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DOCUMENT TITLE
METEOROLOGY FOR AUSTRALIA

CHAPTER 9 – WIND

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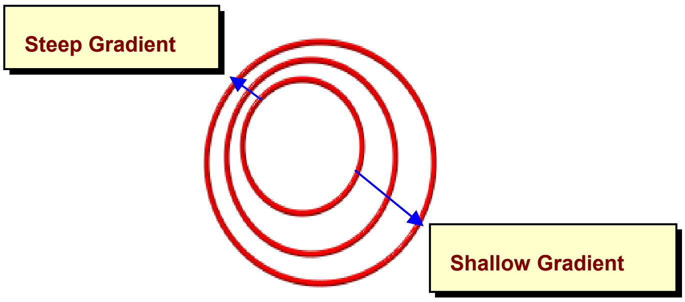
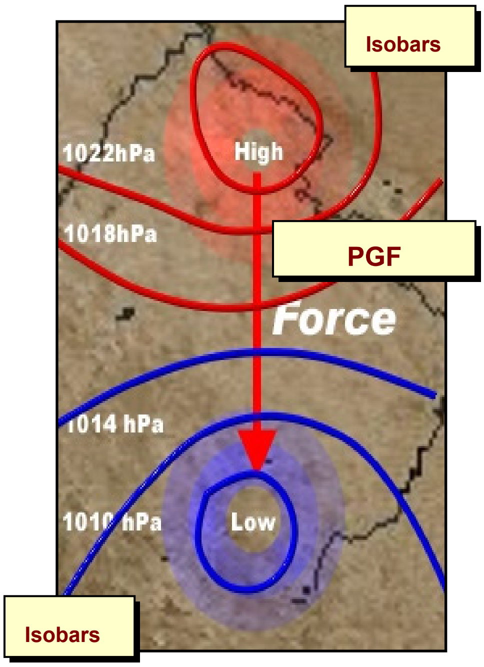
CONTENTS .... PAGE

WIND

PRESSURE GRADIENT FORCE (PGF)

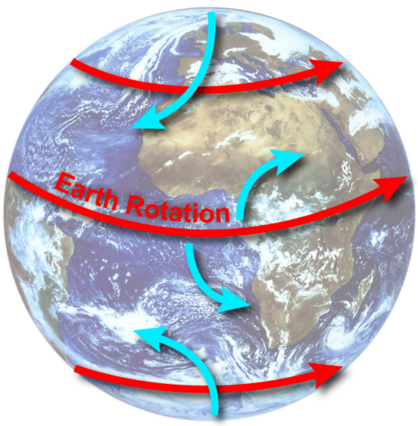
Pressure gradient is the change in pressure with horizontal distance. PGF is measured from a high to a low and at right angles to the isobars. PGF is “strong” or “steep” when the isobars are close together. The PGF is “weak”, “flat" or “shallow” when the isobars are far apart. The magnitude of PGF is inversely proportional to the spacing of the isobars.





CORIOLIS FORCE (CF)

This is an “apparent” force due to the earth’s rotation. If an object is propelled or moving in a straight line, it appears to move in a curve to the left in the Southern Hemisphere and to the right in the Northern Hemisphere.



Coriolis Force (CF) acts at 90° to the wind and to the **left** in the **Southern Hemisphere** and at 90° to the wind to the **right** in the **Northern Hemisphere**.

CF = 2 *p w v* sinθ

Where:

- ***p*** = air density
- ***w*** = rotational velocity of the earth
- ***v*** = air speed
- θ = latitude

From the equation, **CF is proportional to velocity** so if the velocity increases the CF increases and if the velocity decreases, so does the CF.

CF is also **proportional to** sine of **the latitude**:

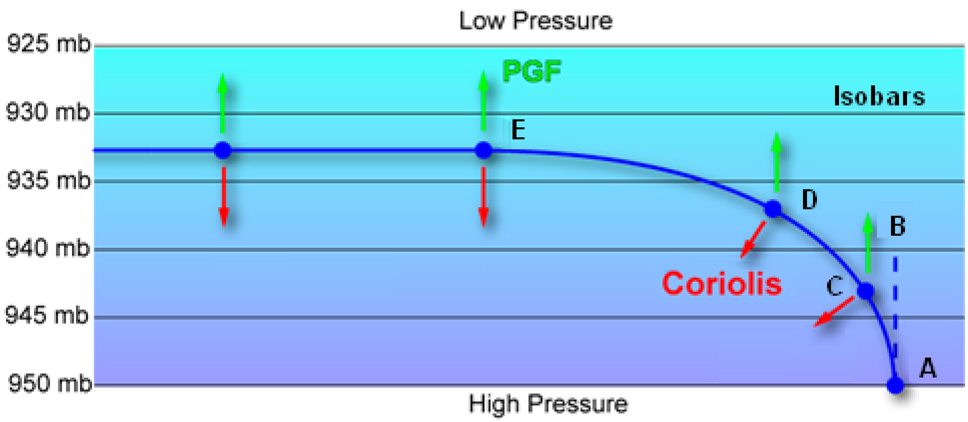
At the equator: $\theta = 0$ **therefore sine $\theta = 0$ and CF= 0 (minimum)**

At the poles: $\theta = 90$ **therefore sine $\theta = 1$ and CF is maximum**

GEOSTROPHIC WIND

Air naturally wants to flow from high pressure to low pressure but in reality it does not do so (except at the Equator).

Given a pressure distribution with isobars as shown below, a particle of air at A will move initially in the direction AB, under the influence of the Pressure Gradient Force (**PGF**) which always acts directly from high pressure to low pressure at right angles to the isobars. As soon as the particle begins to move, however, it acquires a speed V knots, and becomes subject to a **Coriolis Force** of value **2*wp*vSin**θ.



Geostrophic Wind (Southern Hemisphere)

Assuming the example occurs in the Southern Hemisphere, this deflecting force acts to the right of the initial path of the particle of moving air, which is therefore deflected, arriving at C instead of B. The path followed is therefore a curved AC, and but for the continued existence and application of Coriolis Force to the right of the direction of motion, the particle would continue towards D.

It is continuously deflected to the right, however, arriving at E. This process is repeated until such time as a steady state is reached, with the particles moving uniformly under the influence of balanced forces (when the PGF and CF are in balance). This can only occur when the two forces are equal in size and opposite in direction. The PGF has a fixed and unalterable direction across the isobars from high pressure to low. For the CF to be opposite in direction it too must be at right angles to the direction of motion, which must therefore be along the isobars. The direction of flow is therefore determined.

The speed of flow can be deduced from the fact that as well as having to be opposite in direction, CF and PGF must also be equal in size.

i.e. **PGF = CF**

and **CF = 2wpVSinθ**

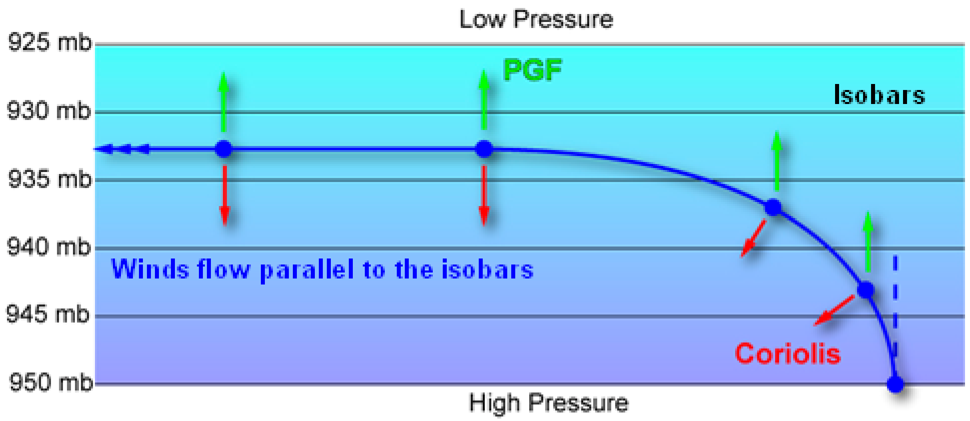
so **PGF = 2*wp*VSinθ**

and **V =** $\dfrac{\textbf{PGF}}{\textbf{2wpsin}\theta}$

Looking at the above formula, it can also be seen that for the same PGF and making "v" the subject, **an increase in latitude will result in a decrease in wind speed. And a decrease in latitude results in a stronger wind**. For example, a PGF that results in a wind of 20kts at 40°, results in a wind of 13kts at 60°, but results in a wind of 44kts at 20°.

The **geostrophic wind** is assumed to blow above the friction layer, at a height of about 2,000 ft and above. (Below about 2,000 ft, friction causes the wind to blow more across the isobars.)

The wind flows parallel to the straight isobars because there is a balance between PGF and CF.

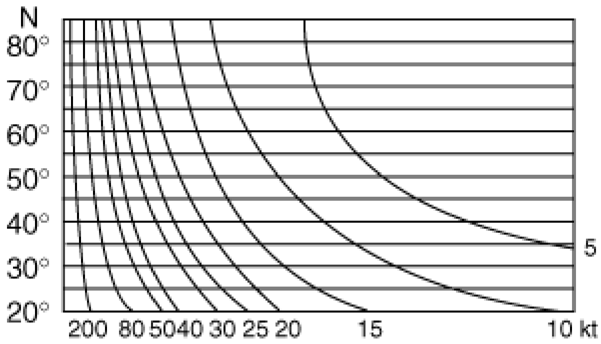


Geostrophic Wind in the Southern Hemisphere

GEOSTROPHIC WIND SCALE

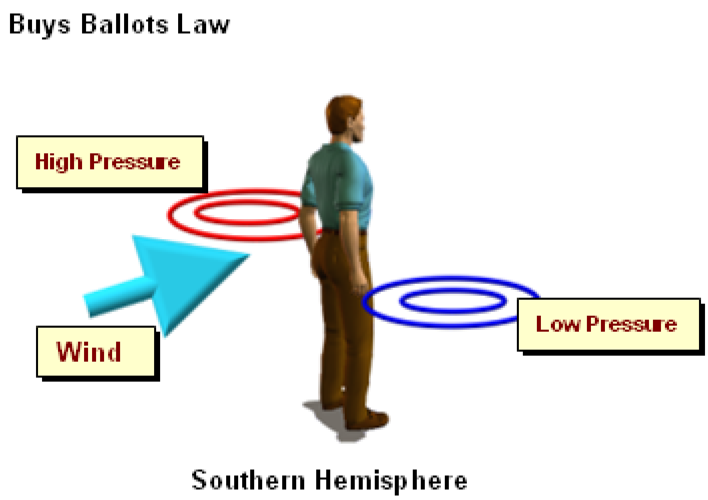
Synoptic charts usually display a geostrophic wind scale so that the wind strength can be calculated by measuring the distance between the isobars at right angles to the isobars, and taking into account the latitude.

Speeds of fronts can also be calculated using this scale, with cold fronts travelling at the full speed of the wind and warm fronts travelling at 2/3 the speed of the wind. **Note that the scale does not start at zero.**



Geostrophic Wind Scale

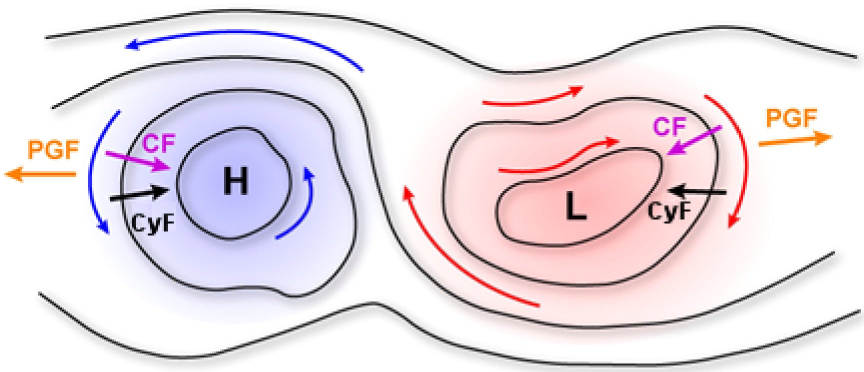
BUYS BALLOTS LAW



"If an observer stands with his back to the wind, the low pressure is on the left in the Northern Hemisphere and on the right in the Southern Hemisphere."

GRADIENT WIND

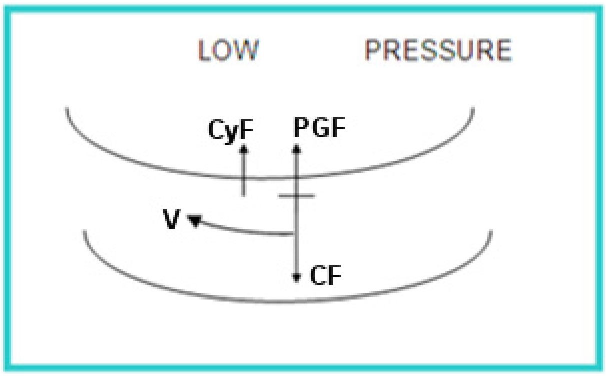
Wind will also blow parallel to curved isobars because there is a balance between PGF, CF and **Centripetal Force** (Cyclostrophic Force).



A 'gradient' wind is that wind which is constrained to blow within curved isobars. It differs from the geostrophic wind in that where the isobars are curved anti-cyclonically, **round a high pressure system, the gradient wind will be of higher speed than the geostrophic wind. Around a low pressure system the gradient wind will be of lower speed than the geostrophic wind**.

GRADIENT WIND - CYCLONIC CURVATURE

With isobars curved around a depression as in the, Coriolis Force (CF) and Pressure Gradient Force (PGF) are present as before.



If the wind is to be constrained to blow within the isobars then the wind must continually change direction as it blows around the low, and there must be a force involved to cause it to change direction.

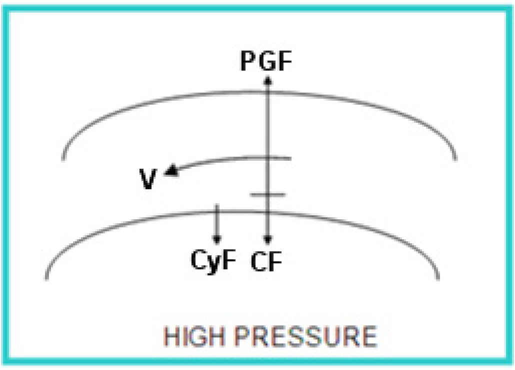
This force is generally referred to as **Centripetal Force** but is known to the meteorologist as **Cyclostrophic Force** (CyF) and it acts towards the centre of rotation.

The energy for this force must be supplied by the PGF.

Because the gradient wind blows steadily along curved isobars, the particles of air must be acted upon by balanced forces. It therefore follows that CF must reduce sufficiently to balance (PGF - CyF). If CF = $2wp\text{V}\text{Sin}\theta$ and CF reduces, some component/s in the formula must reduce. Earth rotation (w) is a constant, and air density (p) and latitude (θ) will change insignificantly, so the one component that has to reduce is the wind speed (V). **The gradient wind speed blowing around a low pressure system is thus less than the geostrophic wind speed produced by the same PGF.**

GRADIENT WIND – ANTI-CYCLONIC CURVATURE

In the case of isobars curved around a high pressure area, the disposition of the forces is different. In the diagram to the right, it can be seen that CF must now supply the CF as well as balancing the PGF so it equals (PGF + CyF). CF must therefore increase and, as explained in the last paragraph, a change in V must achieve the increase. **The gradient wind speed blowing around a high pressure system is thus greater than the geostrophic wind speed produced by the same PGF.**



In summary, compared to geostrophic wind, gradient wind is higher around a high and lower around a low.

CYCLOSTROPHIC WIND

The wind experienced in a tropical cyclone (hurricane) is an example of what is called a cyclostrophic wind. The isobars around such a deep low are very curved and a pressure change of 30 hPa per 100nm is common.

Geostrophic force is small at low latitudes but the cyclostrophic force is large due to the wind blowing in a tight circle. Cyclostrophic force must be supplied by the PGF alone so that PGF = Cyclostrophic force.

DEFINITIONS

Gust: A temporary increase in wind speed above its mean value lasting for a few seconds.

Squall: A marked increase in wind speed lasting for some minutes and which may involve short term changes in direction, e.g. the cold outflow from a thunderstorm.

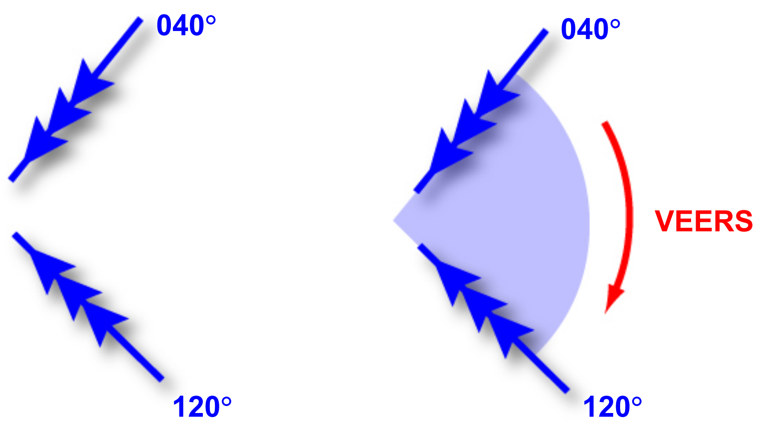
Lull: A decrease in wind speed.

Gale: i winds ≥ 34 kts **and/or**

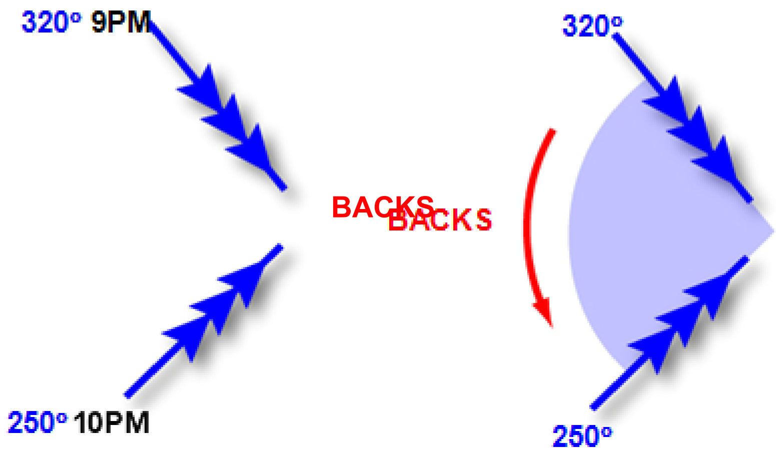
ii gusting ≥ 43 kts

Hurricane: Winds ≥ 64 kts

Veers: The wind direction changes **clockwise.**



Backs: The wind direction changes **anti-clockwise.**



WINDS ABOVE 2,000 FT / WINDS AT GROUND LEVEL

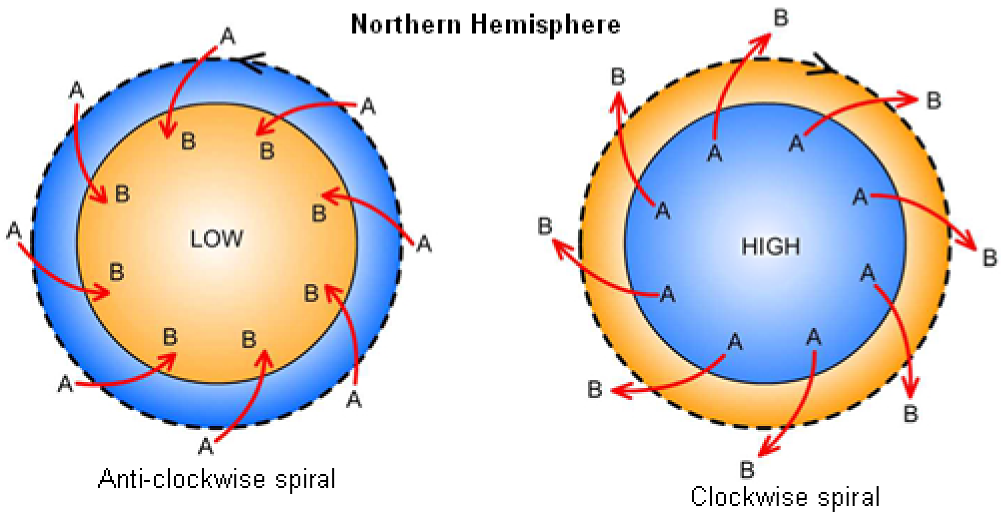
Below about 2,000 ft., friction due to obstructions on the earth's surface slows the wind. Velocity falls, therefore the geostrophic force decreases. There is no longer a balance between PGF and CF. PGF dominates and the wind tends to blow from the HP to LP across the isobars.

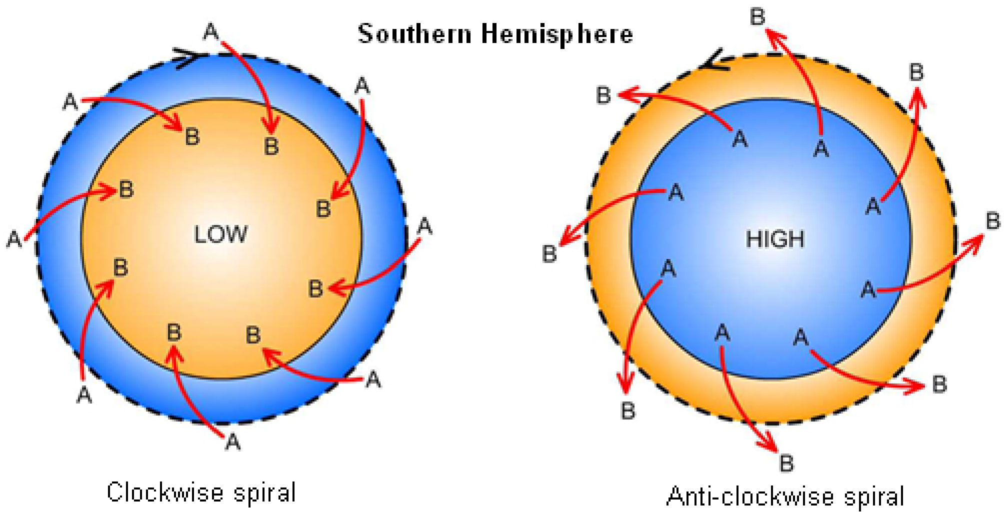
Below 2,000 ft., the wind speed falls by 1/2 to 2/3, and **veers** by 30 degrees in the **Southern Hemisphere.**

The depth of the layer affected also varies, and the associated turbulence by:

- The degree of surface unevenness,
- Wind speed,
- The temperature lapse rate.
- Diurnal heating of the land.

In general, however, the depth of the friction layer is taken as being about 2,000 ft





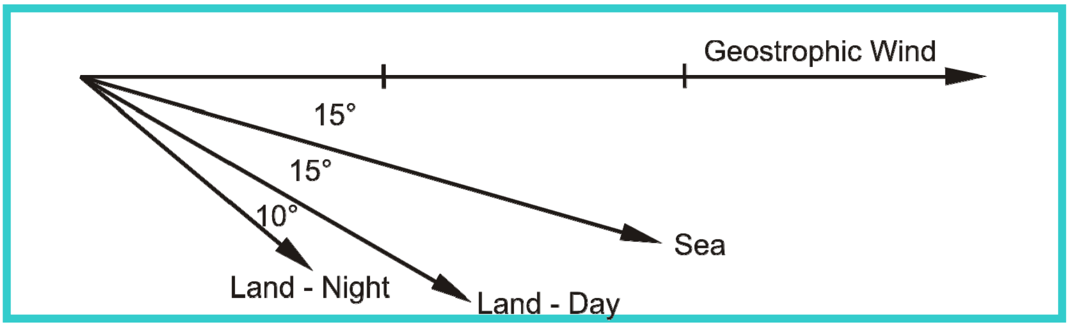
DIURNAL VARIATION OF SURFACE WIND

Over the land, the effect of solar heating during the day is to cause air in contact with the ground to expand and rise. The rising air is of course replaced, but with air from above, from a level previously less affected by friction. The replacing air therefore has a higher wind speed, which it retains until friction reduces it. The surface wind tends to gust, and the average speed is higher than it would otherwise have been.

In the Southern Hemisphere, compared to the geostrophic wind, say 270°/30 kts at 2,000 ft, the surface wind might be veered 30° and half speed (300°/15 kts). At night, however, the heating effect disappears, and the speed reduces, so geostrophic force reduces, and the imbalance becomes greater. The surface wind therefore tends to flow more towards the low pressure, under the stronger influence of PGF, and a typical night wind, over land, might be veered 40° and speed reduced to one third, compared to the geostrophic (310°/10 kts). The diurnal variation of wind in the **Southern** Hemisphere over land is therefore to back and increase in strength from night to day (230°/10 kts becoming 190°/30 kts).

In summary, the following diagrams describe the changes to the geostrophic (2,000 ft) wind caused by surface friction and diurnal variation.

For exam purposes, assume that over water the surface wind will be at 70% of the geostrophic speed and that it will have changed direction relative to the isobars by 10°. Over land the figures to be used are 50% of the speed and a change of direction of 30°.



Surface and Geostrophic Winds (Southern Hemisphere)

As an aircraft descends, the wind veers and slows down.
As the aircraft climbs, the wind backs and speeds up.

STREAMLINES AND ISOTACHS

In tropical areas, geostrophic force is insignificant. PGF is the main force and the wind blows across the isobars from HP to LP. A synoptic chart will show the isobars, HP and LP areas but cannot be used for wind direction.

In the tropics and for upper level flights a streamline / isotach chart is used.

Streamlines show the wind direction. Isotachs join places of equal wind strength.