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RESEARCH ARTICLE

CLASSIFICATION OF CIRCULATION TYPES OVER BULGARIA: METHOD DESCRIPTION, FREQUENCY, VARIABILITY AND TREND ANALYSIS.

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Abstract

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A classification of circulation types for the region of Bulgaria is made on daily basis using subjective (manual) approach, covering 56-year period (1961-2016). The classification is based on mean sea level pressure (MSLP) and 500hPa data from (20th century reanalysis at 00, 06, 12 and 18UTC time) within the area of 30° - 75°N and 20°W - 50° E. 13 types at 500hPa (8 cyclonic and 5 anticyclonic) and 16 types at MSLP (8 cyclonic, 6 anticyclonic and 2 low gradient) are differentiated, described and visualized with examples. The work starts with brief summary of other well-known classifications of the circulation in northern hemisphere and in different parts of Europe. The frequency distribution of circulation types, on the seasonal, annual and decadal time scale are presented and analyzed. Annual distribution and annual trend analyses of the circulation types are described. Finally, additional comments are done about the annual and seasonal variability, concerning some circulation types with greater influence on the territory of Bulgaria.

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Introduction:-

The aim of this work is to classify the circulation types for the region of Bulgaria and to analyze the frequency and variability of each type in the period 1961-2016. The chosen approach is subjective, based on visualized sea-level pressure (SLP) and geopotential height at 500 hPa fields surface maps. A classification similar to another study for the region of Greece is used for this purpose.

There are two basic approaches to the classification of circulation types, subjective and objective. The subjective approach is based entirely on the expert's experience in his assessment of the current synoptic situation and its classification in a particular type. The objective approach, in turn, requires the fulfillment of certain conditions and precise rules in the classification of the types. For this purpose, generally, some numeric algorithm is required to be accurately defined. Classification methods that are a hybrid between the two approaches also exist. In this case the types are defined subjectively, but the specific situations are determined by objective criteria *Huth (2008).*

Manual classification of atmospheric circulation types has been widely reported in studies over Northern Hemisphere *(Vangengeim, 1935)* and Europe *(Lamb, 1972)*, *(Hess and Brezowsky, 1952, 1969)*, despite the fact that this technique relies only on researcher's subjective interpretation. Vangengeim had composed classification of macro-synoptic processes. The classification is based on the concept of elementary synoptic process (ESP) - this is a process during which there is no change in the geographical distribution of the atmospheric pressure field and the direction of the main air flow over the Atlantic-Eurasian sector of the northern hemisphere. For each elementary synoptic process, are made maps on which, in addition to cyclones and anti-cyclones positions, their trajectories are also applied. The maps are compared to others in order to obtain similar groups of (ESP). In this way, the following principles of analogy are introduced between them:

1. analogous geographical distributions of the dominant barric fields and the processes of their formations;
2. similar directions of the dominant wind systems;
3. similar characteristics of invading air masses

The wide variety of observed processes over a 42-year period Vangengeim differentiated into 26 types. These 26 types of processes were summarized in three types of atmospheric circulation – (W) - western, (E) - eastern and (M) – meridional, as they were determined by the predominant direction of the air masses, the thermal and barric gradient in the troposphere in the moderate latitudes. In 1946 Vangengeim concluded that in W, E and M types are in fact forms of the general atmospheric circulation. The classification is based mainly on surface weather maps and refers to the Atlantic-European sector. In 1948 *(Girs, 1948)* further develops this work on the Pacific-American sector and examines the behavior of the types not only on surface level, but also in height.

(*Hess and Brezowsky, 1952*), *(Peter C. Werner. Friedrich-Wilhelm Gerstengarbe (2010)* classification, known also as *"Grossweterlagen"* concerns the atmospheric circulation in central Europe. It is based on positions of the big baric centers (Azores high and Icelandic low), the positions of the frontal zones and also on cyclonic and anti-cyclonic of the circulation. Here, circulation types are divided into three main categories: zonal (Z), half-meridional (H) and meridional (M). Every day is classified according to the shape of the baric field on 500hPa geopotencial surface height. After determining atmospheric flow over central Europe such as M, H or Z, according to the flow type - (cyclonic or anti-cyclonic) and the location of the centers of high and low pressure systems, 29 subtypes *(James et al., 2007)* are formed from the three main categories.

In 1972 Hubert Lamb creates a classification based on the change of the values of the sea level pressure (SLP) about the region of British Isles. His method divides synoptic conditions on 10 categories *(Lamb, 1972*), which are extended to 26 types at a later stage (*Jenkinson and Collison, 1977*). The main difference with Hess and Brezowsky classification is that Lamb uses direction of movement of air masses on the surface level pressure (SLP) for naming the directional weather types, while Hess and Brezovsky - the direction of the centers of baric formations, towards the area of interest.

In Bulgaria categorization of atmospheric processes had been made by *(Kirov, 1942)* and *(Bakalov, 1942)*. In 1960 *(Stefanov et al., 1960)*, present categorization of weather types consisting of two main parts – advective and non-advective. The advective part includes Atlantic (Ocean), Mediterranean and Continental advection types, divided into eleven subtypes, according to the direction of advection, whether it is caused by cyclone or anticyclone and paths of the Mediterranean cyclones. Non-advective part has Anticyclonic and Low Baric Gradient types.

In 2000, the Professor of Climatology Panagiotis Maheras from the Aristotle University in Thessaloniki, Greece, and his team *(Maheras et al., 2000, 2004, 2006)*, had composed classification of circulation types for sea-level pressure (SLP) surface and the level of 500hPa geopotencial height. Their method is half-objective (hybrid), covers period of forty years (1958-1997), gridded data are used from (NCEP reanalyzes at 00, 06, 12, 18 h. and daily mean, φ=2,5 º, λ=2,5 º within European region in the area of 20 º - 65 º N and 20 º W - 50 º E). Twenty (20) SLP types are distinguished: six (6) anti-cyclonal, eight (8) cyclonal, two (2) mixed and four (4) special types according to the location of cyclone and anticyclone centers in relation to Greece. At 500hPa level, 6 cyclonic and 8 anti-cyclonic types are identified.

Methodology:-

The Classification of circulation types for the region of Bulgaria is largely based on this for Greece *(Maheras et al., 2000, 2004)*. The reason for choosing Maheras classification as a model for making this one for Bulgaria is, first, the close location of both countries and the fact that the method of Maheras is relatively newer. While *(Maheras et al., 2000)* use, as mentioned above, semi-objective approach (the definition of each type is subjectively chosen and then a numerical algorithm for the classification is used), in the classification over Bulgaria entirely subjective estimation method for determination of the types is applied. The classification is also based on SLP and 500 hPa data from 20th century reanalyzes *(Compo GP, Whitaker JS et al. 2011)* for the period 01.12.1960 - 31.12.1978, NCEP CFSR/GFS Reanalyses *(Saha S., et al. 2010)* for 1.01.1979 – 31.07.1999 and NCEP/NCAR reanalyzes *(Kalnay et al., 1996)* for 1.08.1999 – 31.12.2016 at 00, 06, 12, 18 h., in the area of (30 º – 75 º N and 20 º W – 50 º E). Visualizations of (http://www1.wetter3.de/Archiv/) are used. For each single day in the period 1961-2016 circulation types are defined separately at 500 hPa and at sea-level pressure (SLP). Comparison was made between the different reanalyzes on more than 200 randomly selected maps on both levels, but no difference was found in interpretation of the concrete synoptic situations.

As a first step we examine whether the circulation on SLP and 500 hPa is cyclonic or anti-cyclonic for every of the four periods each day. The second step is to look for the centre of the low or high pressure. It is determined by the absolute highest or lowest value of pressure in the examined field (30 º – 75 º N and 20 º W – 50 º E). The next third step is to check if there is continuous decrease, or increase of the pressure values, from the centre of that baric system towards the region of Bulgaria, for anti-cyclonic or cyclonic centers, respectively. The final step is to look for regional and local centers. If more than one anti-cyclonic or cyclonic centers are found, then this one located closer to Bulgaria is determined as the centre of the pressure system. After locating the anti-cyclonic and cyclonic centers and before the classification of the anti-cyclonic and the cyclonic circulation types, on the third step, it is checked whether the pressure gradient is greater than 2.5 hPa/2.5 º for the anti-cyclonic fields and greater than 2.0 hPa/2.5 º for the cyclonic fields. In such way, all the fields with lower pressure gradient are considered as low gradient pressure circulation types at SLP, named Mb1 (cyclonic) and Mb2 (anti-cyclonic).

Similar to *(Maheras et al., 2000)*, with several modifications, 13 types at 500 hPa level and 16 at SLP are differentiated. The positions of the centers of the pressure fields are schematically represented at Fig.1 for the anticyclones and at Fig.2 for the cyclones.

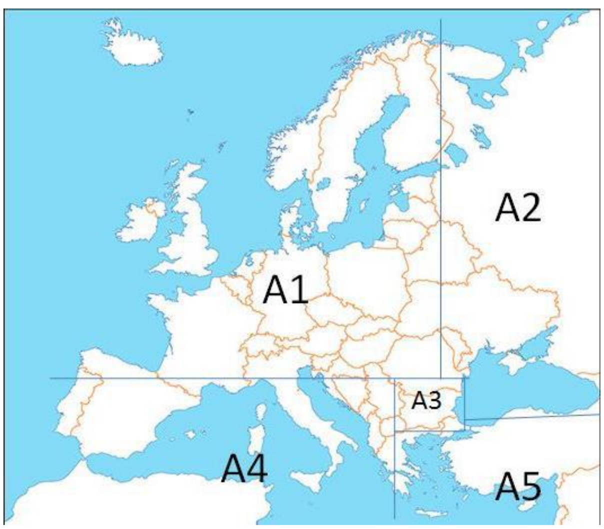


Fig. 1:- *The location of the centre of anticyclonic types*

Fig. 2:- *The location of the centre of cyclonic types*

Description of the circulation types:-

Maps in (Fig. 3, 4, 5), represent contours of the isohypses of geopotencial height at 500hPa (black curves) and isobars at sea level pressure (white curves). (http://www1.wetter3.de/Archiv/)

Anti-cyclonic types:-

A1:- The anti-cyclonic centre is located northwest of Bulgaria (Fig. 3a1), usually over the central, western Europe, Scandinavia, or Baltic sea. This area is shown in Fig.1. At the 500hPa level (Fig. 3a2), a ridge axis could be either vertical or tilted from Sahara to Eastern Europe (not shown). Airflow at both levels is predominantly from the northern quarter. The intensity of this type is greater in the winter than that during the summer.

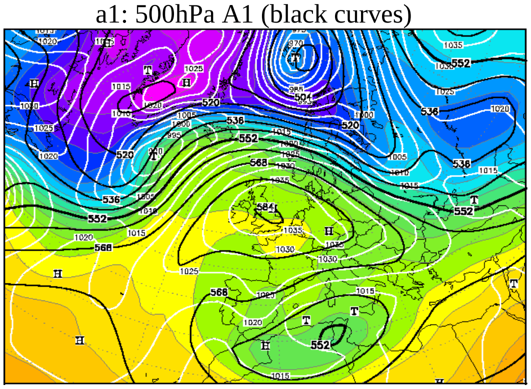
A2:- The high-pressure system is located northeast or east of Bulgaria. Sometimes, during the cold half of the year this anticyclone is a part of Siberian anticyclone (Fig. 3b2). At 500hPa level (Fig. 3b1) the gradient is relatively small, but sufficient for east or northeast airflow. As with A1, the intensity of type A2 is greater during the winter months. The ridge axis of these anticyclones is usually located in the southwest-northeast direction.

A3:- The position of the anticyclone centre is over the region of Bulgaria. In this case there is almost no directed airflow at SLP and at 500hPa level (Fig. 3c2), (Fig. 3c1). The weather is usually calm and sunny, but in winter months, if this situation lasts for more days, fog or low clouds appear in low places due to the appearance of inversion layers at the higher levels in the atmosphere. In the mountain regions the weather remains sunny and almost quiet if the anticyclone is well developed in height.

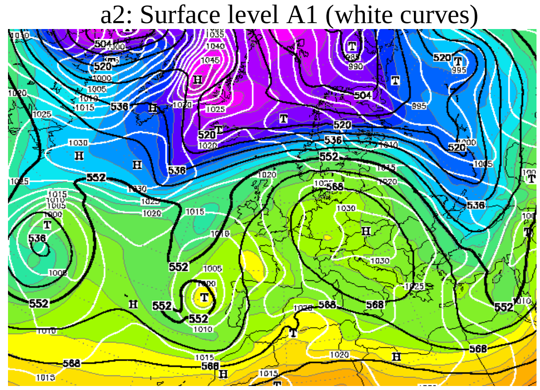
A4:- The high-pressure system is located west or southwest from the Balkans, south of 45th parallel and west of 20th meridian, over western and central Mediterranean or northern Africa. In most of the cases it is a ridge across Mediterranean from Azores anticyclone. Often a new anticyclone breaks out of it and turns into type A3. At 500hPa level and SLP (Fig. 3d1), (Fig. 3d2) airflow is from west quarter, which commonly leads to mild weather in the winter and sometimes hot spells in the summer over Balkan region.
A5:- The center of anti-cyclone is located southeast of the Balkans in the eastern Mediterranean or the Middle East (Fig. 3e1), (Fig. 3e2). The gradient is not as large as in A1 and A2. The winds are mostly weak of the southern quarter. This type is relatively less common than other anticyclone types at SLP level.

Mt2:- The whole continent from Ural to the Pyrenean Peninsula is occupied by a high pressure zone. A weak cyclone field can only exist in the central or eastern Mediterranean, also deeper only north of the British Isles and northern Scandinavia. The appearance of this anti-cyclone type is extremely rare and is only possible during the cold half-year (Fig. 5a3).

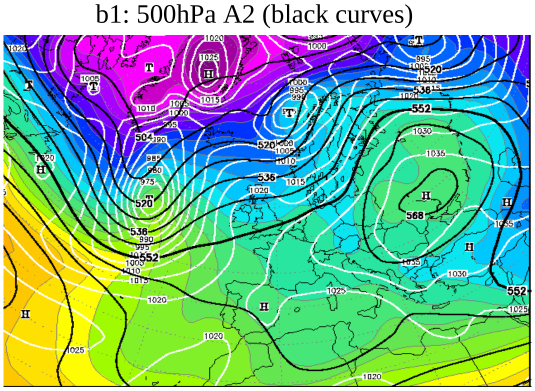
a1: 500hPa A1 (black curves)



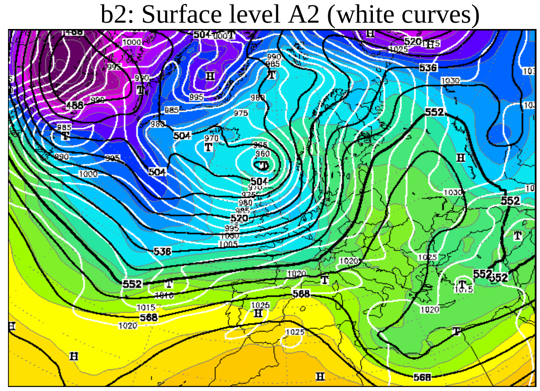
a2: Surface level A1 (white curves)



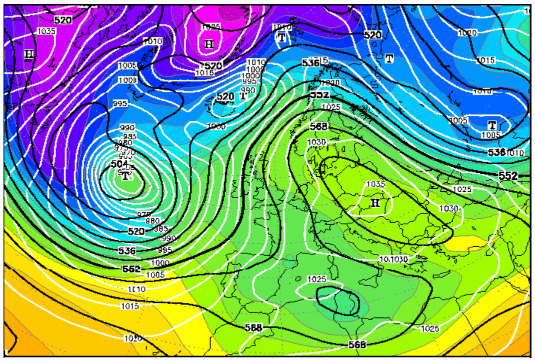
b1: 500hPa A2 (black curves)



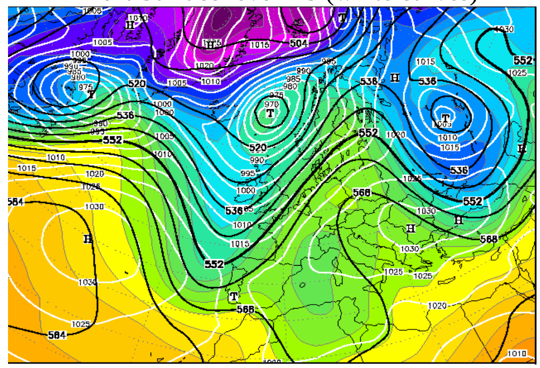
b2: Surface level A2 (white curves)



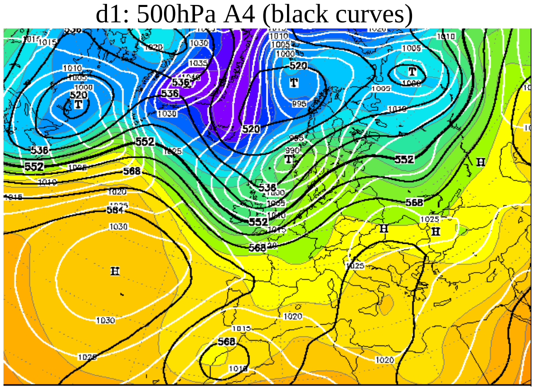
c1: 500hPa A3 (black curves)



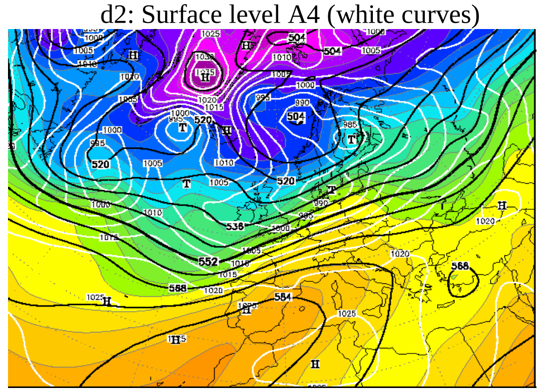
c2: Surface level A3 (white curves)



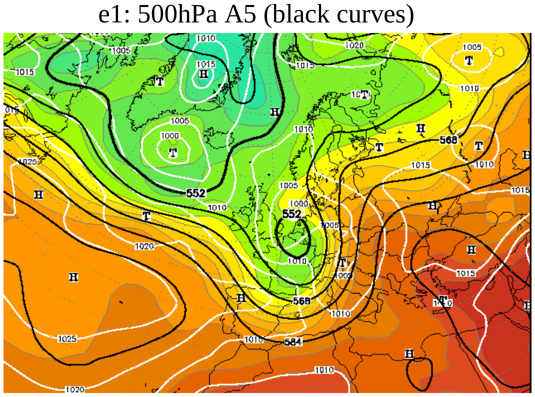
d1: 500hPa A4 (black curves)



d2: Surface level A4 (white curves)



e1: 500hPa A5 (black curves)



e2: Surface level A5 (white curves)

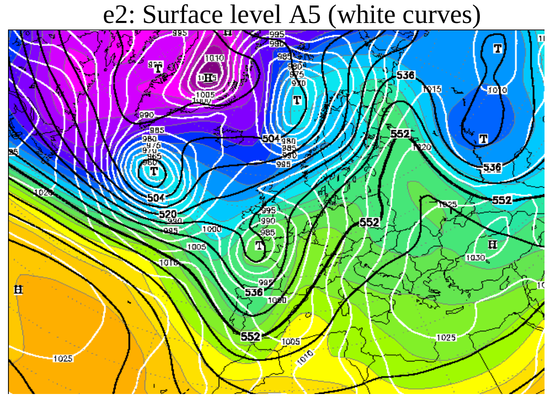
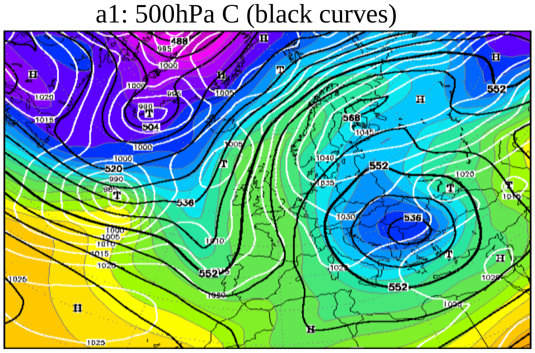
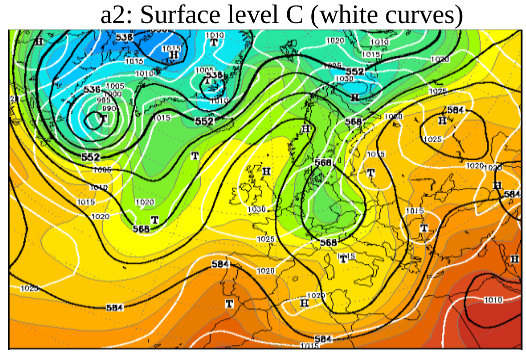


Fig. 3. Anti-cyclonic types: (a1- e1) - geopotencial height (500hPa); (a2-e2) - mean SLP (hPa)

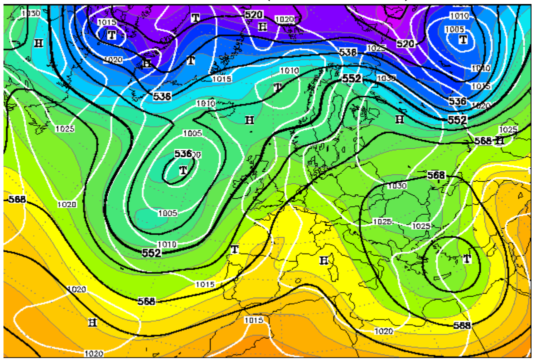
a1: 500hPa C (black curves)



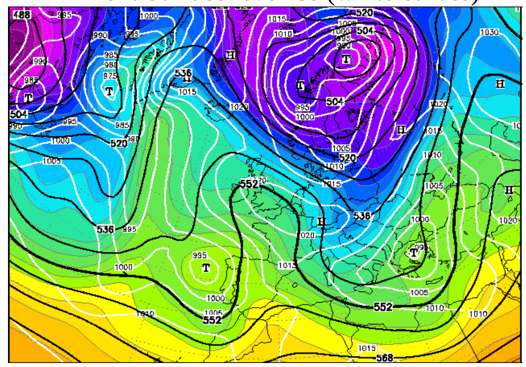
a2: Surface level C (white curves)



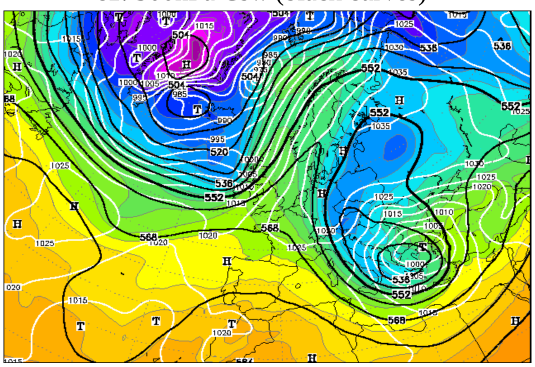
b1: 500hPa Cs (black curves)



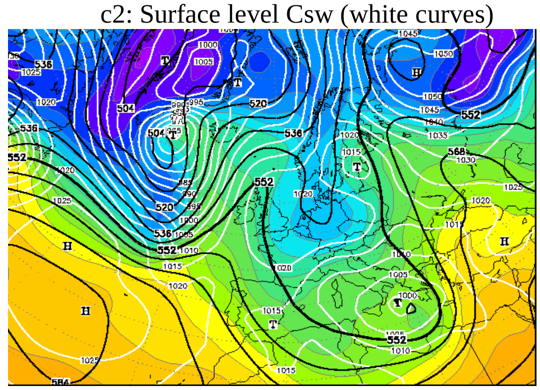
b2: Surface level Cs (white curves)



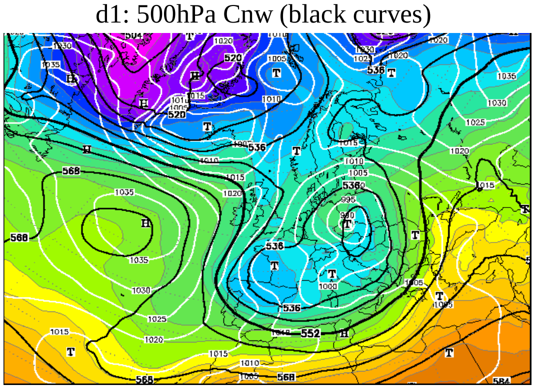
c1: 500hPa Csw (black curves)



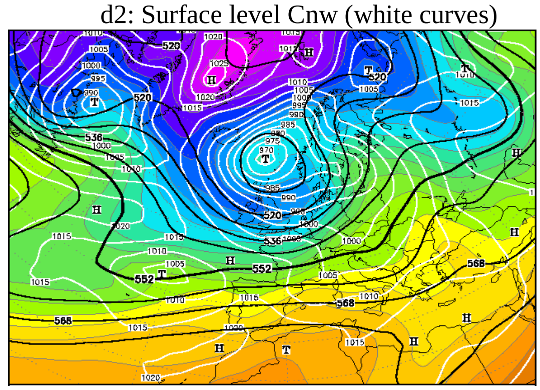
c2: Surface level Csw (white curves)



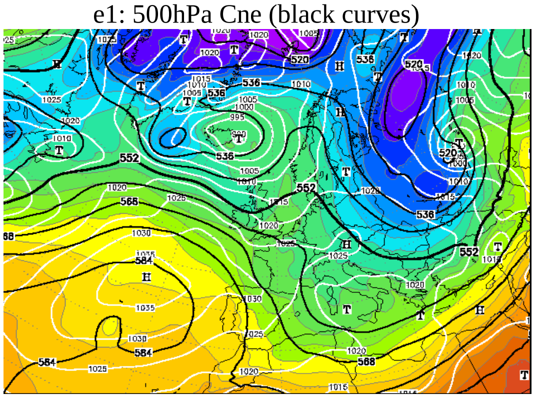
d1: 500hPa Cnw (black curves)



d2: Surface level Cnw (white curves)



e1: 500hPa Cne (black curves)



e2: Surface level Cne (white curves)

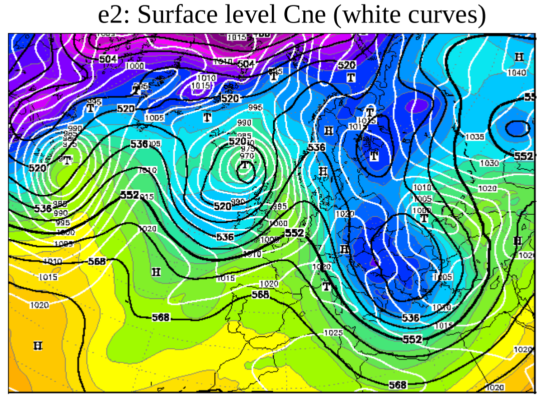


Fig. 4:-*Cyclonic types: (a1 - e1) - geopotencial height (500hPa); (a2 - e2) - mean SLP (hPa)*

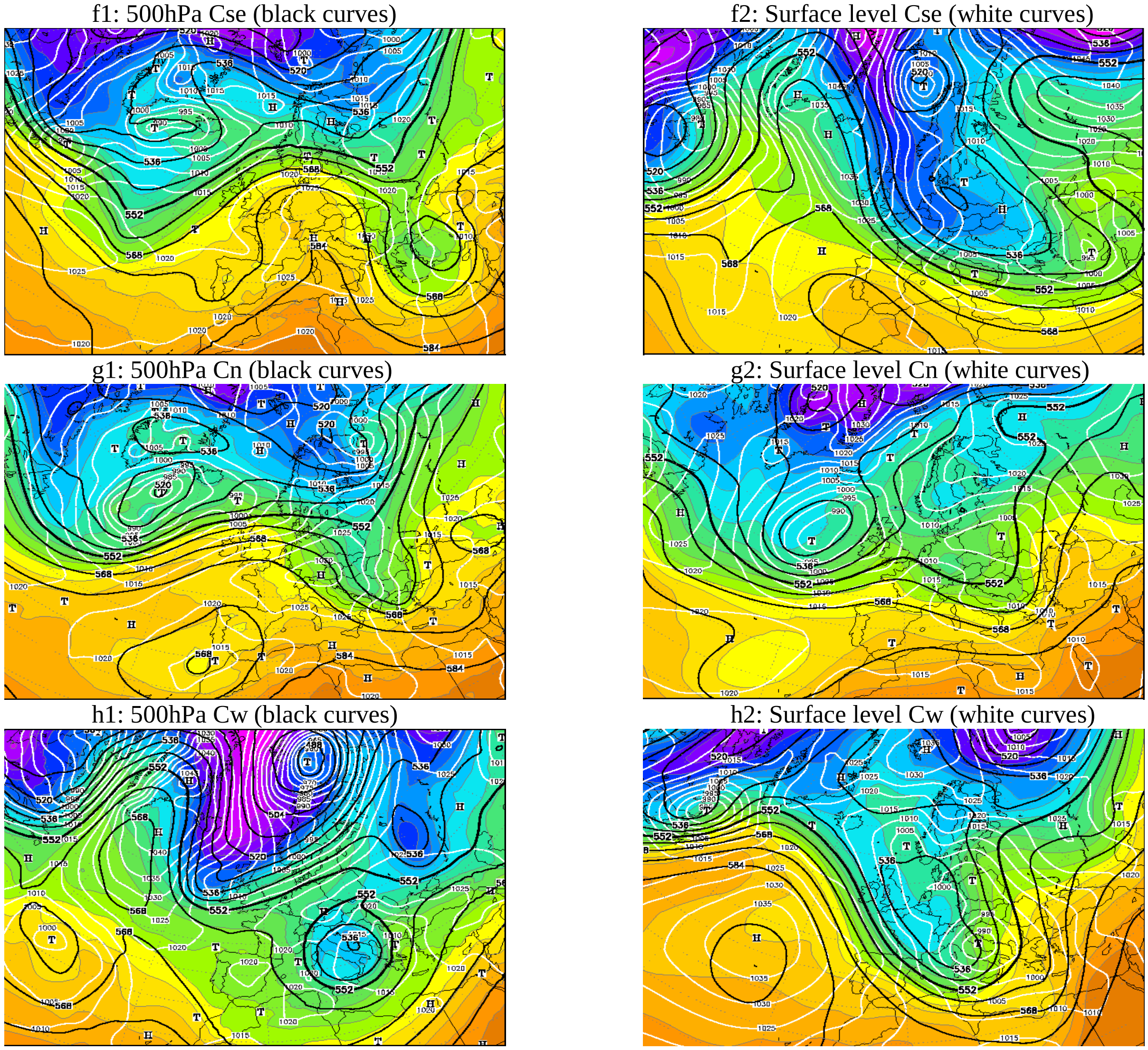


Fig. 4:-*Cyclonic types: (f1 - h1) - geopotencial height (500hPa); (f2 - h2) - mean SLP (hPa)*

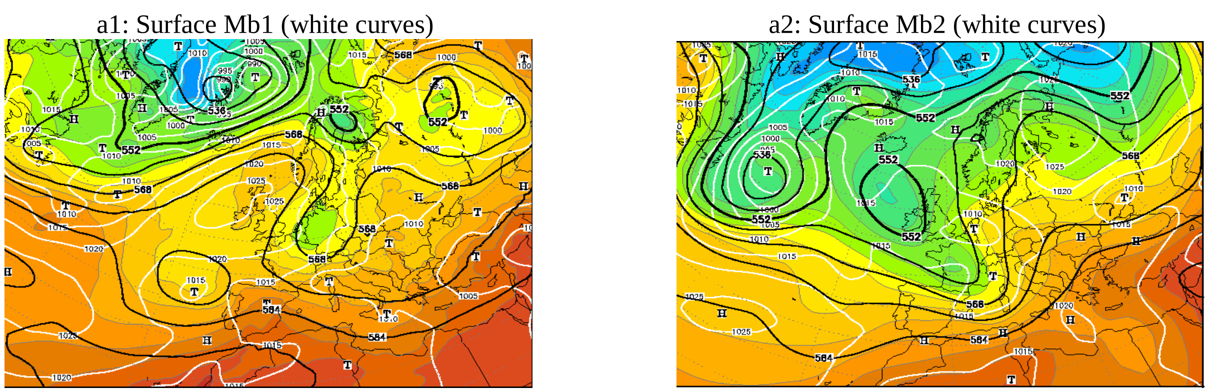


Fig. 5:- *Low gradient types; (a1 - a2) - mean SLP (hPa)*

a3: Surface Mt2 (white curves)

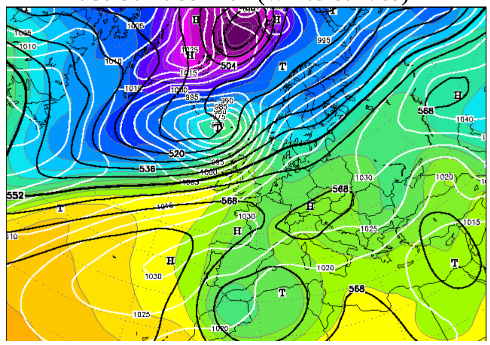


Fig. 5:-*Anticyclonic (a3) - mean SLP (hPa)*

Cyclonic types:-

C:- The centre of the cyclone at 500 hPa (Fig. 4a1), is situated above the territory of Bulgaria. The air flow at both levels in this case is not well directed, in eastern parts of the country having a southern component, and over the more western parts - north, northwest. At SLP level (Fig. 4a2) in most cases these are Mediterranean cyclones crossing the Balkans. The strength and direction of the surface flow depends on the depth and exact position of the center of the cyclone. It is usually associated with significant rainfall or snowfalls. These types of cyclones are more frequent and deeper in cold half-year.

Cs:- Low-pressure centre is in south direction of Bulgaria in the region of Aegean Sea, Crete Island or even towards African coast. Airflow is predominantly from east. This type appears more often in the winter like type C (Fig. 4b1, 4b2). At SLP (Fig. 4b2) it is Mediterranean cyclone and Bulgaria is in its cold sector in this case. The weather is characterized by considerable precipitations, with strong winds from the eastern quarter or blizzards in the winter.

Csw:- The centre of the cyclone is south of 40th parallel and west of 20th meridian over Ionian Sea, Sicily Island, the territory of western Balkans or even towards African coast near Tunisia. Bulgaria falls in its warm, front part. Also typical Mediterranean cyclone, more frequently appeared in the cold half of the year. (Fig. 4c1), (Fig. 4c2).

Cnw:- The axis of the throw or center of the cyclone is northwest of Bulgaria, often in central Europe, but it may also be positioned around British Isles, North Sea, or Scandinavia. The difference with the previous two types is that the low pressure system may be a throw and not as a separated high cyclone cut off from the high frontal zone, the center of which may be far north. The flow at 500hPa above the country is from southwest (Fig. 4d1). At SLP (Fig. 4d2) it can be deep Atlantic cyclone or Mediterranean cyclone moving in northeast direction. In both cases the airflow is from southwest and warm air masses are being transported to Bulgaria.

Cne:- At 500hPa (Fig. 4e1) the cyclone or the throw is positioned northeast of Bulgaria over the European territory of Russia or Ukraine. Airflow is from west or northwest. At SLP (Fig. 4e2) the cyclone may be Mediterranean with trajectory trough Black sea, or such coming from Baltic region in southeast direction towards Black Sea.

Cse:- At 500hPa (Fig. 4f1) in most cases, it is a standalone high cyclone which has been cut off by a throw with the most common axis Minor Asia - European Russia. It is most likely to be predicted by type Cne or Cn. It is possible, after some period of self-existence, to reunite with the high throw from the north. The flow in height above Bulgaria region is north and northeast. At SLP (Fig. 4f2) cyclone is located southeast of Bulgaria in the region of the eastern Mediterranean or Turkey. These are typically Mediterranean Cyclones, passing south of the Balkans or those crossing Aegean Sea to Black Sea through the strait zone. In warm season it can be also extension of the low pressure system over Persian Gulf known as "Persian Gulf Low" *(Guentchev and Winkler, 2010)*

Cn:- The axis of the throw passes through Bulgaria and is parallel to the meridian. The center of the low pressure area is north of Bulgaria in a quadrant locked generally between the 20th from the west and 30th meridian from the east and the 45th parallel from the south and may be far north to the polar region. At SLP it is often the case that if the cyclone is near the country, eastern Bulgaria falls into its forehead and there is the transfer from the southwest to warm air masses while western Bulgaria falls into its rear and the cold air is diverted from the northwest after the cold front. (Fig. 4g1) (Fig. 4g2)

Cw:- The high cyclone (Fig. 4h1) lies west of the country between the 40th and 45th parallel above the countries of the former Yugoslavia or to the west over the Adriatic, the Apennines or the Genoese Bay. A rarely more western throw/cyclone has an influence over our country. At SLP (Fig. 4h2) this is, in most cases, a classic Mediterranean cyclone but may be a very deep Atlantic cyclone. The region of Bulgaria falls entirely in its front part on the warm front. Higher gradients cause strong warm southern winds, especially in the areas north of the mountains – foehn.

Low gradient types:-

Mb1: It describes situations with air pressure gradient (smaller than 2.0 hPa/2.5 º) over the entire Mediterranean and the Balkans and when there is not closed isobar in the area of the peninsula. Sea Level Pressure (SLP) values are relatively low in the area under consideration compared to surrounding areas (Fig. 5a1)

Mb2: It describes situations with air pressure gradient (smaller than 2.5 hPa/2.5 º) over the entire Mediterranean and the Balkans, without closed isobar in surrounding area. Sea Level Pressure (SLP) values are relatively higher in the area under consideration compared to surrounding areas (Fig. 5a2).

Frequencies, variability and trends of the circulation types:-

In this paragraph at fig.(6-12) and tables 1, 2 and 3 are represented annual, seasonal and decadal frequencies for the period 1961-2016 and some variability and trends of the circulation types.

Frequency analysis (Tables 1 and 2, Fig. 6 and 7):-

At 500hPa level anticyclonic type A4 has the highest annual frequencies in the period (1961-2016) – 19.6%, followed by the cyclonic types Cne with 18.5%. Cnw =15.8% and A5=13.1%. The rest of the frequencies are ordered by size as follows: Cn=10.0%, Cse=5.2%, Cw=4.5%, C=3.7%, Csw=3.2%, Cs=2.7%, A1=2.1%, A3=1.1% and A2=0.8%. (Table 1 and Fig.6). The cumulative frequency for the anticyclonic types is 36.6% and 63.4% for the cyclonic At SLP frequencies are as follows: A1=16.4%, A2=15.2%, Mb1=12.6%, Mb2=12%, A4=6.2%, Cne=5.7%, A3=5.4%, Cnw=4.2%, Cw=3.8%, Cn=3.6%, Cse=3.1%, Cs=3.1%, C=3.0%, Csw=2.7%, A5=2.3% and Mt2=0.6%. Cumulative frequencies are 46.1% for anticyclonic types, 29.3% for cyclonic and 24.6% are low gradient types. (Table 2 and Fig.6).

At seasonal basis at 500hPa (Table 1, Fig.10) for the anticyclonic types the maximum frequency occurs in summer (40.2%) and minimum in winter (33.1%). The frequency in autumn (38.6%) is greater than in spring (34.5%). For the cyclonic types, the maximum frequency is in winter (66.9%) and minimum (59.8%) in summer. The frequency in spring (65.5%) is greater than in autumn (61.4%). At SLP (Table 2, Fig. 10) the maximum frequency of the anticyclone types is in autumn (56.0%), the minimum in spring (37.5%). The frequency in winter (50.9%) is greater than in summer (40.1%). The cyclonic types maximum is in winter (38.0%), the minimum is in summer (17.3%). The frequency in spring (36.2%) is greater than in autumn (25.8%). The low gradient types have maximum in summer (42.6%) and minimum in winter (11.1%) and their frequency in spring (26.3%) is greater than in autumn (18.2%). At 500hPa the most frequent types in winter are cyclonic Cne with 20.6% in the examined 56 years period, followed by anticyclonic A5=14.9%, Cnw=14.7%, A4=13.8%. In spring Cne=16.7%, A4=16.5%, Cnw=15.5%, A5=745. In summer the most dominant type is A4 with 28.8%, Cne=18.4%, Cnw=16.2% and Cn=10.0% and in the autumn – A4=19.2%, Cne=18.2%, Cnw=16.6% and A5=15.1%. At SLP the most frequent types are: A1=17.7%, A2=14.6%, A4=7.5%, Mb2=6.4%, A3=6.3%, Cw=6.2%, Cne=6.2% in winter, A2=14.8%, Mb1=14.6%, Mb2=11.7%, A1=10.7%, Cne=6.9% and Cnw=5.3% in spring, Mb1=22.2%, Mb2=20.4%, A1=17.4%, A2=9.8% and A4=7.1% in summer and A2=21.6%, A1=19.6%, Mb2=9.3%, Mb1=8.9% in autumn. Although most of the cyclonic types have less appearance (especially in summer) compared to others, their existence is important, because they are cause of most of the significant precipitations. The biggest difference in frequency between winter and summer season at (SLP) is observed in the types Cw – from 315 days during the winters in the 56 years period (6.2% of all types) to just (49 days/1.0%) in summer and Csw – (264 days/5.2%) in winter to (20 days/0.4%) in summer. This result corresponds very well with the summer minimum of the Mediterranean cyclones. The seasonal distribution of all the types at 500hPa and SLP are represented at (Fig. 7) and (Fig. 10).

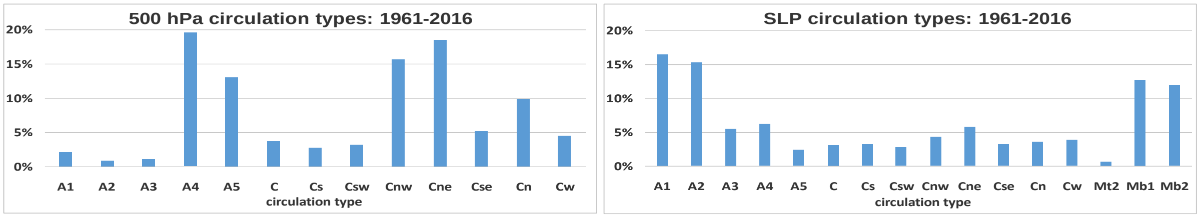


Fig.6:- *Frequency of the circulation types at 500hPa and SPL for the period 1961-2016*

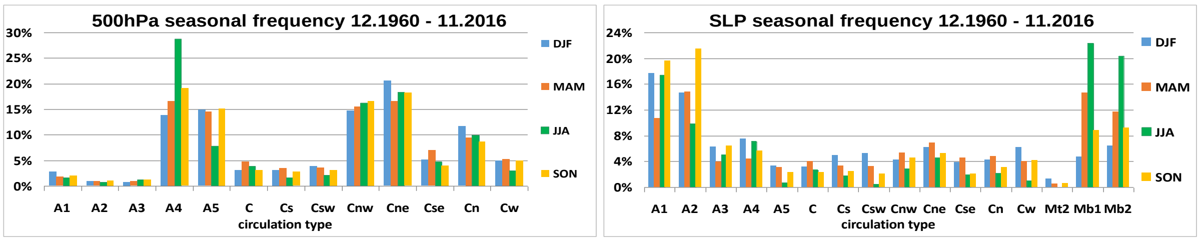


Fig.7:- *Seasonal frequency of the circulation types (**DJF**-winter; **MAM**-spring; **JJA**-summer; **SON**-autumn)*

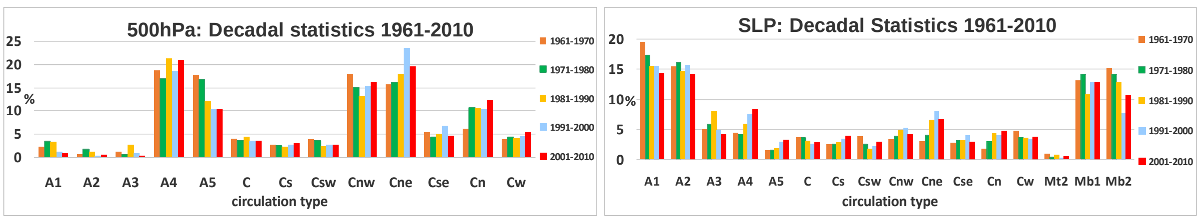


Fig.8a:- *Decadal annual frequency of the circulation types (1961-2010)*

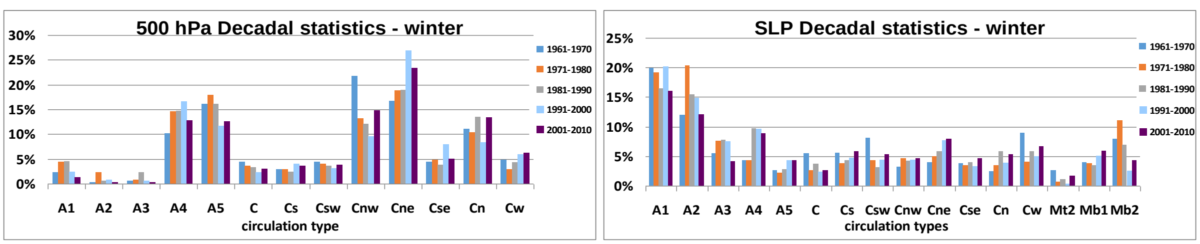


Fig.8b:- *Decadal seasonal frequency of the circulation types (1961-2010) - winter*

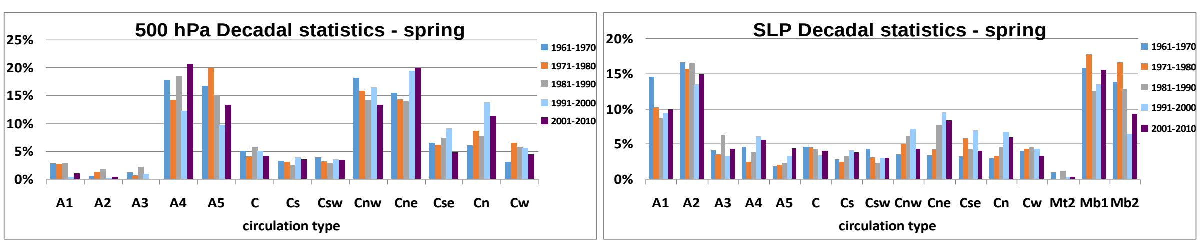


Fig.8c:- *Decadal seasonal frequency of the circulation types (1961-2010) – spring*

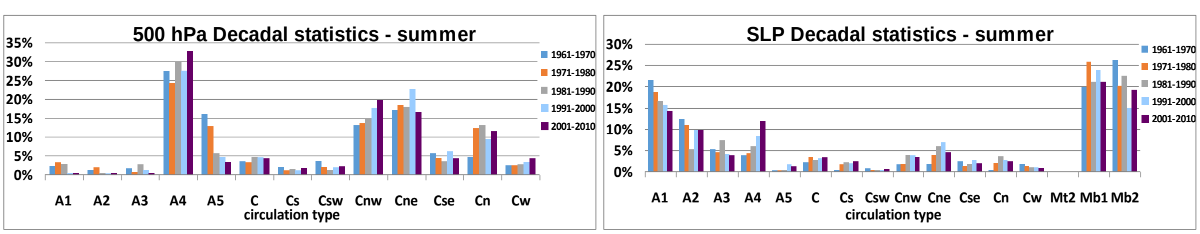


Fig.8d:– *Decadal seasonal frequency of the circulation types (1961-2010) – summer*

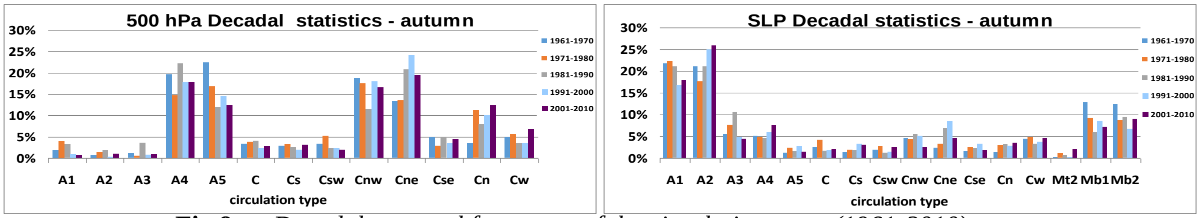


Fig.8e:– *Decadal seasonal frequency of the circulation types (1961-2010) – autumn*

Variability and trend of the circulation types (Table1, 2 and 3, Fig. 8a-8e, 9,11,12,13):-

The variability in the frequencies of the circulation types by decades in the period 1961-2010, annual and seasonal are presented at (Fig. 8a-8e). A significant trend can be observed in some of the types, both on an annual and on a seasonal basis. As a hole at 500hPa there is a decreasing of the anticyclonic types and increasing of the cyclonic types. At SLP surface the frequency of the anticyclonic types stays almost unchanged during this five decades period, whereas cyclonic types have increased of their frequency at the expense of the low gradient types, which frequency decreases (Tables 1 and 2).

At 500hPa about the trend during these 56 years (1961-2016) it can be seen increasing of the types A4, 2.4 for 10 years, Cne – 3.4/10 years, Cn – 2.9/10 years and Cw – 1.3/10 years on an annual basis. The trend for the types Cs, Cse and Cnw is also positive, but less than 1/10 years. There is a weaker negative trend (0 ≥ -1/10 years) in the types A2, A3, C and Csw. With more significant negative trend are the types A1 – (-1.9/10 years) and especially A5 – (-6.8/10 years) (Table 3, Fig. 9). A5 (500hPa) type is often a ridge of Azores high, but located to the east of a weak throw located over Aegean sea. One possible reason for such significant decrease of this type is positive trend of type A4 (500hPa), so this affects more often as stronger ridge from Azores high and thus contributes to dissipation of the throw over Aegean sea. Increasing of type A4 (SLP) also leads type A1 (SLP) to decrease and this dependence is particularly noticeable during the summer (Fig.11), as this fact could be associated with the warmer summers in the last two decades, because A1(SLP) anticyclone type is a cause for invasion of cooler air masses from north and northwest from the Atlantic toward the Balkans and Bulgaria, while type A4 (500hPa and SLP) is almost always a factor when warm and hot air comes from west and south west direction.

At SLP, the types with most significant positive trend are A4 – 3.5/10 years, Cne – 3.3/10 years, Cn – (2.1/10 years) and Cs – (1.4/10 years). Low gradient type Mb2 – (-4.6/10 years) and anti-cyclonal A1 – (-3.6/10 years), are the types with the largest negative trend (Table 3, Fig. 9). Except the trends Table 3 presents also the year and the number of days for that year, when each type has minimum and maximum. The sign of the trends for most of the types is the same at 500hPa and SLP.

			Anticyclonic	types						Cyclonic	types					
500	hPa	A1	A2	A3	A4	A5	Total	C	Cs	Csw	Cnw	Cne	Cse	Cn	Cw	Total
1961-2016	Winter	2.8	0.8	0.8	13.8	14.9	33.1	3.1	3.1	3.9	14.7	20.6	5.0	11.6	4.9	66.9
1961-2016	Spring	1.8	0.8	0.9	16.5	14.5	34.5	4.7	3.4	3.6	15.5	16.7	6.9	9.5	5.2	65.5
1961-2016	Summer	1.6	0.7	1.3	28.8	7.8	40.2	3.9	1.6	2.1	16.2	18.3	4.7	10.0	3.0	59.8
1961-2016	Autumn	2.0	1.0	1.3	19.2	15.1	38.6	3.2	2.7	3.1	16.7	18.2	4.0	8.7	5.0	61.4
1961-2016	Annual	2.1	0.8	1.1	19.6	13.1	36.6	3.7	2.7	3.2	15.8	18.5	5.2	10.0	4.5	63.4
1961-1970	Annual	2.2	0.7	1.1	18.8	17.8	40.6	4.0	2.8	3.8	17.9	15.7	5.3	6.2	3.7	59.4
1971-1980	Annual	3.5	1.7	0.6	17.0	16.7	39.5	3.6	2.5	3.6	15.1	16.3	4.5	10.6	4.3	60.5
1981-1990	Annual	3.3	1.1	2.7	21.3	12.2	40.6	4.4	2.2	2.4	13.2	17.9	4.8	10.5	4.0	59.4
1991-2000	Annual	1.0	0.3	0.8	18.6	10.1	30.8	3.5	2.7	2.6	15.4	23.3	6.7	10.4	4.6	69.2
2001-2010	Annual	0.8	0.5	0.4	21.0	10.3	33.0	3.5	2.9	2.8	16.0	19.7	4.6	12.1	5.4	67.0
1961-1970	Winter	2.3	0.3	0.6	10.2	16.1	29.5	4.3	2.9	4.4	21.9	16.7	4.4	11.0	4.9	70.5
1971-1980	Winter	4.3	2.3	0.7	14.6	17.9	39.8	3.5	2.8	4.0	13.2	18.8	4.8	10.3	2.8	60.2
1981-1990	Winter	4.5	0.6	2.2	14.7	16.2	38.2	3.2	2.4	3.5	12.1	19.1	3.9	13.4	4.2	61.8
1991-2000	Winter	2.4	0.7	0.6	16.5	11.6	31.8	2.3	4.0	3.1	9.5	26.9	8.0	8.4	6.0	68.2
2001-2010	Winter	1.3	0.2	0.3	12.7	12.5	27.0	3.0	3.5	3.8	14.8	23.4	5.0	13.3	6.2	73.0
1961-1970	Spring	2.7	0.5	1.1	17.8	16.6	38.7	5.0	3.3	3.9	18.3	15.4	6.5	6.0	2.9	61.3
1971-1980	Spring	2.6	1.2	0.7	14.2	19.9	38.6	4.0	2.9	3.2	15.8	14.3	6.1	8.6	6.5	61.4
1981-1990	Spring	2.7	1.7	2.2	18.6	15.1	40.3	5.8	2.5	2.7	14.1	13.9	7.3	7.6	5.8	59.7

1991-2000	**Spring**	0.4	0.1	0.9	12.2	9.7	**23.3**	5.0	3.9	3.5	16.3	19.5	9.1	13.7	5.7	**76.7**
2001-2010	**Spring**	1.0	0.4	0.0	20.7	13.4	**35.5**	4.1	3.5	3.4	13.3	19.8	4.8	11.3	4.3	**64.5**
1961-1970	**Summer**	2.2	1.2	1.6	27.4	16.0	**48.4**	3.4	2.1	3.7	12.8	16.9	5.7	4.6	2.4	**51.6**
1971-1980	**Summer**	3.2	1.8	0.5	24.2	12.7	**42.4**	3.3	1.1	2.1	13.7	18.5	4.3	12.2	2.4	**57.6**
1981-1990	**Summer**	2.7	0.3	2.6	29.8	5.7	**41.1**	4.6	1.3	1.2	15.0	17.9	3.4	13.0	2.5	**58.9**
1991-2000	**Summer**	0.4	0.1	1.2	27.4	4.6	**33.7**	4.5	1.1	1.7	17.5	22.6	6.1	9.5	3.3	**66.3**
2001-2010	**Summer**	0.3	0.4	0.3	32.6	3.2	**36.8**	4.1	1.5	2.0	19.7	16.4	4.1	11.3	4.1	**63.2**
1961-1970	**Autumn**	1.8	0.5	1.0	19.7	22.5	**45.5**	3.3	2.9	3.3	18.8	13.4	4.7	3.4	4.7	**54.5**
1971-1980	**Autumn**	4.0	1.3	0.4	14.7	16.8	**37.2**	3.7	3.1	5.3	17.6	13.5	2.9	11.2	5.5	**62.8**
1981-1990	**Autumn**	3.1	1.8	3.6	22.2	12.0	**42.7**	4.1	2.5	2.3	11.4	20.9	4.7	7.9	3.5	**57.3**
1991-2000	**Autumn**	0.9	0.3	0.8	17.8	14.6	**34.4**	2.3	2.0	2.2	18.0	24.2	3.5	10.0	3.4	**65.6**
2001-2010	**Autumn**	0.5	1.0	0.9	17.9	12.3	**32.6**	2.7	3.2	2.0	16.5	19.5	4.4	12.3	6.8	**67.4**

Table 1 – Frequency of circulation types (in %) at 500hPa

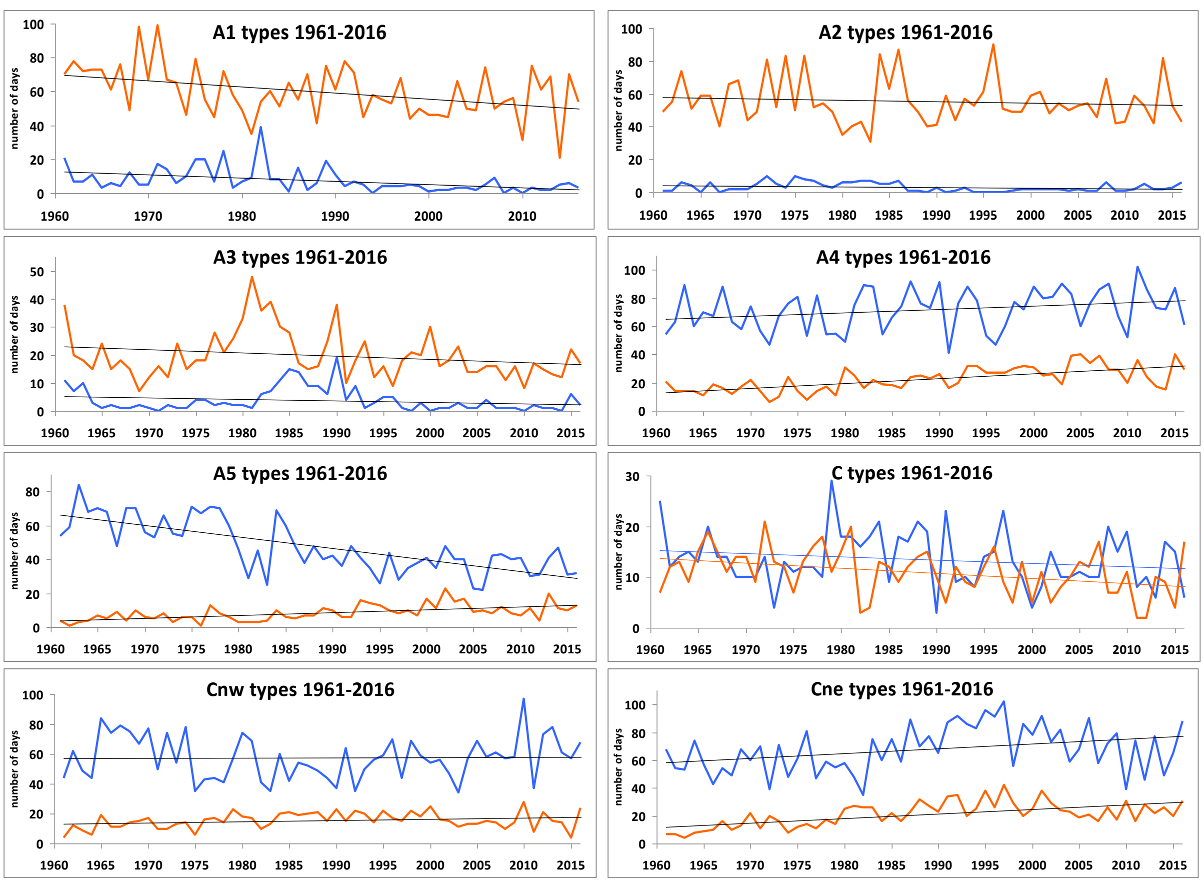
			Anticyclonic			**types**					**Cyclonic**			**types**				**Mb**	**types**	
	SLP	**A1**	**A2**	**A3**	**A4**	**A5**	**Mt2**	**Total**	**C**	**Cs**	**Csw**	**Cnw**	**Cne**	**Cse**	**Cn**	**Cw**	**Total**	**Mb1**	**Mb2**	**Total**
1961-2016	**Winter**	17.7	14.6	6.3	7.5	3.4	1.3	**50.9**	3.1	4.9	5.2	4.2	6.2	3.8	4.3	6.2	**38.0**	4.7	6.4	**11.1**
1961-2016	**Spring**	10.7	14.8	4.0	4.4	3.0	0.5	**37.5**	4.1	3.4	3.2	5.3	6.9	4.5	4.8	4.1	**36.2**	14.6	11.7	**26.3**
1961-2016	**Summer**	17.4	9.8	5.0	7.1	0.7	0.0	**40.1**	2.7	1.8	0.4	2.8	4.5	1.9	2.2	1.0	**17.3**	22.2	20.4	**42.6**
1961-2016	**Autumn**	19.6	21.6	6.4	5.6	2.2	0.5	**56.0**	2.2	2.4	2.1	4.6	5.2	2.1	3.1	4.1	**25.8**	8.9	9.3	**18.2**
1961-2016	**Annual**	**16.4**	**15.2**	**5.4**	**6.2**	**2.3**	**0.6**	**46.1**	**3.0**	**3.1**	**2.7**	**4.2**	**5.7**	**3.1**	**3.6**	**3.8**	**29.3**	**12.6**	**12.0**	**24.6**
1961-1970	**Annual**	19.5	15.5	5.0	4.5	1.5	0.9	**46.8**	3.7	2.5	3.8	3.2	2.9	2.7	1.7	4.7	**25.1**	13.1	15.2	**28.3**
1971-1980	**Annual**	17.6	16.2	5.8	3.9	1.7	0.4	**45.5**	3.7	2.4	2.5	3.9	4.1	3.2	2.9	3.5	**26.3**	14.1	14.1	**28.2**
1981-1990	**Annual**	15.7	14.5	8.0	6.0	1.8	0.7	**46.5**	3.1	2.9	1.7	4.9	6.5	3.0	4.3	3.6	**29.9**	10.7	12.9	**23.6**
1991-2000	**Annual**	15.5	15.8	4.9	7.5	2.9	0.2	**46.7**	2.6	3.5	2.3	5.1	8.2	4.0	4.0	3.4	**33.0**	12.6	7.7	**20.3**
2001-2010	**Annual**	14.3	14.4	4.3	8.3	3.4	0.5	**45.1**	2.8	3.8	2.9	4.2	6.6	2.9	4.6	3.8	**31.6**	12.8	10.5	**23.3**
1961-1970	**Winter**	20.0	12.0	5.4	4.3	2.7	2.7	**47.1**	5.4	5.5	8.1	3.2	3.9	3.8	2.3	8.9	**41.1**	3.9	8.0	**11.9**
1971-1980	**Winter**	19.2	20.4	7.6	4.3	2.1	0.6	**54.2**	2.7	3.8	4.2	4.7	5.0	3.4	3.4	4.0	**31.1**	3.8	11.0	**14.7**
1981-1990	**Winter**	16.5	15.4	7.8	9.8	2.8	1.1	**53.3**	3.7	4.3	3.1	4.1	5.8	3.9	5.8	5.8	**36.4**	3.4	6.9	**10.3**
1991-2000	**Winter**	20.2	14.8	7.4	9.6	4.2	0.3	**56.6**	2.3	4.8	4.4	4.4	7.8	3.3	3.9	5.0	**35.9**	5.1	2.4	**7.5**
2001-2010	**Winter**	16.0	12.1	4.1	8.9	4.2	1.7	**46.9**	2.7	5.8	5.3	4.7	8.0	4.7	5.3	6.7	**43.0**	5.9	4.2	**10.1**
1961-1970	**Spring**	14.5	16.5	4.0	4.6	1.7	0.9	**42.2**	4.6	2.7	4.2	3.5	3.4	3.2	2.8	3.9	**28.3**	15.8	13.8	**29.6**
1971-1980	**Spring**	10.1	15.7	3.5	2.4	2.0	0.0	**33.6**	4.5	2.4	3.0	4.9	4.1	5.8	3.3	4.2	**32.2**	17.7	16.5	**34.2**
1981-1990	**Spring**	8.6	16.4	6.2	3.7	2.3	1.1	**38.3**	4.2	3.2	2.3	6.1	7.6	4.1	4.6	4.5	**36.5**	12.4	12.8	**25.2**
1991-2000	**Spring**	9.3	13.4	3.3	6.0	3.3	0.3	**35.6**	3.4	4.0	2.9	7.1	9.5	6.8	6.7	4.2	**44.6**	13.4	6.4	**19.8**
2001-2010	**Spring**	9.9	14.9	4.2	5.5	4.3	0.3	**39.2**	3.9	3.7	2.9	4.2	8.3	3.9	5.9	3.3	**36.1**	15.4	9.2	**24.7**
1961-1970	**Summer**	21.5	12.2	5.2	3.8	0.2	0.0	**42.9**	2.2	0.3	0.7	1.5	1.9	2.3	0.4	1.7	**11.0**	19.9	26.2	**46.1**
1971-1980	**Summer**	18.6	11.0	4.5	4.3	0.2	0.0	**38.6**	3.4	1.6	0.3	1.7	3.9	1.2	2.0	1.2	**15.3**	25.9	20.2	**46.1**
1981-1990	**Summer**	16.5	5.1	7.3	5.9	0.4	0.0	**35.2**	2.7	2.2	0.3	3.9	5.9	1.8	3.5	0.9	**21.2**	21.1	22.5	**43.6**
1991-2000	**Summer**	15.7	9.8	4.1	8.4	1.5	0.0	**39.5**	3.0	1.7	0.3	3.7	6.7	2.7	2.6	0.9	**21.7**	23.8	15.0	**38.8**
2001-2010	**Summer**	14.2	9.8	3.7	12.0	1.1	0.0	**40.8**	3.3	2.4	0.5	3.4	4.5	1.7	2.4	0.7	**18.8**	21.2	19.2	**40.4**
1961-1970	**Autumn**	21.8	21.1	5.4	5.2	1.2	0.1	**54.8**	2.5	1.3	2.0	4.6	2.3	1.4	1.3	4.4	**19.8**	12.9	12.5	**25.4**
1971-1980	**Autumn**	22.3	17.6	7.7	4.7	2.3	1.0	**55.6**	4.2	1.9	2.6	4.3	3.3	2.5	3.0	4.7	**26.5**	9.2	8.7	**17.9**
1981-1990	**Autumn**	21.1	21.0	10.5	4.6	1.5	0.5	**59.3**	1.6	1.8	1.2	5.5	6.8	2.2	3.1	3.2	**25.4**	5.9	9.3	**15.3**
1991-2000	**Autumn**	16.8	24.9	4.7	5.8	2.6	0.1	**55.0**	1.8	3.3	1.4	5.2	8.4	3.2	2.7	3.6	**29.6**	8.6	6.8	**15.4**
2001-2010	**Autumn**	17.1	20.7	5.1	6.7	3.8	0.1	**53.5**	1.2	3.4	3.0	4.5	5.6	1.2	5.1	4.5	**28.5**	8.8	9.2	**18.0**

Table 2 – Frequency of circulation types (in %) at SLP

type/500hPa	A1	A2	A3	A4	A5	C	Cs	Csw	Cnw	Cne	Cse	Cn	Cw			
min (year)	0	0	0	41 (1991)	22 (2006)	3 (1990)	1(1976,87)	2 (1988,95)	34 (2003)	35 (1982)	4 (1976)	9 (1963)	4 (1997)			
max (year)	39 (1982)	10 (1972,75)	19 (1990)	102 (2011)	84 (1963)	29 (1979)	20 (2006)	24 (1961)	97 (2010)	102 (1997)	33 (2000,05)	64 (2004)	36 (2014)			
trend/10y.	-1.9	-0.4	-0.5	2.4	-6.8	-0.7	0.5	-0.4	0.2	3.4	0.026	2.9	1.3			
type/SLP	A1	A2	A3	A4	A5	C	Cs	Csw	Cnw	Cne	Cse	Cn	Cw	Mt2	Mb1	Mb2
min (year)	21 (2014)	31 (1983)	7 (1969)	6 (1972)	1(1962, 76)	2 (2011,12)	3(1961)	2(1990,00)	4 (1961,15)	4 (1963)	5(1963,16)	3 (1961,63)	7 (1973,98)	0	23(1984)	15(1996)
max (year)	99 (1971)	90 (1996)	48 (1981)	40 (2005, 15)	23 (2002)	21 (1972)	28 (2014)	19 (2015)	28 (2010)	42 (1997)	26(1991,98)	27 (2005)	28 (2013)	13 (1961)	70(1968)	69(1975)
trend/10y.	-3.6	-0.9	-1.2	3.5	1.6	-1	1.4	-0.2	0.9	3.3	0.014	2.1	-0.4	-0.1	-0.6	-4.6

Table 3:- *Linear trends of circulation types for 10 years, number of days and year of minimum and maximum*

Exceptions are only Cw and A5 types. Cw (500hPa) trend is positive (1.3/10 years), while Cw (SLP) trend is downward (-0.4/10 years). A5 (500hPa) has the greatest negative trend of all types (-6.8/10 years), but A5 (SLP) trend is (1.6/10 years). Other interesting dependency is observed about Cnw and Cne types at 500hPa.. Both types are high throws with axis respectively westward and eastward of the territory of Bulgaria. Their distributions are almost in antiphase to each other, as the maximum of Cne type is around nineties and at that time Cnw type has its minimum. This dependence is observed in all seasons, but is strongest in winter and spring. This is presented at (Fig.12) with 5 year running mean for both Cnw and Cne types at 500hPa level. Despite small territory of Bulgaria the exact position of the high throw can affect the meteorological elements in different manner in the different parts of the country. For example Cnw circulation type at 500hPa in common leads to greater amounts of precipitation in western parts of the country, while Cne type is a cause of relatively more precipitations in the eastern parts. Csw (SLP) type linear trend is close to zero for the period 1961-2016 (Table 3), but if that period is divided on two equal parts we are going to see decreasing trend in the first half and increasing trend in the second half of the period with minimum around 1990. Csw (SLP) type is also shown at (Fig. 13) with 5 years moving average trend line. This result is in relation with decreased precipitations in the region of Bulgaria at that time *(Aleksandrov, 2003)*, but such connections between the circulation types and meteorological elements will be searched in more detail in future work.



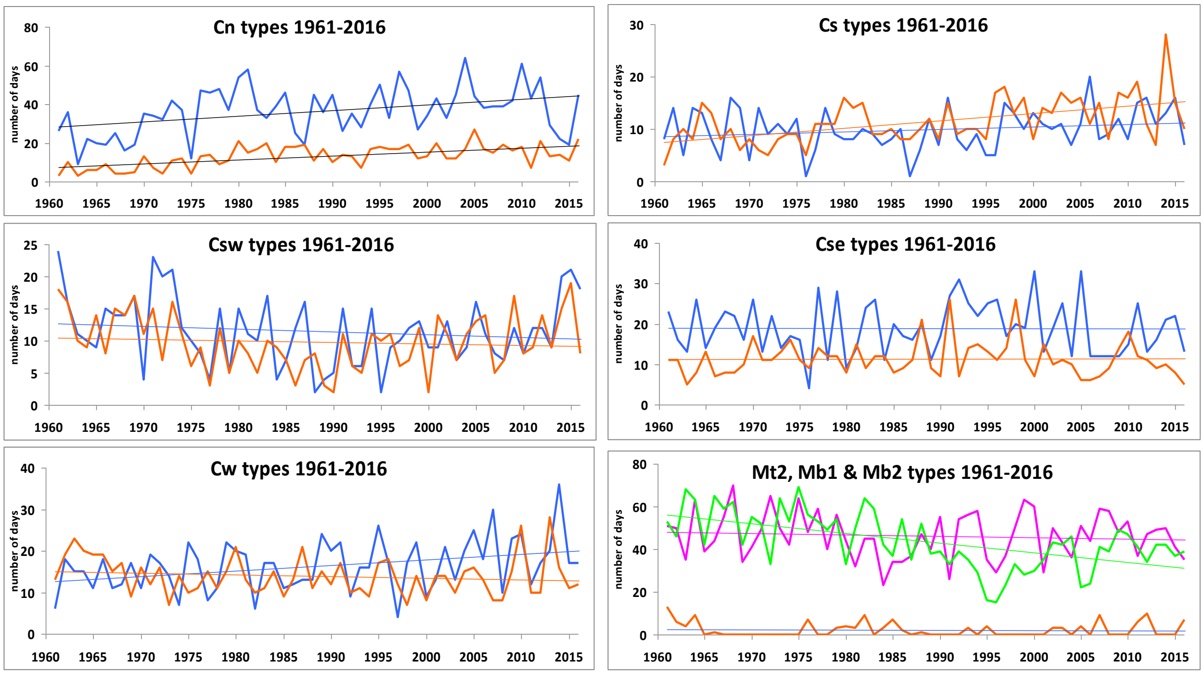


Fig.9:– *Annual number of days of the circulation types (1961-2016)*

- *circulation types at 500hPa*
- *circulation types at SLP*
- *Mb1 - low gradient cyclone type*
- *Mb2 - low gradient-cyclone type*

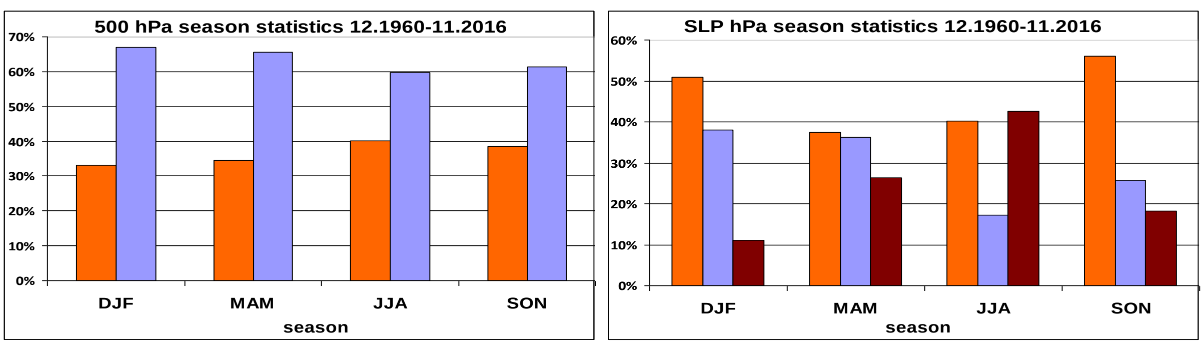


Fig.10:- *Seasonal distribution of the (anticyclone ■), (cyclone ■) and (low gradient ■) circulation types*

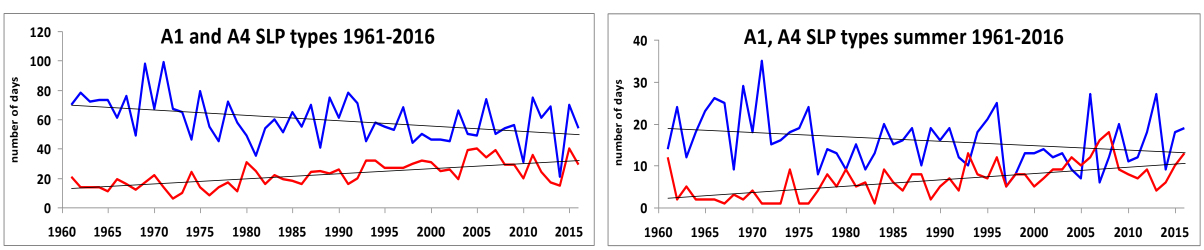


Fig.11:- *Annual (left) and summer (right) (A1 —) and (A4 —) SLP types*

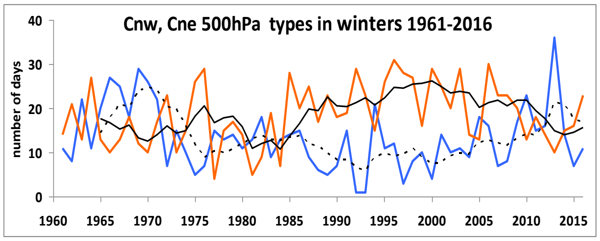


Fig.12: *- (Cnw ▬) and (Cne ▬) SLP winter types*

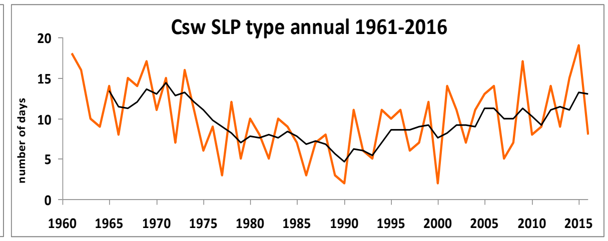


Fig.13:- *(Csw ▬) SLP type - annual*

Conclusions:-

Manual (subjective) approach is used for the classification of circulation types over Bulgaria in the period 1961 - 2016. The main advantage of the manual approach is that every single synoptic map is checked manually in the examined period in 00, 06, 12, 18 UTC each day. One of the main disadvantages is related with the separation between anti-cyclonic and low gradient and between cyclonic and low gradient types which is sometimes difficult to be distinguished subjectively.

At the level of 500hPa in the middle troposphere 13 types are differentiated, 5 anticyclonic (A1, A2, A3, A4, A5) and 8 cyclonic (C, Cne, Cnw, Cn, Cw, Csw, Cs, Cse). From the SLP maps differentiated types are 16, 6 anticyclonic (A1, A2, A3, A4, A5, Mt2), 8 cyclonic (C, Cne, Cnw, Cn, Cw, Csw, Cs, Cse) and 2 low gradient types (Mb1, Mb2). Statistics was made of the frequency of each of the types on a year-round basis, by seasons, by decades and also inter-annual variability. The main conclusions of this work are marked below:

1. For the whole period 1961-2016 at 500hPa cyclonic types with 63,4% prevails over the anticyclonic 36,6%, while at SLP anticyclonic types dominate with 46,1% over cyclonic types with 29,3% and 24,6% for both low gradient types *(Table 1, 2)*
2. The most frequent types at 500hPa is A4 with 19,6%, Cne with 18.5%. Cnw =15.8%. This shows the domination of the ridges from the Azores anti-cyclone and the high throws from the northeast and northwest over the region of Bulgaria. *(Table 1)(Fig.6)*
3. At SLP the most dominant types are A1 with 16,4%, A2 – 15,2%, Mb1 – 12,6% and Mb2 – 12,0%. A1 type is often ridge from Azores high, extended to northeast toward British Isles or central Europe, A2 in most of the cases is a ridge from Siberian high pressure zone. Mb1 and Mb2 low gradient types are the most dominant types in summer season *(Table 2)(Fig.6)*
4. In anticyclonic types at 500hPa A4 has increasing trend, but A5 type has the most decreasing trend of all types which is due to increased activity of Azores high.
5. Cyclonic types at 500hPa with the most significant positive trend are the types Cne and Cn which means increasing number of situations with high throws from northeast towards Bulgaria. *(Fig. 9) (Table 3)*
6. Amongst anticyclonic types at SLP A4 has also as at 500hPa the most increasing trend, A1 has the most decreasing trend and this result is also related with increased activity of Azores maximum. This tendency is most significant in summer, so this type of circulation maybe considered as a major reason of the warmer summers especially in last two decades. *(Fig.11)*
7. Cyclonic types Cne and Cn at SLP as in 500hPa have the most significant positive trend. *(Fig.9)*
8. Decadal statistics at annual basis *(Table 1, 2)* at 500hPa shows decreasing of the anticyclonic and increasing cyclonic circulation in last two decades after 1990. At SLP there is increasing trend in cyclonic circulation and decreasing in low gradient circulation types, while frequency of anticyclonic types stays almost the same.
9. At seasonal basis *(Fig.10)* at 500hPa winter is the season with greatest cyclonic circulation and the least anticyclonic, while in the summer situation is opposite as a consequence of northern position of the polar front of the high frontal zone. At SLP the most frequent type in summer is low gradient, prevailing of cyclonic types is in winter and in spring and in autumn the anticyclonic types have greatest appearance.
10. The sign of the trends for most of the types (except A5 and Cw) is the same at 500hPa and SLP *(Table 3) (Fig. 9)*
11. Cnw and Cne types at 500hPa *(Fig.12)* are in antiphase to each other and this dependence is a fact in all seasons and is strongest in winter. High throws from northwest (Cnw type) are often the cause cold air masses reaching Mediterranean and further forming Mediterranean cyclones to affect the Balkans in different ways, depending on their trajectory. Cnw type has minimum in 1990-2000 decade, when when Cne type has its maximum. Cne

high throws could be a cause for Mediterranean cyclones with more easterly origin, around east from Crete Island or Cyprus, but these kind of cyclones has less influence concerning territory of Bulgaria.

12. Csw type at SLP *(Fig.13)* as mentioned above is typical Mediterranean cyclone with origin usually in Middle Mediterranean. Its minimum, as type Cnw (500hPa), is in the period 1990-2000 which is in relation with decreased amounts of precipitations around 1990. Maximum of Csw is in the first decade of examined period (1960-1970) and there is also second maximum after 2005. These results are also in connection with increased precipitations in these both periods. These high throws from northwest are major cause for type Csw at SLP

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