CHAPTER 27

WIND

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27[1]

AIR MOVEMENTS

What causes air to move?

A pressure gradient is produced when a high-pressure system exists next to a low-pressure system. This results in air moving from the area of high pressure to one of low pressure. The air movement is what we know as wind, which can be described in terms of both direction and speed (i.e., velocity).

High- and low-pressure systems are depicted on meteorological pressure charts called synoptic charts (*Figure 203*). The magnitude, size and movements of air pressure systems can be identified. High pressures are illustrated with red "H", and low pressures with a blue "L". Isobars are graphical lines on the chart that signify areas of equal pressure (i.e., a pressure gradient of zero).

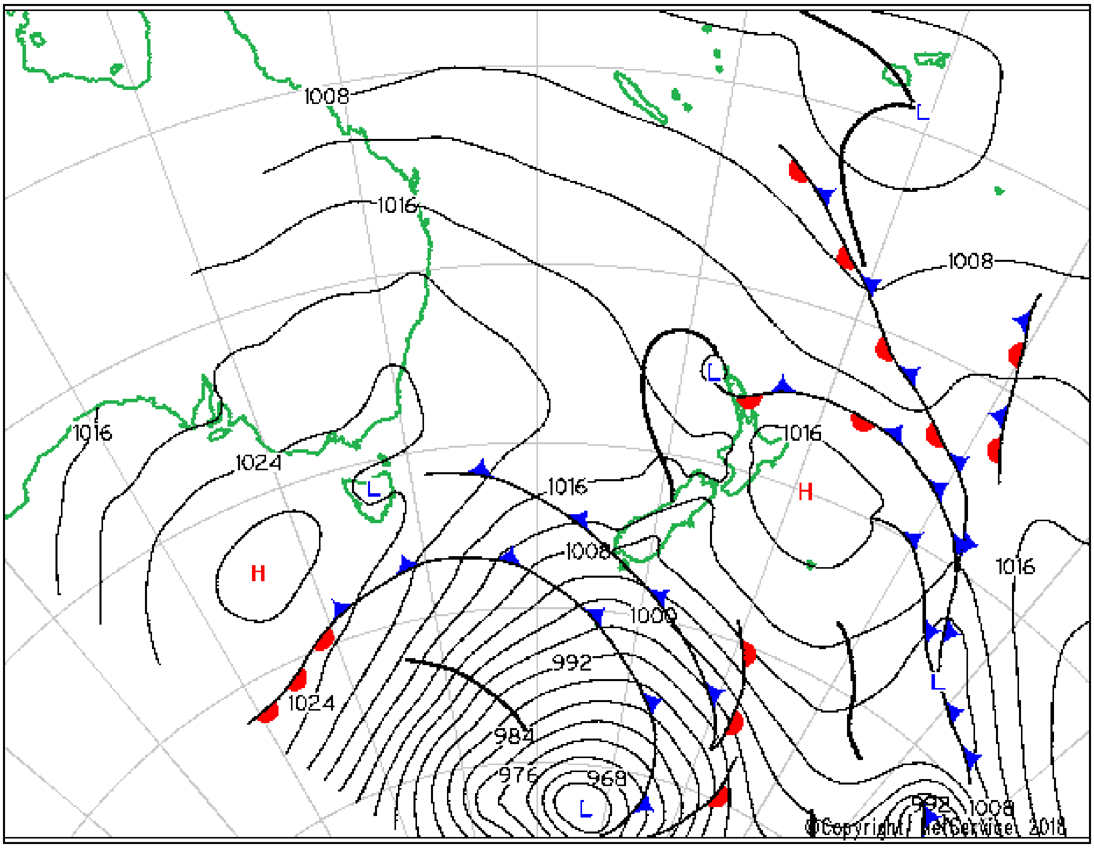

Figure 203. Synoptic Mean Sea Level ("MSL") chart showing common features seen in these charts. ©Meteorological Service of New Zealand. Used with permission.

What determines wind velocity?

There are three main factors that determine wind velocity:

- Pressure gradient force
- Coriolis force
- Surface friction/terrain
- What are the effects of pressure gradient force on wind?

The wind velocity generated depends on the pressure gradient – the larger the pressure difference between the high- and low-pressure systems, the higher the wind velocity. The pressure gradient is the primary determinant of wind speed. When the isobars on a synoptic chart are close together, it signifies a significant gradient, resulting in a strong wind. Conversely, light winds will be present when there is little or no pressure gradient.

What are the effects of the Coriolis force on wind?

A pure pressure-gradient force would cause air to travel perpendicular to the isobars seen on a synoptic chart, i.e., directly down the gradient from high to low pressure. However, air does not tend to move in a straight line from high- to low-pressure systems but instead rotates around them. This is due to the rotation of the Earth on its axis and is known as the Coriolis effect.

The size and strength of the Coriolis force are dependent upon:

- **Latitude –** Lower latitudes (closer to the equator) experience a weaker Coriolis force.
- **Speed of the object** - As wind velocity increases, so does the strength of the Coriolis force.
- **Size of the object –** The Coriolis force affects all terrestrial objects and the strength of the force is proportional to the size of the object.

The direction of wind rotation depends on the pressure system type and whether it is in the Northern or Southern Hemisphere. The Coriolis effect acts to turn the wind to the left (anticlockwise) in the Southern Hemisphere and turn to the right (clockwise) in the Northern Hemisphere (*Figure 204*).

Air will move away from the centre of a high-pressure system toward an area of lower pressure. In doing so, the air is deflected to the left/anticlockwise direction in the Southern Hemisphere by the Coriolis force. This causes the anticyclone effect of a high-pressure system to be an anticlockwise, outward rotation of the wind around a high-pressure system. This means that wind tends to be light in the centre of a high-pressure system, but faster at the system's outer regions than the pressure gradient/isobars would suggest (*Figure 205*).

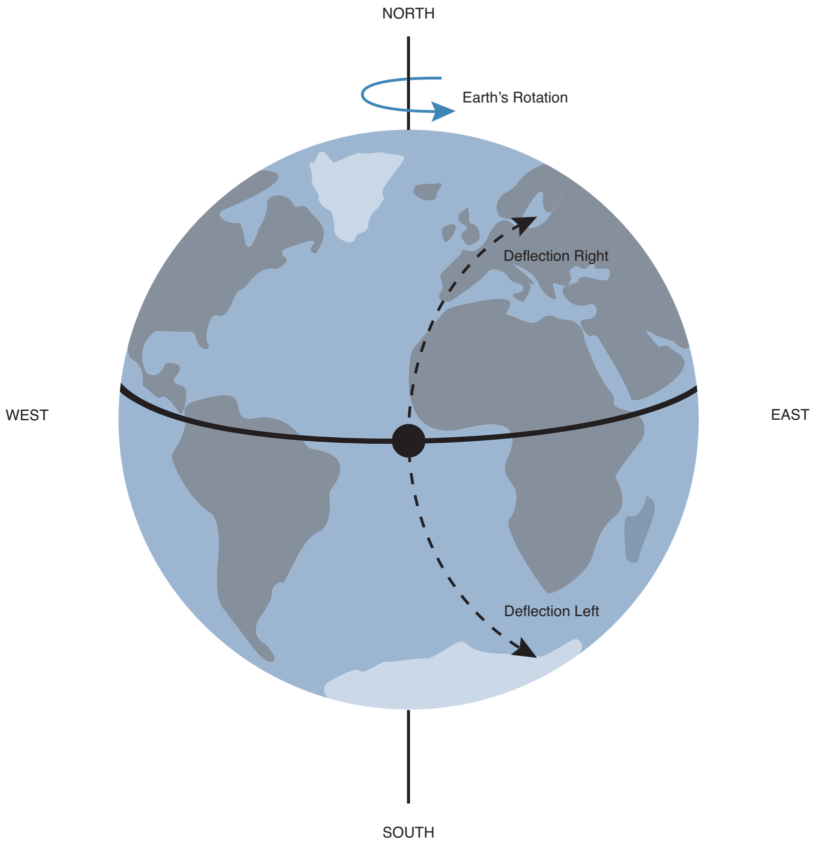

Figure 204. *Diagram showing the deflection of wind due to Coriolis force in the Northern and Southern hemispheres.*

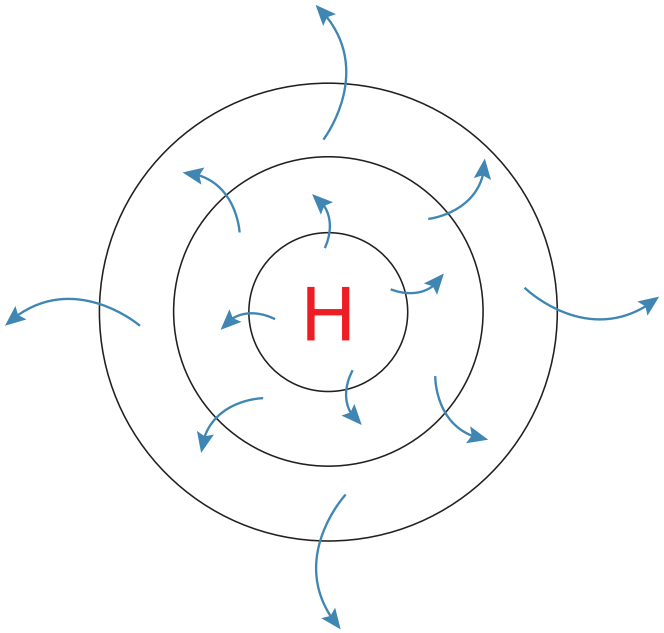

Figure 205. *Diagram showing winds moving around a high-pressure system.*

This is in contrast with a low-pressure system where the air moves towards the centre (away from a high-pressure system). As the wind travels towards the centre, the Coriolis force will cause it to be deflected to the left (in the Southern Hemisphere). Therefore, this deflection relative to the low-pressure system creates a deflection to the right. Therefore, the overall effect of a low-pressure system is that winds travel in a clockwise direction towards the centre (*Figure 206*). Winds tend to be lighter in the outer regions of the system and become faster towards the centre of the low-pressure system. A hurricane is formed by a powerful low-pressure system, where the fastest winds are experienced in the "eye of the storm".

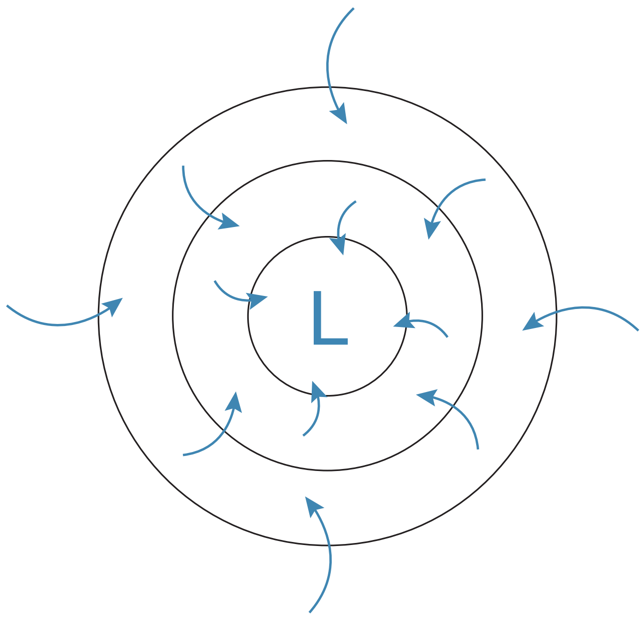

Figure 206. *Diagram showing winds moving around a low-pressure system.*

The resultant wind for large systems moves either anticlockwise around the high-pressure system or clockwise around the low-pressure systems. As there is a balance of the pressure gradient force versus the Coriolis effect force, the wind will travel in parallel to the isobars. This is known as a geostrophic wind (*Figure 207*).

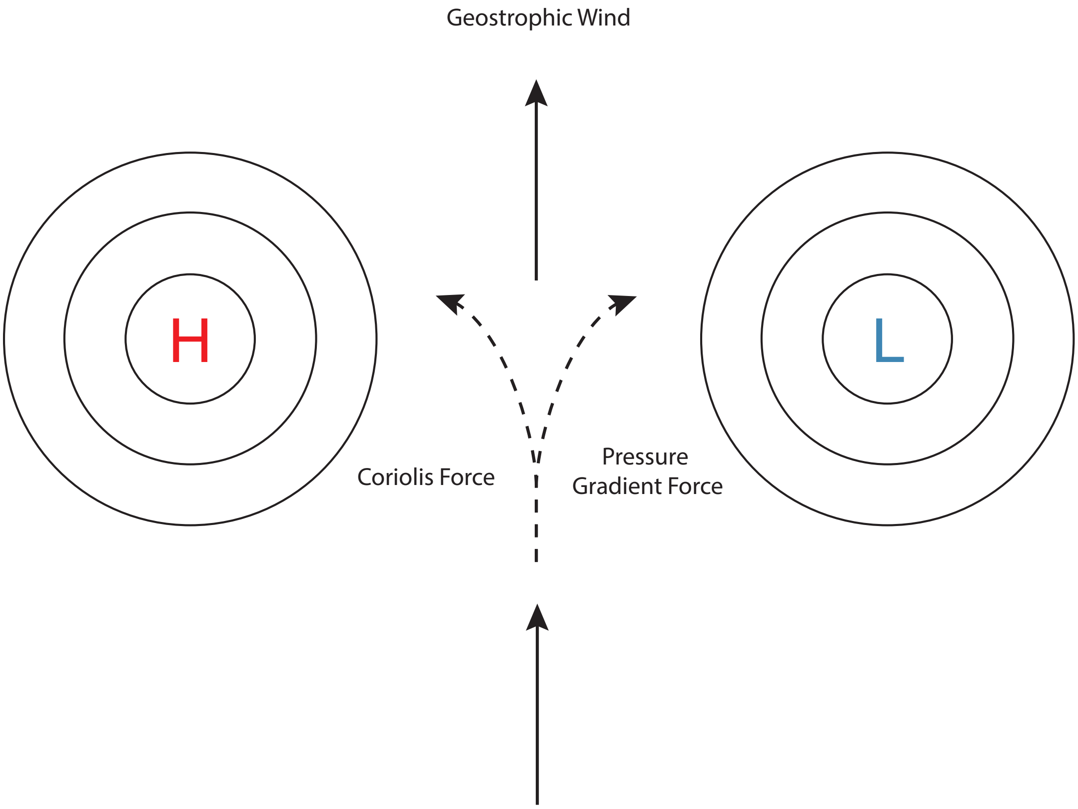

Figure 207. Diagram showing the balance of the Coriolis force and the pressure gradient force to resulting in a geostrophic wind.

What terms are used to describe a wind?

- **Veering –** A wind that turns in a clockwise direction.
- **Backing –** A wind that turns in an anticlockwise direction.
- **Gust –** A brief, intense rush of wind.
- **Lull –** The lowest strength of the wind during a particular time period.
- **Squall –** A sudden, violent gust of wind.

Backing is going back in time – turning in an anticlockwise direction.

What is the friction layer?

The friction layer refers to the effect of the Earth's surface on wind. Friction between air and the Earth's surface causes wind to slow down and lose velocity. Smoother surfaces, such as water, create less friction and as a result, the friction layer is not as thick. This enables faster-moving wind. On the other hand, rough terrain creates more friction, so a thicker friction layer is formed. The magnitude of the effect of the friction layer is also determined by the air density. Denser air will be more viscous, slowing the air to a greater extent than less dense air. The friction layer usually exists up to approximately 2000ft above ground level.

What is the effect of the friction layer?

Due to the reduced velocity of wind within the friction layer, there is a reduction in the strength of the Coriolis effect, as this effect is proportional to wind speed. Therefore, areas that have a significant friction layer results in wind travelling perpendicular to the isobars, i.e., directly from a region of high pressure to one of low pressure (without deviation by the Coriolis effect).

In aviation, as you take off, you will initially climb through the friction layer. The wind can change direction and velocity when the friction layer boundary is reached. The aircraft will move from an area affected by the friction layer (with a slower wind that is less affected by the Coriolis effect) to an increased wind speed area with a more significant Coriolis effect. The net result (in the Southern Hemisphere) is that **wind tends to increase in speed and back** as you exit the friction layer. The reverse occurs on descending, where the **wind tends to decrease in speed and veer** as you enter the friction layer.

How does the friction layer affect surface wind during the day and night?

The change in the surface wind over the course of a day is part of a diurnal variation. As the Sun goes down and night follows, the surface wind over land (in the Southern Hemisphere) will **veer**. During the cooler night, the air becomes denser, leading to a more pronounced effect of the friction layer. Increased friction reduces the wind speed and reduces the left-turning/anticlockwise rotation caused by the Coriolis effect. Therefore, relative to the wind in the day, there is a right-turning/clockwise rotation where the wind is said to veer (*Figure 208*).

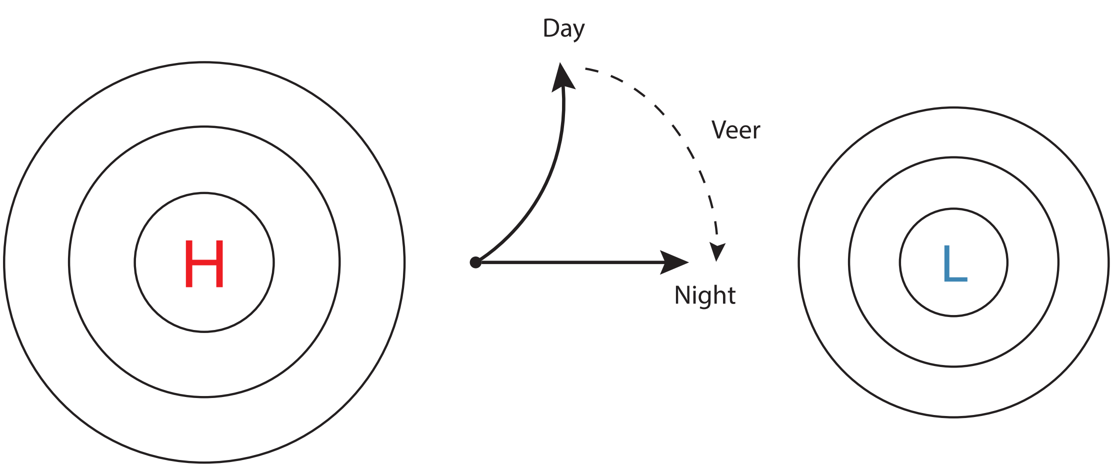

Figure 208. Diagram of wind veer from day to night.

As the Sun rises the next day, the wind will begin to increase again due to a reversal of the process. During the warmer day, the air reduces in density and so the friction effect at the Earth's surface also reduces. This leads to an increase in wind speed and, accordingly, a more pronounced Coriolis effect. Therefore, there is an increase in the left-turning/anticlockwise deviation and, relative to the wind at night, the wind is said to **back** (*Figure 209*).

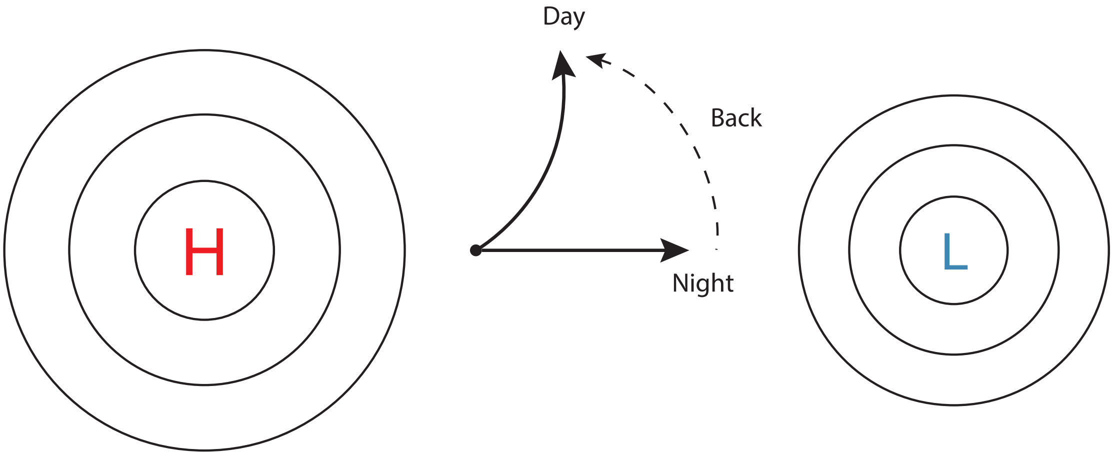

Figure 209. *Diagram of wind backing from night to day.*

To summarise, in the Southern Hemisphere, wind patterns are as follows:
From day to night: The wind veers and speed decreases.
From night to day: The wind backs and speed increases.

This effect can also occur over the sea but it will be far less pronounced because the relatively smooth sea surface has a less pronounced friction layer and thus there is no significant change from day to night.

27[2]

JUDGING THE WIND

How can wind speed be determined?

Wind speed can be determined by the angle a windsock makes with the pole - the angle increases as wind speed increases. For a standard-sized windsock, when the windsock angle is 0-degrees, the winds are 2 knots or less. A 15-degree angle indicates a wind speed of 5 knots. A 45-degree angle indicates a 10-knot wind, while a 60-degree angle indicates 15-knot winds. Fully extended (90-degrees), a windsock indicates at least a 25-knot wind.

Windsocks can, however, sometimes be misleading. For example, they could be stuck in a position, damaged or be faulty. The position of the windsock can also make it susceptible to turbulence not affecting the runway. Also, different sized windsocks will have different wind angles than that standard-sized wind socks.

How can wind direction be assessed?

A windsock can provide a good gauge of wind direction at an aerodrome. Approximate wind direction can also be determined using a variety of references during flight:

- **Water –** Looking at ripples on water, the concave side is generally on the upwind side (where the wind is coming from), but this can be difficult to determine. Wind lanes are long lines aligned with the wind, which form in strong winds, where the wind is funnelled over a body of water. Lastly, wind shadows are sheltered areas of water adjacent to areas of disturbed water. Wind shadows are caused by local terrain and the obstructed areas used to judge the wind direction.
- **Smoke –** Looking at the direction of smoke is a reliable method of determining wind direction.
- **Aircraft ground speed and drift –** A valuable method of how the aircraft behaves in terms of ground speed and drift.
- **Global Positioning Systems (GPS) –** Most modern systems provide real-time information of the wind experienced by the aircraft.

What is Buys Ballot's Law?

Buys Ballot's law is a rule of thumb to deduce where a low-pressure and high-pressure system are relative to your position w flight. In the Southern Hemisphere, the law states that when you stand with your back to the wind, the low-pressure system is to your right while the high-pressure system is to your left. In the Northern Hemisphere, it is reversed with the low-pressure system to your left and high to your right.

This information has practical application. For example, if you are flying in New Zealand with the wind from your tail, turning to the right will turn your aircraft into a low-pressure system. This means you should be wary that the altimeter QNH setting may become incorrect and set too high. Furthermore, the likely change in meteorological conditions can be considered.

27.3

WIND SHEAR

What is wind shear?

Wind shear is a variation in wind velocity (speed or direction) over a short distance that results in zones of different wind velocities. These zones can be either on top of each other, resulting in vertical wind shear, or next to each other, resulting in horizontal wind shear (*Figure 210).*

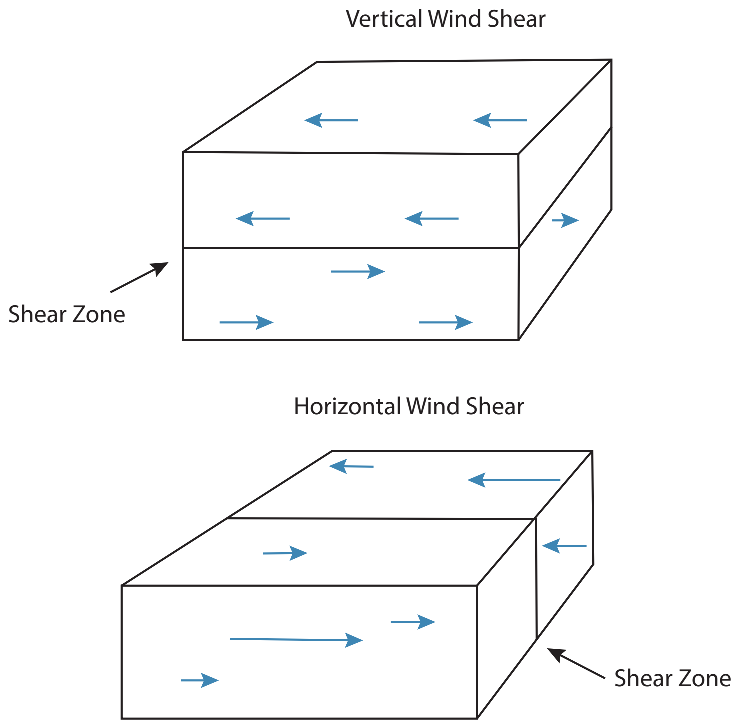

Figure 210. Diagram to show horizontal and vertical wind shear.

Vertical wind shear can cause you to transit from a high wind speed zone to a zone of low wind speed that could be in the opposite direction. This can be problematic, particularly on final descent when wind is required to maintain an indicated airspeed and lift. Horizontal wind shear will have similar effects when transiting from one shear zone into another, where wind shear can be very significant and pose a danger to the aircraft. Pilots should be aware of areas where wind shear is common and warn passengers of likely turbulence.

27[4]

SEA AND LAND BREEZES

How does a sea breeze form?

A sea breeze results from the Sun warming land at a faster rate than the sea. This creates a layer of warmer air over the ground than that over the sea. The warmer air rises and creates an area of low pressure immediately above the land. The area of low pressure draws in the cooler (relatively higher pressure) air from the sea, observed on land as an onshore sea breeze (*Figure 211*). This air will then form a return airflow at a higher level, moving back out to sea.

In regions situated closer to the equator, this effect is exaggerated due to the higher warming effect on the land leading to a rise of the air over land.

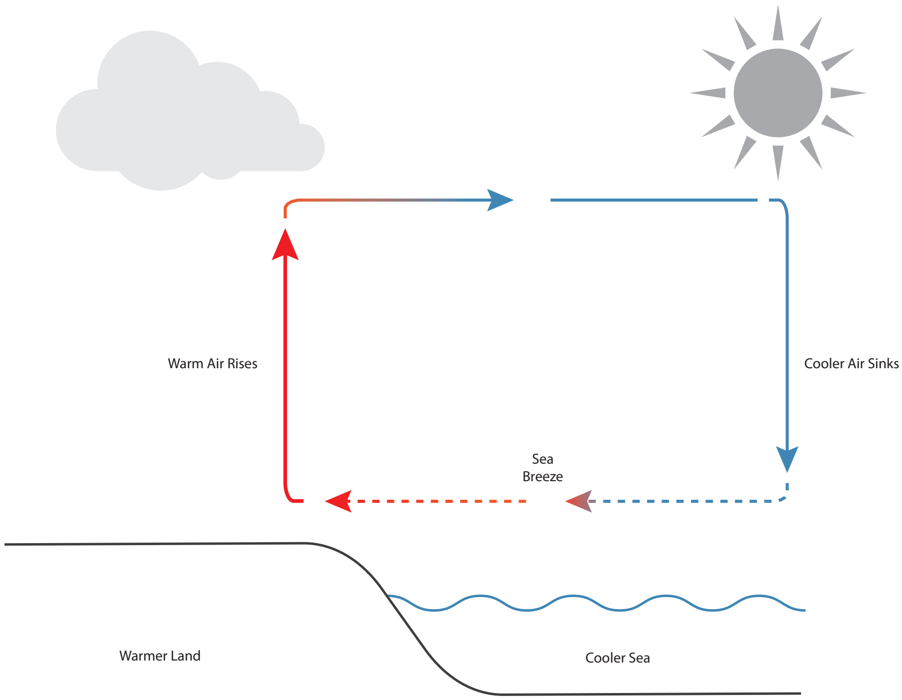

Figure 211. The sea breeze process.

What are the characteristics of a sea breeze?

A sea breeze occurs during the day at a typical speed of 10 to 15 knots. Depending on the geographic location, a sea breeze may commence mid-morning (as the land begins to warm up), peaking mid- to late afternoon (when the land is the hottest) and dying off in the late afternoon/early evening. A sea breeze can extend inland of the coast approximately 10 to 20 nautical miles.

What is sea breeze turbulence?

The turbulence that results from both the horizontal and vertical movement of air is associated with the sea breeze that causes horizontal and vertical wind shear. This is due to the production of a sea breeze front where the cooler onshore air meets the warmer air over the land. Local coastal terrain is also particularly important in determining how air moves and the local effects caused by the sea breeze. Flight conditions are generally significantly smoother over sea than land, as there is a primarily horizontal shear effect until the land is reached, where the vertical component develops.

What is a land breeze?

The land breeze process is the reverse of that of the sea breeze. In the evening, land loses heat more quickly than the sea. Therefore, there is relatively warmer, less dense air over the sea than cooler, more dense air over land. This causes the air to move offshore from land to sea (*Figure 212*). Land versus sea temperature differential varies according to the season, and thus these effects in turn have seasonal variation.

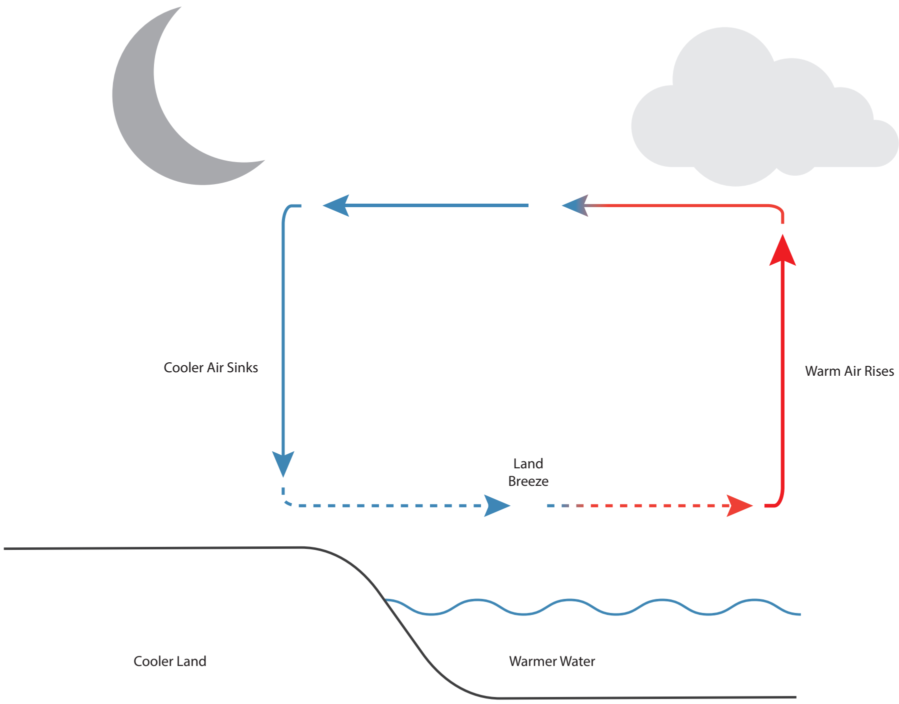

Figure 212. The land breeze process.

What are the characteristics of a land breeze?

The land breeze is a light wind, usually only 3 to 4 knots. A land breeze requires the sea to be warmer than the land. In New Zealand, expect a land breeze to be most prevalent during the autumn months – when the land cools dramatically during a brisk autumn evening, while the sea still retains much of the warmth developed throughout the preceding summer months.

27[5]

MOUNTAIN WINDS

What are valley and mountain breezes?

Valley and mountain breezes are characteristic winds that occur in mountainous regions during the day and night, respectively. They share a similar process to sea and land breezes in coastal areas. During the day, the air over the upper regions of a mountain is heated more effectively than air at the same altitude over a valley. This creates lower-density air nearer the mountain, creating a horizontal pressure gradient. As this effect is more pronounced at higher mountain levels, air will flow towards and up the mountain. This is known as the valley breeze (from the valley to the mountain) and there will be return airflow from the mountain top.

The reverse process occurs for a mountain breeze, which happens at night. Air higher up the mountain cools faster than air lower in the valley, resulting in a breeze that flows down the mountain.

What are anabatic and katabatic winds?

Anabatic and katabatic winds are exaggerated effects of valley and mountain breezes, respectively referring to the rising (anabatic) and falling (katabatic) of air. These types of winds are differentiated from breezes as they generally cause higher wind speed and can affect more extensive areas. The process that leads to the development of these winds is a combination of the gravitational effect on dense air and the mountain/valley breeze formation process.

How is a katabatic wind produced?

Katabatic winds (falling or flowing down a mountain) are caused by the enhanced cooling of air through direct contact with the surface of a mountain. This occurs most significantly near the top of the mountain, where terrain cools faster than lower down the mountain. This effect occurs most significantly during clear evenings and on snow-covered mountains, optimising conditions for radiation cooling. The air becomes denser and heavier through direct cooling of the air and thus heavier. Gravity drives this heavier air down the mountain and produces katabatic wind.

What are the characteristics of katabatic winds?

Katabatic winds are usually cold and dry. The wind speed depends on the steepness of the mountain and the temperature of the region. In extreme regions, such as Antarctic glaciers, with large, steep land formations and freezing temperatures, katabatic winds can reach gale force speeds.

How is an anabatic wind produced?

Anabatic winds rise or flow up a mountain. This wind is produced following sunrise when the Sun's radiation has a more significant warming effect at a higher altitude than lower down the mountain. The effect of this is that it causes the air above the upper mountain terrain to be warmed more than air over the lower mountain terrain. As warmer air is less dense than cooler air, it flows up the mountain creating an uphill, anabatic wind.

What are the characteristics of an anabatic wind?

Anabatic winds are almost always lighter than katabatic wind, as the rising air must compete with gravity to gain altitude.