NOTES

AEROLOGY SERIES ☆ ☆ NO. 4

AIR MASSES AND FRONTS

PREPARED BY TRAINING DIVISION
BUREAU OF AERONAUTICS, U. S. NAVY

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INTRODUCTION

In order to fly weather intelligently, it is necessary to have some knowledge of what weather is—what causes it, and what influences it.

The British evacuation of Dunkirk was successful because of weather—fog was on the side of the Allies during the time the Luftwaffe was trying to break up the evacuation.

When the Japs attacked Pearl Harbor, they rolled in behind a cold front that obscured their movements and contributed to their initial success.

Many a Navy attack has been timed to conform to weather favorable to the tactical situation. The raid on the Gilbert and Marshall Islands, for example, was so planned that our aircraft left their carriers, made their raid, and returned to their bases under favorable flying conditions, after which the ships took cover in a frontal area that protected them from aerial reprisals all the way out of the combat zone.

There is a definite pattern to the weather all over the world. Bombers' moons and thunderstorms aren't things that just "happen." They result from certain occurrences in the atmosphere that create particular effects. They are predictable, and therefore no surprise to the aviator whose knowledge of aerology gives him foresight.

AIR MASSES AND FRONTS

In this booklet we begin a study of the basic causes of weather. There is little direct operational instruction here, but there is information that it is absolutely necessary for you to know in order to understand weather as an aviator must understand it. Learn the basic principles that are set forth here, and you will find their application easy when you come to learn how to fly cold fronts, warm fronts, and occlusions.

There is also much to be learned from this book that will be valuable to you when the time comes for you to learn to read one of the most vital and interesting documents you will ever see in your life—the weather map.

Aerology—the science of meteorology as applied to the upper air—is essential knowledge to you as a naval aviator. You can depend on your plane captain for the condition of your plane and its equipment. Your instructors have given you the knowledge necessary to fly. But as long as you fly, you can never stay out of weather, and in flying the weather you are going to be on your own.

You must depend upon the knowledge you can gain of one of the world's oldest sciences. Writings on meteorology date back to 400 B.C. Aristotle, who observed weather conditions associated with certain wind directions, is credited with being the first meteorologist. Torricelli, who invented the barometer in 1643, carried the science a step further. Then in 1670 Hooke invented the wheel barometer, which shows the relationship between barometric heights and certain types of weather.

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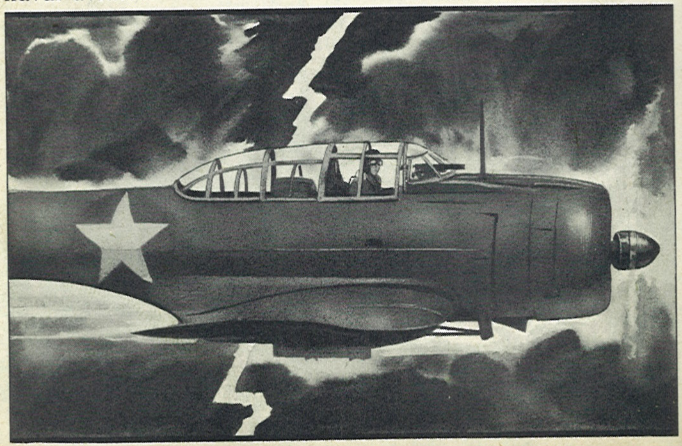
AIR MASSES AND FRONTS

There was rapid advance in the science of weather during the eighteenth and nineteenth centuries as new instruments were developed and more scientists entered the field. Elaborate research was carried on by our universities, but it is obvious that aerology is no easy field for the laboratory scientist.

Take, for example, a local summer shower. The air and water in this shower weigh thousands of tons, and the energy involved would approximate that which could be produced by burning several thousand tons of our best anthracite coal. Other storms take place on a scale much greater than this. Therefore, when you consider that a general storm may cover an area of *five hundred thousand square miles*, you realize the impossibility of duplicating it in the laboratory.

The First World War was a proving ground for many new aerological theories, one of the most important of which was the polar front method of weather map analysis.

It is the purpose of this pamphlet to describe this method for you, and to show how you can use it to advantage in analyzing flying weather every day of your career as a naval aviator.

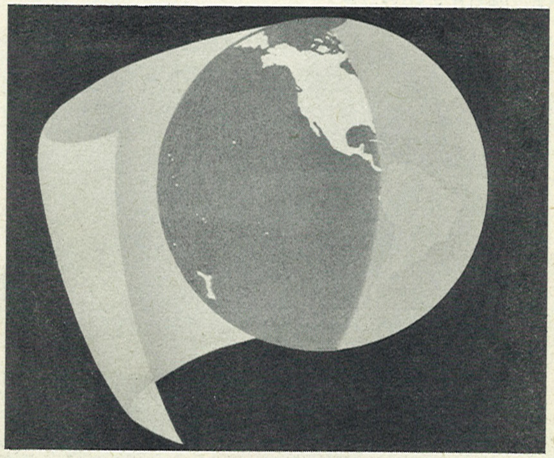


THE ATMOSPHERE

The earth is surrounded by an envelope of gas which is called the atmosphere.

Life is dependent upon this gas, for it contains the air we breathe. Flight is also dependent upon it for it is the action of the airfoil within this envelope of air that provides lift, which makes aviation possible.

In addition, the flow of air from one point to another, commonly referred to as the wind, has a definite influence on the flight path of an airplane.



The vertical thickness of the atmosphere is so small in comparison to the size of the earth that, in proportion, it would be as thin as a sheet of tissue paper tightly twisted around an orange. Therefore in the diagrams of this booklet the depth of the atmosphere has been greatly exaggerated in order to demonstrate the action of the atmosphere in terms that are comparable to the vertical distance an airplane can travel, rather than in proportion to the size of the earth.

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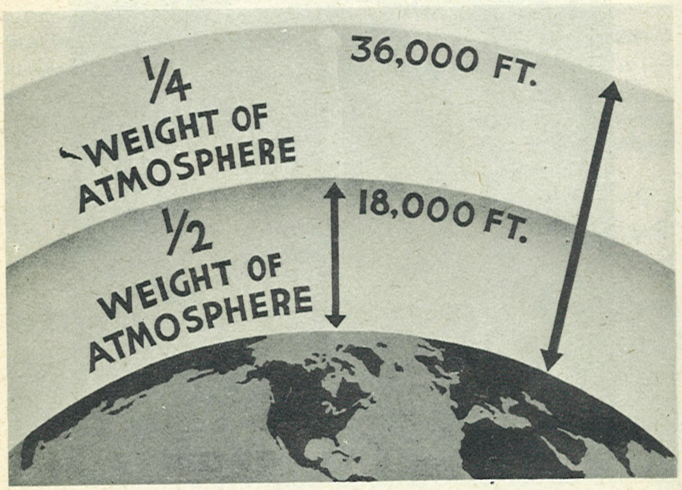
THE ATMOSPHERE

The atmosphere is composed of about ninety-nine percent of oxygen and nitrogen, the remaining one percent being distributed among several other gases of which one is water vapor. As altitude increases, the atmosphere gradually thins and becomes rarefied. Half of the total weight of the atmosphere lies within the first 18,000 feet above the earth's surface; one-fourth of its weight lies within the next 18,000 feet; therefore, below 36,000 feet lies three-fourths of the weight of the atmosphere, the remaining one-fourth being distributed from 36,000 feet up to several hundred miles from the earth's surface.



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DIVISIONS OF THE ATMOSPHERE

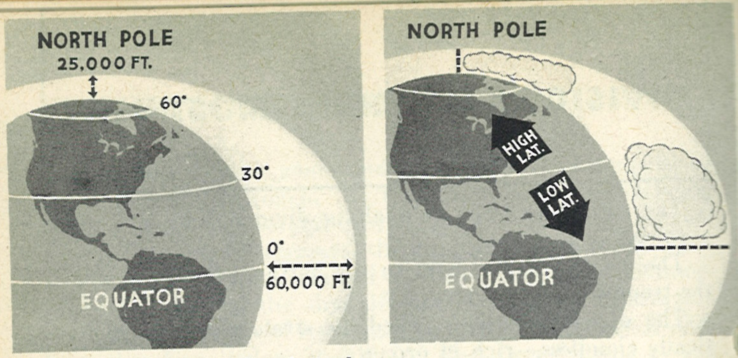
The atmosphere, in general, is divided into two main segments.

The lower portion, next to the earth's surface, is called the troposphere.

The upper division is called the stratosphere. It is practically cloudless—rich in ozone.

Between the two, and separating them, is a narrow transition zone called the tropopause.

All factors which make up the weather as we know it, clouds, rain, snow, and ice, occur in the troposphere. This zone of weather varies in thickness from about 60,000 feet in the tropics to about 25,000 feet over the polar regions. Over the middle latitudes it goes to about 36,000 feet. The depth of the troposphere varies slightly with the seasons, expanding during the summer, and contracting in the winter.

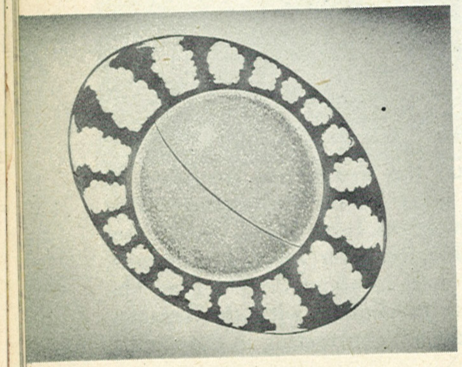


Clouds tower higher in low latitudes

This is due largely to the heating of the earth's surface and the atmosphere by the sun.

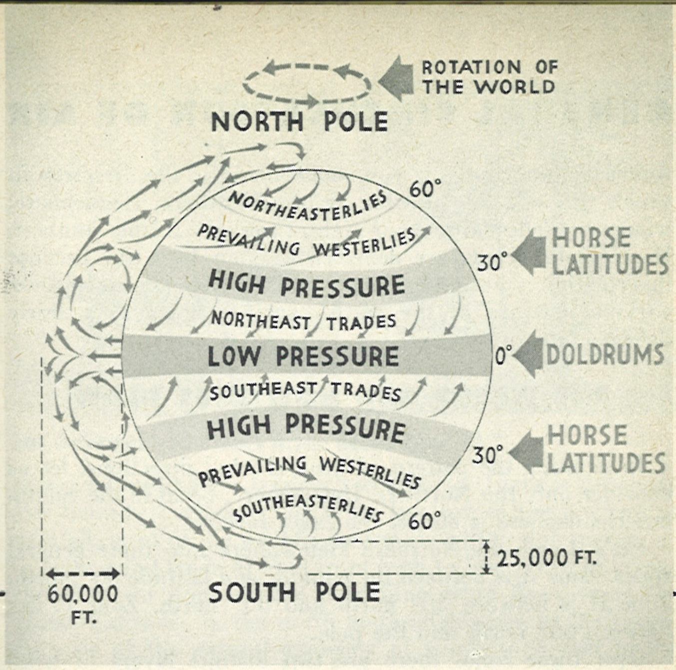
All the energy received on the surface of the earth is radiated from the sun. The earth's surface absorbs this energy, but due to the fact that the earth is composed of land and water, an unequal amount of heat is absorbed over various regions. Land surfaces, which absorb energy rapidly, heat up to a higher degree and more rapidly than water surfaces.

Over the equatorial belt, much more radiant energy is received than over the polar regions. Therefore the air over the tropics is warm, while air over the polar regions is cold. This results in the air over the equator tending to rise, and the cold air over the poles tending to sink.



Cloud pattern around earth

Peculiarly enough, the temperature pattern in the stratosphere is the reverse of that of the troposphere —colder over the tropics than over the poles. Over the Arctic, stratosphere temperature is approximately minus 49°F. Over the middle latitudes, it is about minus 67°F., while over the tropics it drops to minus 112°F.



GENERAL CIRCULATION OF AIR

In the troposphere, there is a general flow of air over the earth's surface which follows a definite and fixed pattern. The *rising* air over the equator results in *low* barometric pressure. The *sinking* air over the polar regions results in *high* barometric pressure. Air flows from high toward low pressures, and therefore there is a tendency for air to flow from the poles toward the equator at low levels and for warm air to flow from the equator to the poles at high levels.

This interchange of air between the equator and the poles is influenced by the rotation of the earth from West to East, which deflects winds. If you stand facing in the direction in which the wind is blowing in the Northern Hemisphere, winds are deflected to your right. Similarly in the Southern Hemisphere, winds are deflected to your left. But because this rotation is a constant factor, atmospheric movement over various portions of the earth's surface holds to a fairly definite pattern.

THE WINDS AND HOW THEY BLOW

In defining the pattern of general wind directions, let us consider only the Northern Hemisphere, because the Southern Hemisphere is almost the exact reverse.

Let's divide the Northern Hemisphere into three general zones. Zone A is between the equator and latitude 30° north. Zone B is between 30° north and 60° north. Zone C lies between 60° north and the pole.

Over these zones there are two distinct layers of wind patterns, one at levels close to the earth's surface, (the troposphere) and the other at high levels, (the stratosphere). Observations in the stratosphere are still meagre and the conclusions are too theoretical to be included here.

In analyzing the various prevailing wind directions in the layer of winds at low levels, let's start at the equator and move north.

Zone A is bounded on the south by a belt of low barometric pressure called the doldrums, a region where the winds converge from both hemispheres and are light and variable. If you have read any sea stories, you know already that the doldrums are an area of calms that used to drive the old sailing shipmasters crazy, and where there are frequent showers, thunderstorms, and heavy rainfall.

On the north, Zone A is bounded by a belt of high barometric pressure known to many generations of seafaring men as the "Horse Latitudes." Here the air currents are

The Doldrums and Desert Areas bound Zone "A"

divergent and have a tendency to subside. There is relatively low humidity, almost clear skies. Because of the scarcity of rainfall, most of the world's deserts lie within this region.

Now, wind tends to flow from high to low pressure areas; therefore, in Zone A, the prevailing wind flows from the Horse Latitudes in the north to the doldrums in the south. Because of the natural tendency of winds to deflect to the right in the Northern Hemisphere, winds in Zone A are northeast, and are known as the Northeast Trades.

Progressing northward, away from the equator, we come to Zone B, bounded on the south by the high pressure belt of the Horse Latitudes and on the north by a low pressure belt referred to as the polar front, or sub-polar low, where winds are stormy and extremely variable. Again, the winds flow from the high pressure toward the low pressure areas, with deflection to the right, in the Northern Hemisphere, caused by the earth's rotation; and therefore the winds of Zone B are southwesterly. Common parlance of sailors has shortened the designation of Zone B to the region of "Stormy Westerlies." These winds gain in strength as the latitude increases.

North of the Polar Front and lying between its low pressure belt and the high barometric pressure area at the North Pole is Zone C, where the winds, flowing from high to low pressure, are known as the Polar Easterlies.

AIR MASSES

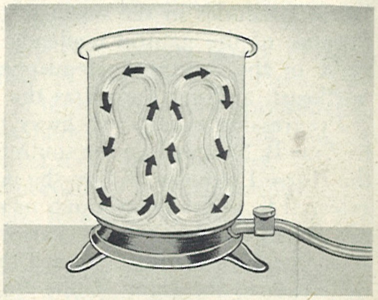
Air that remains in contact with the earth's surface gradually acquires properties that are characteristic of the surface that underlies it. If the underlying surface is uniform and air currents are favorable, the air mass takes on a uniformity in a horizontal direction, notably in its temperature and humidity.

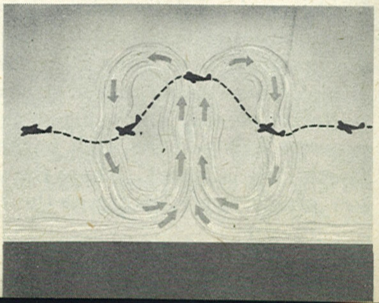
This uniformity, which is the essence of an air mass, depends upon the source from which the air comes, and the path it follows after leaving its source.

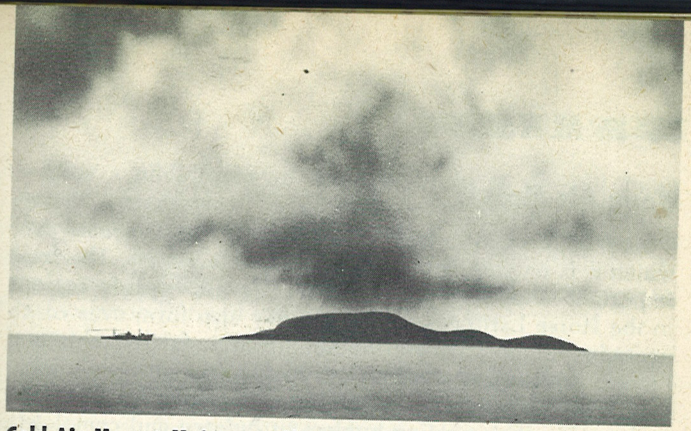
Its source and the path it follows determine whether the air mass is warm or cold, moist or dry, stable or unstable.

Cold Air Masses

A cold air mass is one which is colder than the surface over which it is flowing, as when polar air flows toward the middle latitudes. Upon being warmed by contact with the surface of the earth, the air develops vertical currents, like those you can see in a container of water on a hot stove.







Cold Air Mass + Moisture = Showers

For this reason, a pilot flying through air that is being heated from below may expect to encounter these currents, which give him a bumpy ride in rough air.

Also, because of the same vertical currents, the clouds that this pilot encounters will be characterized by vertical development, called cumulus. If the path of the air movement is over land, not much moisture is picked up and fair weather may be encountered, or there may be woolpack clouds in the sky.

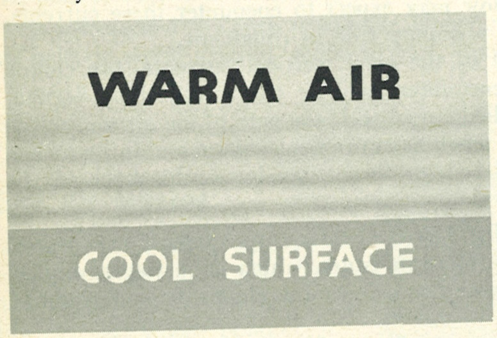
On the other hand, if the cold air mass travels over water, it picks up much more moisture, which is carried to higher and higher levels, and cumulonimbus clouds producing showers may form.

The vertical currents in a cold air mass re-distribute all the factors that tend to reduce visibility near the ground. Smoke, haze, and moisture are carried aloft and spread through a deep layer of air. For this reason, cold air masses tend to bring good surface visibility.

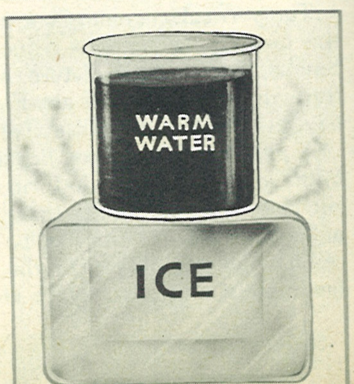
A pilot can often recognize a cold air mass by bumpiness in the air and the cumulo form clouds created by the vertical currents. Once he knows that he is in a cold air mass and not near a "front," he can be reasonably assured of some ceiling and visibility near the surface, no matter how unfavorable conditions may be above.

Warm Air Masses

Any body of air which is warmer than the surface over which it is moving is defined as a warm air mass. The most important sources of warm air masses are oceanic regions in the Horse Latitudes (although they also form over continents in summer). There the air is warm, fairly stable and high in moisture content. When such a mass travels toward colder regions its lower layer becomes cooler and increasingly stable. This cooling hinders turbulence and completely shuts off any vertical currents, so that the air flow is almost entirely horizontal.



This action can be demonstrated by placing a container of warm water over a cake of ice...unlike the water over the open flame, it is settled and static in appearance.

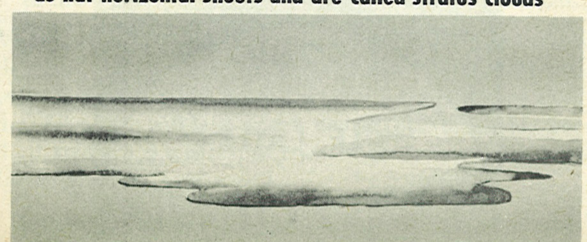


Thus a pilot flying in a warm air mass will encounter smooth air and cloud forms of the stratiform or sheet type. But in contrast to the cold air mass, the warm air mass tends to concentrate all factors that reduce visibility near the surface of the earth. Fog may form, and in any event, surface visibility and ceilings tend to be low.

These various characteristics can be easily recognized when the temperature difference between the air and the surface is large. However, when the difference is slight, the change in surface temperature from night to day may change the air from a cold air mass by day (when the surface is warmed by the sun) to a warm air mass at night (when the ground has cooled by radiation).

Low visibilities, due to fog formation are common in a warm air mass

Clouds that form in a warm air mass appear first as flat horizontal sheets and are called stratus clouds

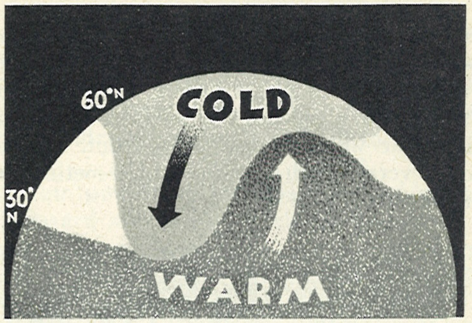


The low pressure belt around the equator is the result of rising air caused by the sun's excessive heating in that region. As the air rises and flows towards the North Pole, part of it sinks at around 30° north latitude, building up the high pressure belt in that region. The remainder of the air continues its northward flow toward the pole and through the region of prevailing westerlies, sinking over the North Pole, contributing to the high pressure dome already existing there.

Now, it is obvious that there cannot be a continual evacuation of air from the equatorial zone and a piling up to the north around the pole. If the process were to continue, eventually all the air would be north of 60° north latitude, and there would be no air at all over the equatorial zone.

Since we know that this is not true, and no vacuum exists in the atmosphere, there must be a means by which the system of circulation of the atmosphere is kept in balance.

There is such a system. What actually happens is that air piles up north of what we call the Polar Front, a zone between air masses of polar origin and air masses of tropical origin. As the air continues to accumulate, the high pressure area becomes stronger and stronger until finally the Polar Front is unable to hold it in that region and the northeasterly current from the pole breaks through into the area of prevailing westerly wind.



Thus the middle latitudes, lying between the cold and warm areas of the earth, become like a battleground, alternately invaded by surges of cold air from the north and warm air from the south.

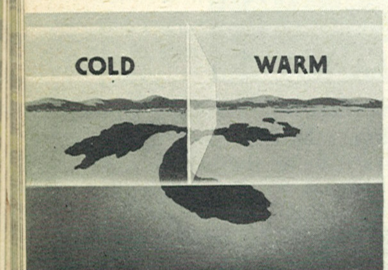
Just like oil and water in the same container.

The water being heavier than oil lies on the bottom.

When cold air meets warm air, they do not mix readily. Each mass tends to remain intact, with the cold air sliding beneath the warm air or the warm air advancing over the cold. The warm air will never crowd out the cold, because of their relative densities, but warm air may *replace* cold air as the cold mass moves out.

FRONTS AND HOW THEY FORM

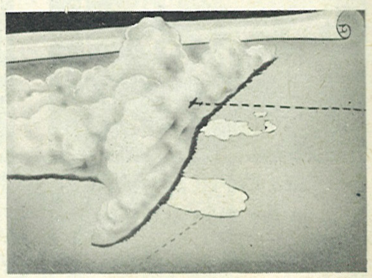
The cold air is separated from the warm by a sloping surface, which is called a front, a boundary surface between the cold and the warm temperatures. It is the mobile line where this boundary touches the surface of the earth that appears on your weather map as a front. Fronts usually extend over several hundred miles and sometimes well over a thousand or two.



A boundary zone beneath the cold and warm air is shown in vertical cross section.

The cold air is heavier than the warm air...therefore it slides underneath.

The intersection of this surface with the earth is the line shown on the weather map.

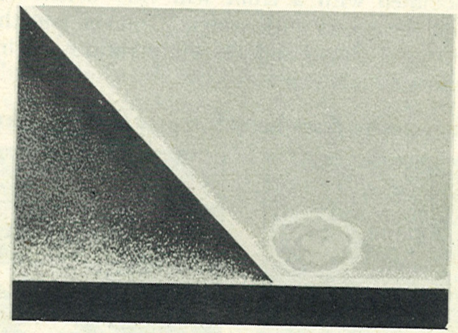


These fronts often extend from several hundred miles to well over a thousand or two.

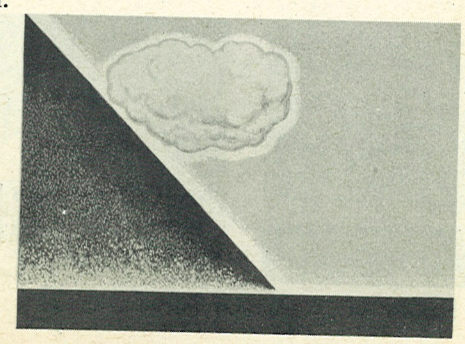
HOW FRONTS INFLUENCE THE WEATHER

The sloping frontal surface is the major cause of weather that constitutes a hazard to flight operations—turbulent conditions, thunderstorms, icing, and all forms of precipitation.

The cold air acts as an inclined plane which forces the warm air upward and lifts it to higher levels.



As air rises it expands, which causes it to cool. When it has cooled so much that it can no longer hold all of the water vapor it is carrying, the excess moisture condenses out as clouds. If the rising and cooling continues, rain or snow may fall.



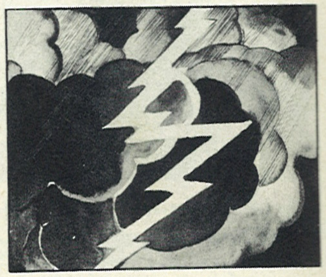
HOW FRONTS INFLUENCE THE WEATHER

Thus the weather along a front is caused by the lifting of warm air by the wedge of cold air, and the extent of the dangerous weather area is governed by the steepness of the slope of the front. A steep slope produces a narrow band of clouds and heavy showers, while a shallow slope causes a wide band of fog and light continuous rain.

All fronts are basically the same—a surface separating air masses of different temperature. The types of weather which may be associated with a front will vary considerably depending upon the speed with which it moves and the steepness of the frontal slope, and the temperature and moisture content of the air masses involved.

You will encounter these hazards caused by sloping fronts

RAIN



THUNDERSTORMS

FOG

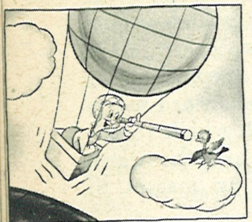
SNOW

HOW FRONTS INFLUENCE THE WEATHER

There are three general types of fronts, and by recognizing them you can anticipate the kind of weather you are about to encounter in flight. There is the *cold front,* which occurs when polar air invades the middle latitudes. There is the *warm front,* which occurs when a surge of tropical air is permitted to enter the middle latitudes by the eastward movement of polar air. There is the *occluded front,* which results when a cold front overtakes a warm front, and the warm air mass is squeezed upward by two meeting masses of cold air.

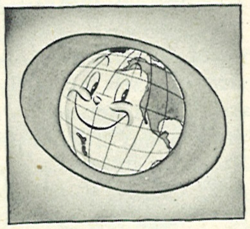
Each type of front brings a distinctive type of weather. The influence of each upon flying conditions is so great that they are to be taken up in detail in booklets to follow, which will accompany motion pictures on the subject.

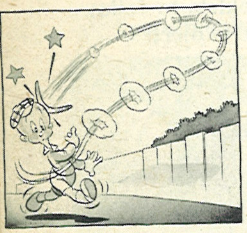
GLOSSARY



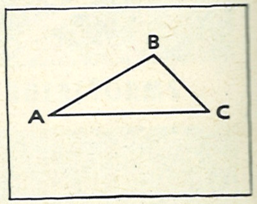
Aerology—The science of the phenomena of free air as revealed by kites, balloons, airplanes and clouds.

Atmosphere—The whole mass of gas which surrounds the earth.





Circulation—The act of moving in a course, not a circle, which brings the moving thing, such as air, to the place where its motion began.

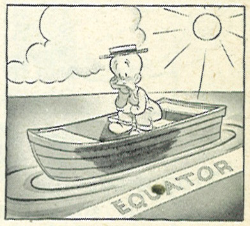


Component—A word used to indicate the steps, in their various directions, which must be compounded or combined geometrically in order to produce a given displacement. In the diagram, AC is the geometrical sum or resultant of the two components AB, BC, wherever B may be. It is not necessary that the components should be at right-angles to each other. The above law of the composition of displacements is applicable to the composition of velocities, accelerations and forces.

Cyclone—A rotation of wind, counter-clockwise in the Northern Hemisphere, around a center of low pressure.

Discontinuity—As a rule, fundamental atmospheric variables, pressure, wind velocity, temperature and humidity, are factors of space and time. Occasionally, however, their variation in short distances (or in a short time at a fixed point) is so much above normal that their distribution is regarded as discontinuous. For example, a 10 degree fall in temperature ordinarily takes place over a period of a few hours at least. If this should take place in a few minutes, it indicates what can be regarded as a discontinuity in the atmosphere.

Doldrums
A part of the world near the equator, abounding in calms and squalls.

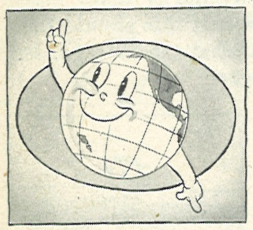


High Pressure System—An area where the barometric pressure in the center is higher than the pressure in the surrounding region, with a clockwise wind circulation in the Northern Hemisphere around the center.

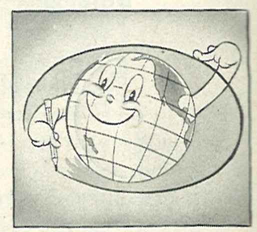
Horse Latitudes—The belts or regions in the neighborhoods of 30° North and 30° South latitude, characterized by high pressure. The horse latitudes got their name from the time when windjammers, carrying livestock, would run out of fresh water and have to push their cargo of horses overboard.

Low Pressure System—An area where the barometric pressure in the center is lower than the pressure in the surrounding region, with counter-clockwise wind circulation around the center.

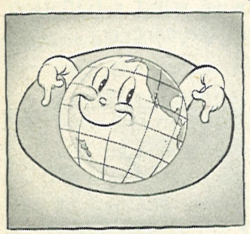
Meteorology—The science treating with the atmosphere and its phenomena, especially its variations.



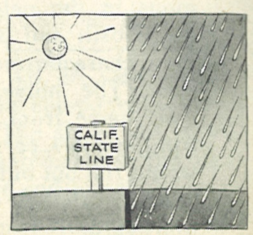
Stratosphere—The upper portion of the atmosphere in which temperature changes but little with altitude and clouds never form.



Tropopause—The narrow transition zone that divides the troposphere from the stratosphere.



Troposphere—The portion of the atmosphere below the stratosphere where weather variations take place.



Weather
The state of the atmosphere.

AEROLOGY SERIES ☆ ☆ NO. 5

THE WARM FRONT

PREPARED BY TRAINING DIVISION
BUREAU OF AERONAUTICS, U. S. NAVY