2 Weather and Water

The pioneering oceanographer Matthew Maury said in 1855 *"Our planet is invested with two great oceans; one visible, the other invisible; one underfoot, the other overhead; one entirely envelopes it, the other covers about two thirds of its surface."*[1]

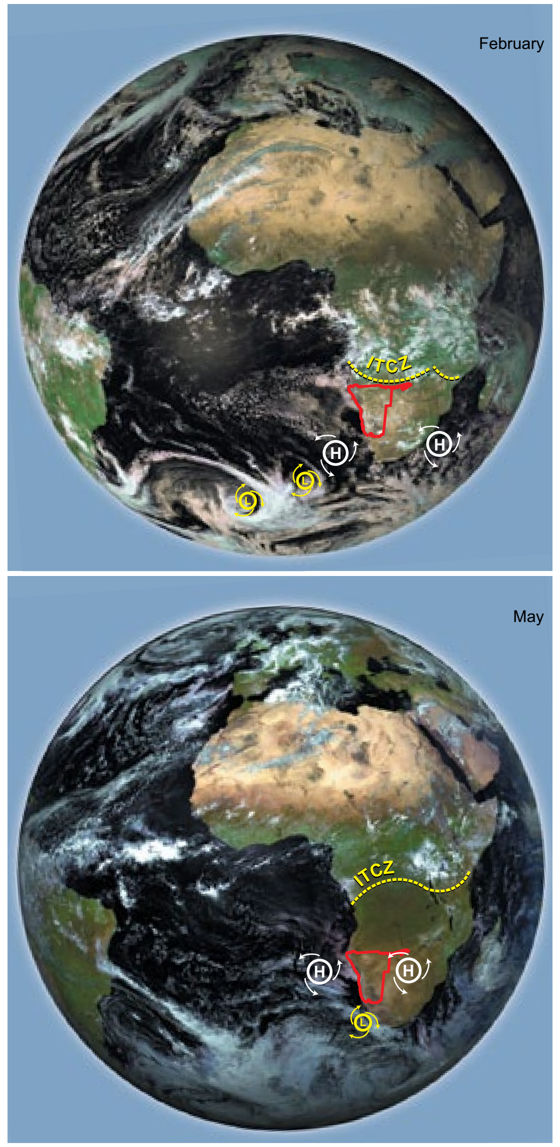


Figure 4. Typical patterns of air circulation around southern Africa in summer (February) and winter (May) showing the major air pressure and convergence zones.
H – anticyclones,
L – cold fronts and cyclones;
ITCZ – southern border of Inter-tropical Convergence Zone.

While walking, driving or sailing along the surface of the coast we are surrounded by three media: the atmosphere above us and the swirling sea, and rocks and soil beneath. The first two are dynamic, pushing and flowing swirls of air and water. These are the subject of this chapter, while the more solid geological foundation is described in Chapter 3.

Water and air are constantly on the move, bringing warmer or colder conditions, as well as supplying the coast with nutrients from the sea or moisture from fog and rain in the air. Predicting what will happen to these media from day to day is difficult, let alone knowing what major changes may happen from one decade to the next. The elements are in constant transition, and an appreciation of the dynamics is crucial if we are to understand the coast and improve its management.

THE CLIMATE

For most of the year the weather along the coast of Namibia is characterised by relatively cool temperatures, strong onshore winds and frequent grey skies. Although rainfall is extremely rare, fog blankets the coast in a shawl of moist air on about a third of the days each year. In winter, winds from the interior bring a cascade of heat and sand (and sometimes swarms of flies) as they blow over the land out to sea.

Why is the climate along the coast so different from that of the interior, and what forces drive this unusual system? The first clue to answering these questions comes from the presence and effects of two high pressure systems: the South Atlantic Anticyclone situated out to sea and the Botswana Anticyclone located over the interior of southern Africa (Figure 4). Add to this a cold ocean current (the Benguela Current described on pages 37 to 45), and answers begin to emerge.

Atmospheric circulation

The South Atlantic Anticyclone is a stable and powerful high pressure cell which has major influences on the coastal climate from its position offshore. The effects emanate mainly from the power and direction of winds driven by the cell as the descending air from the anticyclone spirals outwards in an anticlockwise direction.[2] The South Atlantic Anticyclone is situated offshore to the west, and consequently winds blow up the Namibian coast from the south and south-west (Figures 4 & 10 on page 30).

The winds are often particularly strong because the cell is like a powerful turbine, which helps drive the cold waters of the Benguela northwards, as well as blowing sand (and even diamonds – see page 140) off the beaches inland to form the great

barrier of Namib sand dunes. Coming from the cold south, the winds bring in cool air that characterises the weather at the coast. In essence, without the South Atlantic Anticyclone the coast would not be so windy, cool and dry, and the Namib Sand Sea would not be there.

The location of this anticyclone shifts seasonally, moving south in the summer and north in winter. Weather conditions are also influenced by the shift in position of the Inter-Tropical Convergence Zone (known as the ITCZ), which is the belt surrounding the earth where moisture-bearing trade winds from the northern and southern hemispheres come together. The ITCZ is located north of the equator in winter, from where it moves south in summer, bringing warm, moisture-bearing air and rain to Namibia. The southerly position of the South Atlantic Anticyclone in summer also means that its southerly winds are less effective at blocking the warm moist tropical air from the north. It is for this reason that most rain in Namibia falls during summer.

In summer the South Atlantic Anticyclone also prevents low pressure fronts moving in from the cold Temperate Zone far to the south, thus blocking the moist air these fronts bring with them. This situation is reversed in winter when cold fronts sweeping up from the south bring cold moist air and occasional winter rains to the southern coast. Being further north in winter, the South Atlantic Anticyclone also blocks the inflow of tropical air from the north.

While the South Atlantic Anticyclone dominates air movements at the coast, a second high pressure cell situated over the central sub-region controls air movements in the interior. This is the Botswana Anticyclone. It has little effect on the climate of the

Figure 5. This photograph taken in March 2010 shows a sharp western edge of clouds over Namibia almost exactly above the 700 metre contour line (shown in purple), and immediately west of the escarpment. There are no clouds to the west of this line because the air heats and dries as it moves west and down the escarpment. Clouds over the sea are low-lying fog caused by the condensation of moist cool air just above the cold waters of the Benguela Current.

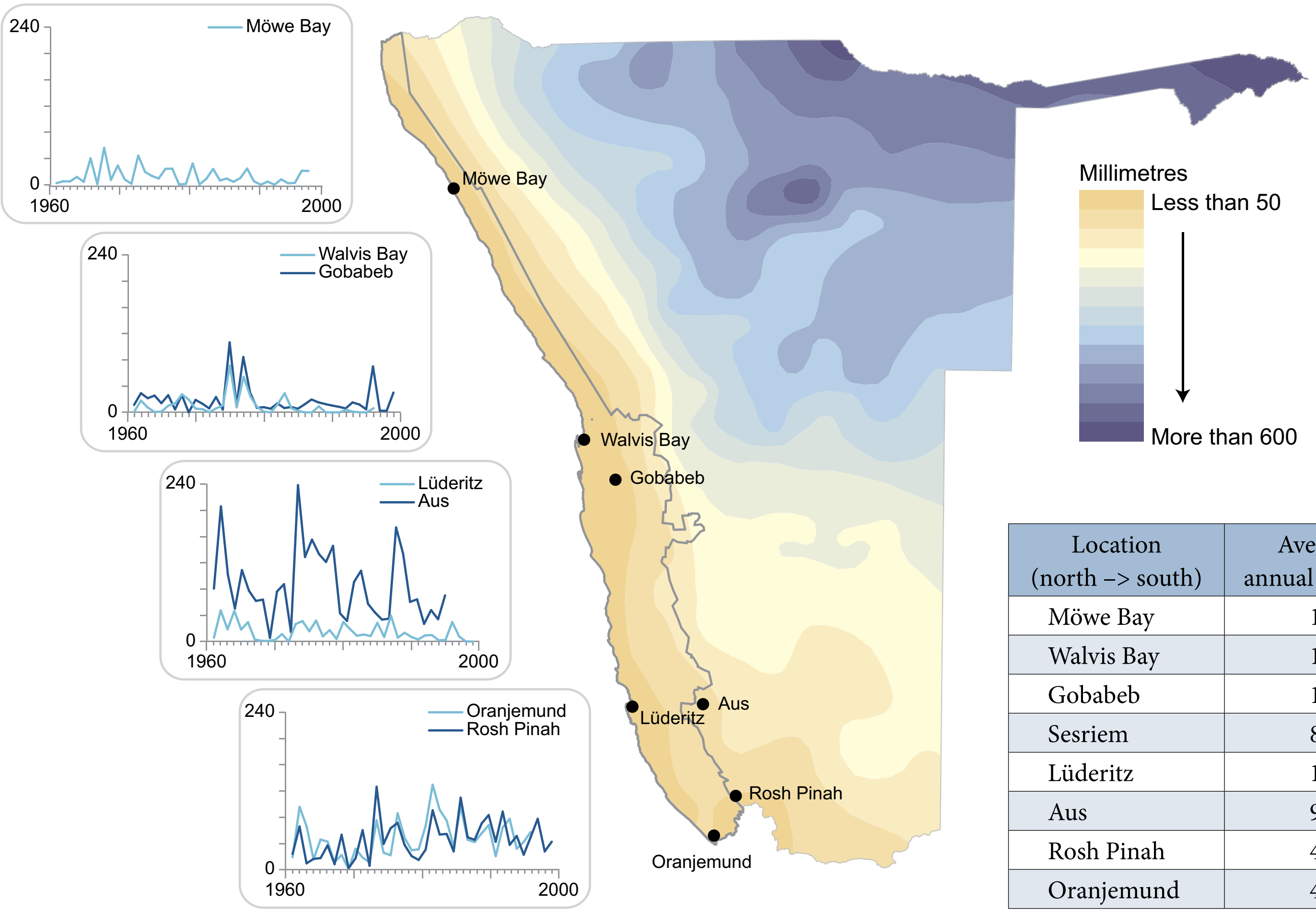
Above left: East winds are common at the coast during the winter months and result in vast quantities of sand being carried from the interior and blown out over the ocean.

coast for much of the year, but its winter position over Botswana results in substantial differences in air pressure between the interior and coast. Strong east winds (also known as Berg winds) then develop, reaching speeds of 50-60 kilometres/hour. The air is warm and dry, and both the temperature and speed of the wind increase as the air drops over the escarpment and moves across the desert, taking with it vast amounts of sand which are blown out to sea in plumes.

Why is the Namib dry?

At least three processes combine to make the coast and adjacent low-lying strip of Namib a desert. Since most of Namibia's rain is delivered from warm, moist air moving south and west from the ITCZ, the northern parts of the country receive most rain. Areas to the south and west receive progressively less rain because less moisture remains available to be condensed into rain in the south. This is one cause for the coast being so arid.

Figure 6. Average annual rainfall in Namibia and total annual rainfall recorded at four weather stations along the coast, and three inland stations between 1960 and 2000.[3] Note how much rainfall varies from year to year. There appears to have been a very slight increase in rainfall over the years at Oranjemund and Rosh Pinah in the south, while the other stations show no trend.



Location (north -> south)	Average annual rainfall
Möwe Bay	13
Walvis Bay	10
Gobabeb	19
Sesriem	81
Lüderitz	16
Aus	91
Rosh Pinah	47
Oranjemund	49

A second process is the warming and drying of any moist air that approaches the coast from the east. The air heats up and any droplets of water evaporate as the air drops down over the escarpment (Figure 5). The third process stems from the cold Benguela Current, which cools the maritime air as it blows across the ocean and inland. Once onshore, the moist maritime air is still so cold that it cannot rise above warmer layers of air that have been heated by the bare surface of the desert. The maritime air therefore usually remains trapped in an inversion layer within a few hundred metres of the ground, where it is often seen as fog.

Average rainfall within 40 kilometres of the coast is less than 20 millimetres per year, almost all of which typically falls on just a handful of rainy days. Towards the eastern edge of the Namib the average annual rainfall increases to between 80 and 90 millimetres (Figure 6). These averages are, however, only meaningful in reflecting the general arid conditions. What is more characteristic of coastal rainfall is its variability (Figure 6). Many years may pass without any significant rain, and then relatively high amounts fall for one or a few years. For example, Walvis Bay recorded a total of only 45.4 millimetres during 10 years from 1990 to 2000 and most of this amount (32 millimetres) fell in just one year: 2000. Weather stations just inland of the coast, such as Gobabeb and Rosh Pinah, have slightly more rain on average, but the year to year variation is just as impressive. These two stations are at altitudes of about 400 metres above sea level, whereas Aus at about 1,400 metres has much higher rainfall than nearby Lüderitz.

Above: Although rainfall at the coast is rare, when it occurs the effects can be dramatic. In May 2011 parts of the coast received more rain in a couple of days than typically falls in one year.

Below: All water courses between the Kunene and Orange rivers are ephemeral, flowing only occasionally and for short periods when sufficient rain falls in their catchments.

Coastal towns are ill-equipped to deal with unusually heavy rain falls and the lack of effective drainage systems causes damage to roads and the flooding of houses.

An important consequence of such low and unpredictable rain is that no one – animal, plant or human – can rely on rain to provide water. This recurrent feature dominates the lives of plants and animals (Chapter 4), people (Chapter 5) and their economic activities (Chapter 6) on the Namibian coast.

Very high rainfall is recorded from time to time during heavy showers that can cause substantial disruption to towns that are not equipped to deal with the drainage of large volumes of water. One such event happened in April 2006 when 101 mm fell over a three day period at Lüderitz.[4] Some predictions from climate change models suggest that episodes of heavy rain may become more frequent and more extreme in the future (see page 34).

While rainfall is generally very low, there are significant differences in the seasonal spread of rainfall between the southern and northern coast (Figure 7). The southern areas lie within the winter rainfall belt and it is the precipitation in the winter period which sustains the vegetation of the Succulent Karoo biome found in the Sperrgebiet (see page 80). Although widely referred to as the 'winter rainfall' area, the southern coast actually receives rain throughout the year, and annual averages are consequently higher than along the rest of the coast. Moving northwards, winter rainfall declines and summer rainfall increases, with the highest summer averages in the far northern stretches a result of more frequent, but nevertheless sporadic, incursions of moist tropical air from Angola.

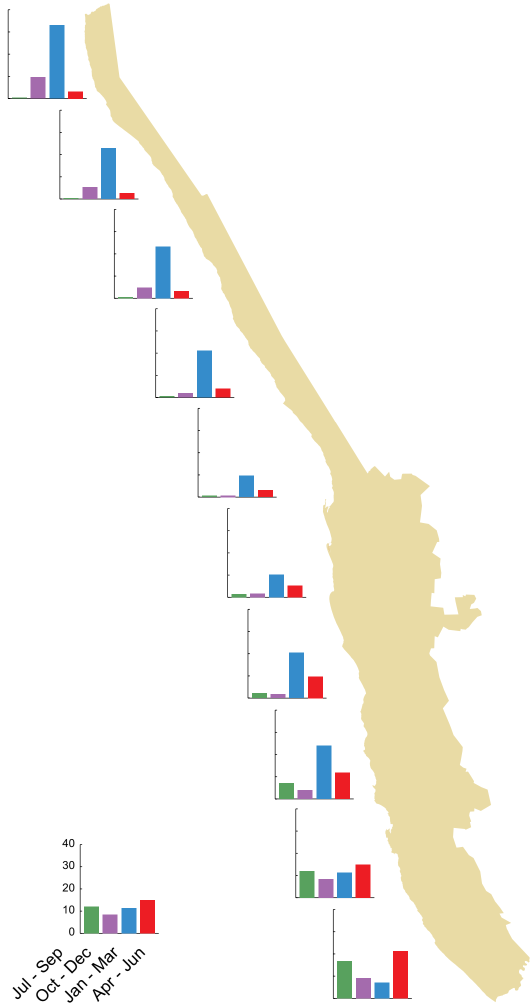


Figure 7. Average rainfall (mm) each quarter along the coast.[5]

Fog

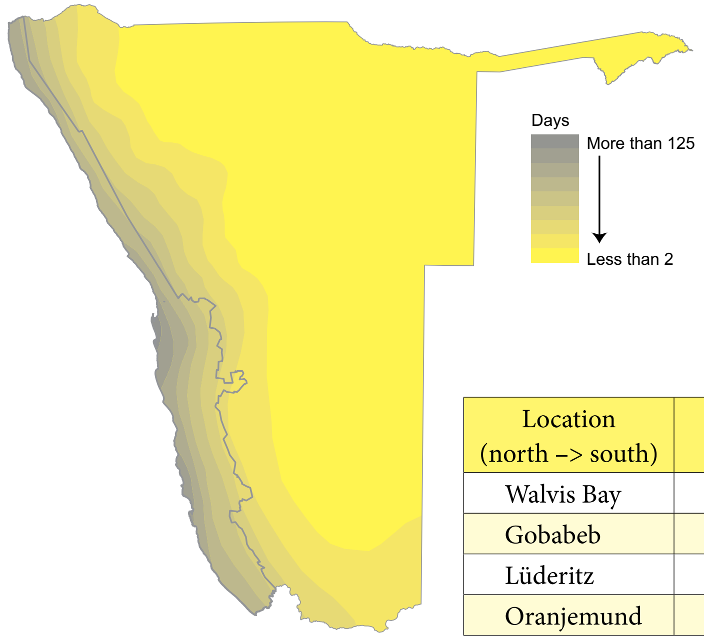
The cold Benguela Current and the replacement of surface waters by deep, cooler layers of water by upwelling results in sea surface temperatures which typically range between 13 and 18˚C (see page 41). The cold water in turn further cools the moist maritime air so that it is too cold to rise sufficiently to form rain clouds, as explained above. Instead, the droplets of condensation often accumulate as fog and low clouds, blanketing the ocean and adjoining Namib.

It is therefore fog – rather than rainfall – that brings most precipitation to the coastal areas of Namibia, for example, producing five times more water than rain or drizzle in the central Namib.[6] Fog is also much more frequent along the coast, and also lasts longer each day, compared to further inland where fog becomes progressively more rare. Gypsum soils at the coast form as a result of the precipitation of hydrogen sulphide carried onshore by fog. The soils are consequently more concentrated and better developed near the coast.

Fog is most prevalent during mornings and evenings and generally dissipates during the middle of the day as the moist layers of air are warmed by the sun. Visibility along the coast is thus generally better later in the day. Two main types of fog occur on the coast: advective fog and high fog. Advective fog forms when humid air meets the cold sea, which is usually at altitudes of less than 200 metres, and the fog is then carried inland by the south-westerly winds up to a distance of 15 kilometres from the coast.

Above: High fog lies like a blanket over the coastal desert and may penetrate up to 60 kilometres inland.

Below: Weather conditions are defined as being foggy when visibility on the ground is reduced to a distance of 1,000 metres or less.

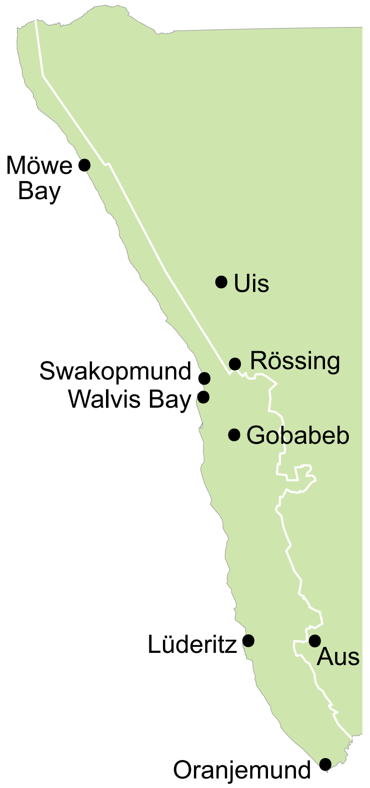


Location (north –> south)	Days of fog [7]
Walvis Bay	140
Gobabeb	94
Lüderitz	117
Oranjemund	81

Figure 8. The average number of fog days per year.

AVERAGE MAXIMUM AND MINIMUM % RELATIVE HUMIDITY

Place	Maximum	Minimum
Coastline		
Möwe Bay	94	79
Swakopmund	96	69
Walvis Bay	95	73
Lüderitz	91	70
Oranjemund	89	47
Inland		
Uis	76	18
Rössing	79	26
Gobabeb	86	23
Aus	57	17



High fog, which forms as stratus and strato-cumulus clouds, develops at altitudes of 100 – 600 metres below strong inversion layers of warm air. High fog can penetrate up to 60 kilometres inland and causes precipitation on the ground on 60 to 120 days per year. Research on harvesting fog as an alternative water source in the central Namib has shown that up to 15 litres can be collected from a one square metre collecting surface per day.[8]

The high moisture content of the air results in the relative humidity along the coast being much higher than elsewhere in Namibia. The winter months are marginally less humid than at other times of the year. Further inland the range in relative humidity values is much greater, as shown in the table.[9]

Producing up to five times as much precipitation as rainfall, harvested fog has the potential to provide a sustainable water resource to meet moderate, local demand.

The southern coast is renowned for being exceptionally windy, and the coastal stretch from Lüderitz southwards to the Orange River mouth is known as being the windiest part of southern Africa. For example, record wind speeds of up to 80 kilometres per hour have been recorded at Pomona in the Sperrgebiet.[10]

Wind

The South Atlantic Anticyclone situated over the ocean to the southwest (summer) or west (winter) of Namibia functions like a giant fan, blowing air out of this centre of high pressure in an easterly direction towards the south-west coast of Africa. The Coriolis force then deflects the air flow northwards so that winds at the coast predominantly blow from the south, and thus oblique to the alignment of the coastline (Figure 9).

While the wind blows most frequently off the ocean from the south, other flows of air develop between the cooler plains and the warm inland mountain areas. These produce westerly and north-westerly winds as the warm air rises and is replaced by cooler air from the plains. In winter, Berg wind conditions bring strong easterly winds from the interior of the country when the Botswana Anticyclone is positioned firmly over southern Africa. While strong, hot and often uncomfortable for people, these easterly winds are relatively short lived.

Although the Namibian coast is seemingly windy everywhere, two areas experience much stronger winds than others. These very windy zones are near the mouth of the Kunene River and at Lüderitz (Figure 10); South Africa's Cape Point far to the south

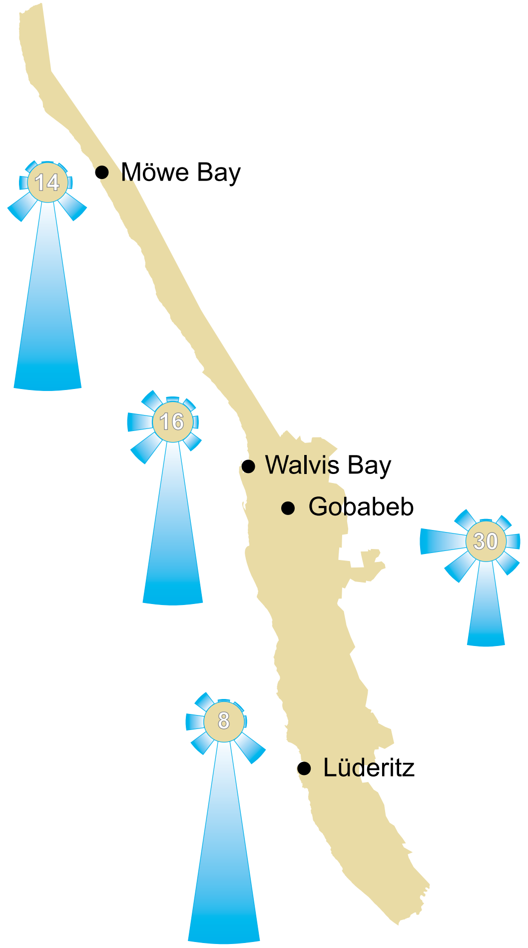


Figure 9. Wind roses for Lüderitz, Walvis Bay, Gobabeb and Möwe Bay. The length of each arm or petal of the rose is proportional to the frequency of wind received from that direction, while the figure in the middle of the rose is the percentage of time that calm conditions were recorded.[11]

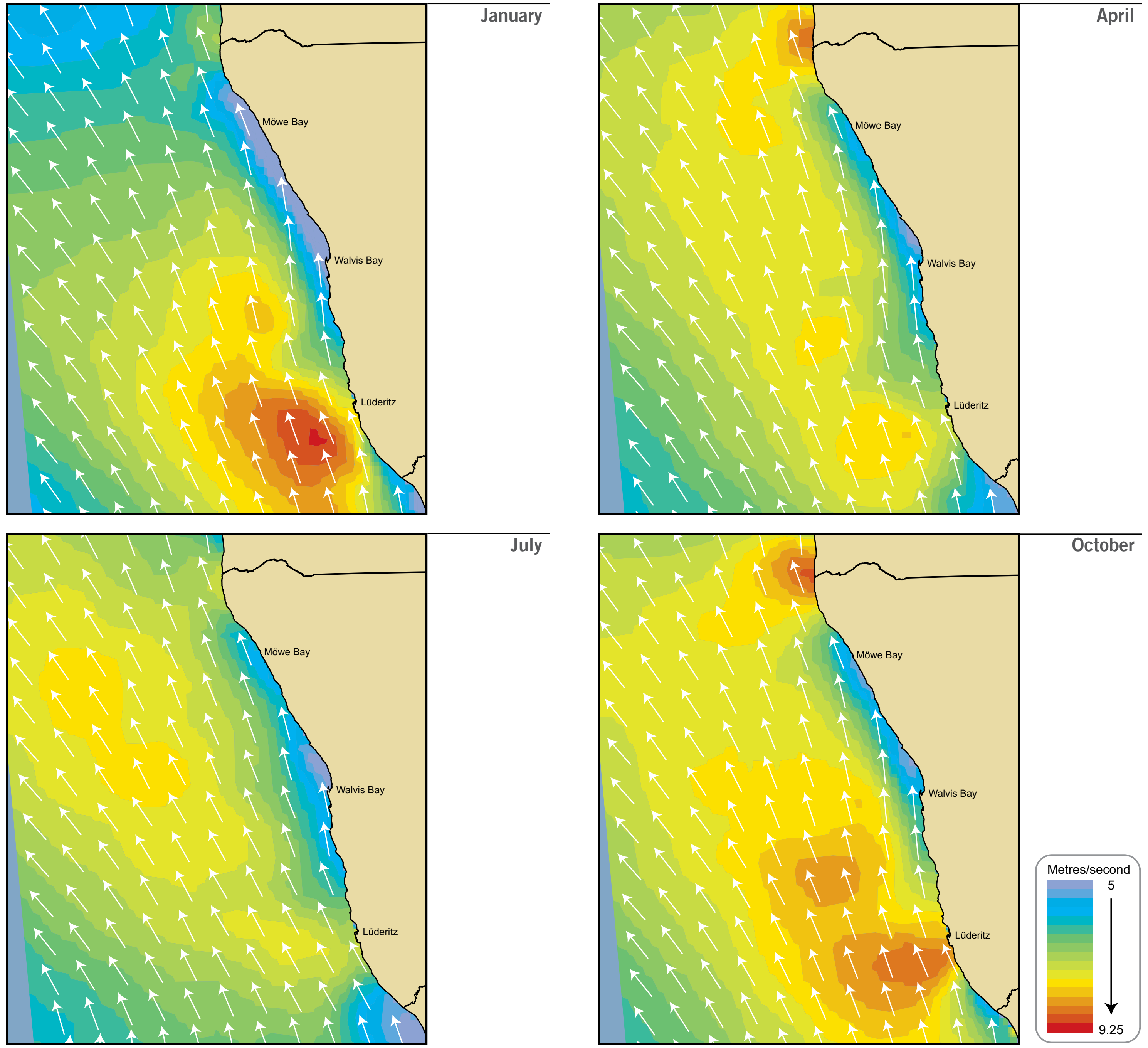
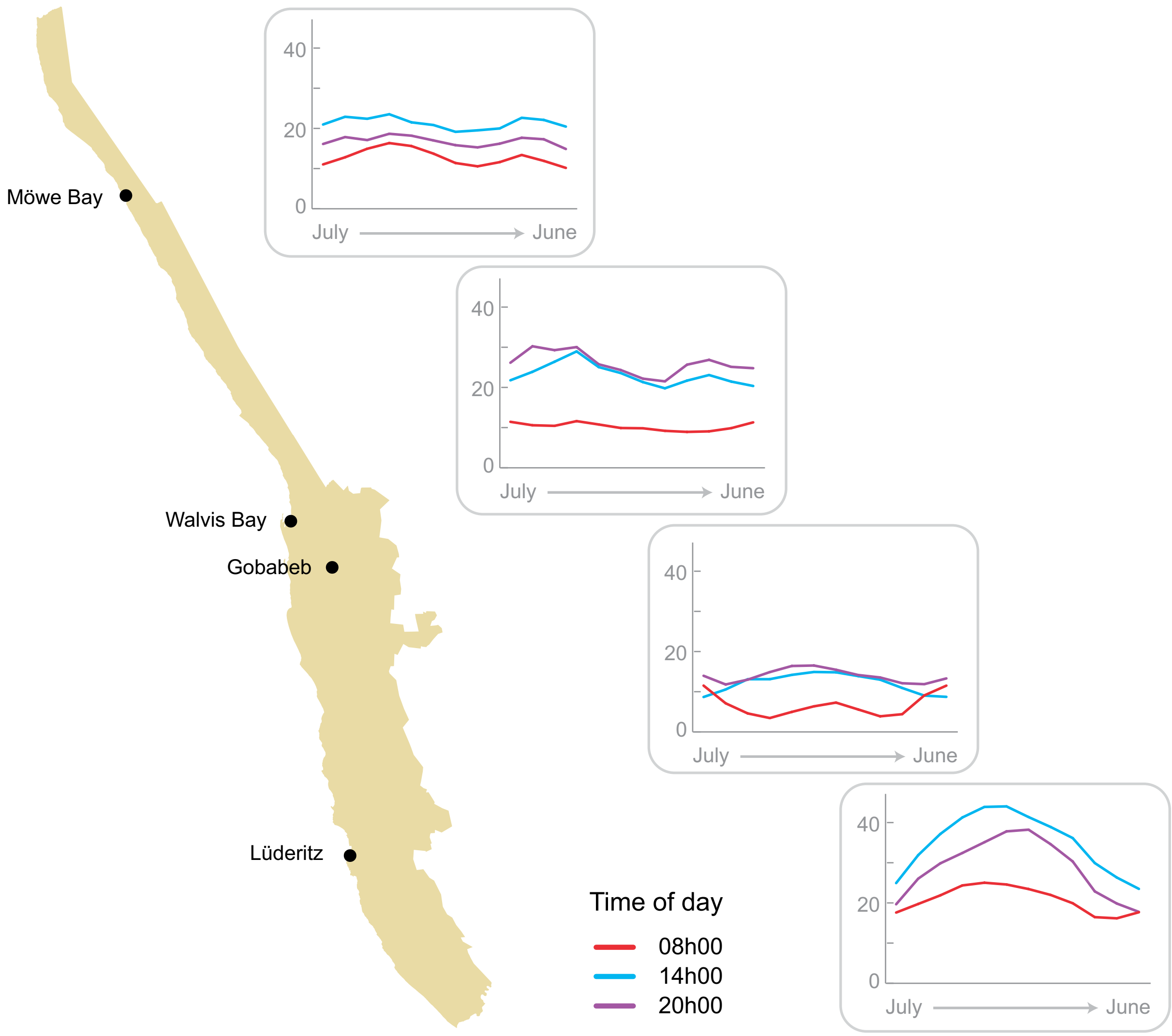


Figure 10. Wind directions and speeds along and off the coast in January, April, July and October. Note the highest speeds on the Namibian coast around Lüderitz and the Kunene River mouth.[12]

is the only other place in the whole Benguela system with such strong winds.[13] The marine zones around both the Kunene mouth and Lüderitz are also upwelling cells to which the strong winds contribute by driving away surface waters to generate the upward movement of deeper water. Not surprisingly, many ships have been wrecked in these two extremely windy stretches of the coast (see page 123).

Wind speeds are highest in the summer months and during the afternoon and evening (Figure 11) when airflows off the ocean are speeded up by temperature gradients between the cold coast (high pressure) and warm land (low pressure). In the north and south peak wind speeds are usually reached by early afternoon, and then decrease slightly by early evening. By contrast, speeds along the central coast remain relatively constant between afternoon and evening.

Figure 11. Average wind speeds (kilometre/hour) during the year at 8 am (08h00), 2 pm (14h00) and 8 pm (20h00) at Lüderitz, Walvis Bay, Gobabeb and Möwe Bay.[14]



Gobabeb Desert Research Station is situated on the bank of the Kuiseb River which separates the southern sand sea from the gravel plains to the north.

Sunshine

As a result of the predominance of fog and cloud, much less sunshine is recorded at coastal weather stations than those inland (Figure 12). For example, Gobabeb is only 50 kilometres inland, but it typically receives an average of about 2 more hours of sunshine per day than coastal Walvis Bay.

Along both the northern and the southern coast the number of sunshine hours ranges between 8 and 10 per day over the year, with slightly more in the south at Oranjemund than in the north at Möwe Bay. The lowest number of sunshine hours is in winter, simply because of seasonal changes in day length. Averages of only 5 to 7 hours of sun are seen per day in the central areas as a result of the greater number of fog days (see the table with Figure 8). The amount of sunshine increases slightly during the winter months when Berg winds help clear away cloud and fog, but for the rest of the year the average daily duration of sunshine varies little.

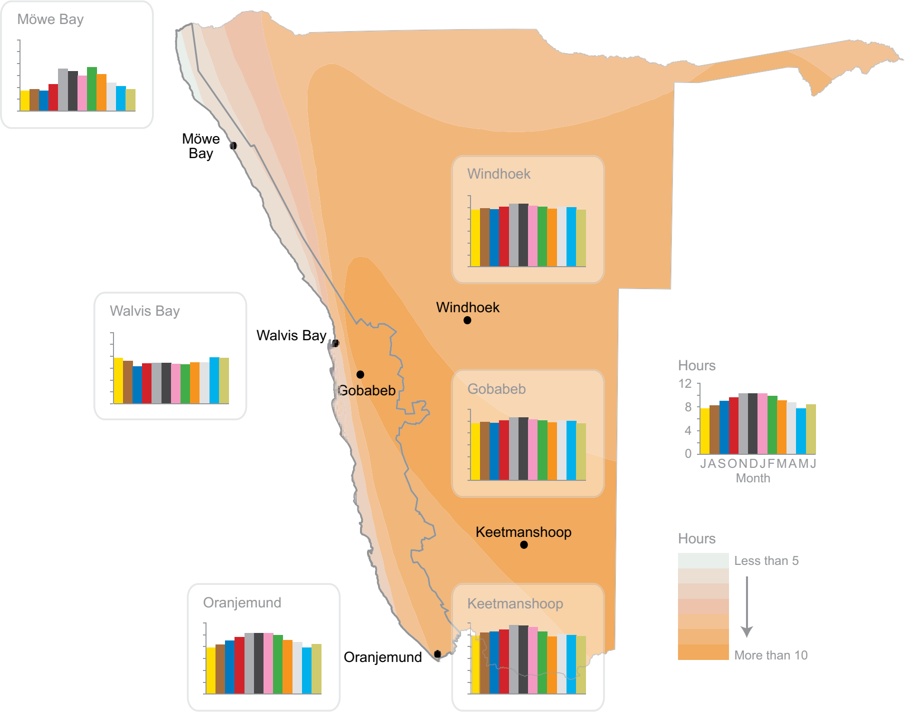


Figure 12. The average number of sunshine hours recorded per day during the year, shown here running from July to June.[15]

Temperatures

Temperatures at the coast are mild for most of the year. Cool onshore winds and persistent fog or low cloud ensure that average temperatures within 50 kilometres of the coast are normally below 20˚C (Figure 13). Once outside the influence of fog and cloud cover the temperatures begin to increase rapidly.

Near the coastline the range in average monthly temperatures is relatively small, and much less than the range inland. The hottest month of the year is February and the coldest is August. Temperatures very rarely approach or drop below freezing.

The highest average maximum temperatures occur not during summer, as might be expected, but during the winter months when Berg winds sweeping down over the escarpment become increasingly hotter as they reach the sea. Consequently, although average temperatures are generally mild, some of the hottest days in Namibia occur at or near the coast. The highest temperature officially recorded at any weather station in the country – a sweltering 43.5°Celsius – was at Gobabeb in 1970. Temperatures of 40°Celsius or more have also been recorded at Möwe Bay, Walvis Bay and Oranjemund. Although the cool humid conditions at the coast lead to less water loss by evaporation than elsewhere in the country, potential evaporation rates are still high, at more than 1.7 metres of water per year.

All of the coastal towns regularly experience a transformation from bleak to sunny as the morning fog dissipates once the cool moist air is warmed.

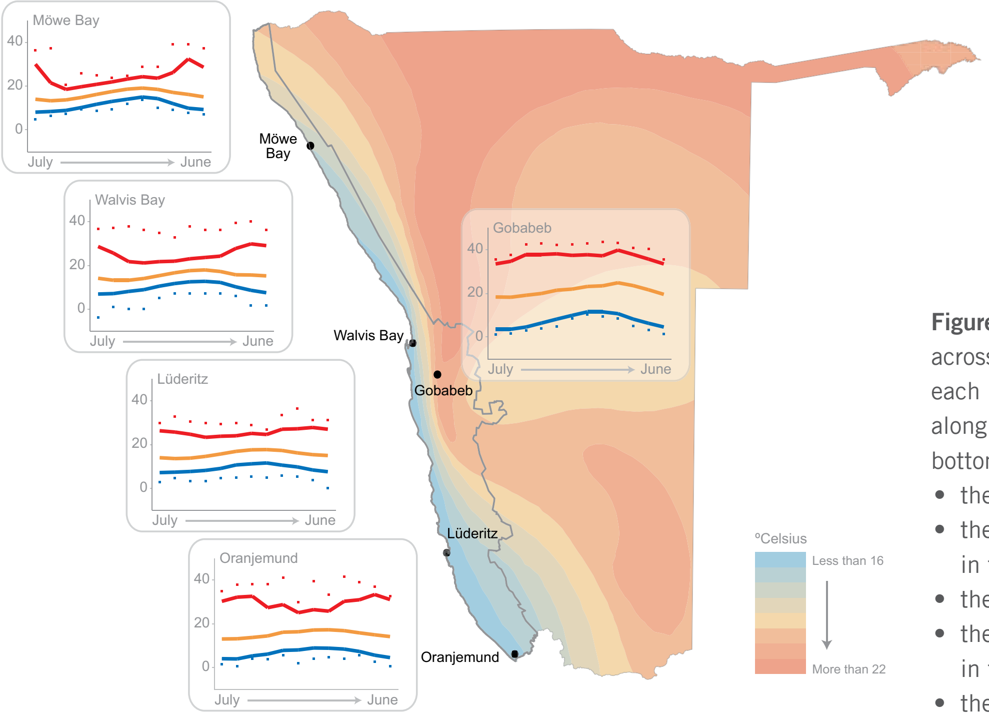


Figure 13. Average temperatures (in °Celsius) across Namibia, and detailed data on temperatures each month (from July to June) for weather stations along the coast.[16] The graphs show, from top to bottom:

- the highest temperature recorded in the month;
- the average of each day's maximum temperature in the month;
- the average temperature during the month;
- the average of each day's minimum temperature in the month; and
- the lowest temperature recorded in the month.

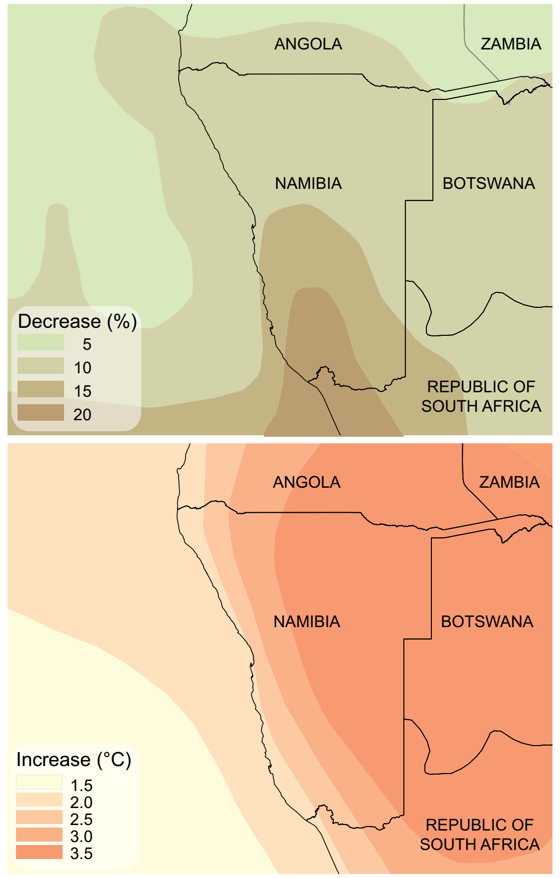


Figure 14. Some predictions as to how temperatures (bottom) and rainfall (top) in south-western Africa might be affected by climate change in the next 100 years.[17]

Climate change

With the current keen interest in climate change and global warming one might ask what will happen to the already extreme environment along the Namibian coast. Predictions made by climate change models come with many 'ifs and buts'. For instance, most scientists who develop the models highlight the paucity of data used for modelling and the difficulties in making predictions at local scales.

However, most models indicate that the drier subtropical regions, including much of Namibia, will warm more than the tropics (Figure 14).[17] In particular, southern Africa will become hotter and drier, temperatures perhaps increasing by 4˚C or more and precipitation possibly falling by 15%. Important wetland areas such as the Orange River mouth could be affected by reduced rainfall in the catchment areas in South Africa. A decline in rainfall across south-western Africa generally is also likely to negatively affect groundwater recharge in the western ephemeral rivers. The Kuiseb, Swakop and Omaruru catchments are currently critical water sources for the coastal towns of Walvis Bay, Swakopmund and Henties Bay.[18] Unfortunately the precipitation estimations in the models do not yet account for the role of fog which, as we have seen, is by far the most important source of moisture for the desert environment. These predicted changes relate to broad zones, and predictions made for local areas carry much less certainty.

One prediction made repeatedly by climate change models for which there does appear to be growing evidence is the increased variability of both temperature and rainfall. The frequency and intensity of extreme events, such as droughts and floods, is expected to increase. Thus, southern African winters are predicted to become even drier and the frequency of extremely wet summers is expected to increase, even though there may be an overall reduction in average rainfall.

Small increases in sea level can wreak havoc to structures close to the shoreline. This popular beach bar was almost washed away by strong seas during an exceptionally high tide in 2011.

It is also expected that sea levels across the globe will rise more rapidly. Some estimates suggest that levels could rise half a metre by the end of the 21st century as a result of sea water expanding as it becomes warmer. The melting of the Greenland ice sheet and other large ice bodies could cause greater rises. Perhaps the most serious effects of a sea level increase on the Namibian coast would be the impact on Walvis Bay, both to the port area if the sea breached the land around Pelican Point and to its associated lagoon area and salt works.

It needs to be stressed that rises in sea level would occur very gradually, at least when measured against human life spans. However, extreme weather should produce higher, more powerful swells that may pound the shore and anything standing in the way of the waves. The rate of erosion of the existing shoreline should also increase, making man-made structures near the coast more vulnerable.

The predicted changes in climate are also likely to affect many of the major river drainage basins. The Orange River is Africa's fifth largest river, and a small drop in rainfall in its catchment is expected to have severe impacts on the river's flow. Much of the Succulent Karoo flora (see page 80) may also disappear as a result of reduced winter rainfall.

Above: The ability of desert adapted plants and animals to capture and utilise moisture in the air creates a delicately balanced 'living' desert.

Below: Many of the up-market holiday homes located along the shorelines of the coastal towns are vulnerable to the effects of climate change. There is currently little infrastructure in place to protect the main coastal towns from flooding should sea levels rise as predicted by climate change models.

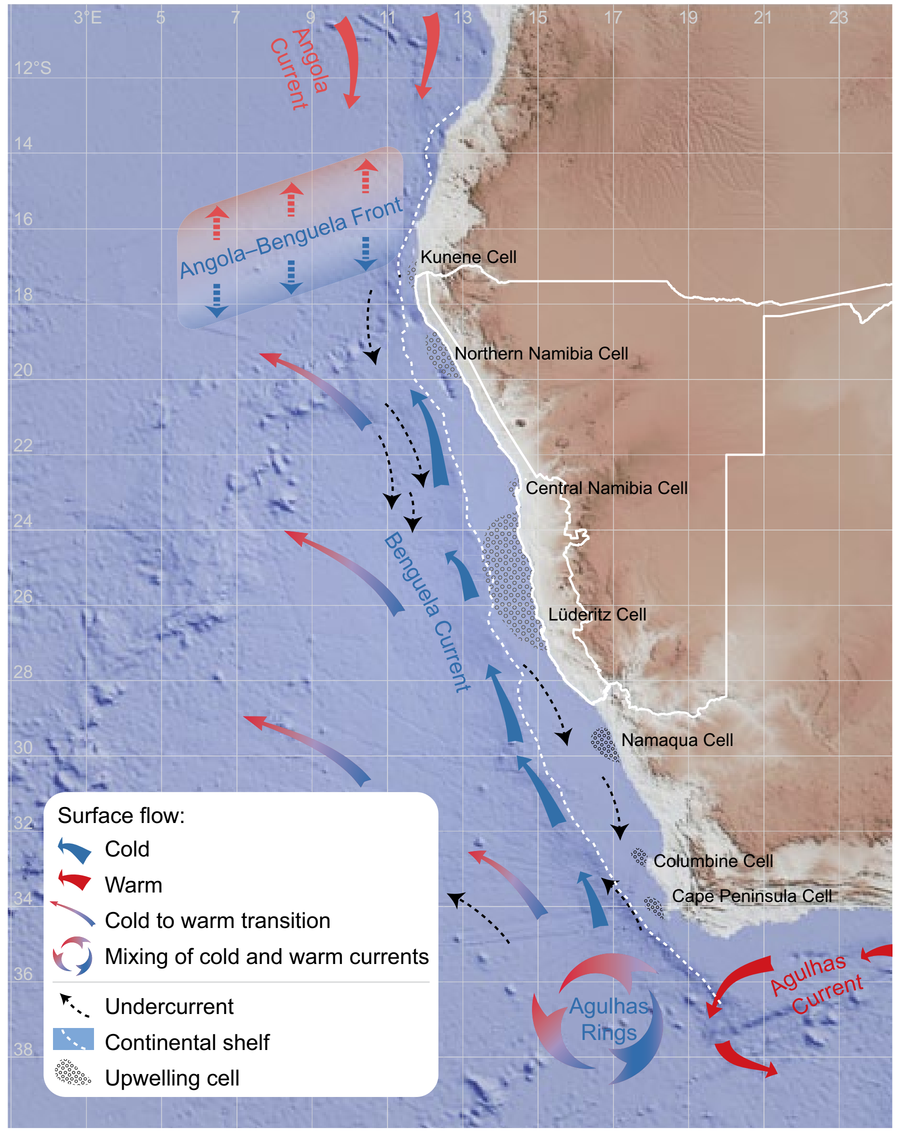


Figure 15. The main features of the Benguela Current system.

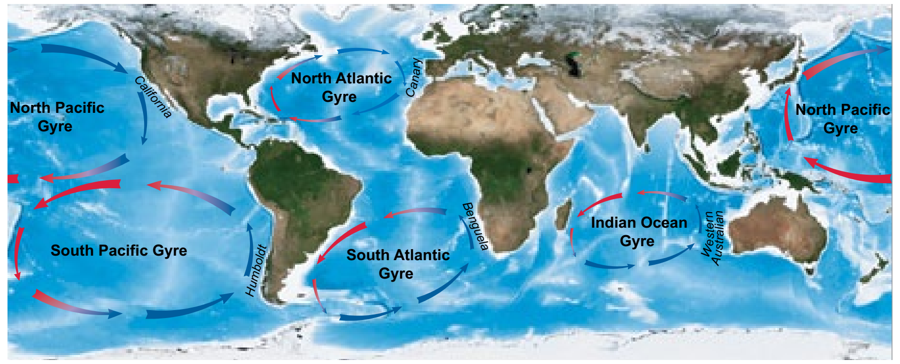


Figure 16. The Benguela is one of several currents that flow and well upwards or rise along the western margins of continents. Each current is generated by a gyre of water circulating one of the major expanses of ocean. The anti-clockwise circulation in the southern hemisphere and clockwise flow in the north is driven by the Coriolis force.

THE BENGUELA CURRENT

No other feature dominates Namibia's coastal environment as much as the Benguela Current. This is a relatively shallow, cool stream of water that forms part of a gigantic rotating current (called a gyre) that flows anti-clockwise around much of the South Atlantic Ocean (Figure 16).

The Benguela's initial northward flows are roughly parallel to the coast at a speed of between 10 to 30 centimetres per second (or between 360 to 1,080 metres per hour) up to about 23° to 25° South, depending on the distance offshore and the season. From there, relatively strong flows split off in a westward direction, thus weakening the northerly current which nevertheless continues up the coast until it reaches and flows under the much warmer south-flowing Angola Current.

The Benguela and Angola Currents typically meet around 16° South, just north of the Kunene River mouth. However, this interface also shifts seasonally, the Benguela pushing further north in winter while the Angola flows further south in summer. The Angola current can even push as far south as Walvis Bay, as described below (see page 42). Conversely, there are sporadic intrusions of cold, south Atlantic water far up the Angola coast.

In addition to the southerly Angola Current, a counter current flows southward beneath the Benguela along the Namibian coast. This counter current is strongest near the edge of the continental shelf.

Upwelling

While the Benguela Current is a product of the much larger South Atlantic gyre, its northerly flow is also driven by winds from the south that are generated by the South Atlantic Anticyclone (see page 22). The winds are further speeded along by the 'pulling' effects of low pressures that develop along the coast when air over the Namib is heated by the sun. The strong winds that result from these steep pressure gradients help generate upwelling along much of the west coast of southern Africa.

As surface water is moved northwards it is also deflected to the left or west by the Coriolis force. Each layer of water drags the layer beneath it along with it, and each successive deeper layer is deflected further left until the direction of deep water movements bears no resemblance to that of the wind on the surface. This dragging and deflecting process is called Ekman transport (Figure 17).

Water that moves offshore to the west as a result of wind and Ekman transport creates a relative vacuum of water that has to be replaced. This relative vacuum is

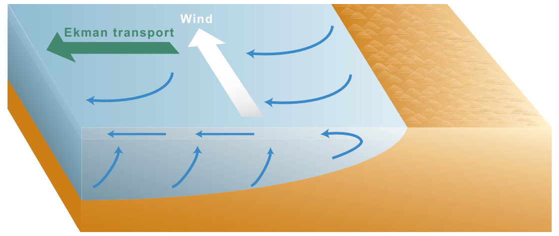
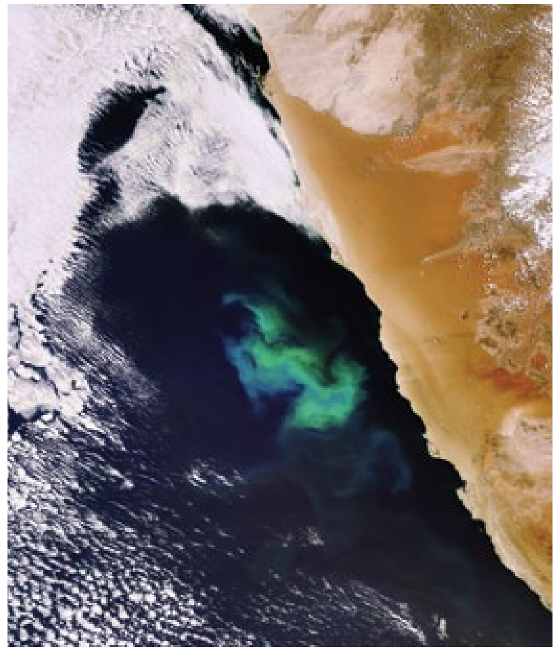


Figure 17. Upwelling along the Namibian coast is driven by wind and Ekman transport, and is most pronounced where the inner continental shelf is narrow and the sea less than 100 metres deep.



Above: A bloom of plankton resulting from upwelling off the Namib coast.

Below: The strong winds generated by the South Atlantic Anticyclone are responsible for the nutrient-rich upwelling cells evident on the surface as powerful waves.

the fundamental cause of upwelling, because deeper, cooler water from depths no greater than 300 metres then moves upwards in a zone some 100 kilometres wide off the coast. Upwelling is particularly pronounced where the inshore shelf is narrow.

Seven major upwelling cells or centres lie along the coast between 15° South (southern Angola) and 35° South (Cape Agulhas). The strongest upwelling along the Namibian coast is in a cell off Lüderitz and in one to the north near Cape Frio (Northern Namibia cell, see Figure 15). The winds are strong (see page 30) and the inner continental shelf is relatively narrow (see page 51) in both areas.

From a biological and economic point of view, the most important consequence of upwelling is the movement of deep water rich in nutrients to the sunlit ocean surface. Tiny planktonic plants then use the nutrients to grow and multiply, thus providing food for the great abundance of fish and other animals described in Chapter 4. In short, the upwelling of nutrients makes the Benguela Current one of the most productive marine areas in the world.

Of the two main upwelling cells on the Namibian coast, the one near Lüderitz is by far the strongest. It also has the greatest impact on Namibia's marine life since waters rich in nutrients and floating plants (phytoplankton) and animals (zooplankton) are continuously further distributed by water flowing in a northerly direction. Much of the biological production off Namibia is thus initiated in the Lüderitz cell and then spread by surface flow over wide areas to the north. The zone between Walvis Bay and the Kunene River mouth has the highest and most consistent rates of plankton production. Further south within the Lüderitz upwelling cell, the strong winds (see page 30) and excessive surface turbulence prevent the formation of dense concentrations of plankton and production.[19]

Above: In years of good rains both perennial and ephemeral river systems pump large quantities of sediments out into the sea. These sediments are carried by the strong Benguela current northwards where they are washed back onto the shore and blown further inland by the strong southerly winds. This is the mouth of the Orange River.

The strong Lüderitz cell effectively divides the Benguela Current into a northern and southern zone. For example, upwelling is more periodic along the southern coastal zone, peaking during bouts driven by winds that last between three and ten days.[20] To the north, by contrast, upwelling is more continuous. Coastal waters south of the cell have higher concentrations of oxygen and are less saline than those to the north.[21] However, only pelagic species appear to be divided by the cell, others showing no differences between the northern and southern areas of the Lüderitz cell.

The geomorphology of the Namibian coast, as described in Chapter 3, is strongly influenced by two sets of swells resulting from the wind patterns described earlier in this chapter (see page 29). The first is an almost continuous bombardment by swells generated by the South Atlantic storm belt or "Roaring Forties". The second set of swells is produced by the strong southerly winds created by the South Atlantic Anticyclone. The overall result is that many swells have long periods (the time between the passing of one wave and the next) and significant heights. For example, 53% of waves have periods of over 12 seconds and heights of more than five metres.[22]

The effects of the swells are far-reaching. Observers in submersibles have reported sediment being moved by these waves at a depth of 120 metres, while cobble-sized material was moved at depths of 15 metres.[23] The strong swells carry sediment brought down to the ocean by the Orange River back towards the shore. As a result sand from offshore the Orange River is eventually carried onshore and on to the beaches from where it is blown further inland to form the Namib Sand Sea (see Chapter 3).

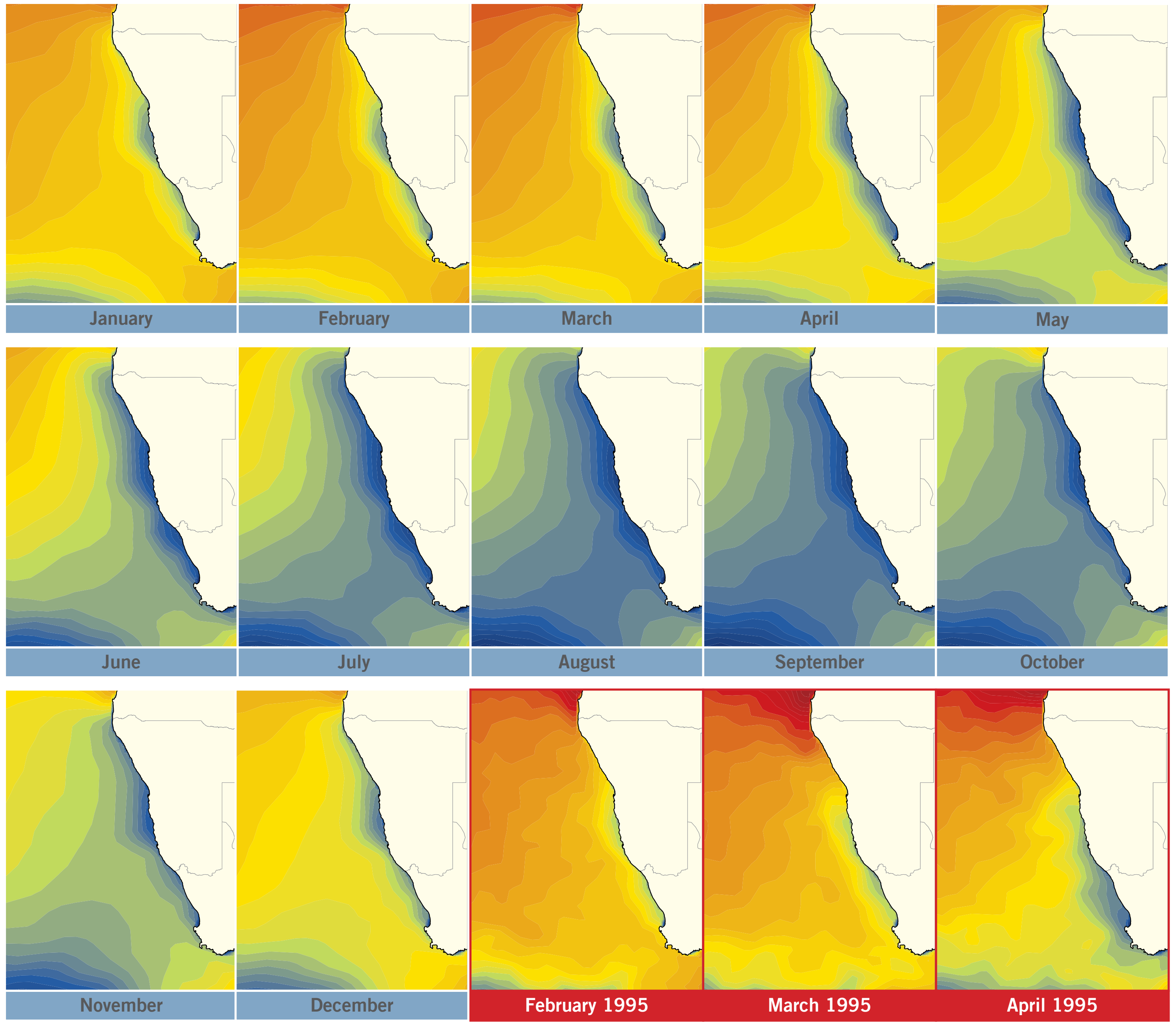
Water temperatures

Although the Benguela is known as a cold water system, its waters are not cold everywhere. Temperatures also vary during the year, particularly in response to cold water being driven north by the South Atlantic Anticyclone and warmer water being pushed south by the Angola Current. The extent and nature of these seasonal changes are shown in Figure 18. These maps also show how offshore water west of the coast is much warmer than the cold inshore water that has welled up from the depths.

Interestingly, sea temperatures have risen more over the past 30 years at the northern and southern margins of the Benguela area than in the central regions. The greatest increases have amounted to between 1 and 1.5°Celsius over this period, while temperatures in the central areas rose by less than 0.5°Celsius[24].

Sea water is of course salty, but there are slight variations in salinity across the Benguela. On average, these range between about 34 and 36 grams of salt per kilogram of water. Northern, warmer water usually has higher levels of salinity, while the converse is true for cold water. Both temperature and salinity influence the density of water, which can have an effect on flows since water, like air, moves from zones of higher to lower density.

Along most of the coast cold temperatures and strong under-currents make the sea a dangerous place for bathers. The popular Mole at Swakopmund is one of the few exceptions and the sheltered water attracts many visitors from across Namibia and from overseas.



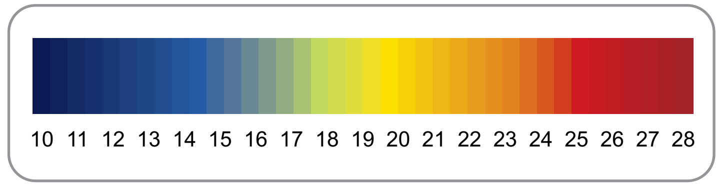


Figure 18. Average temperatures (°Celsius) of the sea surface each month over the period January 1990 to December 2009. Also shown are surface temperatures for three months during the Benguela-Niño in 1995[25].

MINIMUM AND MAXIMUM SEA TEMPERATURES (IN °CELSIUS) AT VARIOUS PLACES AND THE MONTHS IN WHICH THEY WERE RECORDED [26]		
Place	**Maximum**	**Minimum**
Kunene mouth	20.8 March	15.3 August
Ugab	18.9 February	14.1 August
Walvis	17.9 February	13.4 August
Lüderitz	16.4 February	12.9 September
Oranjemund	17.0 January	13.1 August

Deviations

In covering such a large area of the eastern Atlantic, the Benguela might seem too big to vary significantly, at least in having any major impact on its physical and biological functioning. However, several processes and events can cause major disturbances, and can occur in surprising ways and frequencies that scientists are just beginning to understand.

While warm swimming waters please bathers, high temperatures often have disastrous consequences for marine life. Warm water events are characterised by a reduction in oxygen levels resulting in mass die-offs of fish, crustaceans and other marine animals.

Intrusions of warm water from the Angola Current reduce the extent of upwelling along the coast, and the warmer water is also often relatively deficient in oxygen. Both conditions lead to reduced biological production, as well as causing fish populations to move away from their usual feeding and breeding haunts with the result that reproduction and recruitment are curtailed. Major intrusions of warm, Angolan water – called Benguela-Niños – occurred in 1963, 1984 and 1995 (Figure 18).[27] For example, temperatures in March 1995 were 4.7°Celsius higher than normal at the Kunene River mouth and 2.6°Celsius higher at Walvis Bay. Fish stocks and the fishing industry were severely affected in both 1984 and 1995 (see page 148).

What was especially damaging about the Benguela-Niño in 1995 is that it followed a severe episode in 1994 when water in the northern Benguela was depleted of oxygen; called a Low Oxygen Water (LOW) event. While shortages of oxygen limit the respiration of all animals, some are more sensitive to low levels than others. For example, pelagic fish (such as pilchards and anchovy) are less resilient to oxygen deficits than species that live at greater depths in the water column (such as hake).

LOWs are more prevalent in the northern Benguela zone than south of the Lüderitz cell. In addition to warm Angolan water being relatively deficient in oxygen, other factors lead to LOWs.[28] Upwelling may move deep water that is low in oxygen up to the surface waters and on to the continental shelf. Oxygen levels may also be reduced by the cumulative respiration of so many animals in the highly productive waters of the northern Benguela zone. The decomposition by bacteria of accumulations of organic material on the seabed can further reduce oxygen levels. This may even happen in relatively shallow water, sometimes causing rock lobsters to leave the sea and walk out onto land.

The depletion of oxygen by bacteria is sometimes accompanied by the release of methane and hydrogen sulphide which diffuses out of sediments on the ocean bed.[29] However, much more rapid eruptions of methane and hydrogen sulphide gas also occur, and huge areas of up to 20,000 square kilometres may be affected by the 'sulphur eruptions'.[30] Hydrogen sulphide is a respiratory poison and these eruptions may have devastating effects on marine animals. Of particular concern is that the eruptions are frequent in nursery areas for commercially important fish where juvenile and larval fish are especially vulnerable to poisoning. The nauseating smell of rotting eggs is also a product of hydrogen sulphide. Methane is probably not produced in sufficient volumes to have any effect on marine life off the Namibian coast, but methane is of course a major green-house gas.

The Ministry of Fisheries & Marine Resources in Swakopmund.

The Ministry of Fisheries & Marine Resources conducts regular monitoring of oceanographic parameters and processes such as sea temperature, salinity, dissolved oxygen, hydrogen sulphide, nutrients, chlorophyll-a, phyto- and zooplankton, upwelling and frontal movements.

Diatoms are the most important primary producers when the offshore surface waters are normally windy and turbulent. However, another major group of algal phytoplankton – dinoflagellates (see page 85) – flourish when the sea is calmer. Some species of dinoflagellates contain a reddish pigment and they may be so abundant that the sea appears red, giving rise to events known as red tides. Certain species of dinoflagellates also contain a nerve toxin that may cause mass poisonings of hundreds of thousands of fish, shellfish, marine mammals, seabirds and other animals which then wash up on beaches.[31] Red tide events occur relatively frequently, the most recent being in December 2005, June 2006 and March 2008. The last event caused oyster farms in Walvis Bay Lagoon to lose 10 million oysters, amounting to 80-90% of their stock.[32]

Recent studies are beginning to indicate that some of the major changes in the behaviour and functioning of the Benguela Current are related to changes in atmospheric circulation. For example, Benguela-Niño intrusions of warm water appear to occur at intervals of about a decade in response to changes in trade winds in the equatorial regions of the Atlantic. Decadal cycles of wind strength and sea surface temperature have also been detected, while changes in the strength and position of the South Atlantic Anticyclone occur in response to variations in the El Niño-Southern Oscillation (ENSO). For example, ENSO changes are associated with intrusions of cold water northwards along the Angolan coast.[33]

Just what impacts all these wider and greater changes have on production and fish populations remains to be discovered. However, fish populations in the northern and southern Benguela regions have changed in different ways over the past few decades.[34] Those in the north have declined while stocks of fish in the south have maintained more stable levels. There have also been eastward shifts in the distribution of pilchards and anchovies in the southernmost waters of the Benguela Current around the Cape in South Africa. These kinds of major changes and the broader, longer term impacts of atmospheric conditions indicate that the Benguela Current may change in ways that cannot easily be anticipated. They also suggest that a variety of factors may have contributed to the collapse of Namibian fish stocks (see page 148).

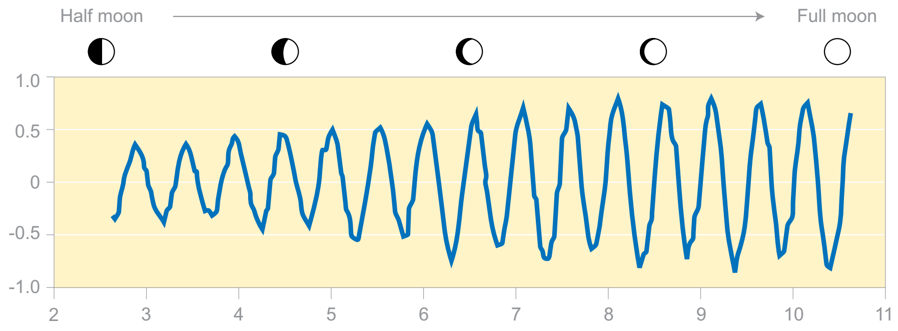


Figure 19. Compared to many other coasts in the world, tide levels fluctuate moderately and usually within less than two metres. This graph shows water levels at Walvis Bay between the 2nd and 11th of April 2009 (x-axis), showing the increasing tidal fluctuation between the neap tide at half moon and spring tide at full moon. The values on the y-axis are metres.[35]

Key points

- Weather on the coast is dominated by the South Atlantic Anticyclone which produces strong winds from the south and blocks the influx of warm moist air from the north.
- A combination of factors make the Namib dry: the progressive decline to the south of moisture fed in from the tropics, the drying of air descending to the coast from the escarpment, and the cooling of moist maritime air by the cold Benguela Current which means that the cool moist air remains trapped beneath warmer air layers.
- Winter rainfall predominates along the extreme southern coast, while north of Lüderitz most rain falls during the summer months. Average annual rainfall is less than 20 millimetres on most of the coast, whilst the southern area around Oranjemund receives around 50 millimetres.
- Fog occurs along the coast on between 80 and 140 days of the year and produces five times more water than rain. The influence of fog is generally restricted to within about 50 kilometres of the actual coastline.
- The entire coast experiences strong southerly winds for most of the year. For short periods in winter east winds bring warm dry air from the interior.
- Temperatures at the coast are mild, normally averaging less than 20˚Celsius; February is the hottest month while August is the coldest.
- Climate change models predict an increase in temperature and a decrease in rainfall. Sea levels are expected to rise and this is likely to cause increasing problems for several coastal towns.
- The cold Benguela Current dominates the marine environment. Of seven major upwelling centres along the coast, the one near Lüderitz is the strongest and produces the greatest supply of cold nutrient-rich water to the surface.
- The sea water is generally cold, but varies between the warmest temperatures during February and March (16-21°Celsius) and the coldest during September and August (13-15°Celsius). As a result of upwelling, offshore water is much warmer than inshore water.
- Events termed ‘Benguela-Niños’ occur when warm water from the Angola Current intrudes into the cold Benguela current. Levels of oxygen in the water sometimes drop, causing mass die-offs of fish and other marine life. Sporadic eruptions of sulphur from sediments on the ocean bed, and occasional blooms of dinoflagellate phytoplankton also periodically poison and kill animals in the marine environment.

This image shows an eruption of hydrogen sulphide along the coast in mid-March 2010. The pale, milky water covers a zone of 12-25 kilometres offshore and extends over at least 150 kilometres from south to north.[36]
John Marsh in his book *Skeleton Coast* describes sulphur eruptions in the Walvis Bay area following the overnight appearance of an island of mud: *“Subterranean eruptions in this area are frequent. They are followed by myriads of sulphuretted hydrogen bubbles that rise to the surface and make the sea boil. The smell of sulphur hangs heavily in the hot air. Millions of dead fish are cast up on the beaches. Columns of yellow smoke, and even flames, have been known to rise out of the sea during these underwater disturbances.”*