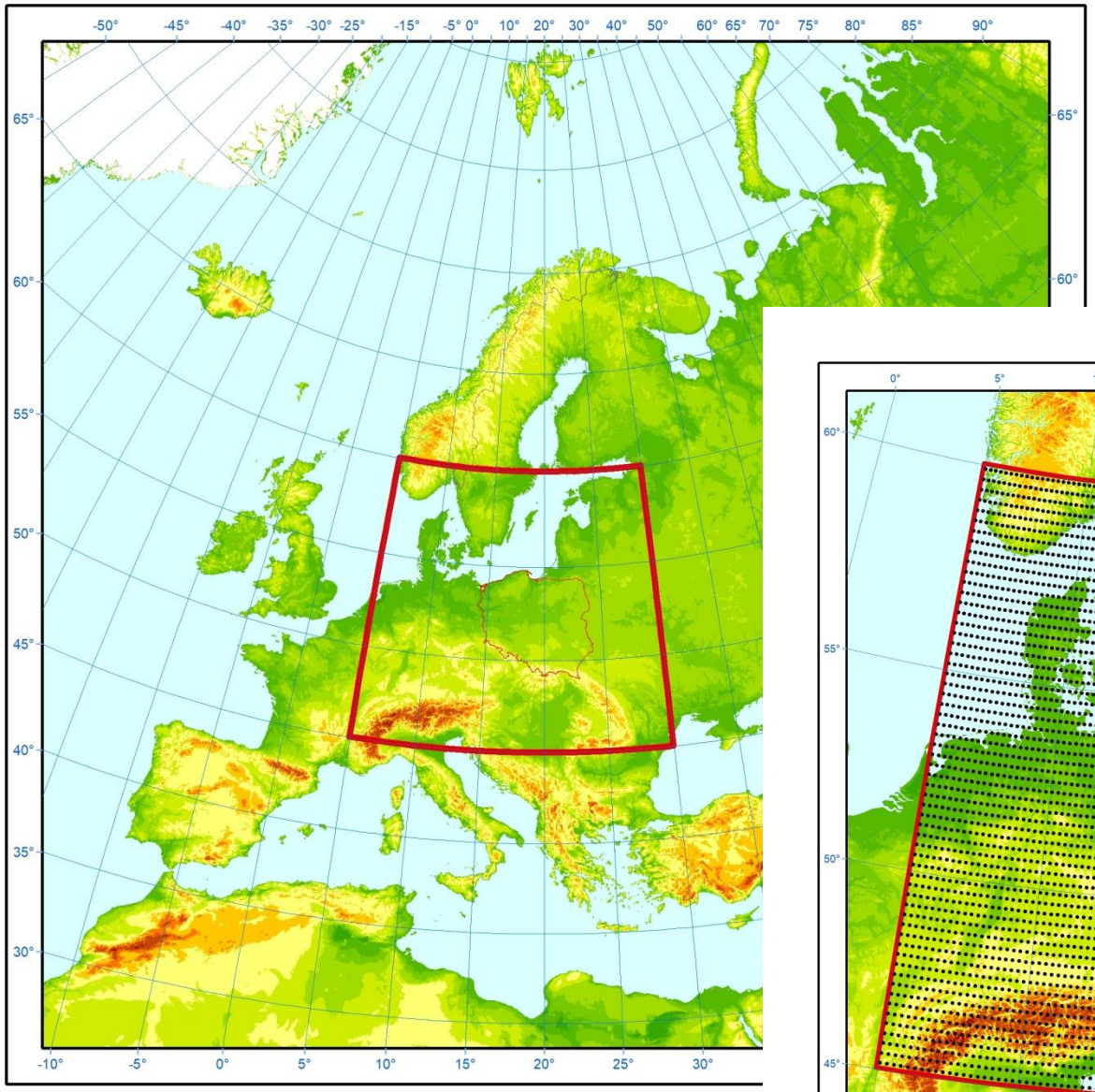
Data period: 1941-2022 *(1873-2022)*

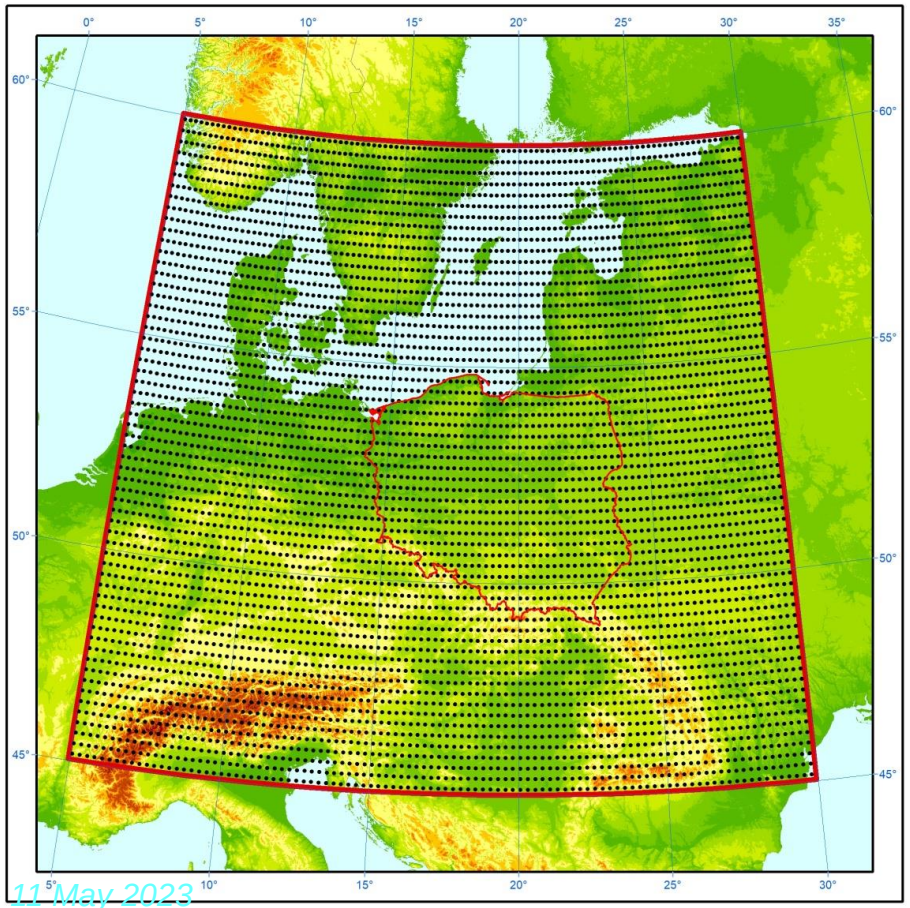
Other data:

- synoptic maps/charts: DWD, Polish Met. Service, Met Office, Meteo France
- + few other
- other data: !?

CENTRAL EUROPE

Domain / region:
45-60°N, 5-30°E





Data

- ✓ Different circulation types calendars
- ✓ Synoptic maps (charts)
- ✓ Numerical datasets

Methods

- ✓ Traditional in synoptic meteorology and climatology
- ✓ Basic methods in the field
- ✓ Expert analyses

After many analyses, we chose the method of convolutional networks (CNN) as the most useful

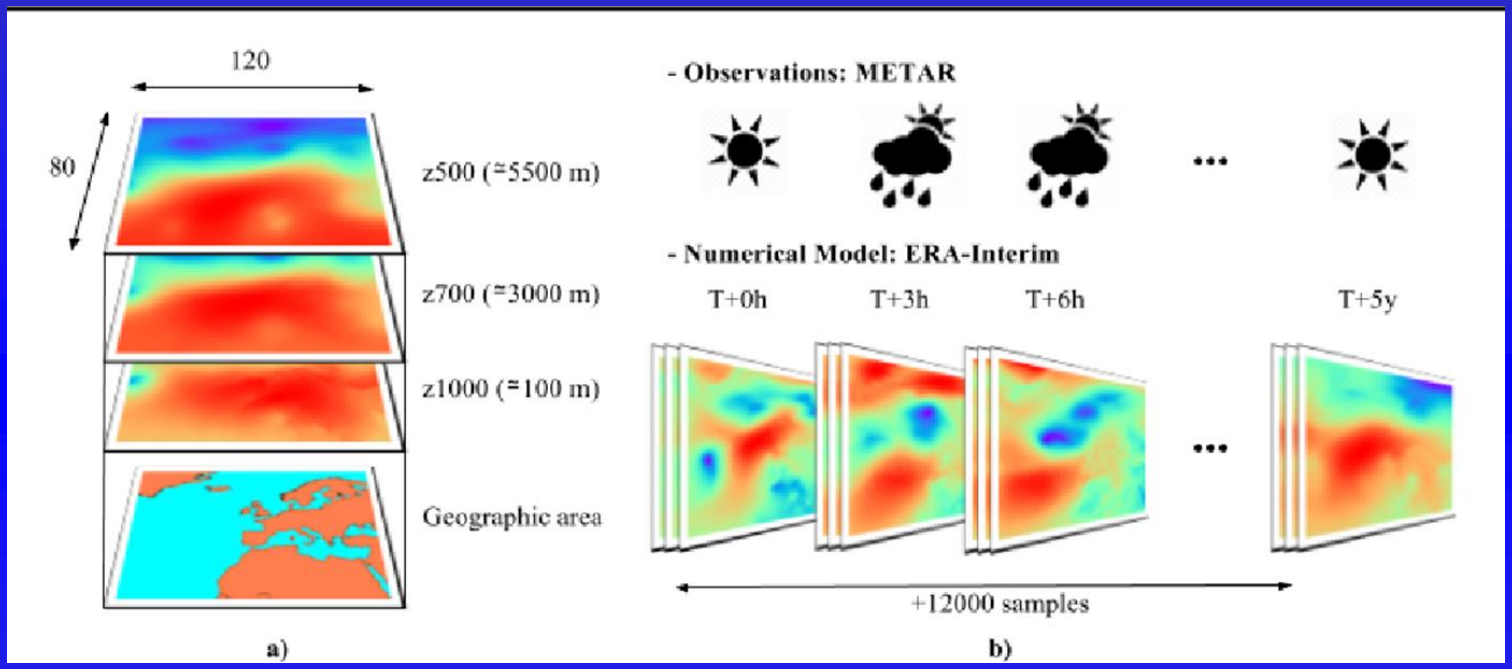
- ✓ Basic data for calculations: 1991-2020
- ✓ Learning data: 2001-2010
- ✓ Testing data: 1991-2000 and 2011-2020
- ✓ Period chosen for the reconstruction: 1941-1990, 1961-1990

- **Learning phase**
- **Testing (validation) phase**
- **Analysis results phase**

Random Forests?

CNN!

Convolutional Neural Network (CNN) is a class of artificial neural network most commonly applied to analyze visual imagery (deep learning method). CNNs use a **mathematical operation called convolution** in place of general matrix multiplication in at least one of their layers. They are specifically designed to process pixel data and are used in image recognition and processing. They have applications in image and video recognition, recommender systems, **image classification**, image segmentation, medical image analysis, natural language processing, brain–computer interfaces, and financial time series.


120
80
z500 (≈5500 m)
z700 (≈3000 m)
z1000 (≈100 m)
Geographic area
a)
- Observations: METAR
- Numerical Model: ERA-Interim
T+0h
T+3h
T+6h
T+5y
+12000 samples
b)

CT	season				YEAR
	MAM	JJA	SON	DJF	
N+NEa	6.9	9.6	3.8	4.0	**6.1**
E+SEa	10.6	7.1	7.2	10.8	**8.9**
S+SWa	5.7	4.9	10.6	8.5	**7.4**
W+NWa	6.3	12.1	15.0	14.1	**11.9**
Ca+Ka	12.0	18.2	16.4	11.6	**14.6**
N+NEc	7.0	7.8	3.6	4.7	**5.8**
E+SEc	8.9	3.1	5.1	5.1	**5.5**
S+SWc	11.1	3.7	9.5	10.4	**8.7**
W+NWc	15.1	15.9	17.8	21.4	**17.5**
Cc+Bc	14.1	15.8	8.3	6.6	**11.2**
X	2.3	1.8	2.7	2.8	**2.4**

TN actual (1961-1990)

Annual/Seasonal frequency of particular circulation types (CT)
TN (version 11 types)

Annual/Seasonal frequency of particular circulation types (CT)

GWL actual (1961-1990)

CT	season				YEAR
	MAM	JJA	SON	DJF	
Wa	2.6	7.7	7.2	5.0	5.6
Wz	11.6	13.7	18.4	18.8	15.6
Ws	3.0	2.6	1.9	5.8	3.3
Ww	2.7	1.7	2.3	3.0	2.4
SWa	2.2	3.3	4.1	3.1	3.2
SWz	4.3	2.2	4.5	4.1	3.8
NWa	1.6	2.2	3.4	1.3	2.1
NWz	5.0	5.7	3.0	6.2	4.9
HM	4.5	6.1	8.5	6.9	6.5
BM	7.3	10.3	11.1	9.0	9.4
TM	4.4	1.8	1.7	1.5	2.4
Na	0.9	1.3	0.2	0.5	0.7
Nz	3.6	2.2	1.8	3.1	2.7
HNa	2.6	2.4	1.4	2.4	2.2
HNz	3.7	2.0	0.5	1.8	2.0
HB	3.6	3.3	3.5	2.9	3.3
TrM	3.5	5.0	4.5	3.5	4.1
NEa	2.0	2.7	0.4	0.5	1.4
NEz	2.1	3.1	1.0	0.7	1.7
HFa	4.3	3.7	2.4	1.7	3.0
HFz	2.2	2.1	1.4	1.5	1.8
HNFa	1.3	1.8	0.2	0.9	1.1
HNFz	3.0	2.0	0.9	2.7	2.1
SEa	1.7	0.7	1.4	2.8	1.6
SEz	1.8	0.1	0.9	2.5	1.3
Sa	1.6	0.3	3.2	2.0	1.8
Sz	0.6	0.2	1.4	1.9	1.0
TB	2.9	2.8	1.8	1.5	2.2
TrW	7.4	5.8	5.1	1.5	5.0
U	2.0	1.4	1.8	1.0	1.5

pred / actual	Wa	Wz	Ws	Ww	SWa	SWz	NWa	NWz	HM	BM	TM	Na	Nz	HNa	HNz	HB	TrM	NEa	NEz	HFa	HFz	HNFa	HNFz	SEa	SEz	Sa	Sz	TB	TrW	U
Wa	41	28	0	0	3	2	1	0	1	13	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wz	68	341	3	1	1	46	4	8	1	21	0	0	2	0	9	0	21	0	0	0	3	0	1	0	0	1	0	9	16	0
Ws	0	14	7	2	0	0	0	3	0	2	0	0	0	0	3	0	16	0	0	0	0	0	0	0	0	0	0	9	3	0
Ww	0	22	0	19	3	2	1	2	1	3	0	0	0	0	1	0	2	0	0	3	3	0	1	1	1	2	0	4	4	0
SWa	15	20	0	0	8	17	1	0	0	18	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	4	0
SWz	12	103	3	1	4	91	0	0	0	8	0	0	0	0	4	0	3	0	0	0	1	0	0	1	0	3	0	7	42	0
NWa	17	9	0	0	0	1	19	5	5	6	0	4	1	0	1	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0
NWz	18	87	0	5	0	0	32	56	2	4	0	1	5	0	2	8	15	0	0	0	0	0	0	0	0	0	0	0	0	0
HM	12	4	0	1	8	1	5	0	74	28	0	2	0	0	3	14	3	2	0	18	1	5	0	1	0	2	0	3	0	0
BM	68	40	0	2	13	25	26	4	26	192	0	3	1	0	6	24	7	12	2	18	4	8	0	16	0	7	0	4	12	0
TM	0	4	0	0	0	1	0	0	0	0	25	0	0	0	3	0	7	0	0	1	10	0	0	0	0	0	0	3	4	0
Na	0	0	0	0	0	0	1	3	0	0	0	0	2	0	0	2	3	1	1	0	0	0	0	0	0	0	0	0	0	0
Nz	1	10	0	1	0	0	6	11	1	0	0	0	12	1	3	7	10	0	2	1	1	0	0	0	0	0	0	0	0	0
HNa	3	0	0	0	0	2	2	0	9	2	0	0	0	5	4	10	1	1	1	2	2	13	1	0	0	0	0	0	0	0
HNz	0	2	5	0	0	0	1	0	0	3	0	0	0	0	13	0	1	1	2	3	0	1	4	0	0	0	0	2	1	0
HB	2	0	0	0	0	0	20	4	15	7	1	6	0	2	0	38	4	5	2	1	1	0	1	0	0	0	0	0	0	0
TrM	3	88	1	1	0	1	2	6	0	33	20	5	6	1	2	6	123	3	6	5	6	0	8	0	0	0	0	5	10	0
NEa	0	0	0	0	0	0	0	0	6	1	2	0	0	0	0	3	0	2	2	2	1	0	1	0	0	0	0	0	1	0
NEz	0	0	0	0	0	0	0	0	2	2	1	1	0	0	3	1	1	3	4	1	0	2	3	0	0	0	0	0	0	0
HFa	0	0	0	1	0	0	0	0	6	6	0	0	0	0	0	1	0	5	1	48	4	2	2	4	1	1	0	0	0	0
HFz	0	0	0	0	0	0	0	0	0	2	4	0	0	2	0	0	4	3	1	15	3	2	2	1	0	1	0	1	0	0
HNFa	0	0	0	0	0	0	0	0	3	1	0	0	0	0	2	4	0	2	1	2	1	16	5	0	1	1	0	1	0	0
HNFz	0	0	0	0	0	0	0	0	1	0	3	1	0	0	5	1	2	1	7	35	7	8	15	0	0	0	0	2	1	0
SEa	0	0	0	1	0	0	0	0	2	4	1	0	0	0	0	1	0	0	0	21	1	12	4	9	2	9	1	4	3	0
SEz	0	0	0	0	0	2	0	0	0	6	4	0	0	0	3	0	4	0	0	11	3	0	4	7	0	2	0	0	1	0
Sa	0	0	0	0	0	1	0	0	7	1	0	0	0	0	2	0	0	0	0	5	0	0	0	9	2	7	1	0	2	0
Sz	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	2	0	1	0	3	9	0
TB	1	9	0	0	0	3	0	0	1	3	0	0	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	10	6	0
TrW	5	34	0	2	2	38	0	0	2	23	7	0	0	0	5	0	28	0	2	5	6	1	0	2	1	3	1	19	75	0
U	3	2	0	1	0	2	1	0	4	3	0	0	0	0	1	2	4	0	0	1	1	1	0	0	0	0	0	0	1	0
accuracy	**0.15**	**0.42**	**0.37**	**0.50**	**0.19**	**0.39**	**0.16**	**0.61**	**0.51**	**0.56**	**0.37**	**0.00**	**0.41**	**0.45**	**0.17**	**0.29**	**0.47**	**0.05**	**0.12**	**0.24**	**0.05**	**0.23**	**0.28**	**0.17**	**0.00**	**0.18**	**0.00**	**0.12**	**0.38**	**0.00**

Testing – annual values (GWL)

PECZ 2001-2010

pred / actual	mCc	AB	CMc	mCw	Ae	CMw	zC	As	Aw	An	AF	A	C
mCc	394	11	0	8	9	34	4	80	2	14	13	3	13
AB	42	140	0	1	3	12	1	70	0	10	7	15	1
CMc	16	1	0	0	1	11	0	3	0	3	3	0	5
mCw	120	1	0	20	5	19	6	8	1	3	4	2	8
Ae	95	11	0	6	181	24	1	46	1	32	2	24	1
CMw	66	5	0	2	4	134	0	19	1	11	1	1	17
zC	40	0	0	0	3	5	8	5	2	0	0	1	0
As	48	18	0	3	1	9	11	300	2	19	4	24	1
Aw	54	3	0	3	11	2	20	40	19	2	6	47	0
An	16	24	0	3	38	26	0	19	0	171	24	29	4
AF	16	33	0	4	6	7	0	3	0	56	87	18	2
A	23	13	0	2	29	4	6	78	4	23	4	198	0
C	74	5	0	0	4	19	0	14	0	2	3	0	38
accuracy	**0.39**	**0.59**	**0.00**	**0.45**	**0.61**	**0.44**	**0.14**	**0.44**	**0.68**	**0.49**	**0.63**	**0.65**	**0.42**

Testing – annual values (PECZ)

pred / actual	Na	NEa	Ea	SEa	Sa	SWa	Wa	NWa	Ca	Ka	Nc	NEc	Ec	SEc	Sc	SWc	Wc	NWc	Cc	Bc	X
Na	57	8	0	0	0	0	0	14	0	23	13	4	0	0	0	0	0	5	0	5	0
NEa	2	55	9	0	0	0	0	0	0	21	0	17	1	0	0	0	0	0	0	9	0
Ea	0	8	75	17	0	0	0	0	0	45	0	2	12	2	0	0	0	0	0	12	0
SEa	0	0	6	70	6	1	0	0	0	37	0	0	0	17	5	0	0	0	0	5	0
Sa	0	0	0	1	40	5	0	0	0	33	0	0	0	1	15	5	0	0	0	8	0
SWa	0	0	0	0	3	78	9	0	0	21	0	0	0	0	2	45	1	0	0	9	0
Wa	0	0	0	0	0	14	148	3	0	61	0	0	0	0	0	2	47	6	0	16	0
NWa	7	0	0	0	0	0	16	84	0	46	4	0	0	0	0	0	1	25	0	6	0
Ca	0	0	0	0	0	0	0	0	4	69	0	0	0	0	0	0	0	0	0	0	0
Ka	4	5	7	3	2	5	15	2	1	403	1	0	3	0	0	1	4	0	0	50	0
Nc	0	0	0	0	0	0	0	1	0	3	47	13	0	0	0	0	3	14	0	14	0
NEc	0	9	0	0	0	0	0	0	0	6	3	51	8	0	0	0	0	0	0	12	0
Ec	0	0	4	0	0	0	0	0	0	4	0	7	49	7	0	0	0	0	0	15	0
SEc	0	0	1	2	0	0	0	0	0	5	0	0	7	55	8	0	0	0	0	16	0
Sc	0	0	0	0	3	1	0	0	0	2	0	0	0	5	62	16	0	0	0	26	0
SWc	0	0	0	0	0	4	0	0	0	2	0	0	0	2	7	149	22	0	0	23	0
Wc	0	0	0	0	0	0	8	0	0	11	0	0	0	0	0	6	268	7	0	32	0
NWc	0	0	0	0	0	0	1	4	0	6	10	1	0	0	0	0	40	95	0	26	0
Cc	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0	13	0
Bc	1	0	0	0	0	0	1	1	0	27	6	9	6	15	7	20	53	10	0	303	1
X	0	0	0	0	0	0	0	0	0	30	0	0	0	1	0	3	4	1	0	29	0
accuracy	**0.80**	**0.65**	**0.74**	**0.75**	**0.74**	**0.72**	**0.75**	**0.77**	**0.80**	**0.47**	**0.55**	**0.49**	**0.56**	**0.52**	**0.58**	**0.60**	**0.60**	**0.58**	**n/d**	**0.48**	**0.00**

Testing – annual values (TN)
2001-2010

pred / actual	N+NEa	E+SEa	S+SWa	W+NWa	Ca+Ka	N+NEc	E+SEc	S+SWc	W+NWc	Cc+Bc	X
N+NEa	172	4	0	19	36	6	0	0	0	6	0
E+SEa	12	245	4	0	49	1	3	0	0	6	0
S+SWa	0	17	150	7	94	0	0	6	0	2	0
W+NWa	6	0	14	336	118	1	0	0	3	8	0
Ca+Ka	11	19	3	19	518	0	0	0	1	8	0
N+NEc	41	3	0	6	8	90	0	0	14	22	0
E+SEc	1	56	0	0	7	13	52	3	0	48	0
S+SWc	0	8	50	0	45	0	4	165	8	44	0
W+NWc	0	0	5	115	49	9	0	5	277	55	0
Cc+Bc	2	8	2	6	71	14	8	15	35	315	1
X	3	1	0	3	48	1	0	0	1	11	0
accuracy	**0.69**	**0.68**	**0.66**	**0.66**	**0.50**	**0.67**	**0.78**	**0.85**	**0.82**	**0.60**	**0.00**

Testing – annual values (TN)
2001-2010
(version - 11 CT)

Annual/Seasonal frequency of particular circulation types (CT)

CT	season				YEAR
	MAM	JJA	SON	DJF	
Na	2.9	5.1	2.3	1.7	**3.0**
NEa	4.1	4.5	1.5	2.3	**3.1**
Ea	5.8	4.7	3.6	5.5	**4.9**
SEa	4.8	2.5	3.7	5.3	**4.1**
Sa	3.3	2.5	5.3	5.0	**4.0**
SWa	2.3	2.4	5.3	3.5	**3.4**
Wa	3.1	6.6	10.1	9.6	**7.4**
NWa	3.2	5.5	4.9	4.5	**4.5**
Ca	1.7	3.5	5.0	3.1	**3.3**
Ka	10.3	14.7	11.4	8.5	**11.2**
Nc	3.6	4.3	2.3	2.7	**3.2**
NEc	3.4	3.5	1.3	1.9	**2.5**
Ec	4.9	1.8	2.6	2.7	**3.0**
SEc	4.0	1.2	2.5	2.4	**2.5**
Sc	4.8	1.3	4.1	4.2	**3.6**
SWc	6.3	2.4	5.3	6.1	**5.0**
Wc	9.7	8.7	12.4	15.0	**11.4**
NWc	5.4	7.2	5.4	6.4	**6.1**
Cc	2.4	1.7	0.9	1.2	**1.6**
Bc	11.6	14.1	7.4	5.4	**9.7**
X	2.3	1.8	2.7	2.8	**2.4**

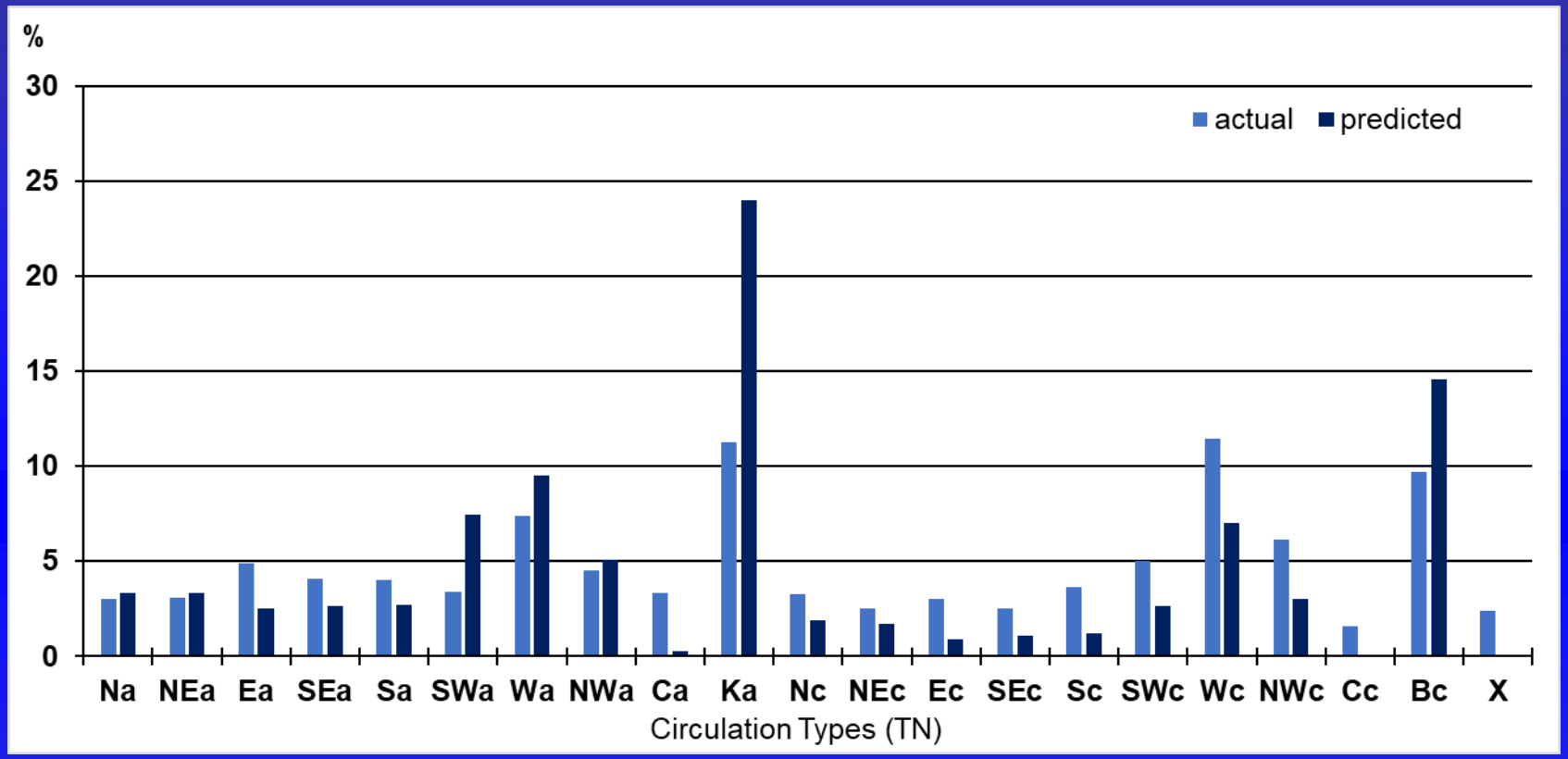
TN actual (1961-1990)

CT	season				YEAR
	MAM	JJA	SON	DJF	
Na	3.5	4.0	2.9	3.0	**3.3**
NEa	5.1	3.5	2.0	2.6	**3.3**
Ea	3.6	0.7	2.1	3.7	**2.5**
SEa	3.7	0.4	2.3	4.1	**2.6**
Sa	3.0	0.8	3.2	4.1	**2.7**
SWa	6.3	4.3	10.5	8.8	**7.4**
Wa	5.5	5.2	13.9	13.6	**9.5**
NWa	3.9	4.5	6.0	6.0	**5.1**
Ca	0.1	0.0	0.3	0.7	**0.3**
Ka	26.1	29.3	27.0	21.2	**24.0**
Nc	0.9	1.0	0.5	1.3	**1.9**
NEc	1.0	0.7	0.2	0.8	**1.7**
Ec	0.6	0.0	0.1	0.6	**0.9**
SEc	2.1	0.3	0.8	1.2	**1.1**
Sc	1.5	0.2	1.4	1.7	**1.2**
SWc	2.8	0.6	2.5	4.5	**2.6**
Wc	3.0	1.0	3.8	6.4	**7.0**
NWc	1.2	0.8	0.7	2.4	**3.0**
Cc	0.0	0.0	0.0	0.0	**0.0**
Bc	15.4	15.9	10.8	10.2	**14.5**
X	0.0	0.0	0.1	0.0	**0.0**

TN predicted (1961-1990)

CT	actual	predicted
Na	3.0	3.3
NEa	3.1	3.3
Ea	4.9	2.5
SEa	4.1	2.6
Sa	4.0	2.7
SWa	3.4	7.4
Wa	7.4	9.5
NWa	4.5	5.1
Ca	3.3	0.3
Ka	11.2	24.0
Nc	3.2	1.9
NEc	2.5	1.7
Ec	3.0	0.9
SEc	2.5	1.1
Sc	3.6	1.2
SWc	5.0	2.6
Wc	11.4	7.0
NWc	6.1	3.0
Cc	1.6	0.0
Bc	9.7	14.5
X	2.4	0.0

Annual frequency of particular circulation types (CT) - TN



Frequency of annual circulation types (TN)
actual vs. predicted
(2001-2010)

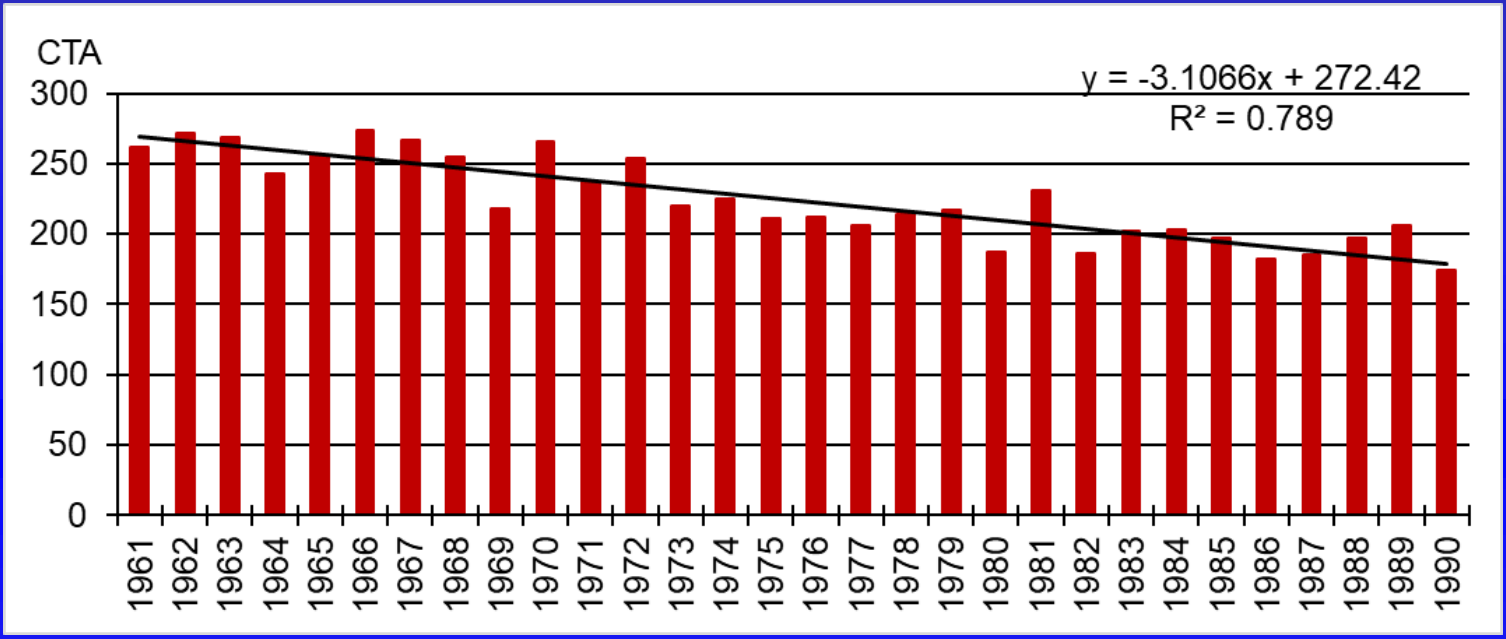
pred / actual	Na	NEa	Ea	SEa	Sa	SWa	Wa	NWa	Ca	Ka	Nc	NEc	Ec	SEc	Sc	SWc	Wc	NWc	Cc	Bc	X
Na	262	37	0	0	0	0	5	46	1	271	1	1	0	0	0	0	0	0	0	10	0
NEa	47	245	8	0	1	0	1	4	1	234	0	5	0	0	0	1	0	0	0	10	0
Ea	2	91	352	53	0	4	2	1	2	496	0	4	1	4	0	0	0	0	0	16	0
SEa	0	3	48	327	58	3	4	1	3	355	0	0	1	5	1	0	0	0	0	11	0
Sa	0	0	0	39	270	187	1	0	1	260	0	0	0	1	10	4	0	0	0	46	0
SWa	0	0	1	2	12	356	24	0	0	151	0	1	0	0	1	21	2	0	0	26	0
Wa	0	0	1	0	1	100	735	83	1	614	0	0	0	0	0	12	21	3	0	17	0
NWa	61	1	0	0	0	6	54	373	0	335	0	0	0	0	0	1	9	5	0	13	0
Ca	3	0	0	0	1	15	13	4	35	557	0	0	0	0	0	0	2	0	0	5	0
Ka	5	11	4	1	4	49	38	14	11	1729	0	0	0	1	1	5	2	0	0	39	1
Nc	171	17	1	0	0	0	2	46	0	124	105	13	0	0	0	0	4	26	0	119	0
NEc	42	122	3	0	0	1	1	0	0	99	16	69	4	0	0	0	0	1	0	68	1
Ec	4	60	101	12	1	0	0	0	0	128	0	22	41	29	0	1	0	1	0	131	1
SEc	0	2	22	88	18	1	0	1	0	87	0	0	7	110	10	1	0	0	0	115	0
Sc	0	0	1	23	122	72	3	0	0	79	0	0	1	29	138	41	0	0	0	181	0
SWc	0	0	0	2	7	338	28	0	0	61	0	0	0	1	30	244	27	1	0	171	0
Wc	2	0	0	0	1	130	657	44	0	358	2	0	0	1	1	118	480	32	0	386	0
NWc	29	1	0	0	1	3	83	311	0	219	22	1	0	0	0	0	51	156	0	207	1
Cc	4	2	1	2	1	0	1	0	0	43	5	4	1	1	2	1	2	1	1	200	1
Bc	11	11	5	5	8	32	16	9	0	477	6	7	4	10	9	23	34	6	0	908	2
X	3	6	2	2	2	16	12	4	0	269	0	2	0	0	0	4	1	1	0	51	0
accuracy	**0.41**	**0.40**	**0.64**	**0.59**	**0.53**	**0.27**	**0.44**	**0.40**	**0.64**	**0.25**	**0.67**	**0.53**	**0.68**	**0.57**	**0.68**	**0.51**	**0.76**	**0.67**	**1.00**	**0.33**	**0.00**

CNN calculations TN (1940-1990)

HOMOGENEITY CIRCULATION TYPE INDEX
(Circulation Type Accordance)

$$\text{CTA index} = \sum (CT_{actual} \neq CT_{pred})$$

For a given period (e.g. month, season, year)



CTA course – annual values (TN)

- Manual CT classifications are still used in many climatological studies where long data series are used and need to be controlled and verified.

- The proposed ML method (i.e. CNN) seems to be a promising tool for detecting possible errors and inhomogeneities of manual CT series. At the same time, this method reveals as a new method of objectifying CT and creating new classifications.

- Although the obtained results are not fully satisfactory, the method seems to be helpful in monitoring and validation of determined types.

- Regarding the classifications used in the analyses the best results were obtained for the typology according to TN. The accordance of approx. 80%, as was the case for some types, should be considered high. The most frequently detected differences between the 'actual' and 'predictable' series were those found for the non-advective types, especially with a high-pressure wedge.

- Defined here a simple CCT (Consistency Circulation Type) inhomogeneity detection index can be used for series of various lengths. It is worth noting that its value significantly decreased (type consistency increased) in the analyzed period of 1961-1990 in the case of the TN classification.

- When using objective methods (including ML), the question arises to what extent only the method of CT separation is made objective (automatization is already a fact) and to what extent a new method is created. This is due to the fact that in the case of manual classifications, there are usually no strict distinguishing criteria.

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Thank you!
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Budapest, 9 - 11 May 2023

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CIRCULATION TYPE

Typical atmospheric circulation characteristic (pattern) for a given area and period (usually one day); there are many independent and multiscale circulation types classifications; most often they are based on the direction of air advection and the type of baric system (high, low).

Discrete characterisation of the current atmospheric circulation conditions on the nominal scale excluding other parameters than those describing the circulation state.

WEATHER TYPE (?)

The most frequently used weather classification unit in complex climatology or in synoptic meteorology; a given weather type has similar features in the course of individual meteorological elements or their complexes.

Simple, discrete characterisation of the current atmospheric conditions on the nominal scale. It may include temperature, precipitation and other climate elements for characterisation.