

AIRMASSES AND FRONTS

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Summary

On the weather maps, one can see regions occupied by some homogeneous airmasses, typically of the size of thousands of kilometers. Relatively narrow (a few hundred

kilometers) transition zones between the airmasses are referred to as atmospheric frontal zones, or fronts. Within the airmasses, the weather is rather quiet, while at the fronts, the weather is usually stormy, with sharp changes. In midlatitudes, precipitation is associated with the atmospheric fronts. Depending on geographic region of formation, the airmasses are referred to as Arctic, midlatitude, tropical, and equatorial. Each type (except equatorial) includes continental and maritime airmasses, with specific weather features. The airmasses migrate from their source region to other locations with respect to which they can be warm or cold. Coming of a new airmass is usually associated with passage of an atmospheric front which can be also warm or cold, depending on temperature of the advancing airmass. When cold and warm fronts join each other, an occlusion forms. Cold fronts, warm fronts, and occlusions are associated with typical cloud and precipitation patterns. Deviations from typical schemes are rather frequent. In particular, properties of the fronts largely vary in the mountainous regions. Depending on temperature and wind field configuration, the fronts can sharpen with time (this is called frontogenesis) or weaken and vanish (frontolysis). In many cases, convective weather (showers, thunderstorms, hailstorms, squall lines) is observed at active fronts with ascending warm air. Internal structure of fronts includes specific features like enhanced precipitation bands and areas, low-level jet streams, etc. Many frontal zones extend through thick air layers and reach the upper troposphere. There, they are associated with strong, large-scale jet streams and deep ascending and descending motions.

1. Introduction

Vast bodies of the tropospheric air, which occupy areas with characteristic horizontal size of order of thousands of kilometers and with rather homogeneous weather conditions, are called airmasses. Their vertical sizes vary from a few kilometers up to the depth of the *troposphere* (8 to 10, 10 to 12, and 16 to 18 km in the high, middle and low latitudes, respectively). Within the airmass, the air temperature and humidity vary but slowly in the horizontal directions (usually by 5 to 7°C and 2 to 3 per mille per 1000 km for temperature and for water vapor content, respectively). In the transition zones between the airmasses, called frontal zones, these variations are 10 to 20 times larger (of order of 10 to 15°C and 3-5 per mille per 100-150 km, respectively). On the weather maps, one can usually see regions occupied by the airmasses with relatively narrow frontal transition zones between them. Within the airmasses, weather is rather quiet, with no significant changes from day to day and with comparatively light precipitation (though, in summer, showers and thunderstorms can occur). Precipitation is mainly associated with the frontal zones.

The airmass basic properties which determine characteristics of weather are vertical distributions of air temperature and moisture. The most important property of this distribution is its stability with respect to cumulus convection (*convective* or static *instability*). If the *temperature lapse rate* in a given layer is large enough for the warm air (usually heated from the surface) ascending due to *buoyancy*, - the layer is convectively unstable; otherwise, it is stable. The most stable conditions are associated with so-called *inversions of temperature* (temperature increase with height). The inversions develop over cold surfaces, especially over ice and snow.

The atmospheric front - a zone of transition between two airmasses with different properties, especially temperature and humidity - can be very narrow.

That is why, in the theoretical studies, the atmospheric front is often approximated by an interface between two airmasses, with temperature (density) and humidity discontinuities.

The transition zone at the surface is called the surface atmospheric front. On the weather maps, the surface fronts are represented by lines. It implies that the frontal zone width is small as compared with the sizes of the airmasses and with the map scale.

In fact, the transition zone width varies largely around the characteristic value of 100 km.

In the atmosphere, the frontal transition layer is inclined with respect to the horizontal plane, because the colder air tends to flow under the warmer one and takes the form of a wedge. For stable fronts, the slope of the frontal layer is defined by an equilibrium between the Coriolis force and that of pressure horizontal gradient.

This slope is not steep: the tangent of the slope angle varies from 0.01 to 0.001. The slopes of the moving fronts can be much steeper, especially in the lower layer. The transition layer thickness in the atmosphere is of order of several hundred meters.

2. Airmasses

2.1. Source Regions, Air Mass Transformation

The air mass acquires its relative homogeneity when the air circulates, for a sufficiently long time, over a region with sufficiently uniform surface (the source region). Favorable conditions for generation of homogeneous air masses occur in steady pressure patterns with slow winds and homogeneous thermal and radiative regime which requires homogeneous surface properties and cloud conditions.

After several days of traveling in the source region, the air acquires properties of an air mass of certain type. If, later, the air mass moves to another region, heat and moisture exchange with the new underlying surface leads to changes of the air properties. This is called the air mass transformation. In fact, the transformation is a continuous process. Its main mechanisms are turbulent and convective mixing and radiative heat transfer. Very rapid transformation often takes place near the coasts, when, for example, warm continental air (in summer) moves onto cold ocean waters.

2.2. Geographic Classification of Airmasses

Depending on the source region latitude, the following types of the air masses are distinguished (Figures 1 and 2): Arctic air (in the Southern Hemisphere - Antarctic air), midlatitude air (also known as polar air), tropical air, and equatorial air. Every type, except the equatorial one, includes maritime and continental air masses.

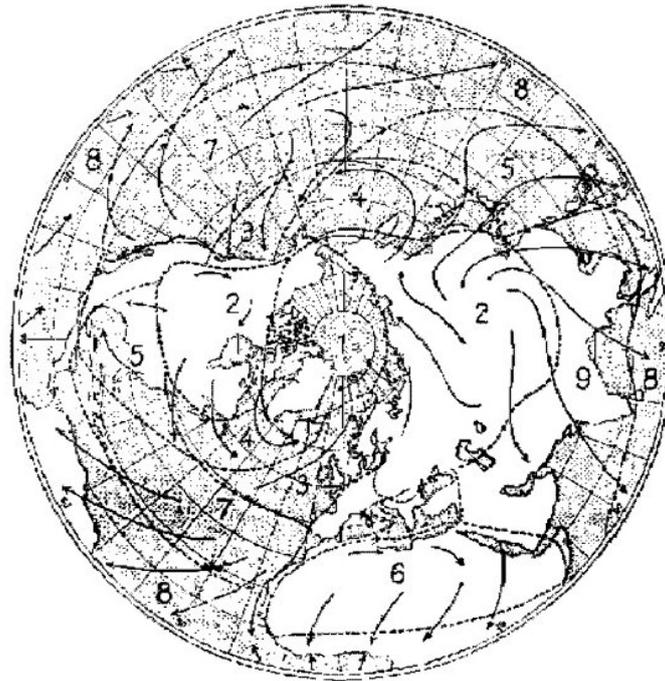


Figure 1: **Source regions in winter:** 1 - Arctic, 2 - polar continental, 3 - polar maritime or transitional, 4 and 5 - transitional, 6 - tropical continental, 7 - tropical maritime, 8 - equatorial air, 9 - monsoon air over South Asia.

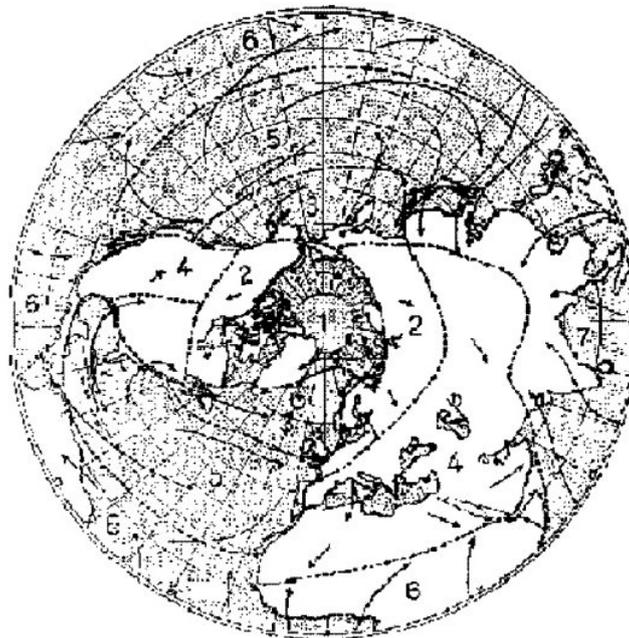


Figure 2: **Source regions in summer:** 1 - Arctic, 2 - polar continental, 3 - polar maritime, 4 - tropical continental, 5 - tropical maritime, 6 - equatorial air, 7 - monsoon air over South Asia.

1. **Arctic air.** Arctic airmasses are, on average, 3-5 and 2 km thick (for maritime and

continental air, respectively), though, in certain cases, the Arctic air thickness can be comparable with that of the troposphere. The Arctic air is very dry, clean, with a bright sunshine, blue sky, and high visibility. The maritime air has slightly higher humidity than the continental one.

The Arctic air source region is Arctic area covered with snow and ice. In winter, this area is larger and includes ice-covered oceans and snow-covered north parts of the continents. In summer, the Arctic air is generated over the oceanic area covered with melting snow and ice. In its source region, the Arctic air is continuously cooling down from below in its lower layer. As a result, temperature inversions develop.

2. Midlatitude air (polar air). The maritime midlatitude airmasses have high humidity and a large vertical scale, usually reaching the *tropopause*. They are often convectively unstable, at least in the lower half of the troposphere. The source areas are oceans to the south of the Arctic ice.

The continental midlatitude airmasses in winter have much in common with the Arctic airmasses (temperature inversion in the lower layer, low temperature and humidity), but the latter is about 10°C colder. In summer, the continental midlatitude airmass is warm and rather dry, convectively unstable, with a low visibility (due to dust). The source regions are continents of Eurasia and North America.

3. Tropical air. The maritime tropical airmasses are very warm and humid, usually convectively unstable. The source regions are represented by a band of subtropical highs which in summer move to the north as compared with winter. The continental tropical airmasses are extremely hot, with a low relative humidity. They are also convectively unstable and contain much dust, which causes low visibility. These airmasses are generated round the year in subtropical and tropical Africa, in summer also in south part of midlatitudes (Southern Europe, Central Asia, Kazakhstan, Mongolia, Northern China). In many respects, they are similar to the summer midlatitude continental airmasses, but are 5-10°C warmer.

4. Equatorial air. Equatorial airmasses have little difference from the tropical ones and often are considered together.

2.3. Warm and Cold Airmasses

When an airmass comes to a certain area, it can turn out to be cold or warm with respect to the underlying surface. In some cases, the airmass can be also neutral. It is evident that the warm airmass will cool down in its lower layer due to transformation over the colder surface. As a result, the warm airmass becomes more *stable*. On the contrary, the cold airmass is being transformed in such a way that the lower layer gets warmer and thus the stability decreases and convective instability can arise. Indeed, convective activity is typical for the cold airmasses.

For instance, the Arctic air, when moving to the south, represents a cold airmass. Though it is very stable in its source region, - heating from the warmer surface leads to gradual development of convective instability. In this air, typical convective clouds,

showers, and thunderstorms occur (even in winter), especially over the coasts. When the air moves further to the south, it is eventually transformed into the midlatitude airmass.

As an example of warm airmass, the maritime tropical air can be considered, when it moves to the continent in winter. Being unstable in its source region, this airmass is transformed over the land and becomes stable. Rains and showers are replaced by stratiform clouds, drizzle, and fogs.

2.4. Transformation Rate

The transformation rate depends on differences in properties of the underlying surface and the airmass. For example, when the Arctic air intrudes Europe in summer, this cold airmass undergoes strong heating over the land. During the first 3 days, the heat exchange is the most intense, and the surface air temperature can increase by as much as 15°C. Then the heating becomes slower. By the 7th day, the transformation is over: the air temperature near the surface and at 1-km level is about 20 and 18°C above the initial values, respectively.

Another example: when the maritime midlatitude air intrudes Europe from the west in summer, the transformation rate is low during first 3 days, due to convective clouds growth in this moist air. Precipitation and the consequent moistening of the soil leads to increasing heat consumption by evaporation, while the air warming remains weak. When the most part of the atmospheric water vapor eventually precipitates, - the cloudiness decreases, and the transformation rate increases. Due to convective mixing, the transformation rate is uniform in a deep layer (in the lower half of the troposphere). The transformation is usually over by the 6th day. During this period, the air temperature in the lower 1-km layer increases by about 10°C.

3. Atmospheric Fronts

3.1. Frontogenesis and Frontolysis

The narrow frontal zone between two airmasses develops under special conditions: during a certain time, the airmasses must converge, in order that the contrasts in temperature and humidity would be concentrated within a transition zone. This process is called frontogenesis.

The opposite process of the contrasts decreasing is called frontolysis. Frontogenesis leads to the formation of new fronts and to the sharpening of previously existing ones, while frontolysis leads to the front weakening and disappearing. Usually, the processes of frontogenesis and frontolysis are considered with respect to the temperature field, because the air temperature represents the main characteristic of the airmass.

Frontogenesis occurs in confluent wind fields.

In Figure 3, a typical streamline pattern (the deformation field) is schematized in which the isotherms come closer together in time. In the real atmosphere, frontogenesis takes place also in the pressure troughs and in the cyclones.

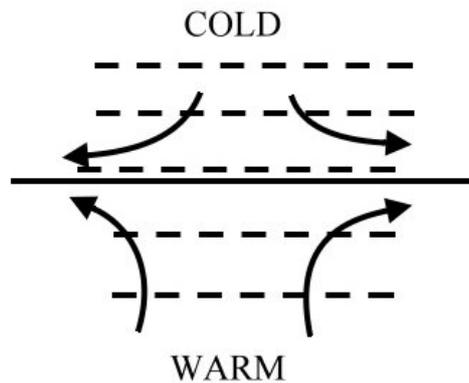


Figure 3: Schematic wind deformation field (streamlines shown by solid lines with arrows) applied to initial temperature field with constant gradient (broken lines are isotherms)

Frontogenesis and frontolysis can occur in the layers of different thickness, both in the *boundary layer* and in the *free atmosphere*, with maximum intensity near the surface and near the tropopause. The processes affect not only the temperature and humidity fields: the feedback effects on the velocity field are also of great importance.

These feedback effects can be shortly explained as follows. In the free atmosphere, *thermal wind balance* exists between the temperature and wind fields. When the temperature horizontal gradient is changing (e.g., increasing, - the case of frontogenesis), the wind field must change, too. The both fields must re-establish the balance and thus must adjust each other. The adjustment is carried out through generation of vertical circulation. In the case of frontogenesis, the circulation cell includes an ascending branch in the warm air and descending one in the cold air. This circulation is called *thermally direct* (because the warm air is ascending, like in the case of thermal convection) and plays a compensating role with respect to the converging effect of horizontal wind. In the case of frontolysis, the compensating circulation is *thermally indirect* (the cold air is ascending and the warm one is descending with respect to each other). In these circulation cells, relatively slow (of order of few cm s^{-1} to $10\text{-}20 \text{ cm s}^{-1}$) but long-lasting (from several hours to several days) ascending motions cause condensation of water vapor and formation of cloud and precipitation. As the warm air usually contains more water vapor, its ascending motion (associated with frontogenesis) generates more clouds and precipitation than in the case of cold air ascending. The clouds in the warm airmass develop above the frontal transition layer, in the deep layer of warm air. On the contrary, the clouds in the cold air develop below the frontal layer, within the shallow wedge of cold air, and thus cannot be as thick and intense as those in the warm airmass.

3.2. Geographic Classification of Fronts

The atmospheric fronts are classified with respect to the type of the airmass which lies on the cold side of the front. So, the front between the Arctic and midlatitude airmasses is called Arctic front. Respectively, the polar front separates the midlatitude (polar) air from the tropical one. In some cases, a tropical front is formed between the tropical and

equatorial airmasses.

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