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A Simple Way of Estimating Geostrophic Wind in Modern Study of Synoptic Chart

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ABSTRACT

At each meteorological observing station, at each standard time of observation, measurements or estimates are made of pressure, temperature, wind speed and direction, humidity, state of the sky, weather at the time, visibility and other parameters. These meteorological parameters are plotted in synoptic charts on which isobars have been drawn containing a vast array of information which are in turn analyzed for use by forecasters, aviators and for other aeronautical purposes. The paper attempted to provide a simple means of estimating geostrophic wind at 3000km-4000km from deduced wind speed

$$G = \frac{p}{2wd\sin\varnothing}$$

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INTRODUCTION

The objective of any observational study is to understand those phenomena which are characteristic of the whole system.

The synoptic chart shows the pressure distribution, temperature, weather, visibility, and tendency at a particular meteorological station. A synoptic chart is the scientific term for a weather map. Synoptic charts provide information on the distribution, movement and patterns of air pressure, rainfall, wind and temperature. This information is conveyed using symbols, which are explained in a legend.

There exists a simple means of obtaining an estimate of the wind direction at 3000km – 4000km on occasions where direct measurement is impossible. The geostrophic wind can be used instead of direct measurements when the isobars on the synoptic chart are nearly straight, and on occasions when the pressure distribution is not changing rapidly (Holton, 1972). The geostrophic wind is the theoretical wind that would result from an exact balance between the carioles effect and the pressure gradient force. This condition is called geostrophic balance. The geostrophic wind is directed parallel to Isobars. The geotropic wind scale is a valuable tool in weather studies and in physical and dynamical meteorology, in that it gives a reasonably close approximation to the wind direction at 3000km – 4000km above the ground. The scale can equally be used to estimate the upper wind on occasions when actual measurements of the wind are not available on account of low cloud or precipitation Richard, (1965). It therefore becomes necessary to study using simple laws of physics and other basic assumptions the pressure gradient and the geostrophic wind in the modern study of the synoptic chart.

Pressure gradients in the atmosphere work about as you would expect them to. The force caused by pressure gradients is a force directed away from high pressure and toward low pressure. So the direction of the force vector is directly opposite the pressure gradient itself, since a gradient vector always points in the direction of higher values.

According to Newton's second law, the acceleration of an object (or a parcel of air, for that matter), is equal to the total force per unit mass. If the pressure gradient force were the only horizontal force acting on the air, we would see the air accelerate toward low pressure. Instead the air blows along with low pressure always to the left. So there must be some force opposing the pressure gradient force and preventing the air from accelerating "down the pressure gradient". That second force is the coriolis force.

The coriolis force has the following characteristics:

- Its magnitude is proportional to the coriolis parameter.
- Its magnitude is also proportional to the horizontal wind speed.
- In the Northern Hemisphere, its direction is 90^{o} to the right of whichever way the wind is blowing.
- In the southern Hemisphere, its direction is 90^{o} to the left of whichever way the wind is blowing.

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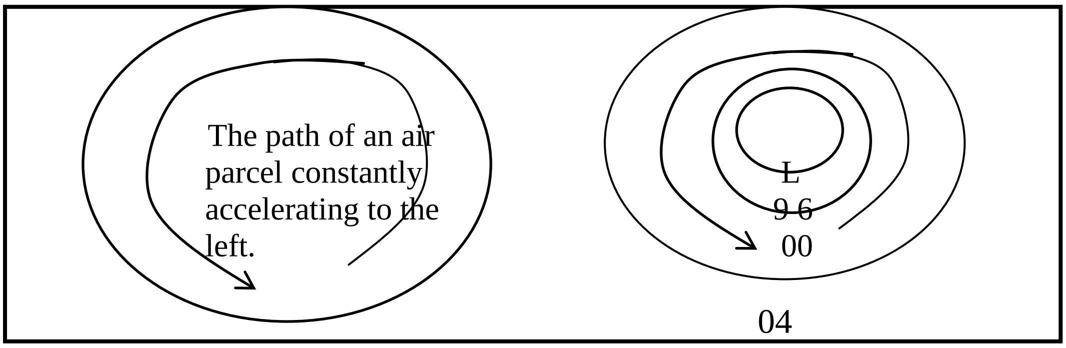


An air parcel in gradient wind balance accelerates so that it stays parallel to the isobars.

THEORY

A close examination of any synoptic chart reveals the obedience of Buys Ballot's Law. It appears that the natural direction for the wind is along the isobars, at heights well away from the ground, and that it is the effect of friction at the ground which causes the surface wind to blow across the isobars.

If one considers the different forces which act upon any small mass of air, and indeed which determines its motion, the effects to which air in motion is subjected are:

- the rate of change of pressure horizontally across the isobars (pressure gradient).
- the effect of the rotation of the Earth, which gives the air acceleration directly proportional to the velocity acting at right angles to the direction of motion.

Let this acceleration be represented by

$$2wV\sin\varnothing \quad \text{-----------} \ (1)$$

Where w = angular velocity of rotation of the Earth,

$\varnothing$ = Latitude, and

V = Velocity of the air

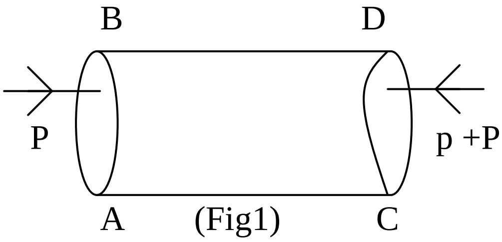
- When the air moves in a curved path whose radius of curvature is r, then its centripetal acceleration can be represented by

$$V^2/r \quad \text{----------------------------} \ (2)$$

acting at right angles to the path of the air, and directed towards the centre of curvature.

- the friction and perhaps the turbulence near the ground which tends to slow down the motion.

Suppose one expresses the effect of pressure gradient in terms of the acceleration which it produces (fig. 1).



(Fig1)

In fig 1, AB represents a unit vertical area, set up parallel to an isobar, and CD represents a similar unit area, at unit distance away from AB.

If p = pressure on AB and

p + P = pressure on CD

where P is the pressure gradient, the pressure being supposed to increase from left to right in the diagram.

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The net force on the small volume ABCD = P, acting towards low pressure, since the volume is unity, the mass of air within it is d, the density.

So that, this force P, acting on mass d, will give it an acceleration.

$^{P}/_{d}$ ------------------------ (3)

If the three accelerations (equations, 1, 2, 3) are in the same straight line, the path of the air must be along the isobars.

The condition that the three accelerations should balance must be such that the term in $V^2/_r$ is in the same direction as, or opposed to, the term 2wVsin∅ (for the two cases). The two cases are as represented by fig 2(a) and fig (2b)

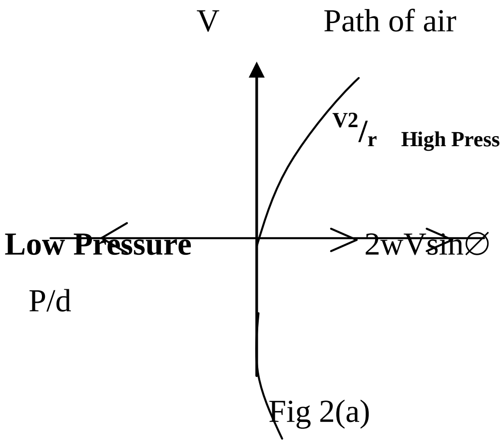


Fig 2(a)

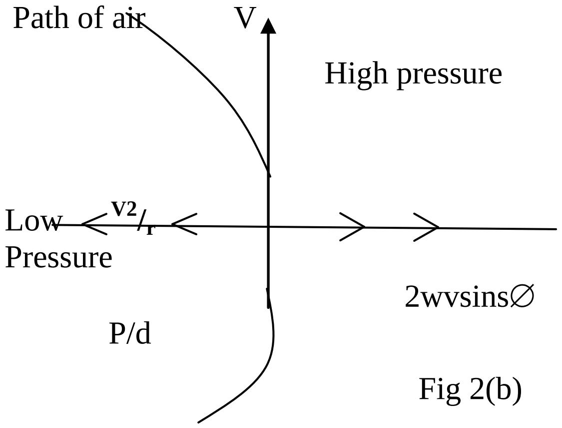


Fig 2(b)

In fig 2(a) the air is moving around a centre of high pressure, and the accelerations are in the directions shown.

For balance of these accelerations

$2wV\sin\varnothing - {}^{P}/_{d} = {}^{V2}/_{r}$ ----------------- (4)

In fig 2(b) the air is moving around a centre of low pressure, and the equation for balance of the three accelerations is

$2wV\sin\varnothing - {}^{P}/_{d} = - {}^{V2}/_{r}$ ------------ (5)

In either case, a quadratic equation exist whose solution will give the velocity of the wind, V, in terms of the pressure gradient and the curvature of the path of the air.

The solution of the appropriate one of the above two equations is the gradient wind.

However, two basic difficulties may be identified in the use of equations (4) and (5). These are:

- It is not certain in any given case that the curvature of the path of the air is equal to the curvature of the isobar.
- It is never possible to evaluate with certainty the curvature of the Isobars.

This paper is only interested in the motion of the air in regions where the curvature of the isobars is slight, or where the isobars are nearly straight, such that the term ${}^{V2}/_{r}$ is so small by comparison with other terms in the equation, and so can safely be neglected; and hence

$2wV\sin\varnothing = {}^{P}/_{d}$ ------------------ (6)

The value of the wind velocity evaluated from equation (6) is the geostrophic wind, G.

i.e

$$G = \frac{P}{2wd\sin\varnothing}$$

The geostrophic wind G is that wind which, blowing along the isobars, would yield an acceleration due to the rotation of the Earth of the right magnitude to balance exactly the effects of the gradient of pressure.

DISCUSSION

The geostrophic wind value, $G = \frac{P}{2wdsin\varnothing}$ has theoretically been obtained by considering certain laws of physics in this paper.

Assuming that the wind is geotropic, or that the effect of curvature of the isobars can be neglected, figs 2(a) and (b) – with the isobar now straight vertical lines, and s the air will move along the isobars, keeping higher pressure to its right than to its left, then the geostrophic wind can be used instead of direct measurements only when the isobars on the chart are nearly straight, and on occasions when the pressure distribution is not changing rapidly. It can also be observed that in a given air density, the pressure gradient is the only variable quantity to be considered in estimating the geostrophic wind. The pressure gradient is inversely proportional to the distance which has to be traversed at right angles to the isobars in order to reach a pressure differing by a given value from that at the starting point. In order words, the pressure gradient is inversely proportional to the distance between two consecutive isobars on the synoptic chart.

CONCLUSION

From the simple theoretical argument used in deriving an equation for the geostrophic wind, the isobars should be drawn for the height at which the wind is estimated.

However, the theoretical consideration shows that it is possible to construct a simple scale by means of which the geostrophic wind can be read from the synoptic chart, for a given density of the air and given Latitude. The geostrophic wind scale is a very valuable tool in meteorology and weather studies, in that it gives a reasonably close approximation to the wind direction at 3000km – 4000km above the ground.

It can also be used to estimate the upper wind direction on occasions when actual measurements of the wind directions are not available on account of low cloud or precipitation. Were it possible to draw charts showing the distribution of pressure at greater heights, the geostrophic wind at those heights could be measured in the same way.

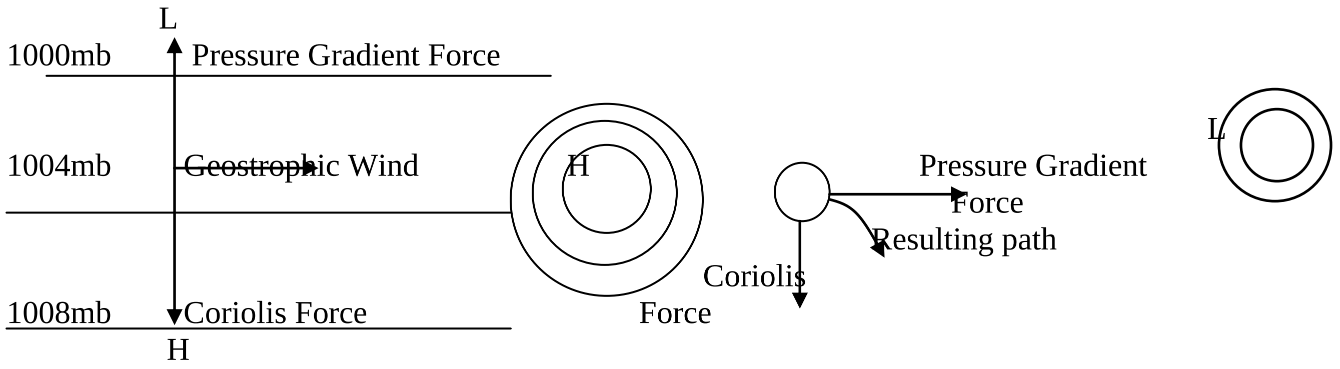
RECOMMENDATION FOR FURTHER STUDIES

It is recommended that a comparism be made between the winds observed by means of pilot balloons and geostrophic winds computed by means of the geostrophic wind formula from synoptic chart reported in this paper based on observations made at about the same time as the pilot balloon ascents, to ascertain if there is a close agreement between the measured winds and the geostrophic winds estimated from the chart.

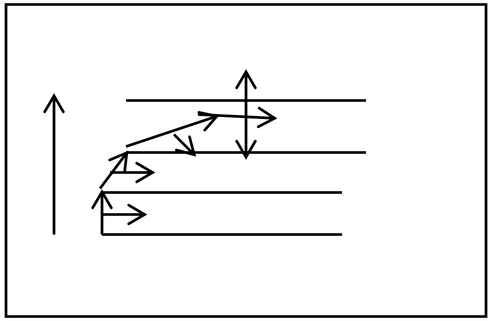
With such agreement, then a simple means of obtaining an estimate of the wind at 3000km – 4000km on occasions when direct measurement is impossible would have been achieved.

Geostrophic Wind

Southern Hemisphere



Geostrophic Wind Scale



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