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INTRODUCTION TO SYNOPTIC METEOROLOGY

ВВЕДЕНИЕ В СИНОПТИЧЕСКУЮ МЕТЕОРОЛОГИЮ

Рекомендовано Учебно-методическим объединением по образованию в области гидрометеорологии в качестве учебного пособия для студентов высших учебных заведений, обучающихся по направлению «Гидрометеорология»

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The book considers the major concepts and terms that students of hydrometeorology are to know while taking the basic course of synoptic meteorology. The aim of the manual is the deeper comprehension of the content of the course.

The manual is intended for students of higher educational institutions specializing in hydrometeorology. It can be also useful for geographers and specialists whose work requires account for weather.

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INTRODUCTION TO SYNOPTIC METEOROLOGY

Foreword

Variation of weather in a region is closely associated with so called synoptic objects acting in the region or passing it. Study of these objects and the associated weather conditions represents the main content of the discipline called *synoptic meteorology*. All synoptic objects are closely related to each other. Therefore, when studying a synoptic object, unavoidably reference to some other objects should be made. It is why, before one starts systematic studying synoptic meteorology, it is worth being, at least briefly, familiarized with basic notions and definitions related to the processes of origination and evolution of the synoptic objects, and with some special features of the meteorological fields structure within the limit of every object. The matter is that the objects themselves and the associated meteorological fields create pre-conditions for developing weather forecasting methods.

Introduction

Synoptic meteorology is the scientific discipline studying macro scale atmospheric processes with the aim of weather forecasting. Actually this definition gives just a notion of the objects to be studied. It says nothing about the studying method, and it does not contain appropriate concept of the weather itself. Therefore, the definition should be added with some explanations necessary for deeper understanding the discipline "***synoptic meteorology***" and the tasks it's supposed to solve.

From the definition of *synoptic meteorology* it follows that not all spectrum of the atmospheric processes is to be studied but only that responsible for weather (weather condition) formation and variation. Various consumers of the meteorological information understand the term "weather" or "weather conditions" in a different way. The majority of general population is interested in air temperature, precipitation, and wind; sailors are concerned with wind velocity, sea choppiness caused by the wind, and visibility; pilots–with visibility, amount of clouds and their form and height. Owing to these facts, weather services are to give the information on weather to various consumers taking into account their particular requirements. Therefore, the term "weather' (weather conditions) must have a wide interpretation. That is why we understand the weather as *the state of the atmosphere at a definite point (interval) of* *time in a given region or point described with the combination of meteorological parameters and phenomena.* This combination includes: pressure, air temperature and humidity, wind velocity, cloudiness, precipitation, visibility range, thunderstorms, squalls, fogs, snow storms, dust storms, and glaze. All these are of interest for a wide range of consumers and those dealing with weather forecasting.

The following questions arise: What atmospheric processes define the weather conditions? Which of the atmospheric processes can be called weather forming ones, and what is their spacial and temporal variation?

First of all it is worth to note that the state of the atmosphere known as weather is referred to the comparably thin layer–*troposohere*, where the larger part of the atmosphere mass is found. It is obvious that the troposphere is the layer, where the main weather forming processes develop. At the same time the processes within thinner layer, nearest to the ground surface, such as airflows streamlining a building, do not significantly affect weather conditions. Hence the vertical scale of the atmospheric weather forming processes, which are considered in synoptic meteorology, is of order of magnitude 10^{-1}–10^{1}km. As to the horizontal scale, it must be adopted according to the sizes of the troposhperic formations, which possess homogeneity of weather conditions, or, just opposite, sharp space variation of the meteorological parameters. According to observations, these sizes vary from 10^1 up to 10^3 km. This range corresponds to the horizontal scale of the processes studied in synoptic meteorology. The time scale is determined by the "life'-span of the above formations i. e. from10^1 to 10^2 hours. However, it should be noted that some atmospheric processes and disturbances with the life time less than 12 hours and horizontal sizes having the order of magnitude from 10^0 to 10^2 km are also studied in the course called "meso-meteorology" intended for very short range weather prediction.

The atmospheric processes of the synoptic scale, first of all, are related to development and displacement of the synoptic objects such as depressions (cyclones), anticyclones, frontal zones, atmospheric fronts, jet streams, and air masses. To study these objects is the main concern of the synoptic meteorology. Also synoptic meteorology includes modern methods for every components of weather prediction with the lead-time from 12 up to 48 hours. These methods are based on the relation between synoptic objects and weather conditions. The forecasting techniques for larger and smaller ranges are studied in some special courses namely *log range weather forecasting* and *meso-meteorology and very short-range weather prediction.* The matter is that they are based on the processes of the scales other than those in synoptic meteorology.

Now let's turn our attention to the discussion of the methods used in synoptic meteorology for studying synoptic objects, their origin, developing, evolution and displacement, and the technique for weather prediction.

One of the special features of the methods used in synoptic meteorology is that the atmospheric processes are studied over a large area taking into account geographic particularity of the area. The necessity to examine the processes over a large territory arises from the fact that the atmosphere is always in motion. For 24 hours synoptic objects being thousand kilometers or so in their horizontal sizes can travel a long distance displacing from one region to another. Coming to the region the weather to be forecasted for, they define weather conditions at the region. Besides, process development and weather variation in any region the weather to be forecasted for results from the process interaction over vast areas.

The atmospheric process character greatly depends upon geographical latitude defining radiation conditions, type and state of the underlying surface, the region orographic features, etc. For instance, extratropical depressions may occupy the area of 10^6 km^2, while a tropical cyclone only 10^4km^2, although it is precisely these cyclones produce the most thick clouds, the heaviest precipitation, and the strongest wind; the extratropical depressions move mainly eastward, while the tropical cyclones move mainly west ward.

Underlying surface significantly influences atmospheric process development and weather character. As we'll below, the atmospheric processes are quite different over oceans and lands, over planes and mountains etc. It is why, that when analyzing weather conditions over vast territory, we use geographical maps. On these maps with meteorological observation data plotted are called **synoptic (weather) maps.** They allow for a broad view of the weather over large geographical regions. The word **synoptic** came to us from Greeks. It means "affording a general view of a whole", we understand it as *a display of atmospheric conditions as they exist simultaneously over a broad area.* For the same reason we call this discipline **synoptic meteorology**.

The second feature of the synoptic meteorology method is the statistical approach the physical atmospheric process analysis. The same approach is used for development 0f the weather forecasting techniques. What is the essence of this kind of analysis, and what is the difference from other kinds of analysis?

As we know, in the process of learning one can distinguish three stages:

– accumulation and primary processing of the data (*"live contemplation"*);

– analysis and interpretation of the processed data (*"abstract thinking"*);

– correction, verification of those theories, models, and hypothesis which were created as result of the analysis of the empirical materials, and obtaining some practical recommendations.

As applied to meteorological problems, the first stage means accumulation and processing of the data on the object to be studied. The second stage means construction on the model of the process (phenomenon) to be studied on the basis of the first stage results. The set of equations describing the process (that is more typical for dynamic meteorology), or a physical system behaving similarly to the process to be studied may define the model. For instance, a set of equation can describe depression displacement (dynamic meteorology approach) or the same displacement can be presented by a physical model according to which depression is regarded as a solid spinning body transferring by air currents (synoptic meteorology approach). Every of these approaches has both advantages and disadvantages and, correspondingly, its field of application.

Once the process physical model has been constructed, the numerical values of its parameters are determined with statistical processing of the observational data related to the process. In our example these are the values of the parameters relating the rate of depression displacement and the velocity of non-disturbed airflows. That is the approach typical for the synoptic meteorology. When making a forecast on the basis of the process physical model, first of all, the initial state of the atmosphere is determined, namely those parameters of the state which defined the values to be forecasted. Then the links between initial and forecasting parameters are obtained using statistical technique.

The third stage is the verification of the model practical application effectiveness that should be made using independent observational data.

Accounting for above reasoning, definition of the synoptic meteorology can be formulated in the following way: ***synoptic meteorology is the scientific discipline studying weather forming processes with the aim of weather prediction on the geographical basis with the aid of statistical techniques.***

1. Basic means used for the synoptic scale process analysis and short-range weather forecasting

The basic means used for the synoptic scale process analysis and short-range weather forecasting are synoptic maps. They are plotted with the information on weather conditions at the Earth surface, namely, atmospheric pressure reduce to the sea level, air temperature, dew point temperature, wind speed and direction, meteorological visibility range, cloud amount and forms at all levels, weather phenomena at the time and between the times of observation, the value and the sign of pressure tendency. The plotting is done with digits and special symbols.

At the surface stations the time interval between observations is 3 hours. The main times are 00, 06, 12, and 18 GMT. Using data of these observations, basic synoptic maps are constructed. The scale of these maps is 1: $1{,}5 \cdot 10^7$. It means 1 cm on the map represents 150 km. To make more detailed analysis of the synoptic process development and weather conditions assessment in the region of interest, somewhat larger scale maps are used, namely 1: $5 \cdot 10^6$ or even 1: $2{,}5 \cdot 10^6$ i.e. 50 and 25 km in 1 cm respectively. In this case some denser network of weather stations must be used, and forecasters can be enabled to scrutinize synoptic process development and make more accurate forecasts.

At the first sight the distribution of the various meteorological parameters, as they are seen on the synoptic map, seems to be of a chaotic character. Actually it is not so. That is just the matter of presentation. To present the weather parameters in more systematic way, various isolines are drawn. The main isolines on the synoptic maps are *isobars* and *isotendencies (isallobars).*

Isobar has two definitions: the first one is simpler. ***Isobar*** *is a line connecting points with the equal values of the atmospheric pressure.* The second involves the notion of *pressure (isobaric surface) i.e. the surface at every point of which the pressure is of the same value.* ***Isobar*** *is the line of intersection of the pressure surface with some other surface,* in our case with the sea level surface. ***Isobaric surface*** can be described as $P = P(x, y, z)$, while ***isobar*** as $P = P(x, y)$.

Accordingly, ***isallobar*** *is the line connecting the points with equal value of pressure variation with time.*

The atmospheric processes are of three dimensions. Therefore, to predict the weather, the upper atmosphere state should be analyzed too. To do this, the upper air charts are used. These charts are constructed for so called **standard pressure surfaces.** They plotted with the geopotential heights of the pressure surfaces, temperature and dew point temperature at the surfaces and wind velocities. The data to plot the charts are taken from radio soundings of the atmosphere. The standard pressure surfaces are adopted to be 1000, 925, 850, 700, 500, 400, 300, 200, 150, 100, 50, and 30 hPa. The average heights of these surfaces are cited in the table 1.

Table 1. Average height of the standard pressure surfaces

P hPa	1000	925	850	700	500	400	300	200	150	100	50	30
Z km	0	0,7	1,5	3,0	5,5	7,0	9,0	12,0	13,5	16,0	20,0	24,0

For the weather forecasting purposes the following charts are usually worked out: 850 hPa chart, 700 hPa chart, and so on up to 200 hPa. In some special cases the charts are drawn up for some other surfaces. It is easy to notice that, at the fixed pressure surface, the higher altitude of the surface corresponds to the higher pressure at the sea level and vice versa (see figure 1). Hence we may state that the chart of the pressure surface heights gives the view of the pressure field structure in the free atmosphere which is similar to what the surface synoptic map does.

The main isolines drawn on the upper level charts are **contour lines (isohypses).** ***Contour line (isohypse)*** *is the line of equal values of the geopotential heights of the pressure surface.*

The heights in the pressure constant charts are plotted in geopotential meters (or decameters) which have dimension of energy but not usual meters, although numerically they are approximately equal to each other's.

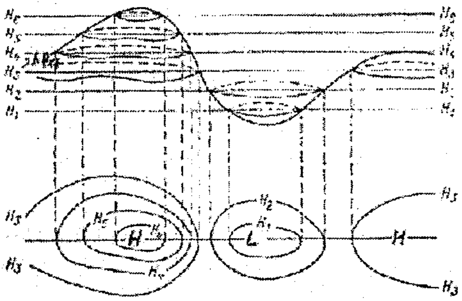

Figure 1. An example of the upper level chart of the pressure surface P=*Const*

Unit of geopotential is the potential energy equal to the work done as a particle of a unit mass has been ascended by 1 m in the Earth gravity field with the acceleration $g = 9{,}8\, m/s^2$. It means that the geopotential unit $\Phi = 9{,}8\ m^2/s^2$. This unit is not convenient for the practical application. To avoid this inconvenient, the Φ value is deviled by non-dimensioned figure 9,8. Doing so, we receive geopotential meters, although their dimension will be m^2/s^2. Thus, the geopotential height can be calculated from the formula

$$H = \frac{gz}{9{,}8}\ \text{gp. m.}$$

In addition so-called ***thickness charts*** are assembled. These charts are plotted with the vertical distance (geopotential decameters) between two pressure surfaces. As we know from dynamic meteorology, the thickness of the layer between two isobaric surfaces is proportional to the average temperature of the layer and depends on this temperature only. It can be calculated from the formula

$$H_{p_1}^{p_2} = 6{,}74\overline{T}\lg\frac{p_1}{p_2}\ dam$$

For the practical purposes the thickness 500 hPa over 1000 hPa chart is prepared. This chart represents the average temperature of the lower half of the troposphere.

Time variation of the meteorological parameters in the free atmosphere is much smaller than that at the surface. This allows for making soundings only four times a day: 00, 06, 12, and 18 GMT, 00 and 12 GMT being the main ones. The results of the soundings allow us to construct upper level charts, to determine the static stability of the atmosphere, and, hence, to predict convection phenomena such as thunderstorms, squalls, hail storms, etc. When forecasting, radar data, satellite images, and pilot reports are also used.

2. Some weather forming features of the meteorological magnitude fields

An important feature of the pressure field is its continuity and smoothness. Consequence of the continuity is that there are no disruptions in the pressure field. Therefore, isobars can be disrupted at the margins of the synoptic map only. Consequence of the smoothness is the possibility to identify synoptic scale systems in the pressure field (see figure 2)

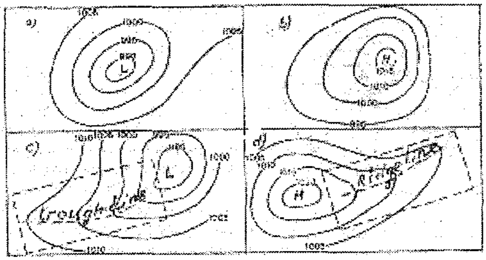

Figure 2. Pressure systems
a) depression (low); b) anticyclone (high); c) trough: d) ridge

An area of lower pressure well defined with closed isobars is called ***low*** or ***depression*** (a). An area of higher pressure well defined with closed isobars is called ***high*** or ***anticyclone*** (b). Since pressure systems determine associated wind systems the low is also regarded as cyclonic vortex of the synoptic scale or **cyclone**, and the high–anticyclonic vortex or **anticyclone.***

An area of low pressure defined with non-closed isobars is called ***trough*** (c), and that of high pressure is called ***ridge*** (d).

The close relation between of pressure and wind fields results in the fact that the pressure systems. In the free atmosphere, where the friction

* According to recent findings high pressure system can not be regarded as a large-scale vortex. It seems to be existing as long as cyclonic vortexes surround it. As soon as the surrounding cyclones disappear, the anticyclones disappear too. However, this point of view needs to have more evidences.

can be neglected, the wind is directed along isobars (isohypses), the low pressure being to the left (in Northern Hemisphere), and the wind speed is determined by the well-known geostrophic relations.

$$u_g = -\frac{1}{f_c \rho}\frac{\partial p}{\partial y}; \quad v_g = -\frac{1}{f_c \rho}\frac{\partial p}{\partial x}; \quad V_g = -\frac{1}{f_c \rho}\frac{\partial p}{\partial n} \qquad (2.1)$$

In the boundary layer, as the surface is approached, the friction effect increases, and the wind speed becomes less than the geostrophic wind speed. It means that the geostrophic balance is broken up, and wind vector deviates from the isobars toward the lower pressure side. In average, over land at the altitude about 10 meters wind speed is 0,55 of the geostrophic one, and the deflection from isobars is about 35–45^0. Over sea surface these values about 0,7 and 15^0 respectively. Wind velocity deflection from isobars in the friction layer to the lower pressure side is an important factor determining weather condition difference in the areas of low and high pressure. Within depressions (figure 3) wind flows converge toward the depression center. This process results in accumulation of the mass of air and ultimately in ascending of the air. As it is seen on the figure 3, converging streamlines create a vast area of the negative wind divergence which determines large scale vertical motion with the speed order of magnitude 10^{-3}–10^{-2} m/s. It follows from the continuity equation.

$$w = -z \cdot div\vec{V} \qquad (2.2)$$

From dynamic meteorology we know that $div\vec{V}$ order of magnitude is 10^{-5}–10^{-6}, therefore, within the boundary layer (order of magnitude 10^2–10^3 m) the rate of the ascent will be cm/s–mm/s. This air ascending motion results in air cooling, water vapor condensation, cloud generation, and precipitation falling. If the ascending air is statically stable, this process results in Ns cloud formation and widespread precipitation. In case the air is unstable, the ascending motion may serve as a trigger for the instability realization, and, hence, convective phenomena formation.

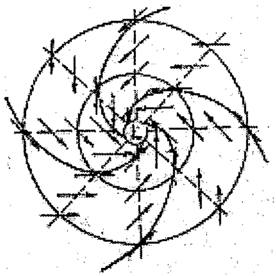

Figure 3. Wind field of a depression at the ground surface

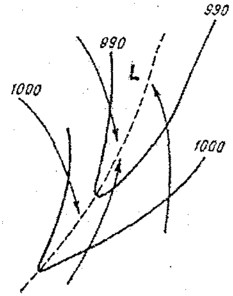

Figure 4. Wind field in the trough

Similar process takes place in the troughs (see figure 4), where the wind confluence occurs at the trough line* forming a convergence line. In addition to the ordered vertical motion, here, some favorable conditions for arising and persisting long duration transition zones between different type air masses are created. At certain conditions these transition zones can become to be atmospheric fronts (see below).

In the high pressure areas (figures 5 and 6), contrary, wind diffluence (stream lines convergence) results in downward vertical motion appearance. They compensate the air mass diminution due to air outflow (see 2.2).

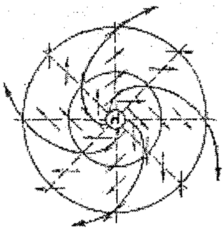

Figure 5. Wind field of an anticyclone

Descending air is heated up causing cloud droplet evaporation, and cloudiness gradually degrades and disappears. The air becomes drier. Under the reason the clear sky weather with significant diurnal variation of some meteorological parameters prevails.

Prevailing ascending motions in the low-pressure areas cause temperature fall within the air column over these areas. It is why seats of cold are formed over depressions and troughs.

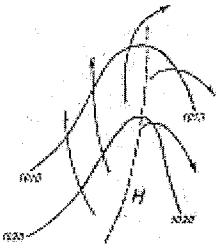

Figure 6. Wind field of a pressure ridge

Contrary, the seats of warmth form over high-pressure areas due to adiabatic heating of the descending air.

Thus one can see an obvious relation of the pressure field space structure and its time variation with the time variation of the wind, temperature, vertical motion, humidity, and precipitation fields. All these mean that the complex of the local characteristics (weather) is determined by the type of the pressure and wind systems, and

* *Trough line* is the line connecting the points of the largest cyclonic curvature of isobars.

the fields of meteorological parameters and phenomena are interrelated. Variation of one of the field structure causes variations of the others, and, ultimately, change of the weather.

3. Air masses

Under the term *air mass* we understand a body of air within which horizontal gradients of temperature and humidity are relatively small and which is separated from an adjacent body of air by a more or less sharply defined transition zone (front) where these gradients are relatively large.

An air mass may cover several million square kilometers and extend up through the troposphere implying uniformity of weather conditions.

Source regions of air masses

The origin of warm and cold air is easier to understand if we remember that whether air is cool or warm depends to a large degree upon the temperature of the underlying surface it's situated over. A warm air mass is produced by prolonged contact with a warm surface, and conversely a cold air mass – with a cold surface. The heat transfer processes that warm or cool the air take place slowly; it may take a week or more to warm up the air by 10°C right through the troposphere, and in order for these changes to take place a large mass of air must stagnate over the region. Parts of the earth's surface where the air can stagnate and gradually attain properties of the underlying surface are called *source regions*. The main source regions are the high-pressure belts in the sub tropics (giving rise to *tropical* air masses) and around the poles (the source for *polar* air masses).

Air mass types

We have already identified two main sources of air, that is, polar and tropical air masses.

These two main types of air mass can have a maritime or continental track after leaving their source region. Four main air mass types can therefore be identified, with two further sub-divisions, giving a total of six air masses that affect the British Isles. These are named:

Tropical continental	Tc
Tropical maritime	Tm
Polar continental	Pc
Polar maritime	Pm
Arctic maritime	Am
Arctic continental	Ac

Each of these air masses has properties in terms of:

- temperature
- moisture
- change of lapse rate
- stability
- weather
- visibility

Table 3.1 shows the conditions in every of these air masses.

Continental air masses are colder in winter and vice versa in summer. The reason is that in winter the ocean surface is warmer than the ocean surface, and in course of heat exchange with underlying surface the maritime masses become relatively warmer while the continental masses become colder. In summer the situation is opposite. The continents are warmer than oceans. Therefore in course of heat exchange the continental masses became warmer than maritime ones.

In addition to geographical air mass classification there is so called thermodynamical (or synoptic) classification. This classification is based on the thermal state of the air mass and its static stability. According to this classification there are warm, cold, and neutral air masses, every of them can be stable and unstable. They also can be dry and humid (moist). The types of air masses and the typical character of weather is cited in the table 3.2.

An air mass is regarded to be warm if its temperature higher than the temperature of the neighboring air mass and the normal temperature for the given region. In the opposite case the air mass is regarded to be cold. If the air mass temperature close to the normal for the region, the air mass is regarded to be neutral. In case a neutral air mass is warmer than the neighboring one, the air mass is considered to be relatively warm air mass. In case a neutral air mass is colder than the neighboring one, the air mass is considered to be relatively cold air mass.

Table 3.1. Weather conditions in air masses of different geographical types

Air mass type	Summer	Winter
Tropical continental	Hot, dry air, generally unstable, occasional showers, visibility moderate or poor	Relatively warm and moist air, generally stable, St and Sc cloudiness, visibility poor.
Polar continental	Relatively cold unstable air, unstable, Cb clouds, showers, visibility good.	Cold dry air, stable, generally clear, visibility moderate or good.
Tropical maritime	Warm, moist air, generally unstable, Cb clouds, showers and thunderstorm, hailstorm with squalls, visibility poor.	Warm, moist stable air, St, Sc cloudiness, drizzle and fogs, visibility very poor.
Polar maritime	Cold moist air, unstable, Cu, Cu cong, Cb clouds, showers, visibility moderate or poor	Relatively warm, moist air, generally stable, St, Sc and Ns cloudiness, visibility poor.
Arctic maritime	Cold moist air, unstable, Cu, Cu cong. Cloudiness, occasional Cb clouds and showers, generally visibility good.	Cold moist air, stable, overcast stratiform cloudiness, visibility moderate.
Arctic continental	Very cold, relatively dry air, generally unstable, visibility good.	Very cold, dry air, stable, visibility very good.
The geographical classification of the air masses usually made with regard a definite geographical region. The weather condition in a definite type in western Europe can be quite different at, for instant, Siberia.		

An air mass is regarded to be unstable if its lapse rate is larger than the moist adiabatic lapse rate. Otherwise it is regarded to be stable. It should be noted that the lapse rate is a subject to significant space and time variation, and when determining the type of the air mass, this must be accounted for.

An air mass is regarded to be humid if the relative humidity of the air mass at daytime more than 50%.

The geographical air mass classification is mostly used for climatological descriptions of various situations, and for analysis of some synoptic processes caused some anomaly weather conditions such as droughts, frosts, storms etc.

The thermodynamical (synoptic) classification is used for current synoptic processes analyses and short range weather forecasting.

Table 3.2. Weather conditions in air masses of different types according to thermodynamical classification

A.M. Type	Weather in summer	Weather in winter
Stable, warm and humid air mass	Hot, humid. Ac. As. Sometimes Ns and rain	Low clouds, drizzle, fogs. Thaw.
Stable, warm and dry air mass	Fair, hot weather	–
Stable, cold and humid air mass	Sc, chilly.	Moderate cold weather. Fogs, glaze, sleet, low clouds
Stable, cold and dry air mass	Cold, fair weather	Very cold, fair weather.
Unstable, warm and humid air mass	Convective phenomena: thunderstorms, squalls, hail, and tornado.	Shower type snow, snow-storms, gusty winds etc.
Unstable, warm and dry air mass	Gusty winds and dust storms.	Thaw Snow melting
Unstable, cold and humid air mass	Showers, Cb clouds	Rime, snowstorms, gusty winds and convective type clouds.
Unstable, cold and dry air mass	Cu hum, cold gusty winds and separated Sc. Chilly weather.	Fair weather with frosts and gusty cold winds.
In this table the typical for the air masses weather condition are cited. However, in reality, they may be deviate from these types depending on the local feature influence and other synoptic object impacts.		

4. Atmospheric fronts

As two air flows (air masses), one warm, another cold, approach each other, a narrow transition layer with significant temperature gradient is created. This layer is called *frontal layer,* or just *front.* In the process of these two masses approaching the frontal layer acquires a tilt to the cold mass side (see figure 7).

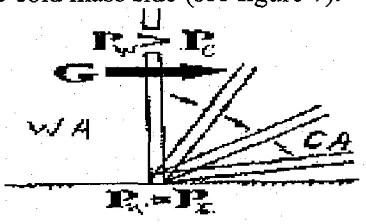

Figure 7. The frontal tilt angle variation in the process of cold and warm air approaching.

Figure WA means warm air; CA means cold air; P_W denotes pressure in the warm air; P_c denotes pressure in the cold air; G is horizontal pressure gradient.

As we already know, the pressure does not have discontinuity.

Hence, near the ground surface the pressure in the cold air is equal to the pressure in the warm air, i. e. $P_w\big|_{z-0} = P_c\big|_{z=0}$. However, the pressure step in the warm air is larger than that in the cold one. Therefore, when ascending, the pressure in the warm air becomes larger than in the cold air at the same altitude, i. e $P_w\big|_{z-0} > P_c\big|_{z=0}$, it means that a pressure arises. The warm air stars moving along the pressure gradient force to the cold airside. As result, the frontal surface takes a tilted position. Ultimately the process of this kind can come to an end as the frontal surface has taken a horizontal position. However this process never comes to its end, and the frontal surface remains in the tilted position. The angle of the frontal surface inclination is very small, it is a few tenths of minutes only, and sometimes it may reach 1^0. It must be noted that on the vertical cross-sections this angle is significantly overstated. The matter is that on the vertical cross-sections the vertical scale is much larger than the horizontal one. An example of such a cross-section is shown on the figure 10. Here the vertical scale is $1{:}10^5$

(1 cm corresponds to 1 km), and the horizontal scale $1{:}10^7$ (1cm corresponds to 100 km). One can see that the vertical scale 100 times larger than horizontal one. As it's seen on the cross-section, the front slope angle is about 30^0, but in reality, as we account for the scale difference, it is 100 times smaller, i. e. $0{,}3^0$, or about 20'

The order of magnitude of the temperature difference between warm and cold air masses is usually 10^1K, and the frontal zone width order of magnitude is 10^5 m. hence, the horizontal temperature gradient in the frontal zone is of 10^{-4}K/m order of magnitude (or 10^1 K/100km). Thus, it is at least 10 tomes larger than within an air mass at any side of the front.

Since the warm air flows over wedge of the cold air (figure 8), within the frontal layer air temperature rises up, i. e. an inversion forms (frontal inversion). Thickness of the frontal layer is just a few hundred meters. In the scale used for theoretical analysis and cross-section construction the frontal layer is drown as a frontal surface or a line (on the vertical cross-sections) as it is shown on the figure 9. In this case the temperature seems to have discontinuity.

Atmospheric fronts can be of various vertical and horizontal extensions, and also various structure. That is why there are **principal, secondary** and **closed up**, or **occlusion,** fronts.

The **principal** fronts divide the air masses significantly different in their properties that is the masses of different geographical types. These fronts are of 5–7 km vertical extensions, sometimes they can extend up to tropopause, their longitudinal size is a few thousands kilometers. The "life" time of these fronts is 5–7 days. When passing they cause sharp change of the weather conditions. The principal fronts are responsible for depression formation.

The **secondary** fronts are found themselves within an air mass. They appear due to small local difference in air characteristics, which can arise mainly because of airflow convergence in the boundary layer. Therefore, the secondary front vertical extension does not exceed 1–1,5 km, i. e. they are found themselves within the boundary layer only. Their horizontal extension usually is not more than 1000 km. Noticeable phenomena are observed near the front only. Soon after the front passage the weather conditions become practically of the same kind they were before the front passage.

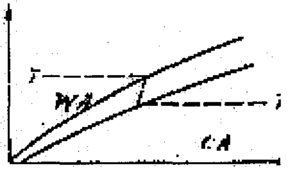

Figure 8. Scheme of the frontal layer on a vertical cross-section. T is isotherm, WA is warm air, CA is cold air

The **upper** fronts are those observed in the upper troposphere only. Formation of these fronts is rather complicated process. It will be discussed later.

The **closed up** fronts result from combination of two atmospheric fronts. Closing up warm and cold fronts is known as occlusion process, and, therefore, these fronts are called **occlusion** fronts, or just **occlusion.**

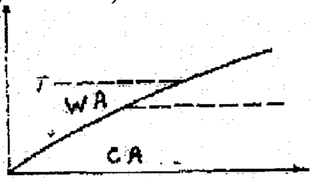

Figure 9. Scheme of the frontal surface on a vertical cross-section. T is isotherm, WA is warm air, CA is cold air.

Atmospheric fronts can be also classified according to geographical types of the air masses they divide. The fronts dividing arctic and polar air mass are named **arctic fronts,** polar and tropical air–**polar fronts.**

Depending on displacement direction, the fronts are subdivided into **warm, cold,** and **stationary fronts. Warm fronts** are those moving toward the side of the cold air. **Cold fronts** are those moving toward the side of the warm air.. The fronts keeping their positions unchanged or change them just a little are called **stationary (motionless) fronts.**

Fronts with well-defined weather conditions ate named **sharp** fronts, and in opposite case they are named **weak** fronts.

On the basis of the principal front structures empirical models of the warm, cold, occlusion, and stationary fronts were worked out. The models are represented in forms of vertical cross-sections. The figure 10 shows the vertical cross-section of the warm front. The front moves from the left to the right. The warm air ascends along the wed ge of the cold air with the vertical component a few cm/s, and gradually cools down according to the adiabatic lapse rate. As result of the ascent a large cloudiness system arises. This system consists of *Ns, As,* and *Cs* clouds. The diametrical horizontal size (width) of the system for a well-defined front can be as large as 1000 km and that of the precipitation zone 300–400 km (rain) and 400–500 km (snow). Widespread precipitation with intensity up to 3 mm/hour associated with warm fronts can last up to 15 hours.

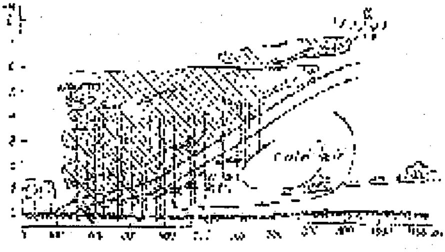

Figure 10. Vertical cross-section of the typical warm front.

As all other fronts, the warm front is found itself in the pressure trough, the trough line being coincide line with the front line (figure 11). Prior to the warm front passage the atmospheric pressure intensively decreases, and after the passage it remains unchanged or slightly rises. It is natural that the temperature rises up and the precipitation ceases after the front passage.

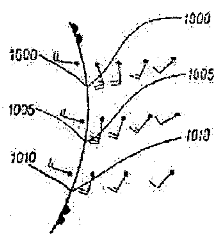

Figure 11. Pressure and wind field at the warm front

The **cold front** moves toward the side of the warm air forcing the latter to ascend along the frontal surface. In case the front displacement is small, the vertical component of the warm air movement over frontal surface is also small, cm/s. Such fronts are called **cold fronts of the 1-st kind.** Upward moving air creates a cloud system similar to that of the warm front but situated backward (see figure 12). As soon as the 1-st kind cold front starts passing the station widespread precipitation from *Ns* begins. The precipitation intensity decreases as the front moves off the station. The diametrical sizes of the cold front cloud and precipitation systems are similar to that of the warm fronts. They are 300–400 and 150–100 km respectively.

The foregoing part of the cold front surface steepness is rather large. Due to this fact "Cb" clouds develop over it and shower type precipitation and thunderstorm occur in case the warm air is statically unstable.

Fast moving cold front, known as **cold front of the 2-nd kind,** is active to force out warm air upward causing so-called **dynamic convection** that results in formation of dangerous convective phenomena. A chain of "Cb" clouds are formed along the cold front line producing a narrow zone (about 50 km) of showers accompanying by thunderstorms, hail and squalls.

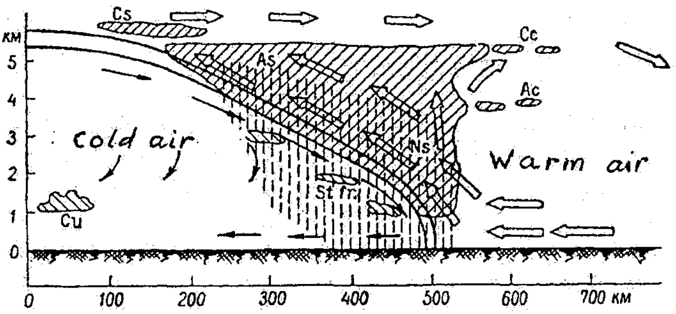

Figure 12. Vertical cross-section of the 1-st kind cold front

Behind the cold front at the middle troposphere downward vertical motion development results in clear sky weather condition. However, cold strong wind persists after the front passage (figure 13).

The cold fronts, as well as any other fronts, are found themselves in troughs. It means that after any front passage over station, the wind direction turn to the left. Prior to the cold front the pressure slightly falls down, and after the front passage it significantly rises up.

Closed up fronts (occlusion fronts) arise as result of approaching each other and following closing warm and cold fronts. Process of this kind can be presented in the following way. Imagine a stationary front such as shown on the figure 14.

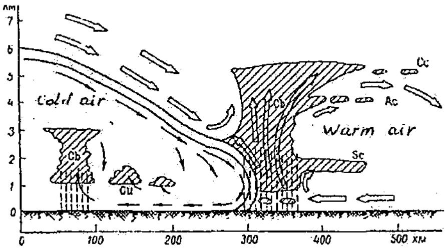

Figure 13. Vertical cross-section of the 2-nd kind cold front

Suppose the pressure starts falling down at some point of the front resulting in cyclonic type circulation. The latter will cause one part of the front to move toward the warm airside (cold front formation), and the other part to move toward the cold airside (warm front formation).

The cold front is faster to move than the warm one. Therefore the cold front will "catch up" the warm front, and the front will close up (see figure 15)

Figure 14. A scheme of warm and cold front system formation from a stationary front

The temperature contrast between more cold and less cold air masses is much smaller than that between warm and cold air at the warm and cold fronts existed before occlusion formation.

The cloud system and precipitation field at the closing up moment is an aggregate of those for the cold and warm fronts. The width of the cloud system can be as large as 1000 km and even more, and the diametrical size of the precipitation zone can reach 400–600 km.

The temperatures of the cold air masses prior to the warm front and behind the cold front determine the next stage of the closing up process particularities. In case the air moving behind of the cold front is less colder than the air prior to the warm front, the cold front surface will move up on the wedge of the more colder air, i.e. on the warm front surface (figure 16).

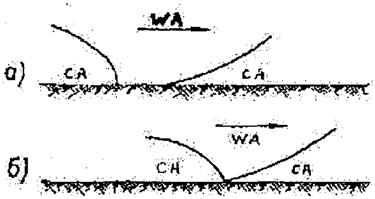

Figure 15. Schematic vertical cross-section illustrating the moment prior to an occlusion front formation

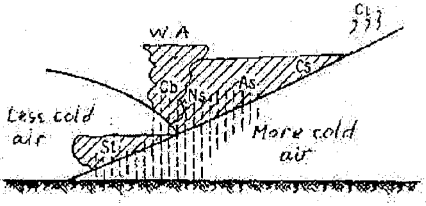

Figure 16. Vertical cross-section of the warm occlusion front
in its middle stage of development.

This frontal system is named **warm occlusion front** or just **warm occlusion.** The cold front (transition zone between the cold and warm air) can be found now in a position above the ground surface. Now it is **upper-level cold front.** If the air behind the cold front turns to be colder than that before the warm front, then a **cold occlusion front** forms (figure 17). In this case the warm front that before occlusion formation was found beginning from the ground surface becomes now to be **upper-level warm front.**

As result a complicated frontal system arises. It consists of an upper-level front (cold or warm) and an occlusion front itself. This front extends from the ground surface and divides more cold and less cold air masses.

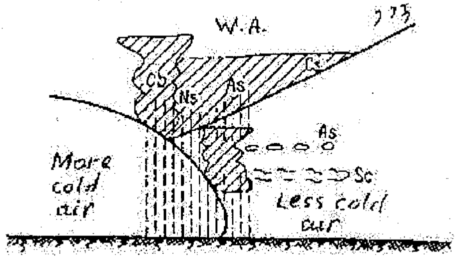

Figure 17. Vertical cross-section of the cold occlusion front
in its middle stage of development

In course of occlusion process development the warm air is forced out upward. Due to this fact, the cloud systems related to the principal fronts become degraded, and the width of the precipitation zone and precipitation intensity decreases. At the same time a new cloud system and precipitation zone associated with the occlusion front develops.

5. Upper-level frontal zones and jet streams

The area found between a high, warm anticyclone (ridge) and a high, cold depression (trough) in the free atmosphere is called **upper-level frontal zone (ULFZ).** Within this zone horizontal geopotential and temperature gradients are rather large (see figure 18). The central isohypse of the zone is called **core isohypse.** The ULFZ part facing low geopotential area is known as **cyclonic side** of the zone, and that facing high geopotential area is known as **anticyclonic side** of the zone. The inflow part of the ULFZ is named **entrance,** and the outflow part–**delta.**

The lower part of the ULFZ very often associated with well-developed atmospheric front. Sometimes even two fronts can be found at the ground surface as it is illustrated on the figure 19.

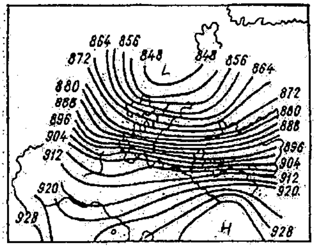

Figure 18. An upper-level frontal zone at 300 hPa chart

In the middle and upper parts of the troposphere several upper-layer frontal zones can simultaneously exist. They smoothly transit from one to another forming so-called **planetary upper-level frontal zone** (see figure 20).

Large horizontal geopotential gradients in the central part of the ULFZ result in strong winds. Their speed decreases toward peripheries of the zone. The altitude of the strongest winds is found itself a bit lower tropopause. Upward and downward from this altitude the wind speed decreases. Therefore the wind field in the ULFZ has a form of a jet. It is why the air current of the high speed at the upper troposphere has been named **Jet Stream.**

Aerological commission of the World Meteorological Organization has defined the jet stream as "a narrow strong air current with quasi-horizontal axis in the upper troposphere and lower stratosphere that is characterized by significant vertical and horizontal wind shears and by one or a few maxima of the wind speed". The following criteria are recommended to detect jet streams in the atmosphere. Usual longitudinal size of a jet stream is a few thousands km, its width is a few hundreds km and vertical extension is a few km. Vertical wind shear can reach 10 m/s per 1 km, and lateral wind shear 10 m/s per 100 km. The lower limit of the wind speed in the jet streams is 30 m/s.

Core of the jet stream is the streamline connecting points of the maximal wind speed. It is not horizontal, it changes its vertical position. Due to this fact, it is very difficult to make diagnosis and forecast of the jet stream position on the basis of the constant pressure charts. Instead the maximal wind charts are used. They are constructed from the data of the rawind soundings. The altitude (in hPa) of the maximal wind level and the wind speed (m/s) are plotted on these charts. The charts allow detecting the jet stream and to draw its core (figure 21).

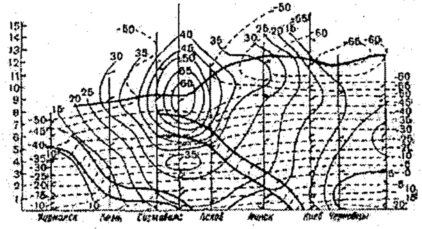

Figure 19. Vertical cross-section along the meridian of 30^0 E.L.

As it was already mentioned, jet streams are related to atmospheric fronts. Therefore, they are classified in the same way as fronts are. The jet streams related to the arctic front are named **arctic jet streams.** The jet streams related to the polar front are named **polar jet streams**. There is also **subtropical jet stream** banding over whole Northern Hemisphere.

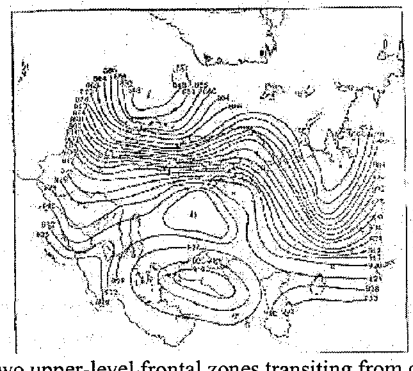

Figure 20. Two upper-level frontal zones transiting from one to another.

This jet stream is found itself over northern periphery of subtropical anticyclones and related to so call upper-level subtropical front. This front does not exist in the lover troposphere since it is diffused by diverging flows in the anticyclones.

All these jet streams are strong westerly systems.

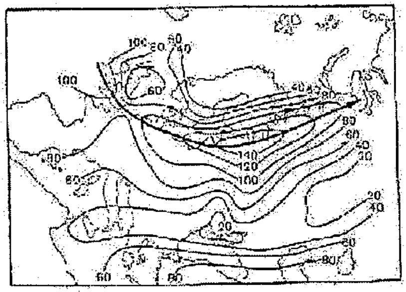
Figure 21. An example of the maximal wind chart. The solid thick curve represents the jet stream core.

6. Cyclones and anticyclones

Cyclones and anticyclones are **three-dimensional atmospheric vortexes** of the synoptic scale. Meteorological fields related to them have some specific features. Combination of these features in different parts of the vortexes defines weather conditions in every part of the cyclones and anticyclones.

Cyclone (low) is circular or nearly circular area of low pressure (geopotential) with closed isobars, around which the winds blow counterclockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere. The word **cyclone** was introduced into meteorology in the middle of the XIX century as the generic name for all circular or highly curved wind systems, but it had since undergone modification in two directions.

In the first sense, the term “tropical cyclone” is used to designate a relatively small, very violent storm of tropical latitudes that is also known as **hurricane (typhoon).** The diameter of a tropical cyclone ranges from 100 to 500 km. In the second sense, the term is used to designate **extratropical cyclone** that is also called **low** or **depression.** This is a low-pressure system of much greater size and, usually, less violent, frequent in the middle latitudes. Its diameter is about 2000 km. Cloudiness and precipitation is associated with the extratropical cyclones. The lowest pressure point within the low is called **center of the cyclone.** The pressure in the extratropical cyclone centers is found to be in the limits 950–1010 hPa. In the tropical cyclones it is 950–970 hPa, sometimes it can be as low as 900 hPa. The lowest pressure ever had registered in the tropical cyclone center was 877 hPa.

Anticyclone (high) is the area of relatively high- pressure (high geopotential) with closed isobars, around which winds blow clockwise in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere. Francis Galton, in 1861, when plotting wind and pressure charts, noted that regions of high pressure were associated with clockwise rotation of the wind around calm centers. He named such a system anticyclone, and the term came rapidly into general use.

The highest pressure point within the high is called **center of the anticyclone.** The pressure in the anticyclone centers is found to be in the limits 1010–1035 hPa. Isobars outlining anticyclones mostly have an elliptic form. The size of a mature anticyclone is a bit larger than that of cyclone; it ranges from 2000 to 3000 km.

As cyclones and anticyclones develop, the corresponding circulation, first of all, is seen near the ground surface. In course of development it spreads up to occupy higher levels. Therefore, according to degree of vertical development the cyclones and anticyclones can be divided into **low-level, middle-level, and high-level-pressure systems.** The low-level ones can be seen on the surface weather maps and on the 850 hPa charts; the middle-level ones can be also seen on the 700 hPa charts, and the high-level ones can be seen on 500 hPa charts and higher.

When developing the cyclones and anticyclones go through four stages.

1. Arising stage. At this stage the first evidences of the system appear.

2. Young stage. At this stage the pressure in the central part of the developing cyclone intensively falls down and that in anticyclone rises up. The cyclones are said to be deepening, and the anticyclones are said to be strengthening.

3. Mature stage. At this stage the pressure variation at the central parts of the vortexes is not significant.

4. Weakening stage. Pressure in the central parts of the cyclones rises up, and for the cyclones it is also **filling in stage;** Pressure in the central part of the anticyclones falls down, and for the anticyclones it is also **decaying stage.**

Transiting from one stage to the following one, the cyclones and anticyclones spreads upward and finally become high-level pressure systems (or high-level cyclones and anticyclones). As we already know, the low-pressure systems are accompanied by large scale ascending motions, and high-pressure by large-scale descending motions. Therefore, developing, the cyclones ultimately become to be **high-level cold bodies**, and anticyclones **high-level warm bodies**. Depending upon the conditions they develop at, the cyclones and anticyclones can be divided into **air mass** and **frontal systems.**

Tropical cyclones, subtropical anticyclones, extratropical thermal cyclones and anticyclones are air mass systems.

Tropical cyclones arise and develop over warm tropical parts of oceans between 5 and 20° latitude. Since their sizes are smaller, and the pressure at their centers is lower than that of the extratropical cyclones, the pressure gradients in these cyclones are rather large, and, hence, the winds are very strong. At any case their speed exceeds 20 m/s. With respect to the wind speed there are two types of tropical cyclones. The first one is **tropical storm,** the wind speed ranges between 20 and 32 m/s. The second one is **hurricane,** the wind speed is more than 32 m/s (the strongest wind registered was 92 m/s). In addition to the very strong winds, abundant pouring precipitation is associated with tropical storms and hurricanes. When passing a location during 24 hours the tropical cyclone can have precipitated a few hundreds mm of rain.

Every year 50–80 tropical cyclones develop in the Earth atmosphere. Tremendous amount of energy needed to form these violent cyclones comes from the warm ocean surface through eddy exchange and water phase transfer.

Subtropical anticyclones are situated over subtropical altitudes of both Hemispheres. In the northern part of Atlantic Ocean that is so called Azorian anticyclone; in the north Pacific– Hawaiian anticyclone. In the Southern Hemisphere there are their counterparts. These anticyclones are known as **action centers of the atmosphere.** They permanently exist for the whole year, being stronger in summer.

Extratropical air mass thermal lows arise over superheated land surfaces in summer, and over open seawater in winter. Usually these lows are outlined by one, rarely two, closed isobar drawn 5 hPa apart.

Extratropical air mass thermal highs arise over supercooled surfaces in winter. They are stronger at night, however even at this time they are outlined by one closed isobar only.

Over extratropical regions the weather forming processes are mostly associated with **frontal cyclones and anticyclones.** The upper level frontal zones are responsible for their formation and evolution. At some favorable conditions some considerable amount of the ULFZ energy is sacrificed for origin and development of a synoptic object possessing vortex structure.

Pressure fall over an area situated at principal atmospheric front results in cyclonic type circulation arising. This circulation, in turn, results in wave disturbance at the front, which is found itself under ULFZ. Actually this is the frontal low (cyclone) origin stage, or **wave stage** (figure 22). This stage continues from the frontal wave formation up to the first closed isobar appearance. In the foregoing part of this wave the atmospheric front moves toward the cold air (warm front), and in the rear part it moves toward the warm air (cold front). This way the warm sector of the low starts forming between the warm and cold fronts. The wave stage is quick to pass, it lasts not more than 12 hours.

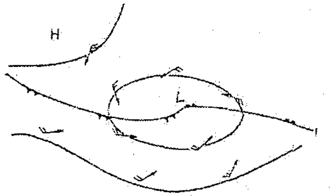

Figure 22. A frontal low in the wave stage

During its second stage, which is named **young cyclone,** the low is intensively deepening. The number of closed isobars on the weather map increases, and the wind speed grows up (figure 23). Due to airflow confluence the large-scale upward motion appears, and, as result, the cloud and precipitation systems form, the thickest clouds being at the fronts. The duration of this stage is about 1,5–2 days.

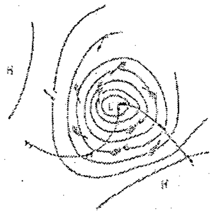

Figure 23. A frontal low in the young cyclone stage

Within the young cyclone there are three areas with different weather conditions. *The first area* is found itself at the foregoing part of the low. Here, in the cold air, which is situated prior to the warm front, a cloudy weather is observed. Widespread precipitation falls down from *Ns–As* cloud system, the intensity of the precipitation increasing as the warm front approaches.

The second area is found itself at the rear of the low behind the cold front. Here the weather depends upon the kind of the cold front. If the front is of slow moving type, its cloud system consists of *Ns–As* cloudiness, and after its passage the widespread precipitation is observed. Their intensity decreases as the front goes away. If the front is of the fast moving kind, the character of the weather depends upon the following front air mass properties. If the air mass is dry no precipitation may occur. Usually just gusty winds are observed here. In case the air mass is humid, shower type precipitation pours down. It should be noted, however, that whichever kind of the cold front passes, at the front, usually just before the front, "*Cb*" clouds always exist, and associated phenomena can occur.

The third area is **the warm sector**, where the weather is defined by the properties of the air mass situated here. In winter a warm, stable and humid air mass occupies the warm sector. Hence, *St, Sc* clouds and drizzle type precipitation occur here. In summer, as the air mass is dry and stable, the fair weather is observed. However, if the air mass is humid, at daytime it may become unstable and, consequently, can produce *cumuliform* clouds and other convective phenomena.

The third stage, **mature cyclone,** is the shortest one. Its duration is just a few hours. It begins as the first evidence of occlusion front formation appears, and it ends as the pressure at the low center starts rising up. Sometimes, at a certain condition, the occlusion process and filling in begin simultaneously. In some other cases for a few hours the pressure continues slightly falling down or stays unchanged. The weather at this stage has the same character as at the previous stage.

The forth, **filling in stage,** is the longest one. Its duration is about 3–4 days. It begins the pressure starts growing up over whole body of the low, and it continues until on the weather map all closed isobars disappear (figure 24). One can distinguish a few zones with different weather conditions in the filling in low. Near to the central area of the low there are two zones divided by occlusion front.

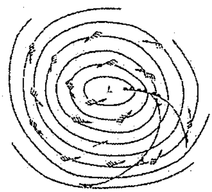

Figure 24. A frontal low in its last stage.

The parts of these zones directly adjusted to the occlusion front experience the effect of the front. Here the type of the occlusion front (cold or warm) and the uplifted warm air properties define the weather. At some distance from the front the types of the air masses divided by the front define the weather. On the periphery of the filling in depression, where the warm and cold fronts keep their activity, the weather is of about the same character as it was in the young cyclone.

Favorable conditions (ULFZ and associated atmospheric front) for cyclogenesis at the same region can persist for a long time. This fact results in generation of a few cyclones under the same ULFZ. These cyclones constitute **cyclonic series** that is also known as **cyclonic family**. An example of such family is shown on the figure 25.

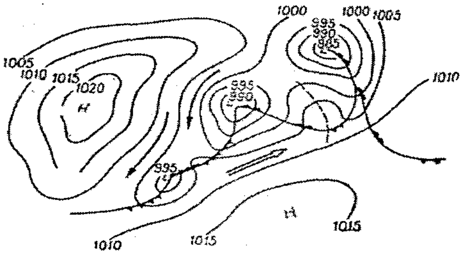

Figure 25. An example of cyclonic series.

The members of the cyclonic family have different degree of development. On the figure 25 the first cyclone is in the filling in stage., and the last one is in the wave stage.

Cyclogenesis is responsible for the mass redistribution. Under the same ULFZ two opposite processes take place. The low formation associated with the mass losses. If at some places the mass of the air decreases, it must increase in some other places. It means that the pressure fall at some area must be compensated by the pressure rise in some other area. Hence, along with low-pressure systems formation the high-pressure systems must be formed too. Therefore, under the same frontal zone pressure ridges and anticyclones arise simultaneously with depressions. That is why we call these high-pressure systems frontal anticyclones (ridges).

The anticyclones or high-pressure systems, which are, found between two cyclones of the same cyclonic series, are called **intermediate highs.** On the figure 25 the intermediate high-pressure formation is seen between the first and the second cyclones of the series. The anticyclone moving after the last cyclone of the series is called **conclusive anticyclone.** On the left-hand side of the figure 25 this large-size anticyclone is shown. The pressure in its center is 1020 hPa. Such kind of anticyclone usually forms in the cold air. Arriving to a region, it brings cold weather. Such anticyclones are fast moving objects. Their trajectories have rather large component directed southward. Moving southward, they may merge with subtropical anticyclones strengthening the latter. In extratropical latitudes, after certain development, they may become stationary anticyclones and create blocking situations.

7. Synoptic situation and synoptic process

Synoptic situation is an aggregate of synoptic objects (air masses, atmospheric fronts, frontal zones, and pressure systems) over a definite geographical region at a certain moment of time. To get the complete idea on the current synoptic situation at a given time, one should analyze surface weather map. The analysis includes drawing isobars and atmospheric front lines, marking centers of cyclones and anticyclones, shading areas with particular weather phenomena such as fogs, precipitation, thunderstorms, snowstorms, and glaze.

Upper-level constant pressure charts (absolute topography charts) serve to determine synoptic situation at upper levels. Geopotential field expressed by the isobar pattern allows for estimating the degree of cyclone and anticyclone vertical development and displacement velocity of the low-level pressure systems. It also allows forecasters to determine positions of the upper level frontal zones and jet streams. The maximal wind chart serves for refinement of the jet stream axis position. The charts of the tropopause heights are composed to analyze the tropopause position. To refine further the synoptic situation, large-scale vertical motion charts are used. These charts allow for distinguishing area of ascending and distending motion, and, hence, the area of possible of cloudiness and precipitation development or degradation. Besides, rawinsonde data and satellite images are accounted for the purpose.

The aim of the synoptic analysis is to get an idea on the character of the current physical processes going on in the atmosphere and their possible development in the future.

Synoptic process is a temporal sequence of the synoptic situations. Comparing the results of the synoptic analyses of the previous and current situations, one can determine the tendency of the process development i.e. to forecast synoptic situation and, at some degree, weather conditions.

At present, numerical weather prediction methods allow meteorologists to forecast the pressure, geopotential, large scale vertical motion fields for the lead time 48–72 hours and more, i.e. to make the charts of expecting synoptic situations. In turn, these charts can be used to predict the weather conditions at any region accounting for the local features of the location the prediction is to be made.

8. Short range weather forecasting

Weather forecast is scientifically based description of expected weather conditions. Contents and formulation of the weather forecast depends upon what it is intended for.

The short-range forecasts for general usage by public and for spreading by mass media (newspapers, radio, TV) include air temperature, relative humidity, pressure, wind speed and direction, cloudiness, precipitation, and other phenomena such as snowstorm, duststorm, fog, squall, hail, thunderstorm, glaze, and rime. Except thunderstorm and rime, these phenomena are divided into weak, moderate and strong ones. In the forecast text the wind direction is indicated in cardinal points, and wind speed in ms or knots. The forecast includes night minimal and day maximal temperatures.

Enumeration of the meteorological parameters and phenomena, which are to be included into specialized forecast intended for various category of consumers, is determined by corresponding agreements. For instance, in the forecasts intended for airport operation the following parameters and phenomena are included.

- Wind speed in m/s and wind direction in degrees.
- Visibility range.
- Cloudiness (cloud amount, form, and height of the cloud lover boundary).
- Air temperature, and
- Expected atmospheric phenomena (the same mentioned above).

Knowing current and expected synoptic situation, the forecaster can get an idea on the weather character in the nearest 24–36 hours. However, as rule, it is usually not sufficient. Therefore, the forecaster has to apply various reckoning methods for meteorological parameter and phenomenon prediction. These methods are based on functional and statistical relations between current and expected values of the meteorological parameters. In this case, the parameter to be forecasted is called **predictand**, and the parameter (parameters) to be used for making the forecast is (are) called **predictor (predictors).**

The forecast of winds at the upper levels is usually made from numerically predicted geopotential fields at the corresponding levels. To make this forecast, geostrophic wind velocities are simply calculated assuming that the actual wind does not significantly deviate from the geostrophic one.

The situation is quite different at the surface. Here, the friction effect diminishes the geostrophic wind speed value and makes the wind direction to deviate from isobars to the left, i.e. to the side of the lower pressure. The angle of deviation depends on the type (roughness) of the underlying surface and on the wind speed. The stronger the wind, the smaller the angle. Over land the angle is larger than over the water surface. The forecasting procedure, therefore, includes the following steps. First of all the geostrophic wind speed and direction at the given locality is determined from the numerically predicted pressure surface field. Then the expected actual wind speed is calculated from the simple formula

$$V_a = kV_g \tag{8.1}$$

Here k is transfer coefficient. Its average value over land is equal to 0,55, and over water surfaces is equal to 0,70. Deviation angle is determined for every place based on the local underlying surface features.

The basis for the **air temperature** forecasting is the equation of energy (heat influx equation).

$$\frac{\partial T}{\partial t} = -\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) - w(\gamma_a - \gamma) + \frac{\partial}{\partial z}k\frac{\partial T}{\partial z} + \frac{\varepsilon_r + \varepsilon_{ph}}{c_p} \qquad (8.2),$$

where u, v, and w are the wind velocity components along axis x, y, and z respectively; γ_a is the dry adiabatic lapse rate; γ is actual lapse rate; k is eddy coefficient; ε_r and ε_{ph} are radiation and water phase transfer heat influxes; c_p is the air heat capacity at a constant pressure.

This equation represents all known reasons for air temperature variation at a given point. The *first term* in the right hand part of the equation represents the temperature variation due to advection; the *second term* describes the temperature variation due to vertical motion, the *third term* represents eddy heat transfer, and the *fourth term describes* the temperature variation due to radiation and water phase transfer heat influxes. The first term in the equation is the largest one, the second one does not play any role at the ground surface since the vertical motion speed here strives to zero. However it is not the case for the free atmosphere, here this term is rather large, and it should be accounted for when forecasting temperature at upper levels. The third term plays an important role at the surface and boundary layers. It responsible for heat exchange between the surface and the atmosphere and, hence, for the diurnal temperature variation. In the free atmosphere it is very small and can be neglected. The fourth term, although influences somehow the temperature variation, but in majority if cases it is much smaller than other terms, and, usually, it is neglected.

The basis for **air humidity** forecasting is the moisture transfer equation.

$$\frac{\partial q}{\partial t} = -\left(u\frac{\partial q}{\partial x} + v\frac{\partial q}{\partial y}\right) - \Delta z\left(\rho\overline{q} \cdot Div\vec{V}\right) + \frac{\partial}{\partial z}k\frac{\partial q}{\partial z} - \frac{dm}{dt} \qquad (8.3)$$

Here, q is specific humidity; ρ is air density; $Div\vec{V} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$ is airflow divergence; m is the mass of evaporated (condensed) water; Δz is thickness of the layer we deal with. The meanings of the rest notations are the same as in the equation (8.2).

The *first term* in the right hand part of the equation represents the air specific humidity advection. The *second term* describes the specific humidity divergence. The *third term* represents the eddy exchange of the water vapor. The *last term* is to be explained in more detail. As the evaporation process takes place in the atmosphere or from the underlying surface, the amount of water vapor in the atmosphere increases, i.e. $\frac{\partial q}{\partial t} > 0$ and $\frac{dm}{dt} < 0$; in case of condensation the situation is just opposite i.e. $\frac{\partial q}{\partial t} < 0$ and $\frac{dm}{dt} > 0$.

In the frontal zones all terms of the equation (8.3) are of the same order of magnitude, in a homogeneous air mass the first and the second terms strive to zero. The third term is responsible for the water vapor exchange between the surface layer and the atmosphere, its value depends upon the state of the underlying and the properties of the air mass acting in the region of interest. The fourth term is difficult for accounting. Its impact on air humidity variation depends on many circumstances. Therefore, it is taken into account qualitatively.

When forecasting the **air temperature near the ground surface,** the following steps are to be done.

1. Determination of advective temperature variation from the initial moment of time to the time the prediction is to be made for. To do this, one should determine the place the air parcel will come from during the lead-time and "bring" its temperature value T, for this purpose the air parcel displacement trajectory is to be constructed.
2. Estimation of a possible temperature transformation in the moving air parcel due to interaction with the underlying surface (the third term).
3. Accounting for the diurnal variation (the third and the fourth terms).

Similar steps are to be done when forecasting **air humidity.** An additional step must be made, namely, the forecaster must account for divergence in case of an atmospheric front approaches the region of interest.

When forecasting the **air temperature in the free atmosphere,** the forecaster is to determine advection temperature variation in the same manner as it is done for the surface layer. As to the transformation, the reason for it in the free atmosphere is the vertical motions (the second term in the equation (8.2)). Thus, accounting for the transformation, predicted vertical motion charts must be used. The diurnal variation in the free atmosphere is negligibly small.

Similar steps are to be done when forecasting **air humidity** in the free atmosphere.

Methods for short-range prediction of various phenomena (fog, thunderstorm, hail, etc) are based on the relations between the phenomenon formation and values of initial (actual) and expected atmospheric parameters. For instance, forecasting shower type precipitation, thunderstorms, and squalls is based on calculated **convection parameters** such as heights of condensation and convection levels, thickness of the convectively unstable layer (CUL), convective available potential energy, convective motion speed, etc. These parameters are calculated from observed and predicted values on the air temperature and humidity at all standard levels. Temperature of the convectively ascending air is determined with the aid of aerological diagram, where stratification and state curves are constructed (figure 26). If the convection parameters reach critical values, then corresponding phenomenon is forecasted. The critical values of the convection parameters were determined as result of processing a large number of cases with various convective phenomenon formations.

Any other phenomena (fog, snowstorm, glaze, etc) are also related to some appropriate parameters. Their critical values are determined in the same way as it was done for the convection phenomena, i.e. by statistical processing of a big amount of the observed and calculated parameter values, as well as observed the phenomena themselves.

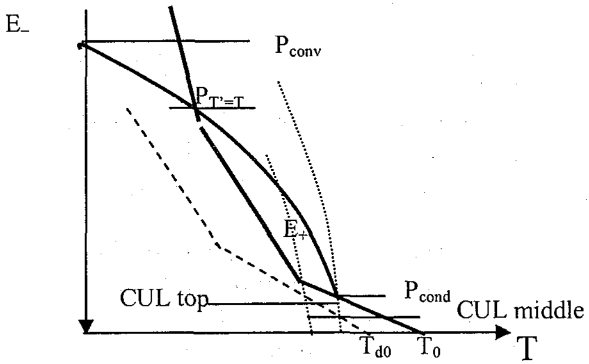

Figure 26. Determination of the convection parameters.
CUL means convectively unstable layer

Concluding remarks

Studying this "Introduction to Synoptic meteorology" will allow students to manipulate without difficulties with basic notions and terms they will use while learning the main course of synoptic meteorology and other meteorological disciplines such as long-term weather forecasting, nowcasting, tropical meteorology, etc.

Having been well acquainted with the bases of synoptic meteorology, students will easily understand regularities of the atmospheric process development and weather variations caused by the synoptic processes. On this ground and using recent statistical and hydrodynamic achievements, they will be able to work out some new methods and techniques for short-range weather prediction.

Knowledge of Synoptic Meteorology will facilitates students to get ideas on basic directions and methods of research activity in the field of weather forming processes, and, hence, to be prepared for further sophistication of existing weather forecasting methods.

Acknowledgement

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Questions

1. What do we understand by the terms "synoptic object" and " synoptic scale"?
2. What methods are used to study synoptic objects?
3. What data are plotted on the synoptic maps?
4. What is the difference between constant pressure level and thickness charts?
5. Write the formula to calculate geostrophic wind speed from the pressure field charts.
6. How does the confluence (diffluence) of the airflows in the boundary layer at the central parts of lows (highs), and at the trough (ridge) lines affect the weather variations?
7. Why does a low become a cold pressure system in its course of development, and an anticyclone become a warm pressure system?
8. What is the air mass transformation, and how does the process of the transformation go on?
9. How can one classify the air masses on the basis of the weather conditions observed in the air masses? When answering this question, take into account a season (summer, winter) and the type of underlying surface (water, land, plane, and mountains) the air mass has formed over.
10. What principles were put into the base for air mass classification?
11. How are the atmospheric fronts classified by their movement direction and by geographical types of the air masses they divide?
12. What are the particularities of the pressure, temperature, wind velocity, cloudiness, and precipitation fields at the warm front?
13. What are the particularities of the pressure, temperature, wind velocity, cloudiness, and precipitation fields at the cold fronts of the first and the second kind?
14. Describe the occlusion front formation process.
15. Give the definition of the upper-level frontal zone (ULFZ). What are the particularities of the geopotential field at this zone?
16. What is the jet stream? How does the WMO define them?
17. What are the common stages the cyclones and anticyclones go through in course of their development?
18. Describe the probable weather conditions at every stage a frontal low go through.
19. What are the sizes of the extratropical cyclones and anticyclones? What is the pressure range in their centers? How long is the "life" time of these cyclones and anticyclones?
20. What are the sizes of the tropical cyclones? What is the pressure range in their centers? How long is the "life" time of these objects?
21. What do we understand by the terms 'synoptic situation" and "synoptic process'?
22. Why is it necessary to predict synoptic situation prior to weather condition forecasting?
23. Define the terms *predictand* and *predictor*.
24. What are the "convection parameters", and why should we know their values?

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