3 CLIMATE

Namibia’s weather patterns

Namibia is among the most arid countries on Earth. The weather is characterised by high daytime temperatures, short seasonal summer rainfalls, high rates of evaporation and crystal-clear blue winter skies. It is wettest in the northeast, where total annual rainfalls can reach 650 millimetres or more, but half of the country receives less than 350 millimetres of rainfall in a year. Farther south and west, rainfall declines and becomes increasingly erratic; it is rare along the entire coast. Yet potentially unbearable weather along the country’s western edge is ameliorated by cool sea breezes, and fog which enshrouds the coastal belt on about one in three days of the year providing an important water source for desert plants and animals.

These weather patterns experienced across Namibia are strongly influenced by a dominant high-pressure system over the ocean, and the cold Benguela ocean current. Although these and other factors determine our broad climate, the air and the oceans are part of one entire global system – a system that is always in dynamic balance. Changes in one part of the system affect the rest of it. Cyclical perturbations in atmospheric pressure in the eastern and western tropics of the Pacific Ocean influence ocean surface temperatures causing what is known as the El Niño Southern Oscillation when warm water builds up in the equatorial region of South America. The influence of this event is felt on weather patterns throughout the world. For Namibia specifically, El Niño tends to increase the probability that the country will experience drier conditions for a time. La Niña is the opposite side of this cycle; it occurs when Pacific Ocean surface waters are cooler than normal and increases the likelihood of wetter conditions in Namibia.

Seasons in Namibia are not equally divided across the year. Spring and autumn are short transitional periods between the summer months (October–March) and the mid-year winter months. Although summer is considered the rainy season, for much of the country rainfall is low, variable and unpredictable.

In many ways Namibia can be thought of as a country that is perpetually thirsty. Potential moisture loss through evaporation is many times greater than the amount of water that falls as rain. Temperatures rise in spring, but it is too soon for rain and there is little moisture to speak of – everywhere is dry. With summer comes the welcome promise of moist air and a smattering of early rain, but temperatures rise further and moisture quickly evaporates. The long-awaited late-summer downpours bring some relief, but there is always room for much more and the moist air swiftly abates to be replaced by dry wintery winds. And although there is a bounty of fog at the coast, most of this moisture remains tantalisingly suspended in the surrounding air.

Why is Namibia so dry?

The flow of air around the planet – together with the oceans and their currents – determines how thermal energy and moisture are redistributed around Earth. Although influenced by various factors from one year to the next, these large-scale air movements are consistent in structure and are important factors in determining the climate at any location in the world. This is especially true for Namibia which straddles the Tropic of Capricorn and is bounded by the Atlantic Ocean with its powerful Benguela Current. Namibia's arid nature results from the persistent presence of dry air for most of the year and high rates of evaporation. Moist, warm air that can fall as rain reaches Namibia infrequently. This aridity is the product of the three major circulation systems discussed below.

Atmospheric circulation

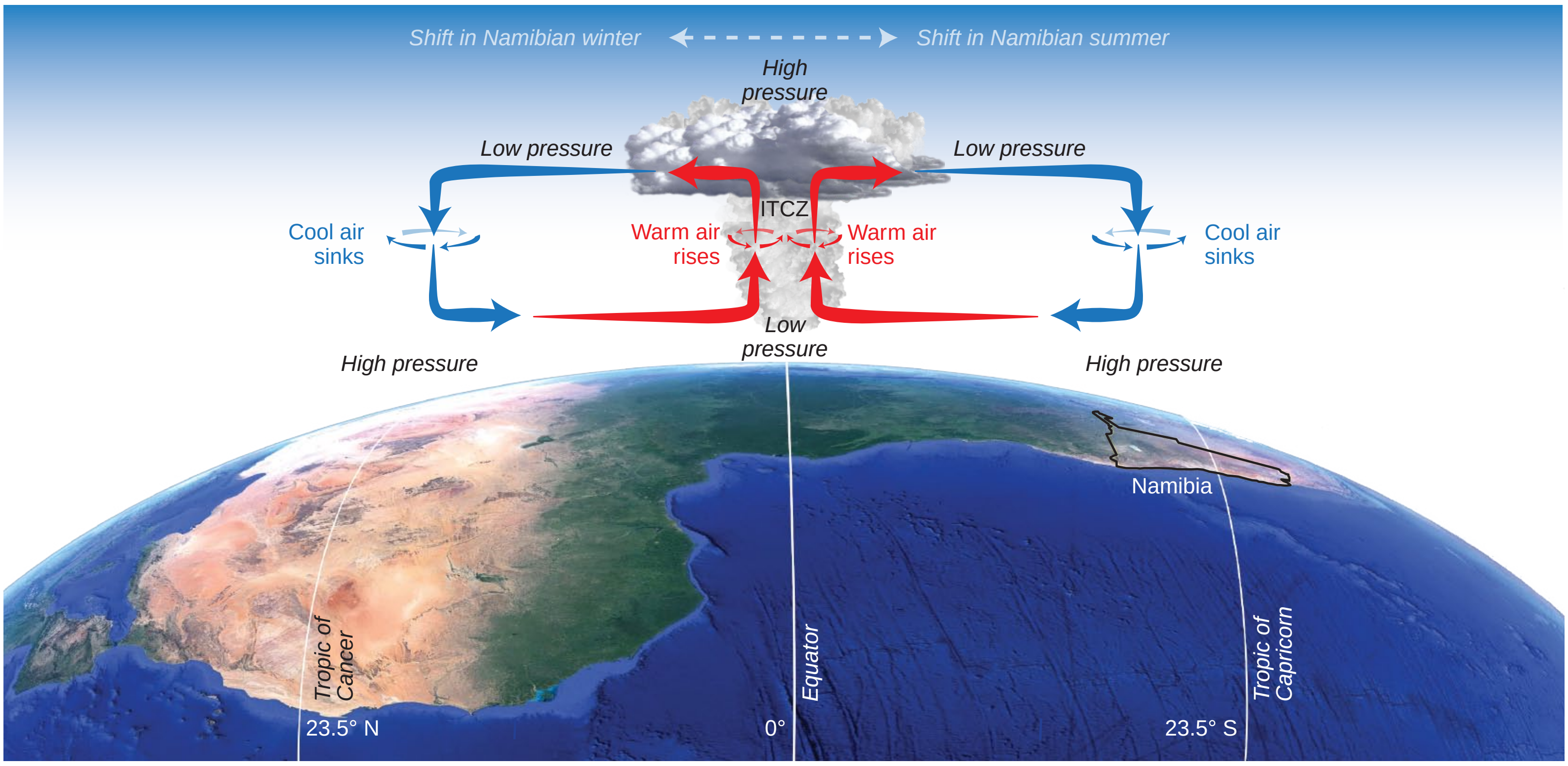
Namibia's geographical position spans a zone roughly between 17 and 29 degrees south of the equator, along the southwestern coast of Africa. This places Namibia in an area where it is exposed to air movements in three major circulation systems or belts described below and illustrated opposite:

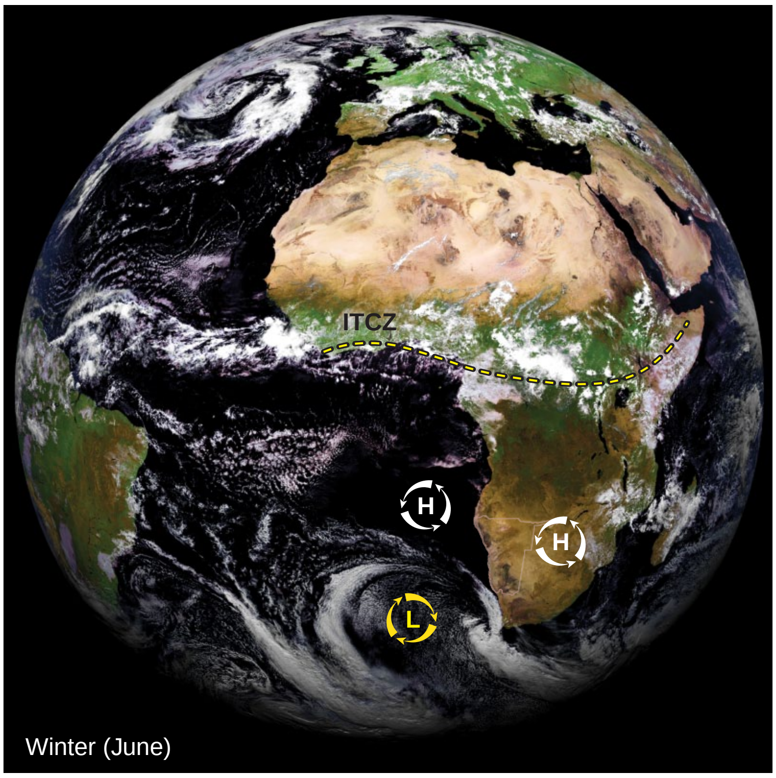
1. The Intertropical Convergence Zone – or ITCZ as it is often referred to – near the equator is where the air masses from the northern and southern hemisphere come together. Air in the Intertropical Convergence Zone is moist and warm and it spirals upwards creating a belt of low pressure. As it rises, the air cools and the moisture condenses forming the great band of cloud clearly visible in the images in figure 3.01. This zone shifts seasonally, southwards towards Namibia in the southern hemisphere's summer, retreating northwards in the southern winter. Its position follows that of the sun overhead, shifting annually between the Tropic of Cancer in the northern hemisphere and the Tropic of Capricorn in the southern hemisphere (just south of Rehoboth). The positions of these two imaginary lines of the tropics are equidistant from the equator and determined by the 23.5-degree angle of tilt of the earth on its axis.[1]

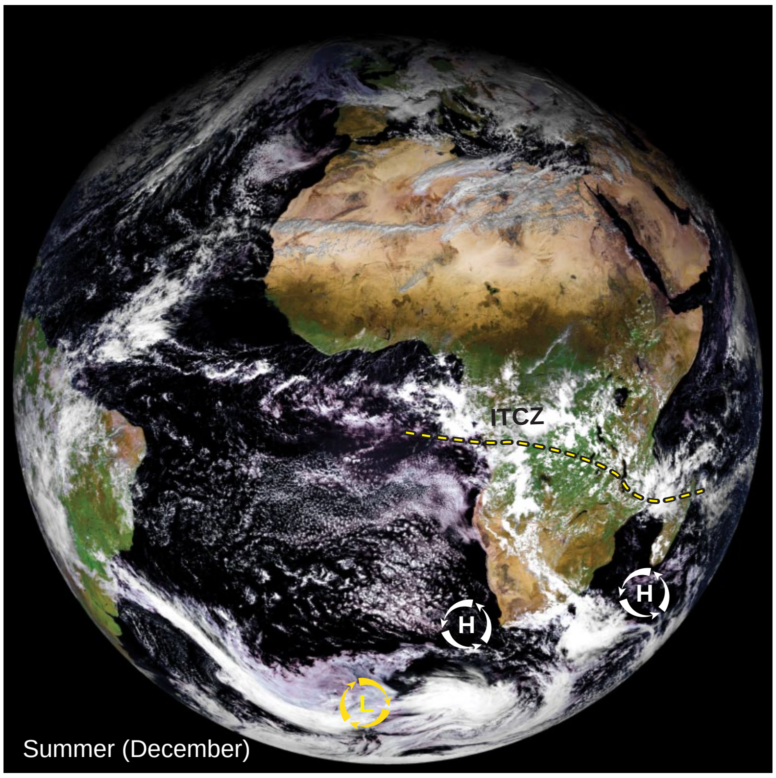
2. The middle belt is the Subtropical High-Pressure Zone. The air in the upper atmosphere, becoming cold and dry as it is forced out from equator towards the poles, subsides in the subtropics forming centres of high pressure. Two high-pressure centres – the South Atlantic Anticyclone and the Botswana Anticyclone dominate weather patterns over Namibia. In winter, the South Atlantic anticyclone is positioned off the west coast of Namibia while the Botswana anticyclone lies inland. The descending air from these high-pressure centres inhibits the formation of clouds and results in dry, clear winter days. Their influence weakens when the centres of high pressure are pushed southwards in summer, making way for warm moist air to be drawn in from the north and east to form clouds and rain.

3. The southernmost Temperate Zone, extending from Antarctica to the Tropic of Capricorn, is characterised by cold, moist air. The influence this zone has on Namibia is greatest during the winter months when it moves northwards and prevailing winds carry a succession of low-pressure systems and cold fronts from west to east that sweep across southern Africa. Although the impacts of these fronts weaken as they move over the land, they are responsible for the small falls of rain over the southern parts of Namibia in winter. These frontal weather systems bring much more winter rain to the southern Cape in South Africa.

Descending dry air from high-pressure cells create Namibia's cold and cloudless winter skies. One can literally see forever …





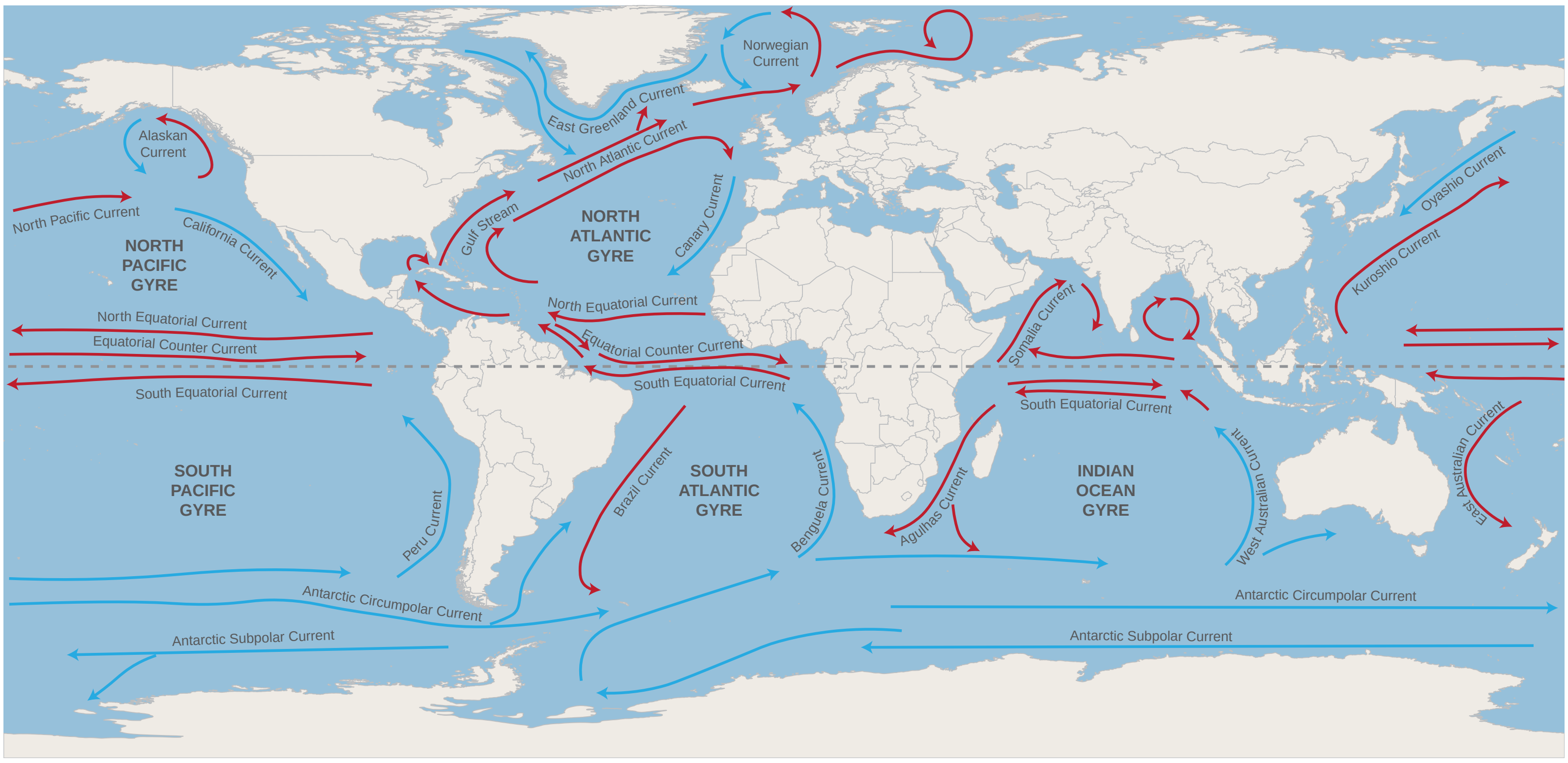


3.01 Patterns of air circulation around southern Africa

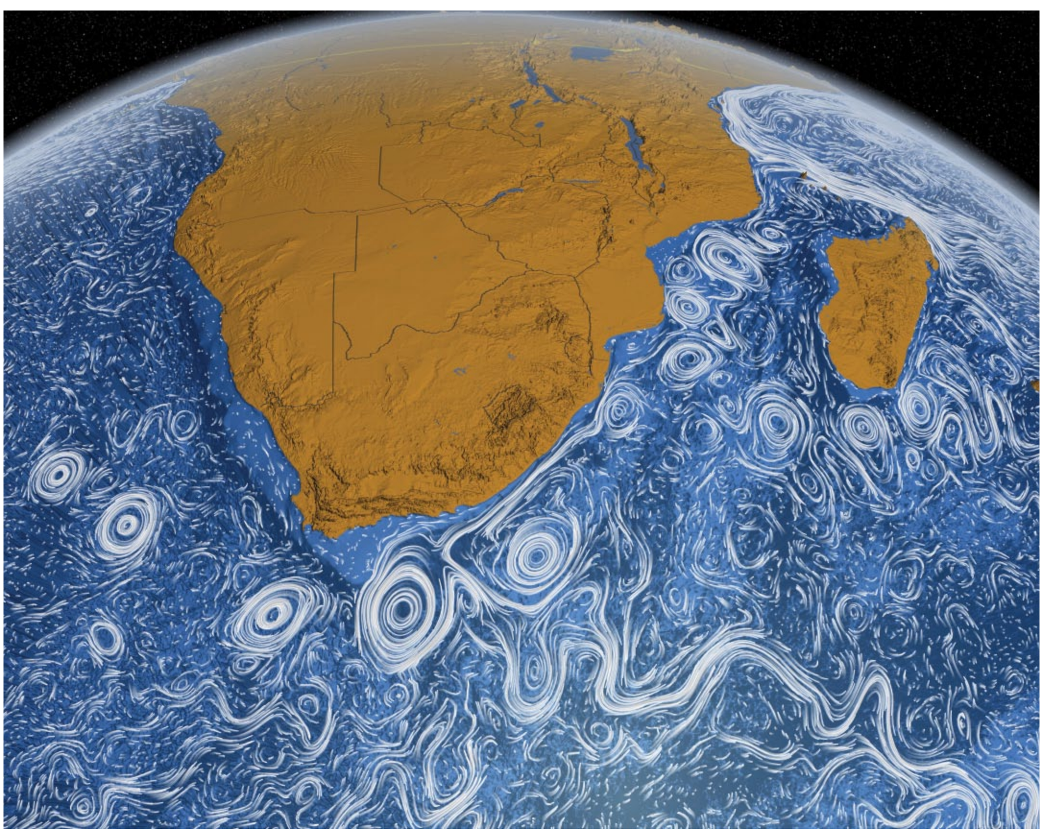
The schematic representation of air circulation (top) illustrates the vertical and horizontal movements of air between the equator and the tropics and how this circulation shifts in relation to Africa between summer and winter. Moist warm air from the Intertropical Convergence Zone spirals upwards causing heavy precipitation over the equatorial region. It is visible as a broad band of cloud in the two satellite images. Now cold and dry, this air is forced out from the equator to the poles where it subsides and forms centres of high pressure. It then moves towards the equator completing the cycle. The two satellite images show the typical patterns of air circulation around southern Africa in winter (left) and summer (right) and the major air pressure and convergence zones.[2] The dry high-pressure anticyclones (H) dominate over southern Africa in winter, with low-pressure cold fronts (L) bringing rain to the southwestern areas of the continent. In summer, the Intertropical Convergence Zone (ITCZ) – and other zones – migrate southwards allowing some cloud development over Namibia. Note the drier cloudless regions to the north and south of the ITCZ where the high-pressure systems dominate.

Ocean currents and upwelling centres

Earth's oceans have a much greater capacity to absorb and store energy from the sun than the atmosphere above the water surface. The natural flow of the oceans distributes this heat energy – cold dense water moves from the poles towards the equator, while warm lighter water is carried from the equator polewards. By distributing the heat in this way, these ocean currents regulate the temperature of the oceans and the temperature of the air above them, and have a major influence on the weather and climate. This is particularly true when the current that flows along the coast is much colder than the tropical air above it, as is the case with Namibia.



Due to the rotation of the earth, the waters of the world's oceans form currents. The larger and more permanent currents form giant, rotating systems called gyres responsible for regulating temperature, salinity and nutrient movements in Earth's oceans. In the southern hemisphere the direction of rotation is anticlockwise while in the northern hemisphere it is clockwise. There are five major gyres in circulation across the globe.

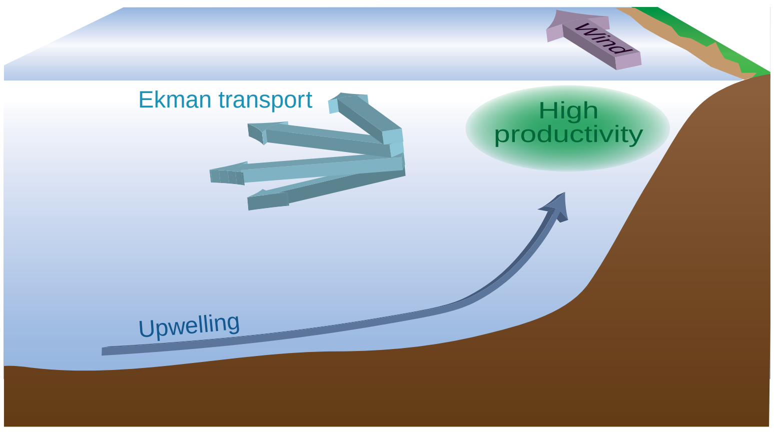


This is an image taken from an animation of the world's ocean currents generated by NASA's Goddard Space Flight Center. It is a synthesis of modelled and empirical data assembled between June 2005 and December 2007. The eddies, known as the Agulhas rings (figure 3.02), are clearly visible where the southerly moving Agulhas Current of the Indian Ocean meets the northward moving Benguela Current of the southern Atlantic.

3.02 The Benguela Current system

Namibia's coastal environment is dominated by the cold Benguela Current which forms part of what is known as the South Atlantic gyre.[3] The current moves in an anticlockwise direction on its path from south of the African continent towards the equator.

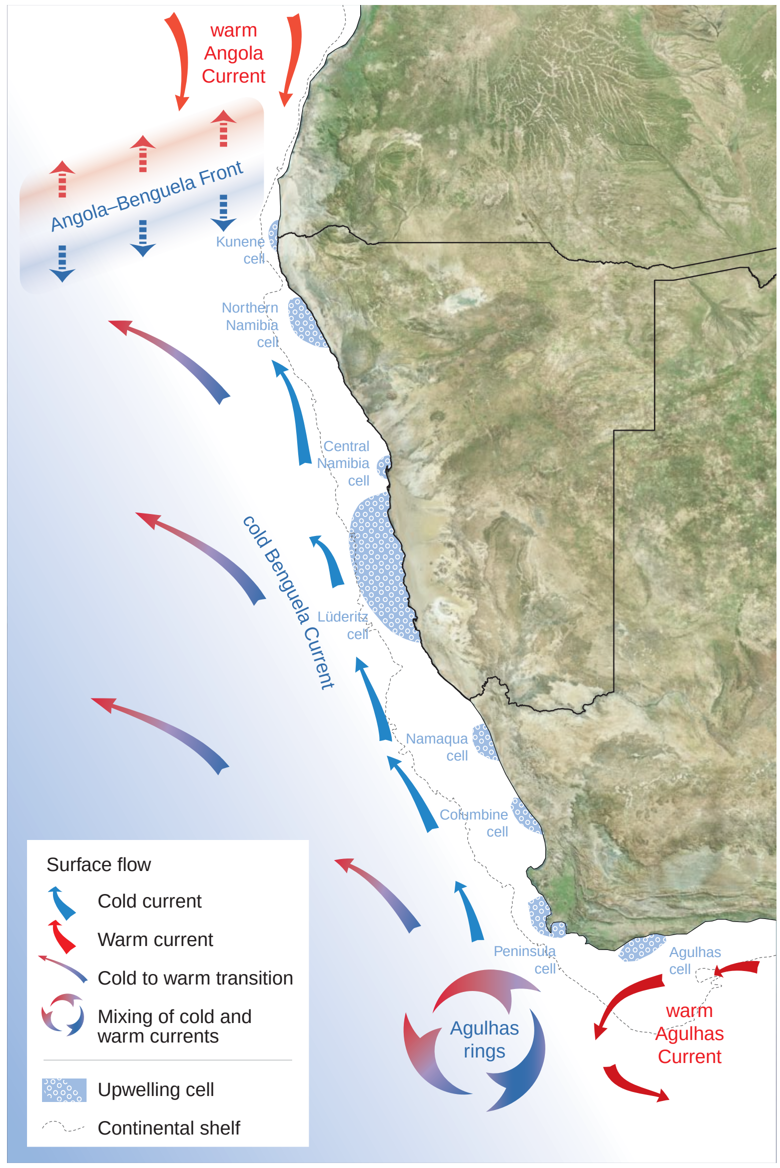
The movement of surface waters results from the dragging effect of the dominant southerly winds (figure 3.04). Although the impetus of the wind would tend to push the waters parallel to the coast, the Coriolis force (resulting from the anticlockwise rotation) deflects these surface waters towards the northwest. The speed of the water in the upper 100 metres decreases with increasing depth and its direction of movement is influenced more and more by the Coriolis effect so that farther down it is deflected at right angles to the wind. This spiralling motion of the surface water and resulting perpendicular water movement at lower depths is known as Ekman transport.



The water that is forced to move away from the shore creates a relative vacuum that causes deeper water to rise and replace it. This is known as 'upwelling' and is the reason why the waters within 100 kilometres of the coast are rich in nutrients and bountiful with life. Upwelling is most pronounced where the continental shelf is narrow.

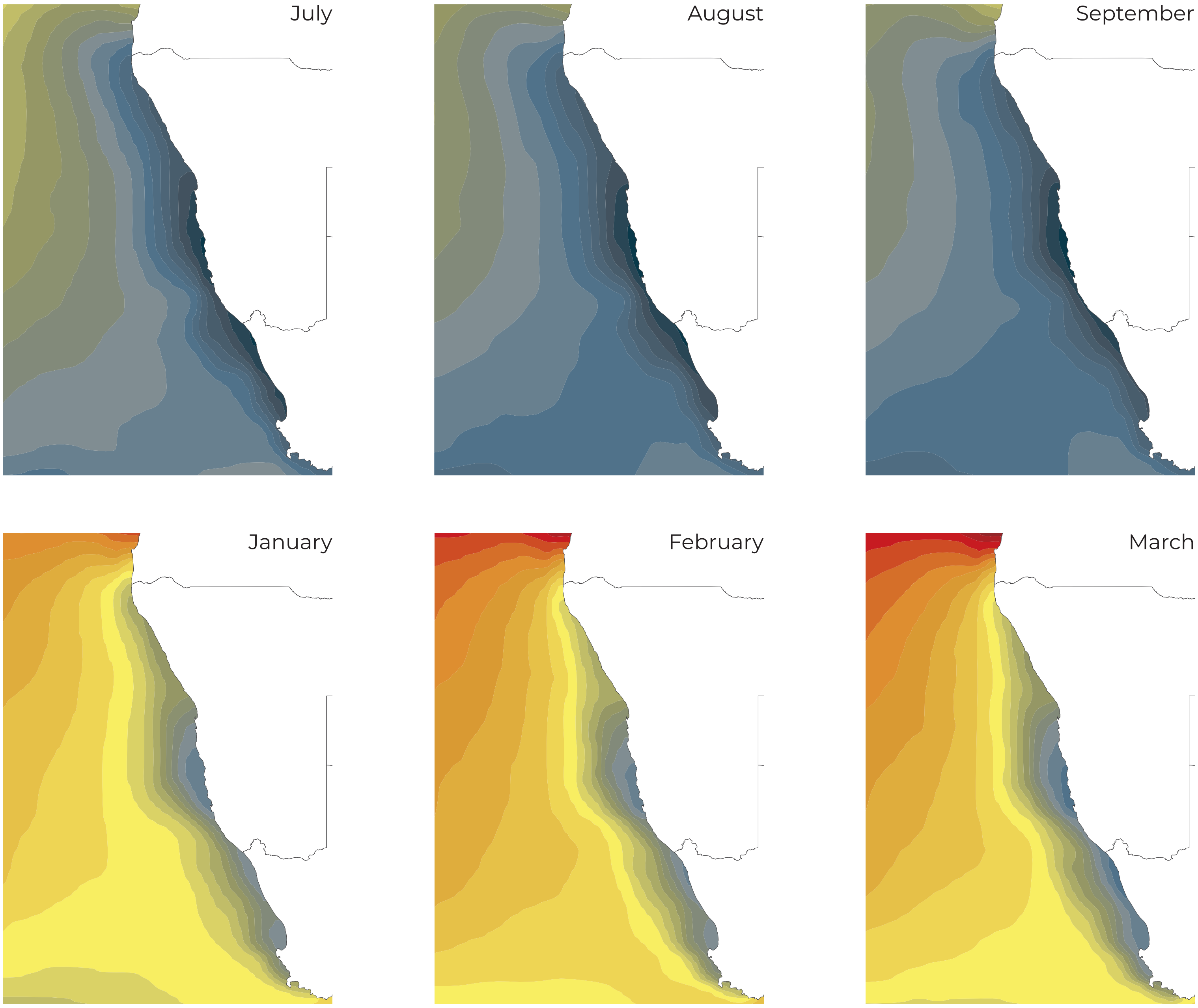
Seven major upwelling cells or centres occur along the Atlantic coast between southern Angola and the southern Cape.[4] The strongest upwelling cells off the Namibian coast are near Lüderitz and Cape Frio. In both areas the winds are powerful, and the inner continental shelf is relatively narrow. The Lüderitz cell is by far the strongest and has the greatest impact on Namibia's marine life since the phytoplankton and zooplankton sustained by the nutrient-rich waters here are subsequently distributed farther northwards by the Benguela Current.

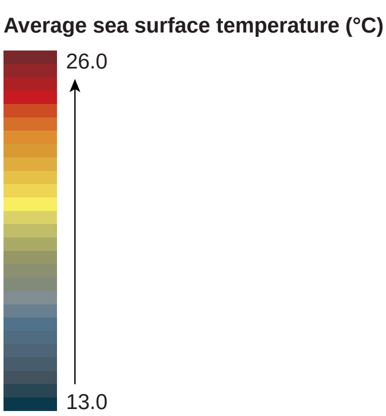
The Benguela Current is active as far north as the waters off Angola where it meets the warm and southerly flowing Angola Current. In addition to this, there is also a southerly flowing countercurrent beneath the Benguela which flows parallel to the Namibian coast, and which is strongest near the edge of the continental shelf.



The nutrient-rich waters of the Benguela Current fuel a diverse ecoysystem and sustain large populations of seabirds such as these cormorants.

Sea surface temperatures

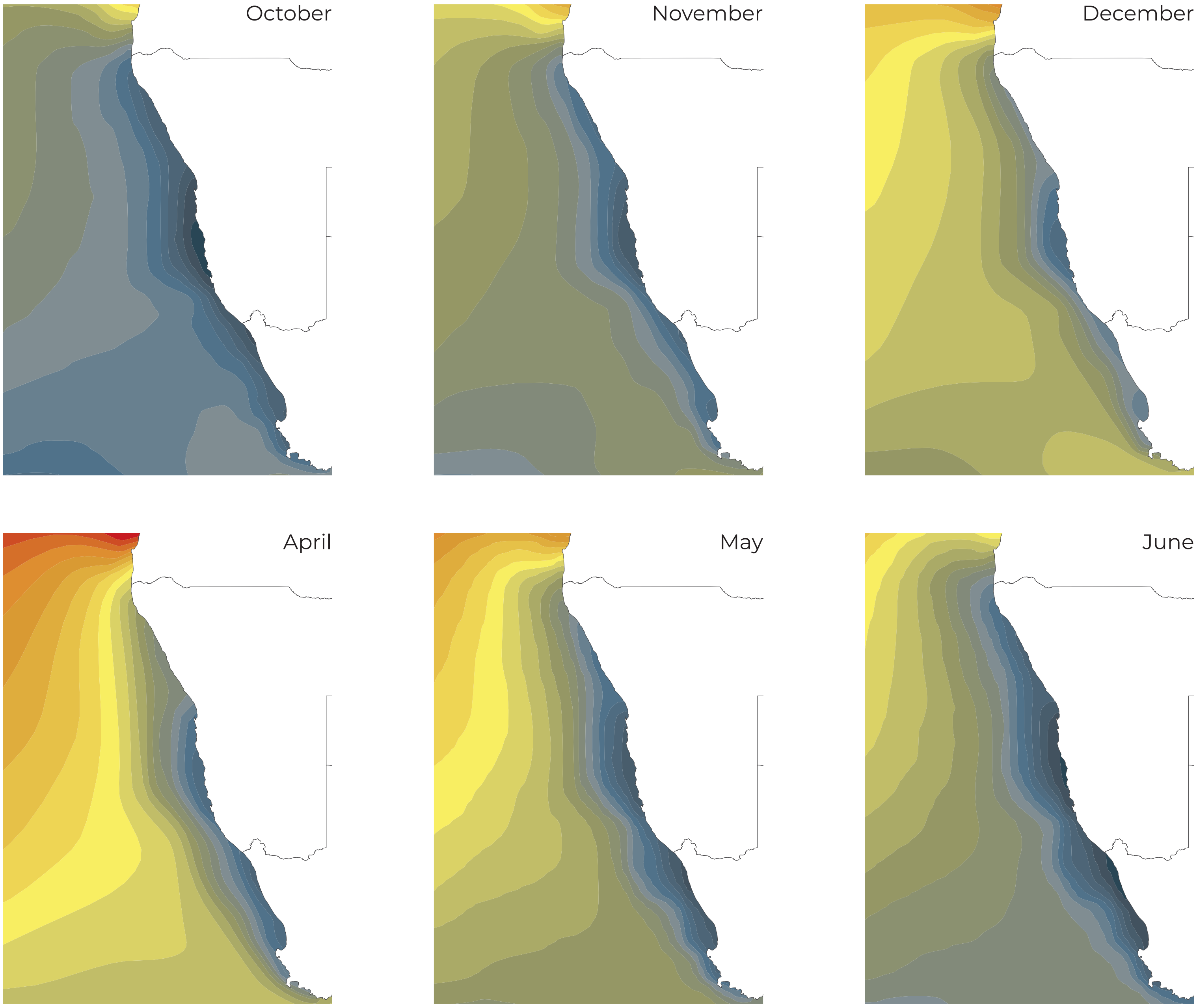




3.03 Monthly sea surface temperatures, 1982–2011[5]

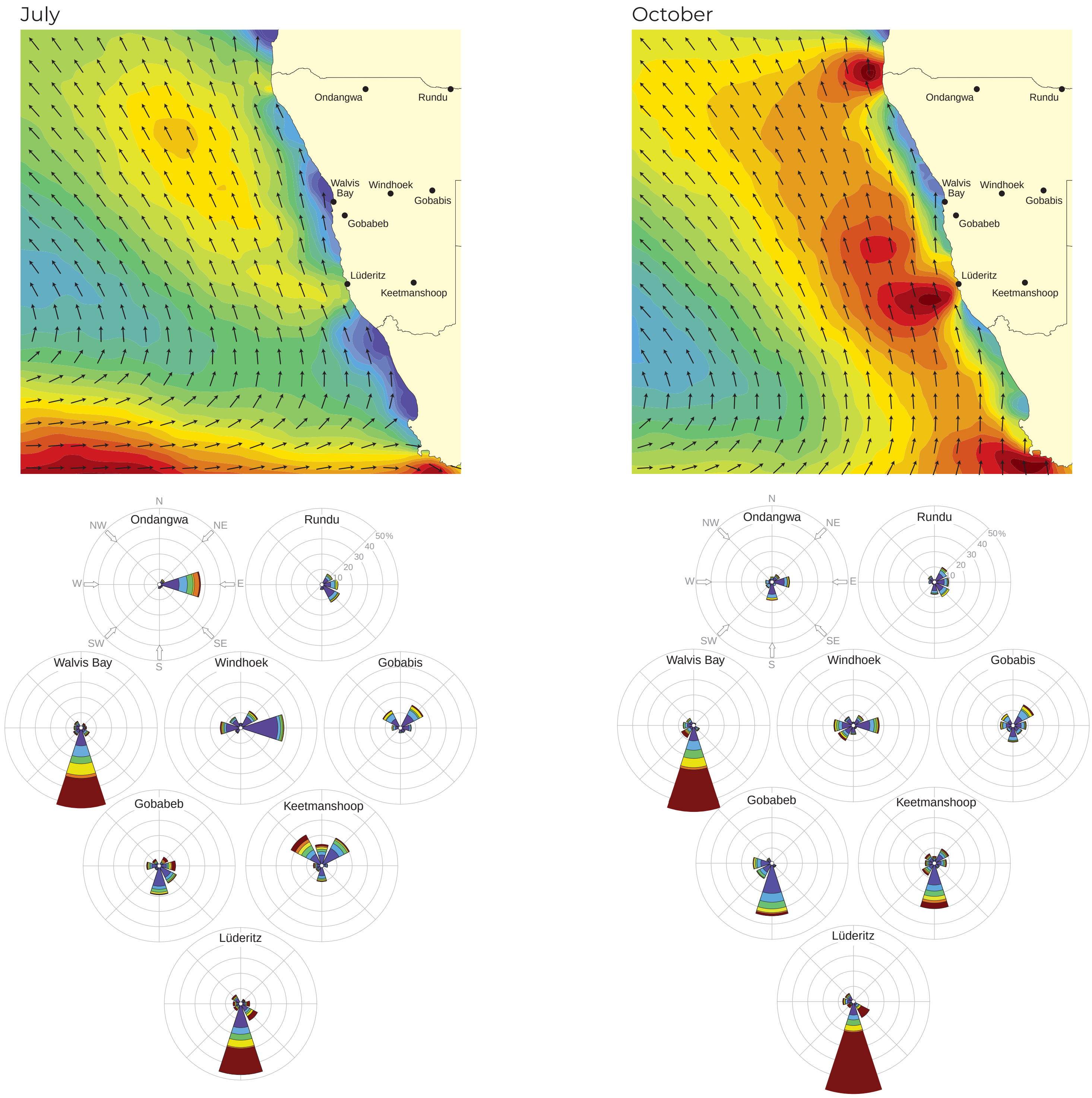
Although the Benguela is a cold-water system, surface temperatures vary geographically, as well as over the course of the year. The coldest waters are in the south and close to the coast. They are driven north in winter by strong southwesterly winds of the South Atlantic Anticyclone. In summer, warmer waters from the Angola Current push south, but sea surface temperatures remain cold close to the Namibian coast. Warm waters from Angola sometimes persist much longer than usual; such major warm-water events occurred in 1963, 1984 and 1995. Water temperatures off the northern Namibian coast in 1995 were about 8 degrees Celsius higher than usual for that time of year, an event known as a Benguela El Niño.

Sea temperatures have been rising. Over the 25-year period between 1982 and 2007 average sea surface temperature in the coastal and offshore parts of the northern Benguela rose by up to 1 degree Celsius.[6]



Oysters are normally associated with warm ocean waters where they can breed. However there is a small but growing coastal oyster industry in Namibia. The oysters are bred locally onshore and then transferred to ocean baskets that hang from floatation barrels (left). The greater levels of oxygen and nutrients in the cold Benguela waters mean that the oysters can be harvested much earlier than their European counterparts.

Wind

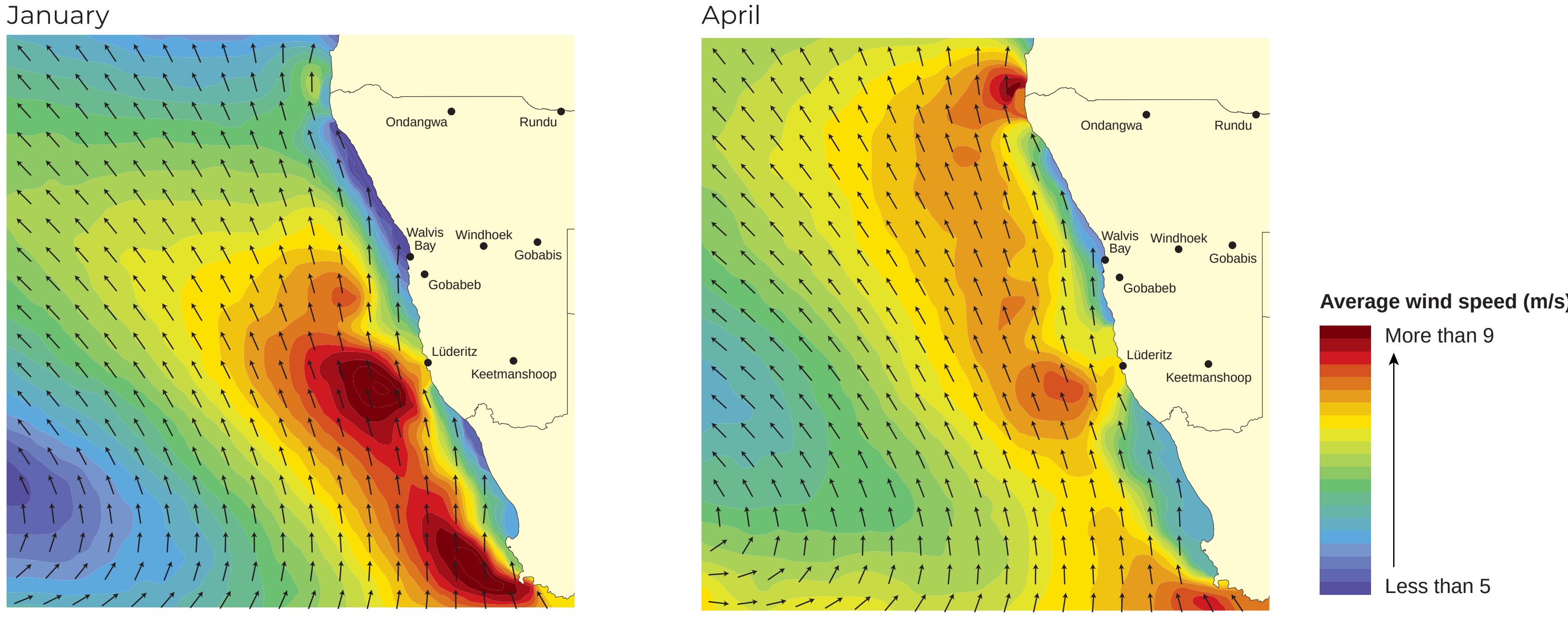


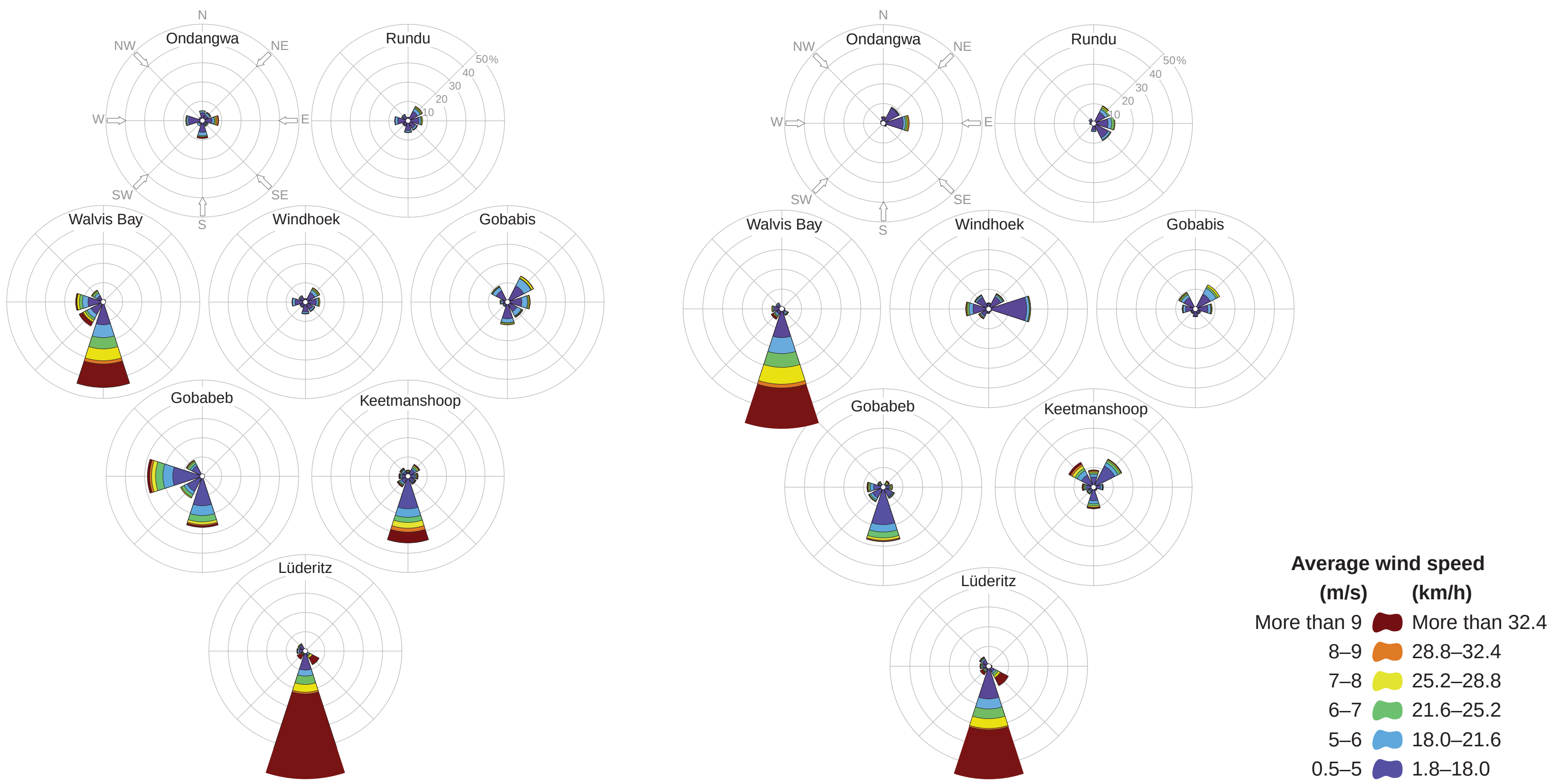
3.04 Wind offshore and over Namibia[7]

Average wind speeds and directions for July, October, January and April are shown here for eight places in Namibia (wind roses) and offshore (maps). The cold Benguela Current fuels the South Atlantic high-pressure cell located offshore (figure 3.01). This anticyclone acts like a giant turbine blasting air in an anticlockwise rotation towards the coast. This, combined with the Coriolis force (figure 3.02) that deflects the winds northwestwards, produces the wind patterns we see off the Namibian coast. The deflection of winds close to land results in the predominance of southeasterly, southerly and southwesterly winds along the entire coast. Over the land, wind speeds are generally lower and wind directions are more variable, and the proportion of calms (when wind speeds are less than 0.5 metres per second) is higher.

Two zones of strong winds, one around the Kunene River mouth and one at Lüderitz, coincide with upwelling cells caused by the displacement of surface waters and the resulting upward movement of deeper waters to replace them. Wind speeds are highest off the coast during the summer months when temperature gradients are steepest between the cool ocean and the warm land. The coastal stretch from Lüderitz southwards to the Orange River mouth is recognised as being the windiest area in southern Africa and record wind speeds have been measured at Pomona in the Sperrgebiet.[8]

January April

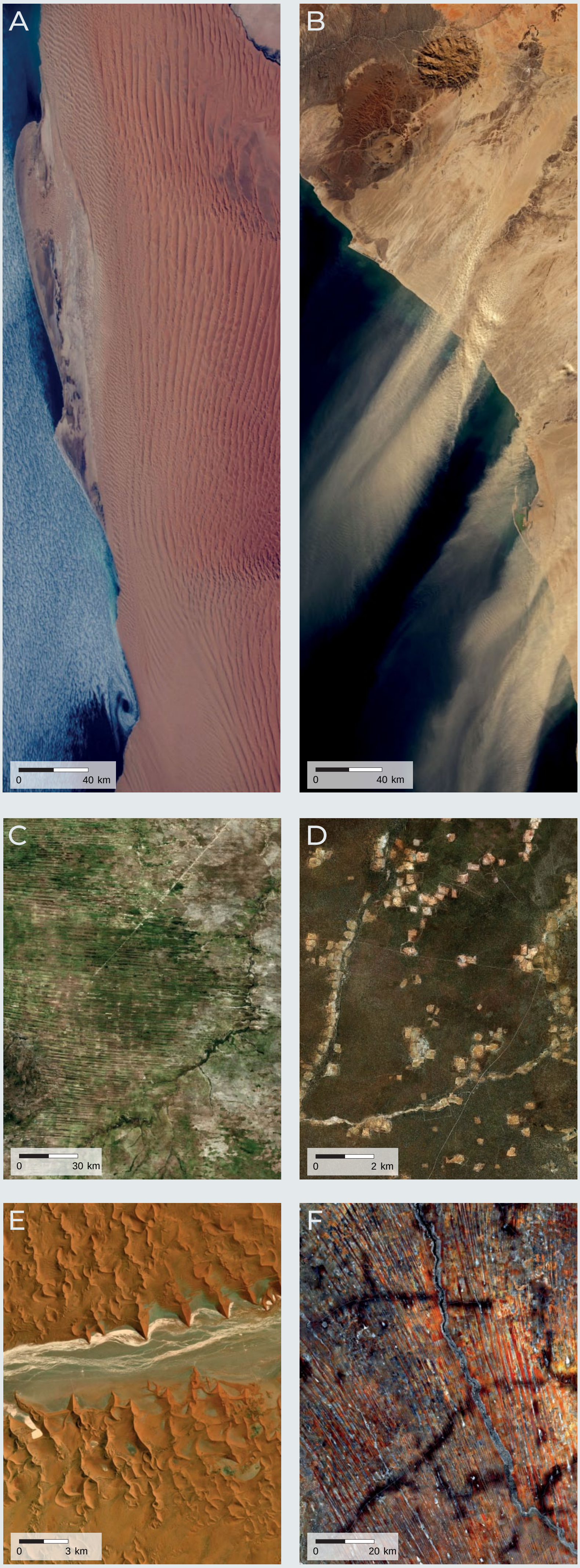




The wind roses below the maps contain several layers of information. They show the direction from which the wind blows (represented by the position of the arm) and how frequently it blows from that direction (represented by the length of each arm). In addition, the colour gradient shows (proportionally) how strong the winds are. In winter the influence of the Botswana Anticyclone results in the prevalence of more easterly airflow in many areas. These East Winds, as they are known, strengthen and become very warm as they descend from the escarpment and blow across the Namib Desert to the coast. The frequency of calms in the table (right) represents the proportion of all records in the set of wind measurements with values less than 0.5 metres per second.

Frequency of calms (%)

	January	April	July	October
Gobabis	36	51	49	36
Lüderitz	9	14	14	8
Ondangwa	55	68	63	53
Rundu	56	59	62	49
Walvis Bay	17	17	18	13
Windhoek	42	37	28	34



Shaping our sands[9]

Wind has had – and continues to have – a major impact on shaping Namibia's landscapes by moving great amounts of sand. Much of the sand is transported offshore to the Atlantic, some sand is mixed into more fertile soils that attract farmers, and other sands are moulded into the many forms of dunes that are found in different areas of Namibia (pages 40–41). Wind patterns differ greatly, not only across the landscape, but also between the seasons (see the wind roses in figure 3.04). Some of the strongest and most persistent winds are the southerly winds along the west coast that have been instrumental in shaping the Namib Sand Sea. Linear dunes (A), which characterise much of the sand sea and other areas, are commonly considered to be shaped by the counter influence of oblique winds against the dominant air flow. [Image centre 24.19° S, 15.18° E]

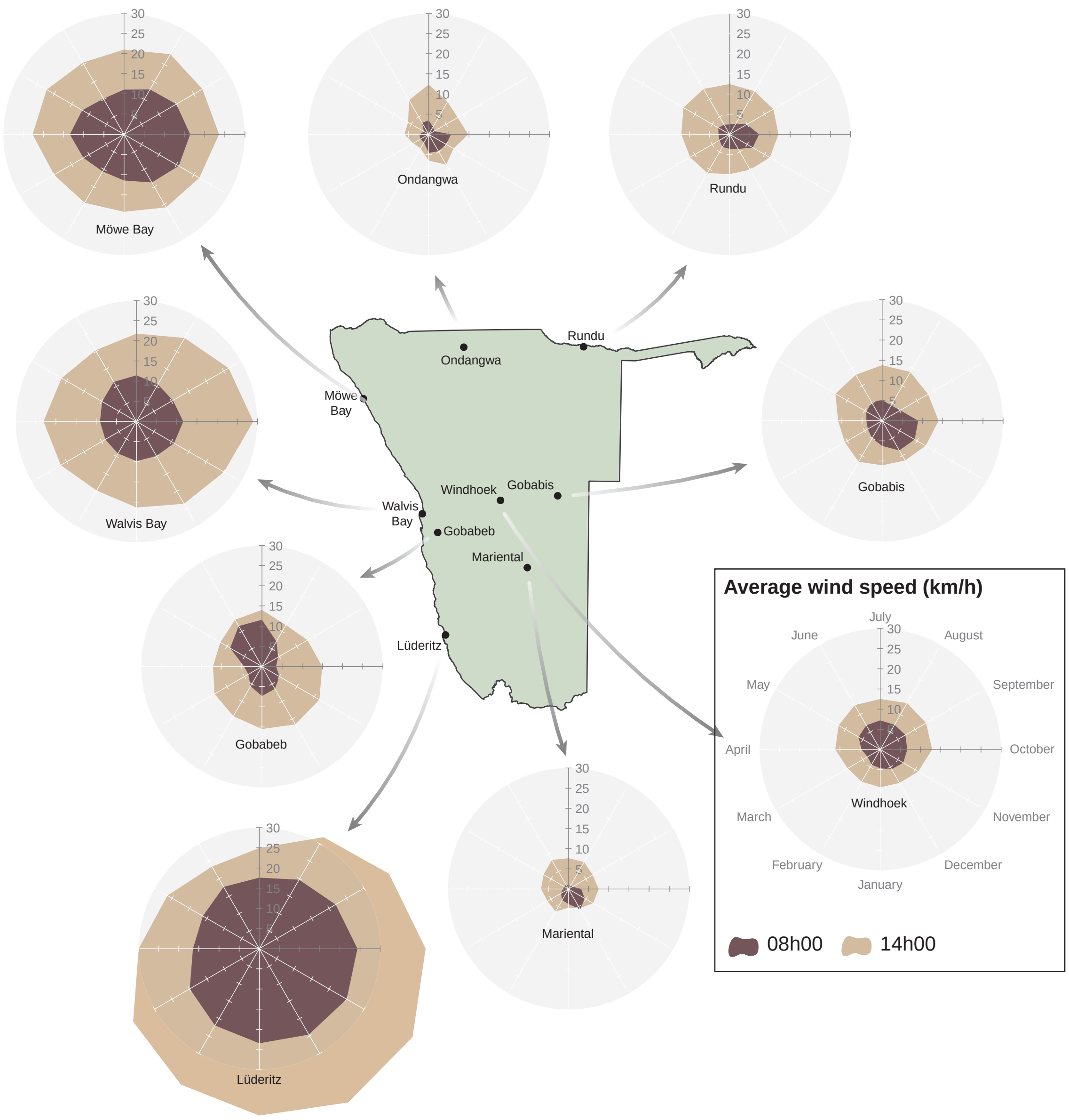
Coastal residents are also only too familiar with fiery blasts of air in the winter months. Namibians call them East Winds (or sometimes Berg Winds); the winds are particularly strong and hot. These winds from the east descend over the escarpment, and pick up and carry large quantities of sand over and into the Atlantic Ocean (B). [22.65° S, 13.82° E]

Inland, easterly winds are normally mild, and have evidently been prevalent for many thousands, perhaps millions, of years during which they have moulded landscapes in surprising ways. For example, during long arid periods easterly winds have blown alluvial sands out of drainage courses such as the then-dry Kwando and Okavango rivers and Omatako Omuramba (C) to form the parallel vegetated dunes that we see across large parts of northern Namibia today (page 41). [18.96° S, 19.58° E]

More locally, easterly winds have scoured alluvial silts from ancient channels and pans in central-northern Namibia and deposited them just west of the channels where they slowly mix with sand to form the most fertile soils in the area. As a result, people settle and farm crops along the western margins of these old watercourses and pans, where each smallholding is visible as a pale clearing in the surrounding woodland (D). [17.49° S 16.95° E]

The easterly and westerly winds in contest with the southerly winds continue to mould the mobile dunes of the Namib, resulting in the multifaceted star dunes found around Sossusvlei (E) and elsewhere in the eastern Namib Sand Sea. [24.72° S, 15.51° E]

Southern Africa's largest dune field stretches 850 kilometres from north to south and up to 200 kilometres from east to west across much of southeastern Namibia and into Botswana and South Africa. These linear dunes, with a northwest–southeast alignment, were formed during two phases 28,000 and 17,000 years ago by a more intense but similar wind regime to that which occurs there today (F). [23.72° S, 18.81° E]



3.05 Monthly wind speeds at 08h00 and 14h00[10]

As with seasonal effects on wind intensity, temperature gradients also influence prevailing wind speeds during the day with stronger winds experienced in the afternoon compared with the morning and evening. At night the land surface cools and so too the air above it; there is consequently less vertical air movement and mixing of air. As the land heats up during the day there is much more vertical air movement and mixing of air layers. At the coast, the rapid heating of the land surface (after the fog has dissipated) during the day results in pressure differences between the warm air over the land (low pressure) and the cool maritime air (high pressure) over the sea. This results in very strong coastal winds with Lüderitz having average wind speeds of over 40 kilometres per hour on summer afternoons. By contrast, wind speeds over the interior of the country are much more moderate.

The strong winds at the coast, particularly in the southern parts attract the attention of wind surfers and kite surfers in search of an adrenalin rush. Winners of the annual Speed Challenge at Lüderitz commonly record speeds in excess of 90 kilometres per hour.

Fog

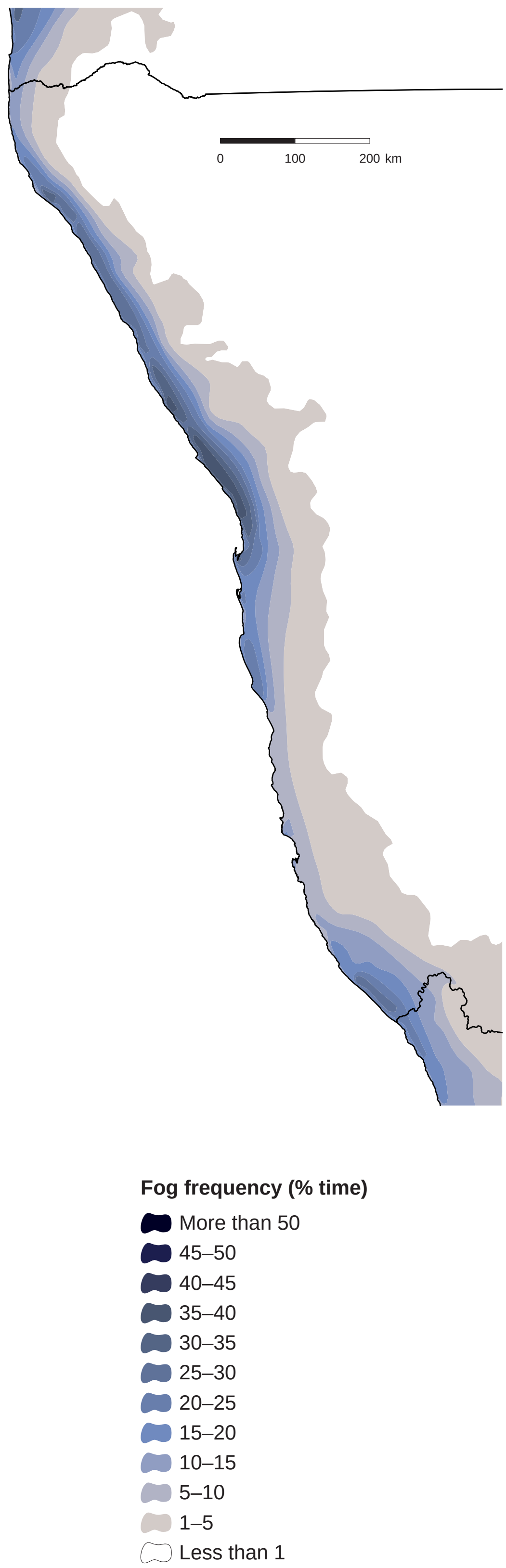
3.06 Annual and monthly frequency of fog and low cloud in the Namib Desert[11]

Fog defines much of the Namib Desert's climate. It occurs during all months of the year in a band along the coast that may extend more than 100 kilometres inland. The maps here, derived from satellite and ground data, illustrate the average frequency of fog and low cloud along the entire Namibian coast over the year and from month to month. Inland fog or low cloud occurs most frequently in the spring and summer months between September and March. Seasonal changes in airflow (figure 3.01) likely drive this pattern.

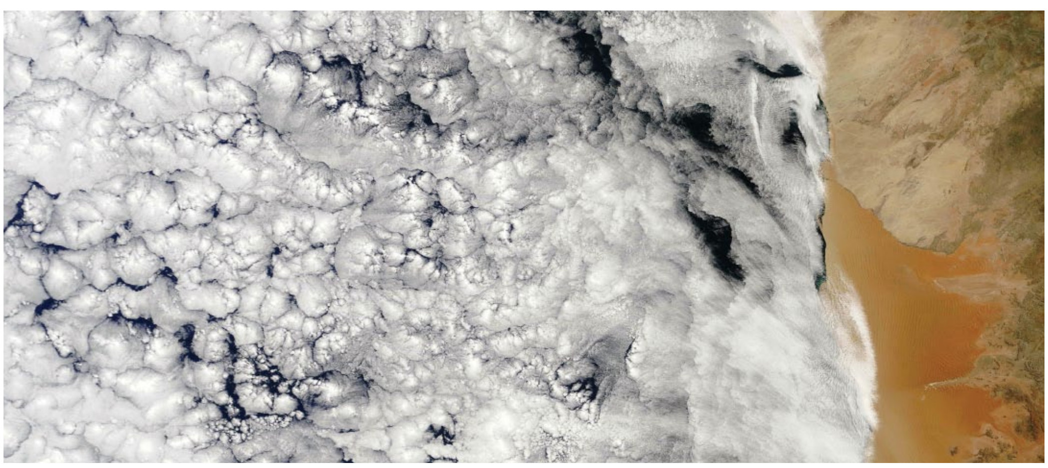
The central area of the coast experiences the highest frequency of fog, with a third of the days in each year having some fog. Ground-based measurements at the coast suggest that, here, fog peaks in winter, between April and August.[12]

While the satellites detect the presence of all low cloud, the distinction between fog and cloud is often difficult. The height of the cloud base increases between August and March, and much of the cloud at the coast at this time (which is evident in the maps) would not be recorded as fog at ground level.

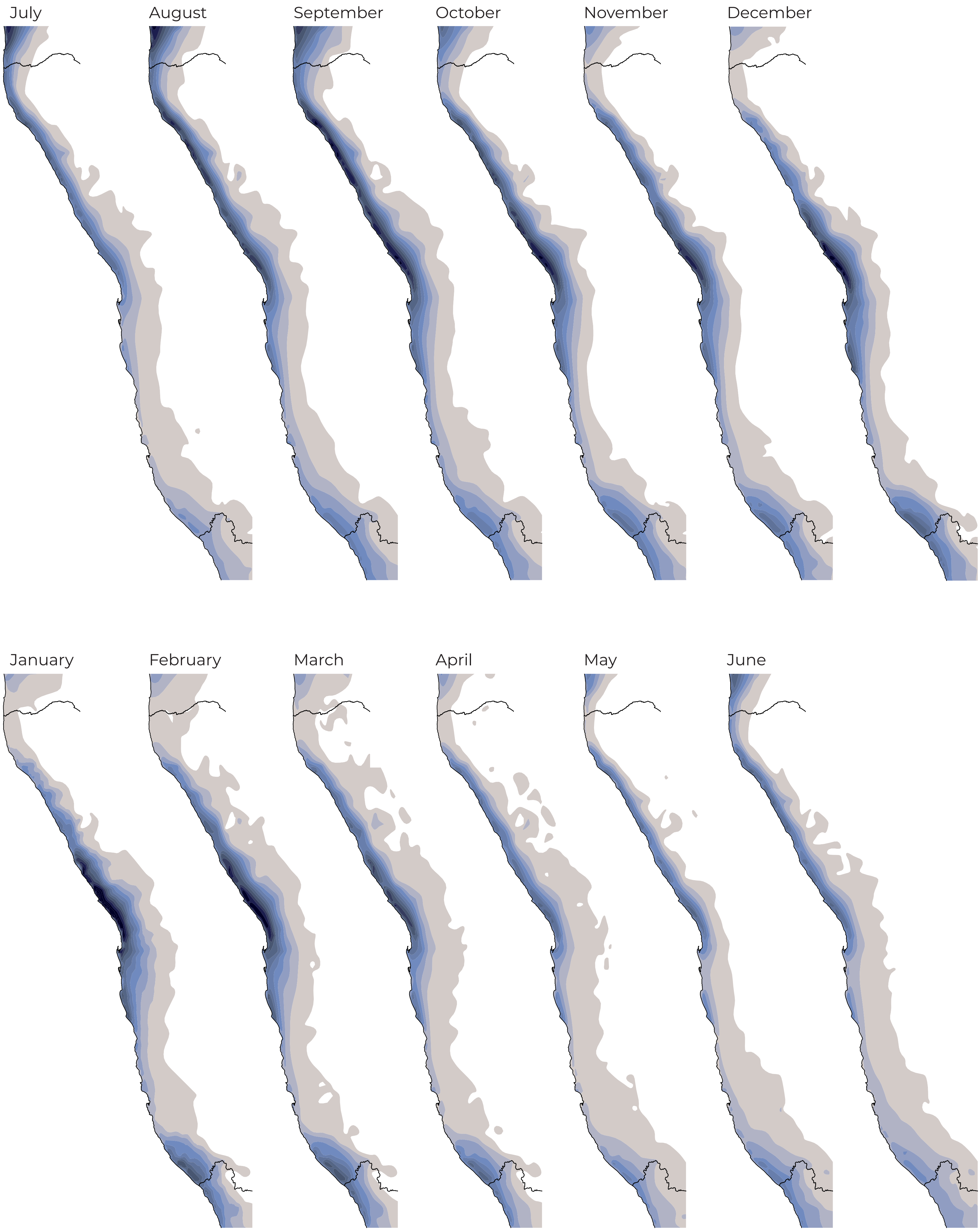
Annual average



The presence of fog enables many of the plants and animals in the Namib to survive, despite the lack of rain. In some areas, fog can also play an important role in soil water dynamics.[13] Research has shown that on average 3.5–5.0 litres of water per day can be harvested from fog on a square-metre collecting surface.[14] Many plants and at least 48 animal species are known to use free water from fog – for example, by channelling water to their roots (plants) or drinking condensed water droplets (animals) – but only a few animals, such as this tenebrionid beetle, actively harvest fog; it stands with its abdomen facing the fog, which allows droplets to condense on its body and run down to its mouth.[15]



Fog in the Namib is often associated with extensive marine stratus clouds. These are low-level clouds (below a few hundred metres) that typically form during the night and dissipate during the day. The clouds form when moist air, trapped by a layer of sinking air produced by the South Atlantic Anticyclone, is cooled by the low sea surface temperatures and becomes saturated. In situations where stratus clouds extend over land, the altitude of the clouds and the local topography determine whether fog occurs at the ground or not. It is still an open question as to how much of the water in the fog is from marine sources and how much comes from condensation over the cool night-time desert.


July
August
September
October
November
December
January
February
March
April
May
June

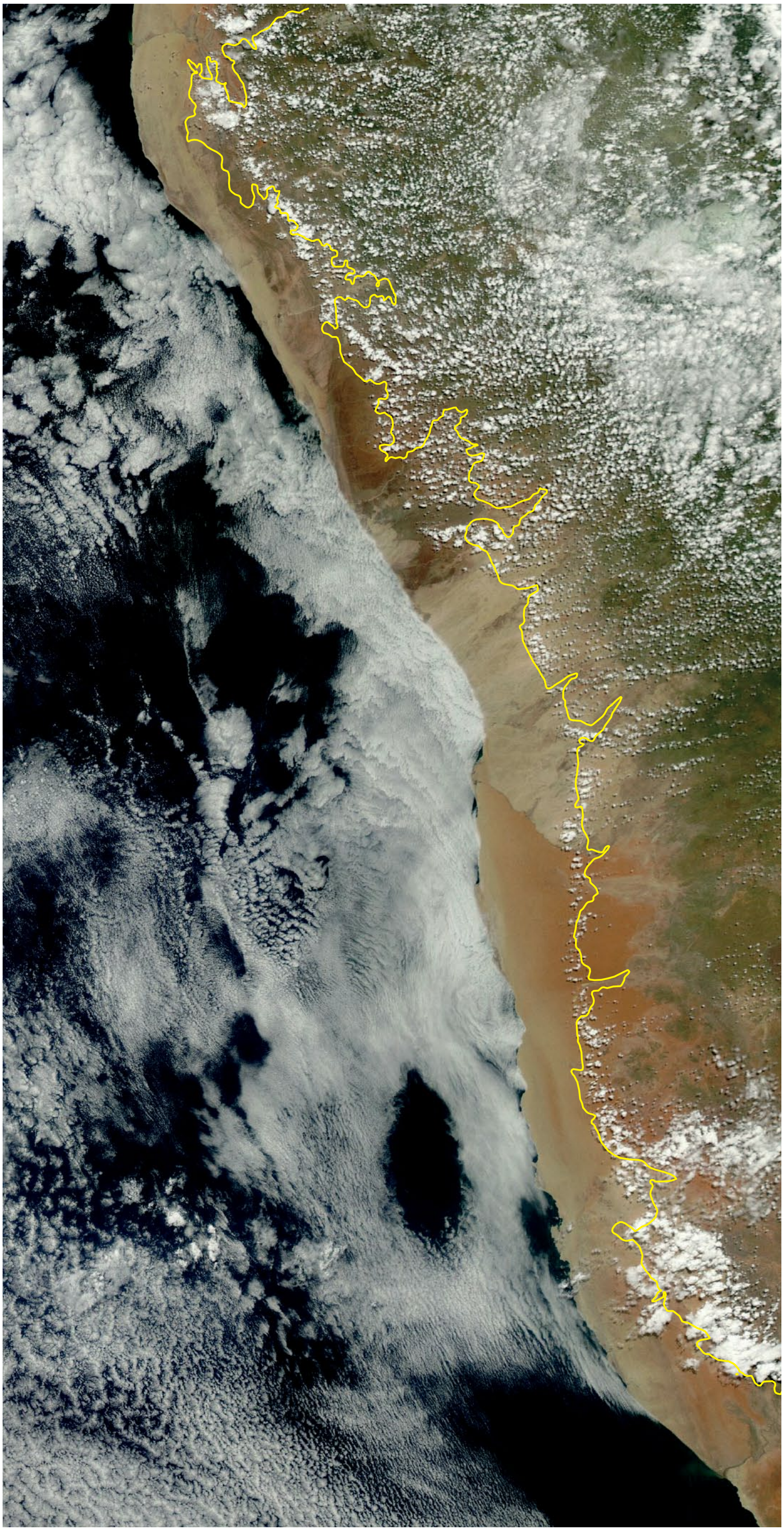
The infamous Namib Desert

The Namib is a true dry desert formed by the combined effects of at least three climatic processes:

First, the cold Benguela Current, which cools the maritime air as it blows across the ocean and then inland, inhibits the formation of rain along the entire coastal belt. 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 unable to rise, cool and condense into rain droplets, and often remains suspended in the air as fog during the evening and morning.

Second, the moist tropical air that is drawn in with the seasonal southward progression of the Intertropical Convergence Zone precipitates first in the north and east, and then in the central parts of Namibia leaving less and less water available to fall as rain across the southern and western areas of the country.

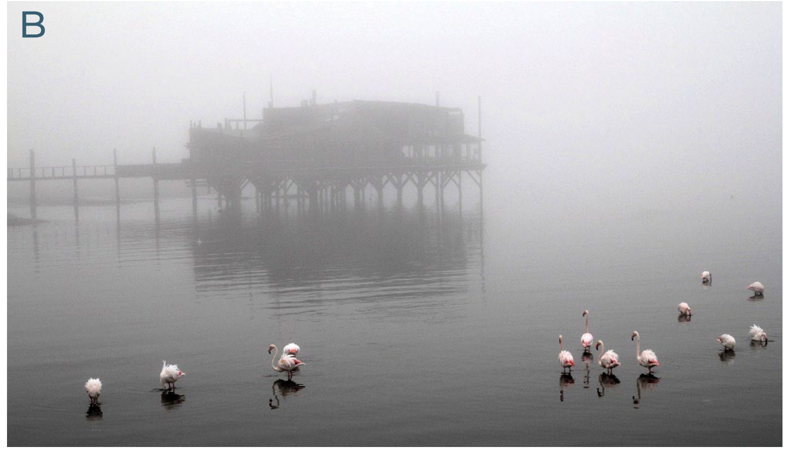
Third, the escarpment drops sharply down to the coastal plain (figures 2.07 and 2.08). Any moist air approaching from the eastern interior warms as it drops down over the escarpment, causing any moisture to evaporate. On the day this MODIS image was taken, most of the moisture evaporated at the point where land elevation dropped below 700 metres above sea level, marked by the yellow contour line. East of this line, the moisture is visible as clouds; west of the line, there are no clouds.



Some features of the Namib Desert (opposite page):

- A Desert plains and flat-topped mountains are iconic to the Etendeka Tablelands (page 14) of northwestern Namibia.
- B Fog shrouds the lagoon at Walvis Bay.
- C Sossusvlei dunes rise above the fog, a rare occurrence so far east.
- D The sand sea meets the ocean at Conception Bay.
- E A nutritious melon of the Namib's !nara plant is highly sought after, in spite of its thorny features (page 192).
- F Sandy plains at Puros Conservancy harbour seeds that will take advantage of rain when it comes.
- G Extensive plains of gravels have been exposed where winds have blown away the finer sands.
- H One of many succulent plant species that is adapted to survive the Namib, *Hartmanthus pergamentaceus*.
- I The iconic *Welwitschia mirabilis*, like many desert plants, provides a refuge for insects, birds and small mammals in the central Namib.
- J This lichen, photographed at Cape Cross, is a symbiotic relationship between an alga and fungus; a variety of lichens occur in several discrete areas or 'lichen fields' in the central Namib Desert.
- K The coastal desert town of Swakopmund is one of few hubs in the Namib's vast, arid wilderness.


A


B


C


D


E


F


G


H

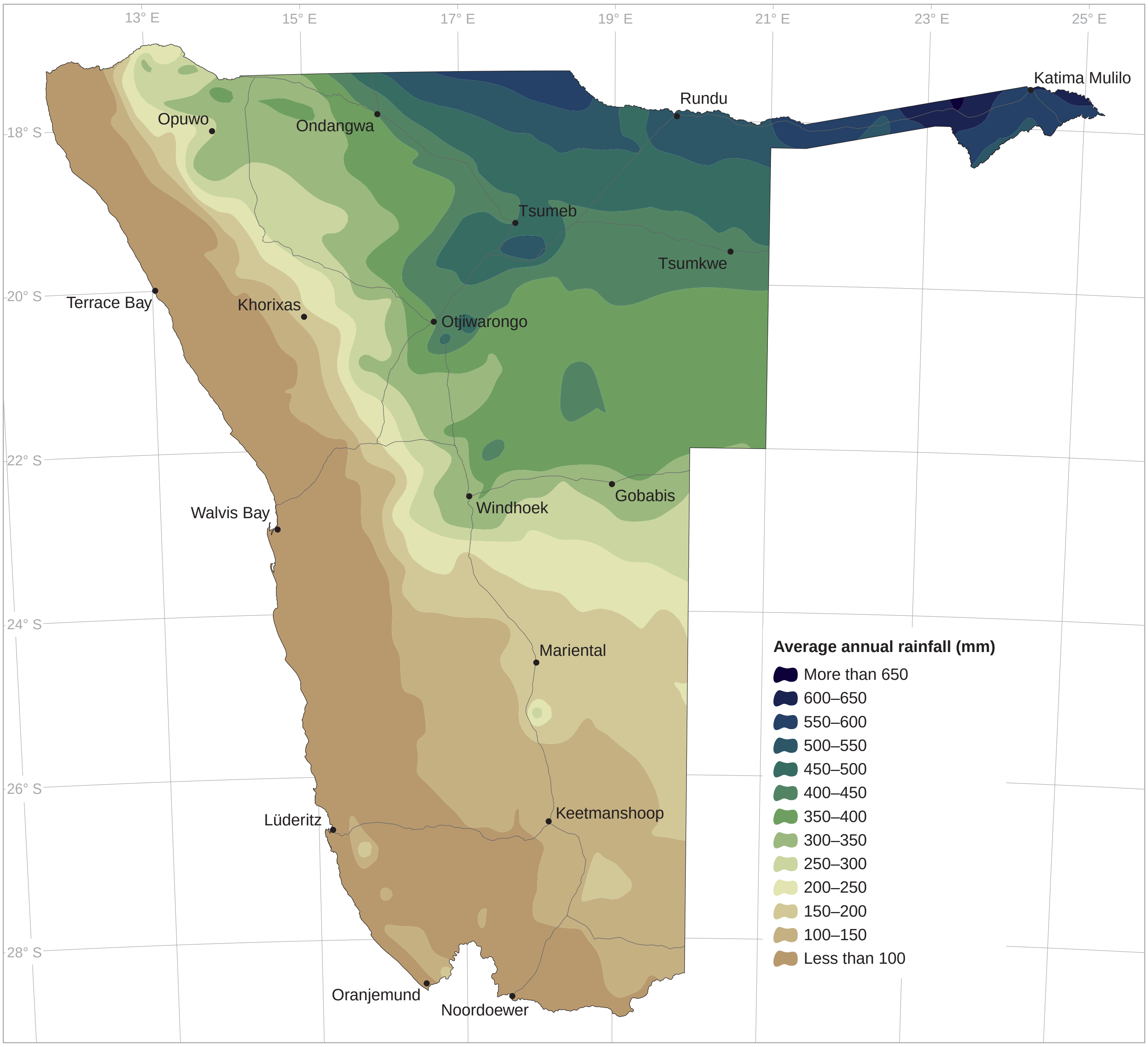

I


J


K

Rainfall patterns

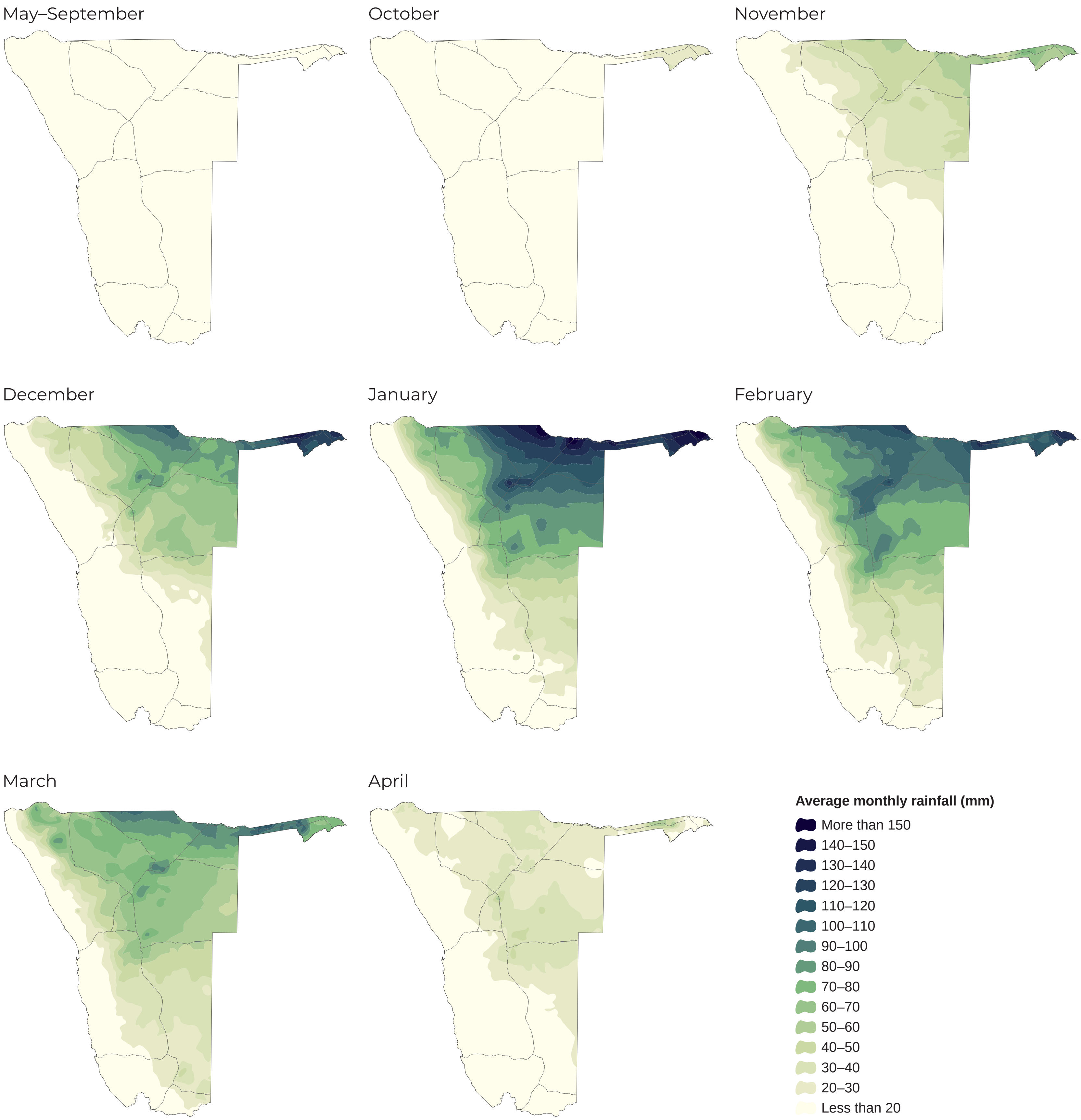
In a country as arid as Namibia, rainfall is the single most important factor in sustaining life and livelihoods. It varies dramatically seasonally, annually and geographically. Each year's falls are essential for replenishing Namibia's limited freshwater supplies, supporting natural vegetation, and determining the yields of crops and the success of domestic and wild animals in breeding and rearing their young.



3.07 Annual rainfall (left) and monthly rainfall (right)[16]

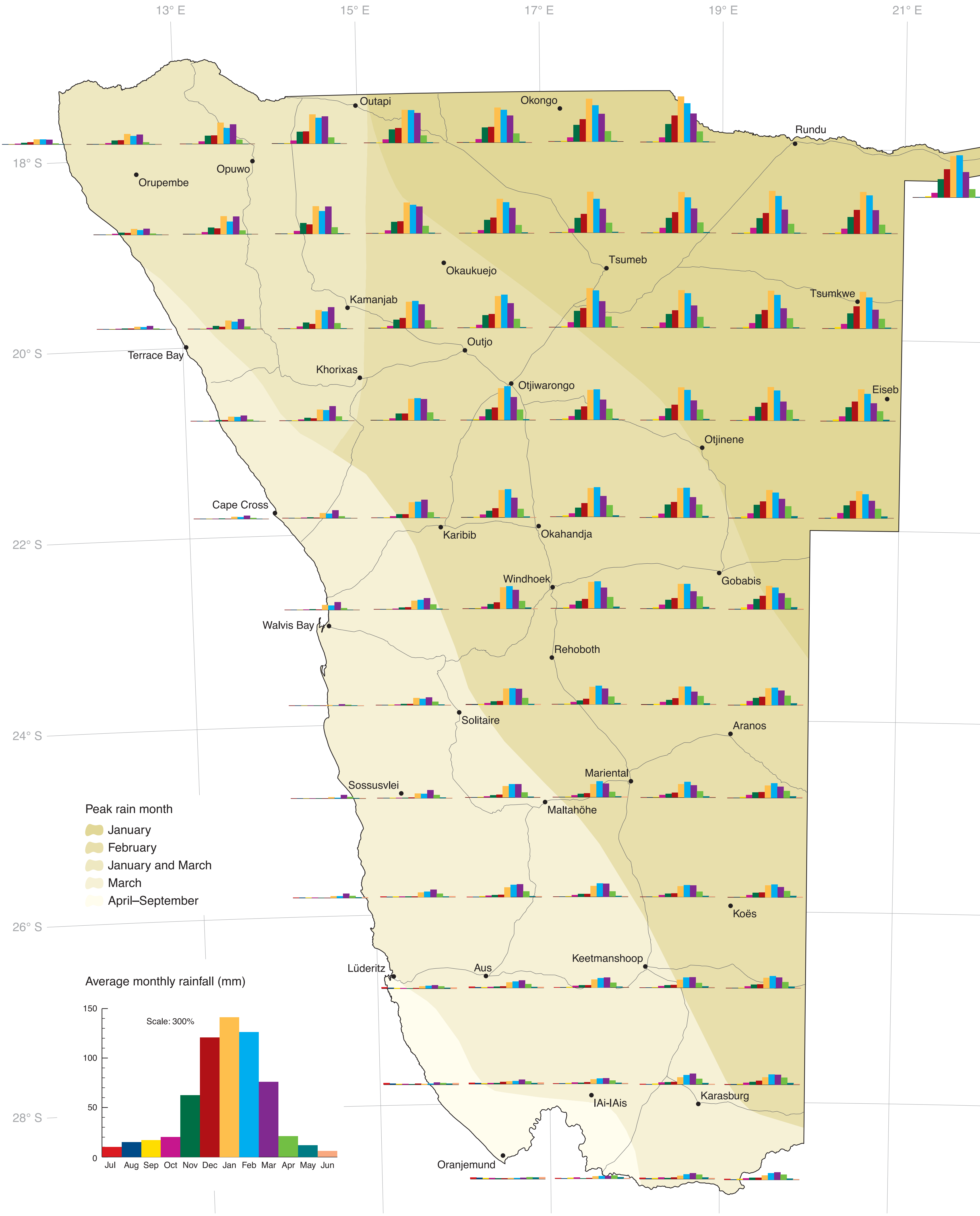
Average annual rainfall (above) is calculated for the rainfall season, from the beginning of July of one year to the end of June in the following year. Along the coast and for some way inland rainfall is extremely low and highly variable (figure 3.10). Average rainfall within 40 kilometres of the coast is less than 20 millimetres per year, and most of this typically falls for short periods on only a few rainy days. By contrast, the northeastern areas of Namibia receive on average falls of more than 650 millimetres a year.

The great majority of rain in Namibia results from convective processes whereby heat causes moist air to rise, cool, condense and form dense cumulus clouds. Some inland areas, such as those around Otavi, Tsumeb and Grootfontein, have slightly higher rainfall than their surrounding areas due to orographic rainfall, which results from moist air being forced up over hills or mountains and cooled. Slightly higher patches of rainfall in the far southwest are the result of frontal rain received during the winter months when substantial cold fronts farther south reach into Namibia (figure 3.01).



With the exception of the southwest, rainfall in Namibia is strongly seasonal. As the maps of average monthly rainfall show, from October to February rainfall gradually increases across the country from the east and north, retreating again during March and April.

But what makes Namibia so dry in-between times? As the Intertropical Convergence Zone shifts south in summer, the South Atlantic Anticyclone and Botswana Anticyclone push south, where their impact on Namibia's weather is limited (figure 3.01). However, they dominate weather in winter when they resume their northerly positions west and east of the country. Air descends in the anticyclones, drying as it subsides and spreads across Namibia and the rest of southern Africa. With the warm tropical air effectively blocked, the prevailing anticyclonic conditions produce clear, cloudless skies day after day between May and September.


13° E
15° E
17° E
19° E
21° E
18° S
20° S
22° S
24° S
26° S
28° S
Outapi
Okongo
Rundu
Opuwo
Orupembe
Okaukuejo
Tsumeb
Tsumkwe
Kamanjab
Outjo
Terrace Bay
Khorixas
Otjiwarongo
Eiseb
Otjinene
Cape Cross
Karibib
Okahandja
Windhoek
Gobabis
Walvis Bay
Rehoboth
Solitaire
Aranos
Sossusvlei
Mariental
Maltahöhe
Koës
Lüderitz
Aus
Keetmanshoop
IAi-IAis
Karasburg
Oranjemund
Peak rain month
January
February
January and March
March
April–September
Average monthly rainfall (mm)
Scale: 300%
150
100
50
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
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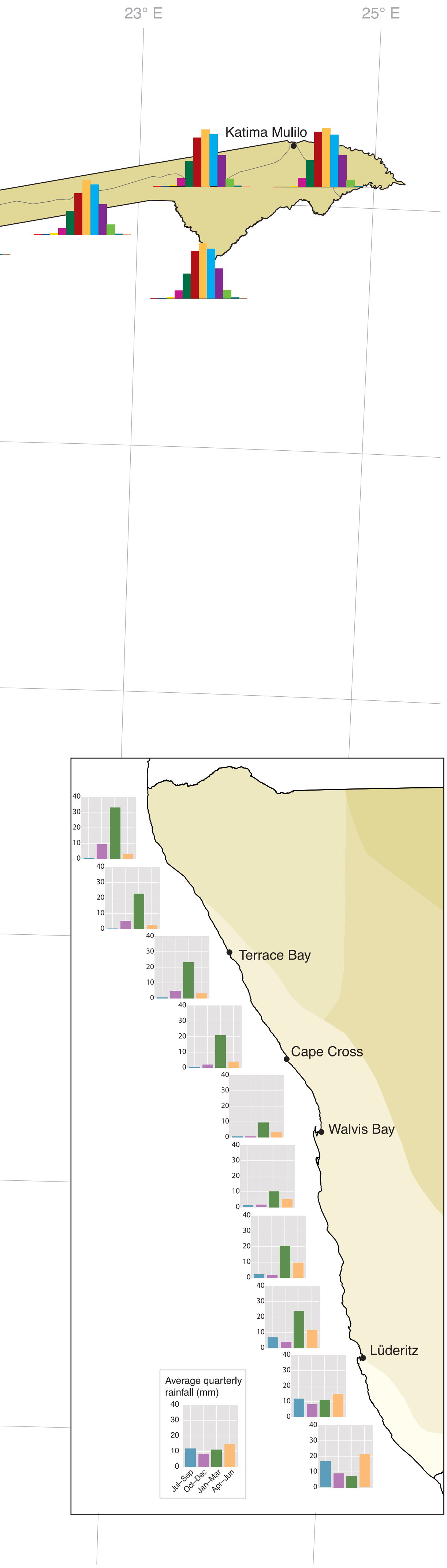
Mar
Apr
May
Jun



3.08 Monthly rainfall in detail[17]

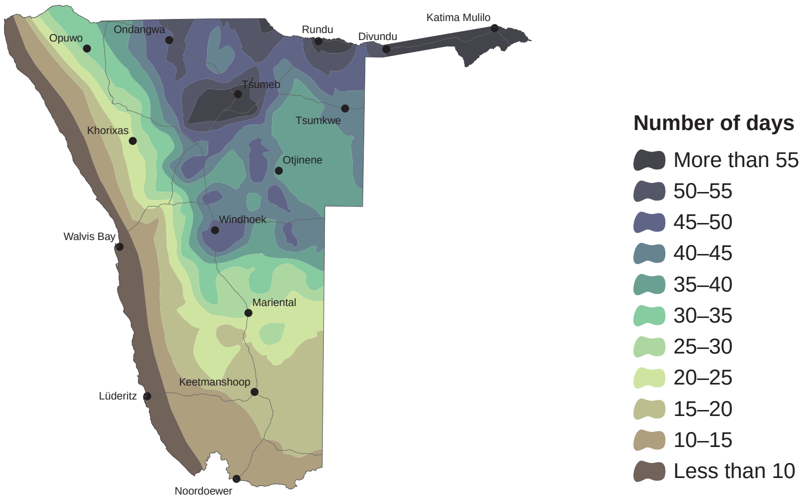
The maps in figure 3.07 provide an overview of rainfall patterns throughout the summer rainy season. This more detailed breakdown highlights east–west and north–south differences in the distribution of rain. Each graph shows the average rainfall per month in each degree square of latitude and longitude.

For most areas in Namibia, almost all rain falls in spring and summer between September and April. The only exception is in the southwest which lies in the winter temperate rainfall belt; here, monthly totals are similar throughout the year.

Within the summer rainfall area there is a clear trend linked to the movement of moist air. In the northeast rains start earlier, and peak months are December to February. Rain starts later in the south and west, with peak months from January onwards. On average, February and March are the months with the highest falls over the southern and western thirds of Namibia.

Along the entire coast, rainfall is generally very low. However, there are significant differences in the seasonal spread of rainfall between the southern and northern coast, as shown in the inset map. In the extreme southern areas, precipitation in winter sustains the Succulent Karoo vegetation (figures 6.01–6.03), which results in amazing desert blooms in August or September. Moving northwards up the coast, the chance of winter rainfall decreases while that of summer rainfall increases with highest summer averages in the far north which receives incursions of moist tropical air from Angola.

West of the escarpment, average rainfall figures are not terribly meaningful. Years may go by without a drop of rain. But, indigenous flora and fauna take advantage of a once-in-a-long-while good rainfall or a good season that transforms the landscape. Here and elsewhere, these first rains trigger the emergence and activity of invertebrates such as red velvet mites (top left) and dung beetles (top right). The Succulent Karoo stretches from the Sperrgebiet in Namibia down the west coast of South Africa (figure 6.01). Although rainfall in this biome is very low, it can receive moisture all year round (figure 3.08). In spring, blooming wild flowers dress the landscape in a sea of colour (bottom).

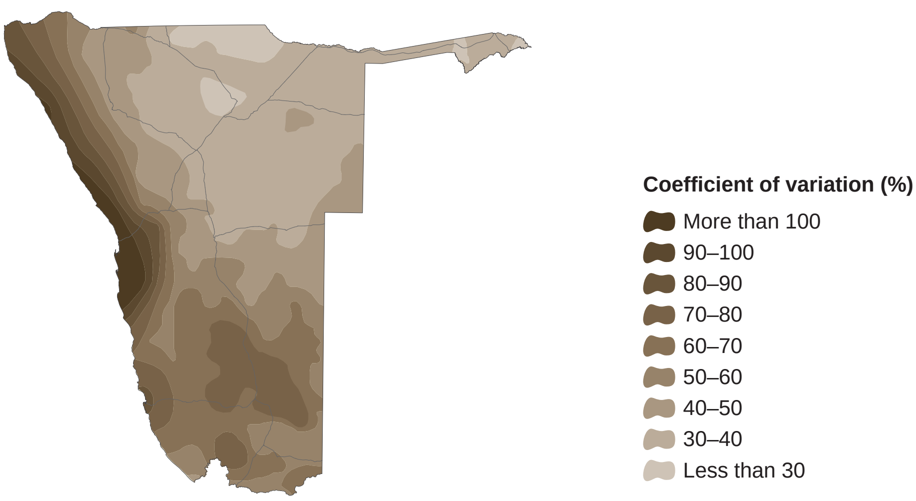


A rainstorm gathers over the Fish River Canyon in December 2010. This part of the country receives rain on only a handful of days each year. Within hours after a downpour shoots of green growth appear in what was previously a barren landscape.

3.09 Number of days per year with 1 millimetre of rainfall or more[18]

How does the limited rain in the western parts of Namibia fall – in light showers over many days or in heavier falls on just a few days? Taking a cut-off of 1 millimetre to exclude minor rainfall events, this map shows that the average frequency of rainy days rapidly increases eastwards of the coast. The coastal towns have significant rain on fewer than seven days per season on average while this increases to about 64 rain days at Katima Mulilo. Opuwo, on the escarpment, receives an average rainfall of 285 millimetres which falls over 33 rain days on average.

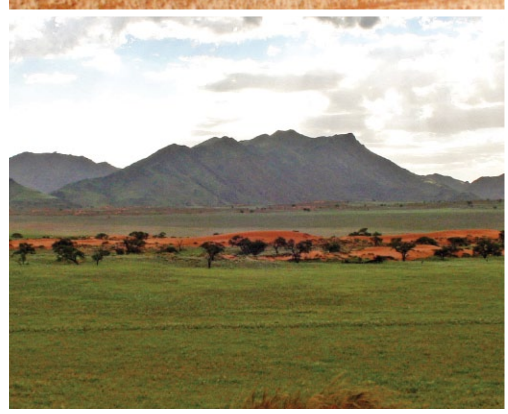
Interestingly, Ondangwa in northern Oshana Region receives 175 millimetres less rain on average than Divundu in Kavango East, but its number of significant rain days is similar (50 and 55, respectively). This suggests that the intensity and/or duration of rainfall events increases eastwards in northern Namibia. In general, the pattern of this map mirrors that of annual rainfall (figure 3.07). The higher frequency of rain days in some areas reflects the increase in rainfall caused by local relief, such as around Otavi–Tsumeb–Grootfontein (Otavi Mountains), Windhoek (Auas Mountains) and west of Otjinene (Waterberg area).



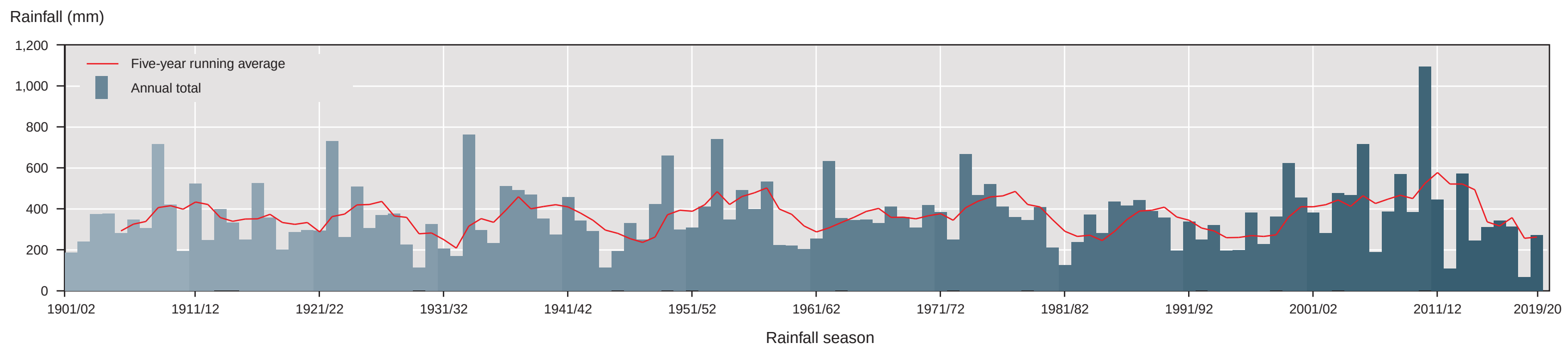
3.10 Variation in annual rainfall[19]

With the decline in rainfall from east to west, the frequency of rainfall events becomes more sporadic. This is reflected in the increasing degree of variability in annual rainfall compared to the long-term average, and is expressed as the coefficient of variation. As variability increases, rain-fed cultivation and other land-use practices become more marginal and risk increases.

In Namibia's far western areas where variability is greatest, rainfalls may be brief but intense and cause disruption to coastal towns. For example, the long-term average annual rainfall at Lüderitz is just 16 millimetres but, in April 2006, 102 millimetres fell on the town over a three-day period. Such events are rare, irregular and are not expected to occur more than once in a century.[20]



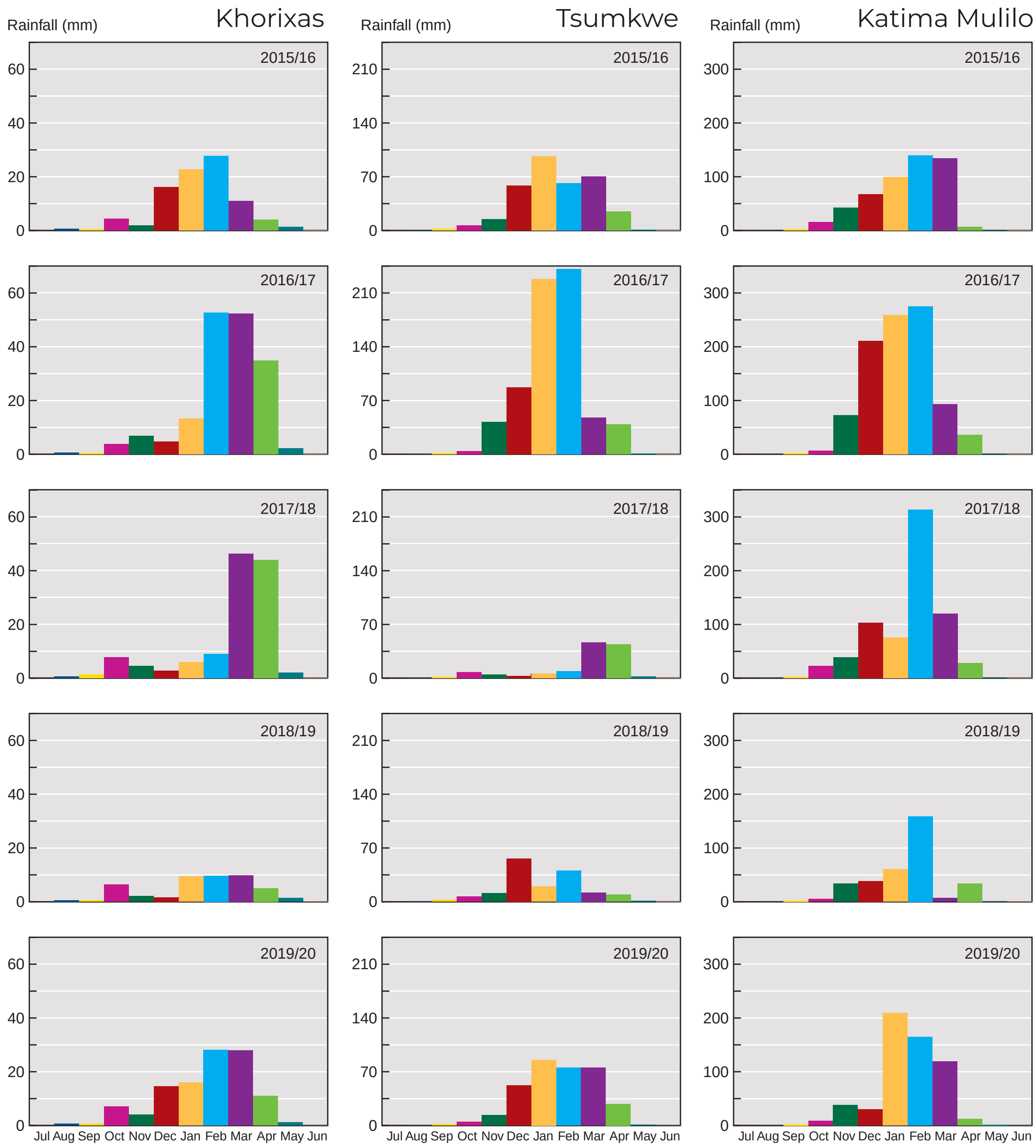
The NamibRand Nature Reserve south of the Naukluft Mountains most commonly looks like the image taken in December 2000 (top). The eastern margin of the reserve normally receives around 100 millimetres of rainfall; about twice as much fell in the 2010/11 rain season, transforming the landscape (bottom).

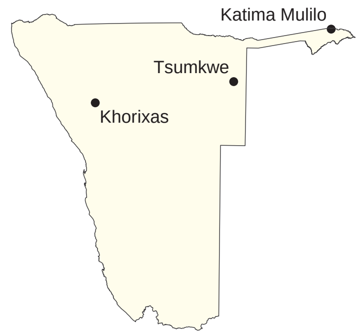


3.11 Windhoek's annual rainfall, 1901/02–2019/20[21]

The amount of rain that falls in one place in Namibia differs each and every year; in the best seasons it can be several times higher than rainfall in the worst seasons. In this series of total annual rainfall for 120 years, the five-year running average highlights the cyclical nature of longer-term changes. Troughs of low rainfall occur roughly every 14–15 years. While each cycle has had its highs and lows, it is the most recent cycle that has been the most variable, and is perhaps linked to the rapid change in climate over recent years (figure 3.23).

Global weather patterns influence rainfall variability between seasons, and extended dry periods are associated with well-known El Niño phases. These have their origins in the Pacific Ocean and are related to changes in sea surface temperature and atmospheric pressure. In general, lower falls are received in Namibia during El Niño years and higher falls during La Niña years (page 73).

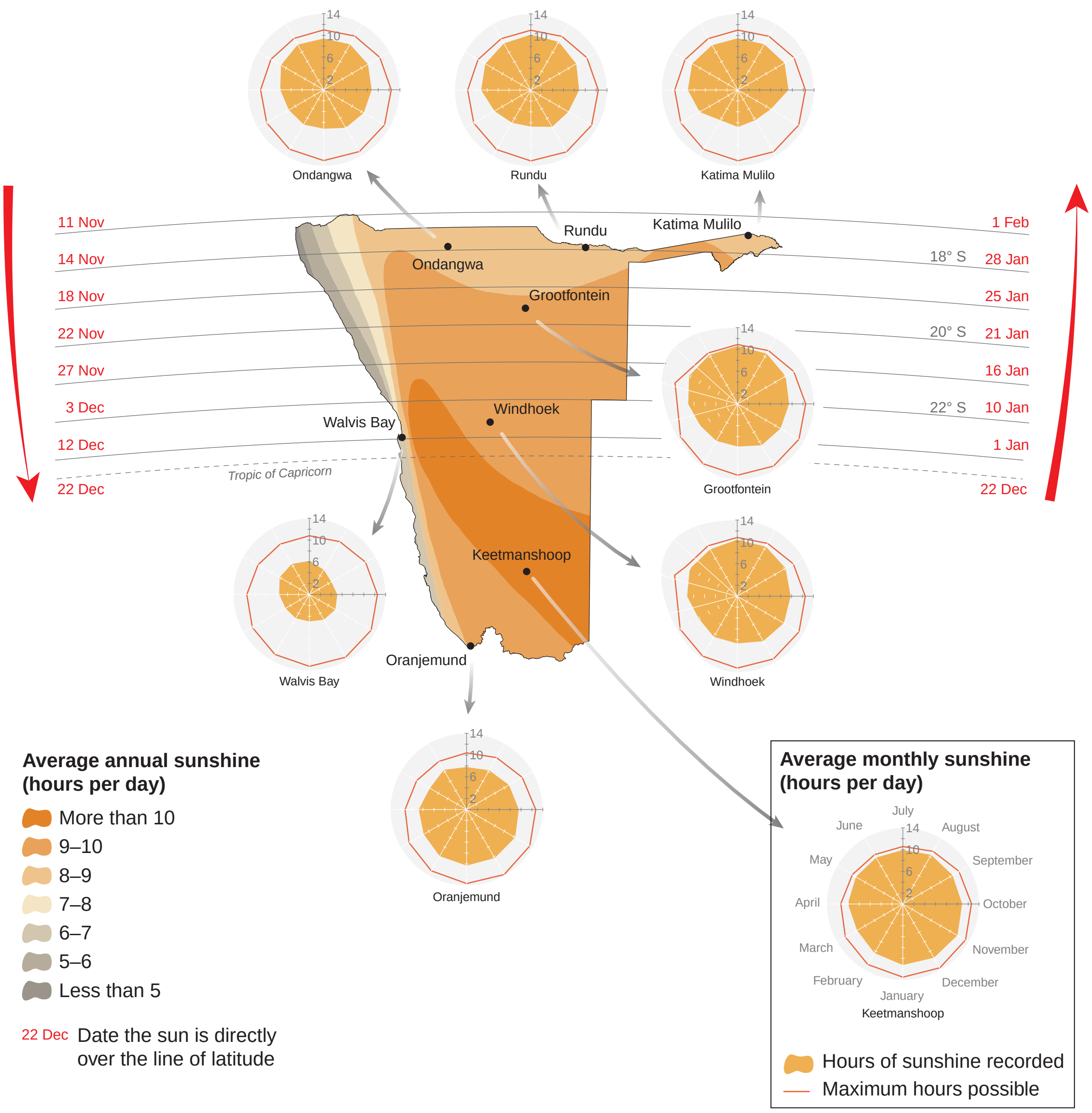




3.12 Monthly rainfall totals at three locations, 2015/16–2019/20[22]

Rainfall from one season to the next is erratic. This holds true for most places in Namibia and is illustrated in these graphs of monthly rainfall over five consecutive seasons from 2015/16–2019/20 at Khorixas, Tsumkwe and Katima Mulilo. They show a high degree of variation in the amounts of rainfall received each month, in the spread of rainfall over the seasons and in the peak rain months each season. Successful crop farming requires some stability in the timing and consistency of rainfall events, and the inherent variability of rainfall in Namibia often leads to crop failures, or makes dryland cropping impractical.

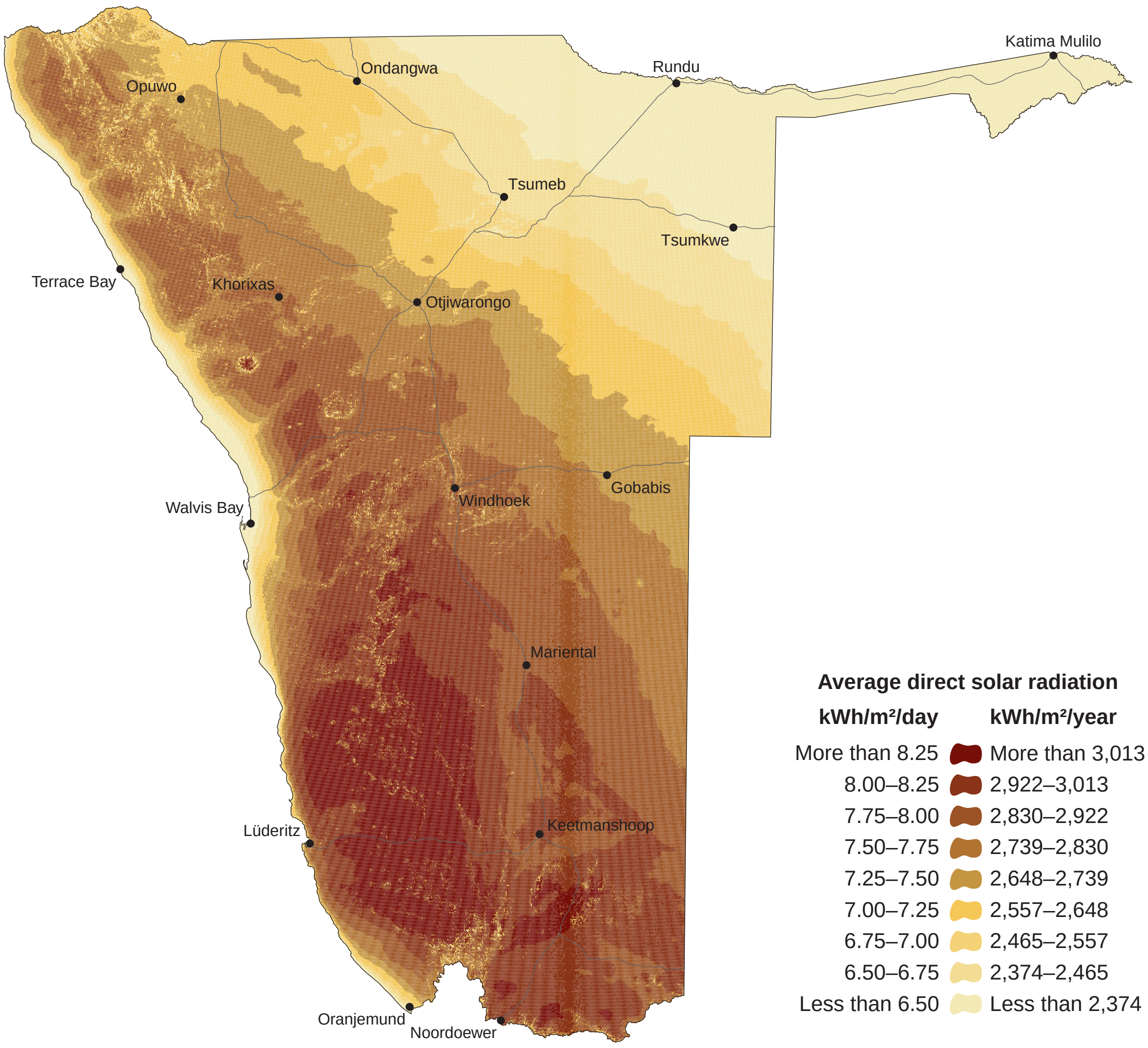
Sunshine hours and radiation



3.13 Number of sunshine hours per day[23]

The radial charts show the average number of sunshine hours each month at various locations as well as the maximum amount of sunshine possible. The predominance of fog and low cloud along the coastal belt limits sunshine along the coast. Averages of only 5–7 hours of sun are seen per day in the central coastal areas around Walvis Bay compared to 8–10 at Windhoek. During the rainy season, cloud cover limits the amount of sunshine received and this is evident by the decrease in sunshine hours during the rainfall months (October–April) in the northern and northeastern parts of the country. The southern central areas of Namibia see the most sunshine. Here, the days are the longest (in summer), cloud cover is rare and there is no fog. Along the central coast the amount of sunshine received increases slightly during the winter months when East Winds help clear away cloud and fog, but for the rest of the year the average daily duration of sunshine varies little.

The map shows the average number of sunshine hours over all months of the year. It also shows how the position of the sun shifts during the year by indicating the latitude at which the sun is positioned directly overhead at midday. This point gradually moves south in summer until Midsummer's Day on 22 December – the longest day of the year – when it is positioned directly over the Tropic of Capricorn, just south of Rehoboth. This point then retreats northwards again with the seasonal progression into the longer nights of autumn and winter. These seasonal changes are due to the orbiting of the tilted earth around the sun because in summer more of the southern hemisphere faces the sun, while in winter more of the northern hemisphere faces it. This causes day length to vary by several hours between the shortest and longest days. For instance, there is a difference of approximately two hours in day length between June and December at Ondangwa, while at Keetmanshoop the difference in day length is about 3.5 hours.



3.14 Average solar irradiance, 2005–2015[24]

Solar power – or solar irradiance – is the amount of the sun's electromagnetic energy falling onto the surface of the earth. This is usually measured in the number of kilowatt-hours per square metre per day, or per year.

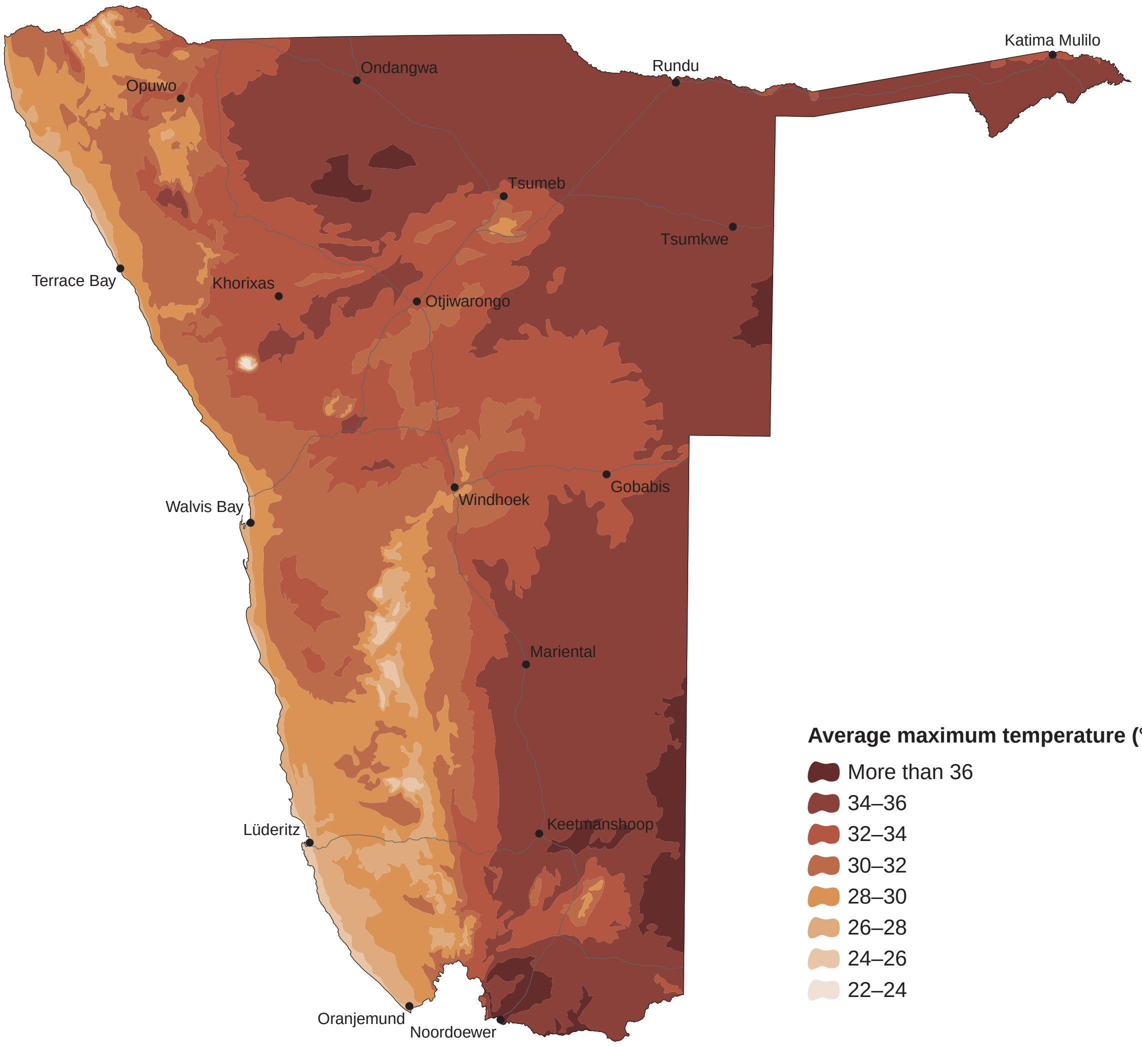
Several factors influence how much energy from the sun reaches the surface. First, atmospheric conditions such as cloud cover, dust and pollutants obscure the sun's direct rays. Second, is the effect of latitude. At places farther north or south of the equator the sunlight is angled increasingly more obliquely relative to the earth, so that solar radiation reaching its surface is spread diffusely across a greater area, and it has to pass through thicker layers of the atmosphere. Third, the seasons affect day length, which determines the number of hours the sun's rays hit the earth (see 3.13). Fourth, topography influences how shaded or exposed an area is to the sun.

This map shows the average amount of solar radiation received both directly and diffusely from the sun – known as global horizontal irradiance – across Namibia. This measure is important in the assessment of solar power potential for electricity generation (page 347). What is most noticeable in this map is the general inverse relationship between irradiance and rainfall (figure 3.07). The arid southern and western parts of the country, which have little cloud cover for much of the year, receive more solar radiation. Close to the coast, however, irradiance decreases sharply as the land surface is often shielded by fog and low cloud.

Temperature

Namibia is generally considered to be a hot country. However, average temperatures are surprisingly moderate because hot weather is balanced by cold periods in winter, low night-time temperatures even in summer, and by fog and low cloud along the coastal belt. The diurnal and seasonal changes in temperature (considered first below) are the result of variations in sunshine and radiation, vegetation cover, altitude, cloud cover, fog and humidity.

Adapted to widely ranging diurnal temperatures, these springbok huddle under the shade of a lone tree in an attempt to find some relief from the midday heat. Temperatures can reach the mid-forties in some areas in summer; the heat is accentuated by sharp reflection off sparsely vegetated pale soils and dry, dusty air.



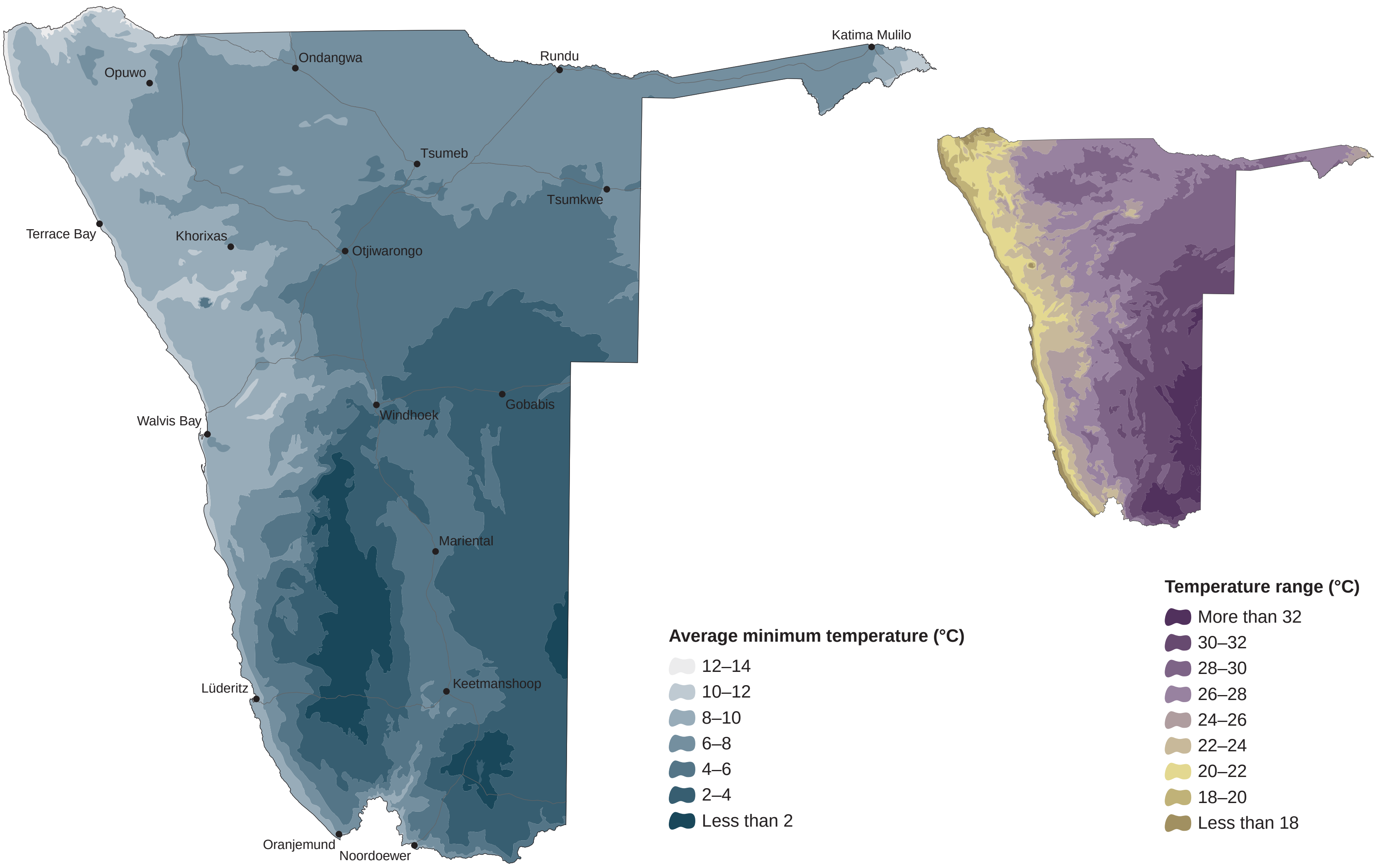
3.15 Maximum and minimum temperatures, and annual temperature range[25]

Average maximum temperatures (the average of all monthly maximum temperatures over a selected time period) during the hottest months are generally above 30 degrees Celsius everywhere east of the escarpment. The central highlands around Windhoek are slightly cooler while temperatures in the coastal belt are moderated by the presence of fog and low cloud. Some of the hottest parts of the country are in the far south and southeast where average maximum temperatures are in excess of 36 degrees Celsius. In the central and northern coastal areas, the highest average maximum temperatures are not experienced in summer, as might be expected, but during the winter months (see the monthly charts in figure 3.16). This is when warm East Winds sweep over the escarpment, becoming hotter as they drop down towards the coast (figure 3.04).

July is the coolest month over much of the country. Average minimum

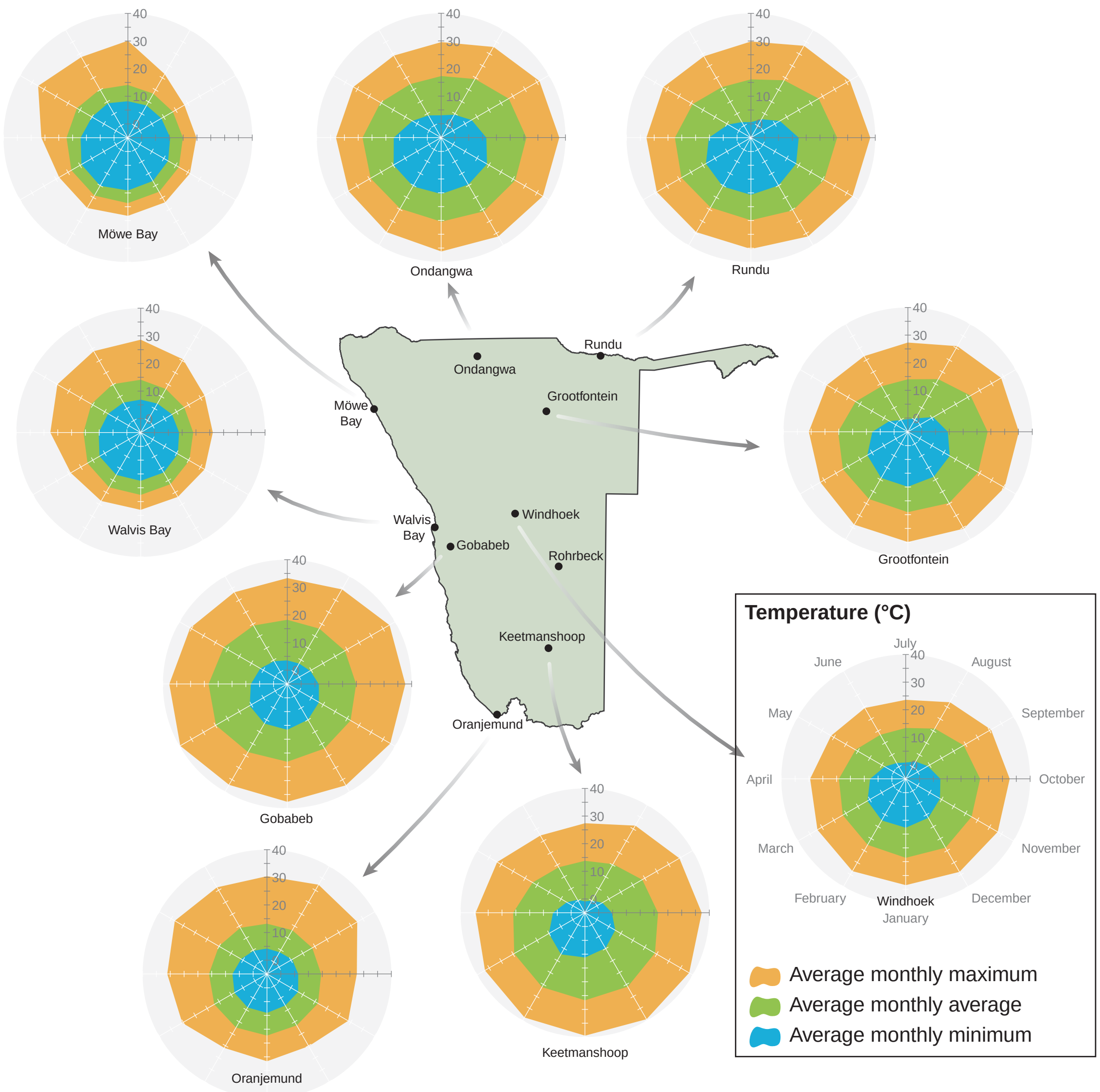


Some of the lowest monthly temperatures have been recorded in the south of the country (figure 3.16) which experiences the greatest range between maximum and minimum temperatures. When frontal systems, originating over the southern Atlantic Ocean in winter, move northwards across Namibia, extreme temperatures (below –10 degrees Celsius) can be experienced. Frost is then common (left and centre), and snow occasionally falls in some areas, such as shown here in Aus (right).



temperatures in the coldest months are less than 10 degrees Celsius in most areas (above). The coldest areas are along the southern escarpment, where average minimum temperatures are less than 2 degrees Celsius. Inland and over much of northern Namibia, the average minimum temperatures are generally above 6 degrees Celsius, whereas close to the coast, the moderating effects of onshore winds (and the warm East Winds) keep temperatures above 10 degrees Celsius.

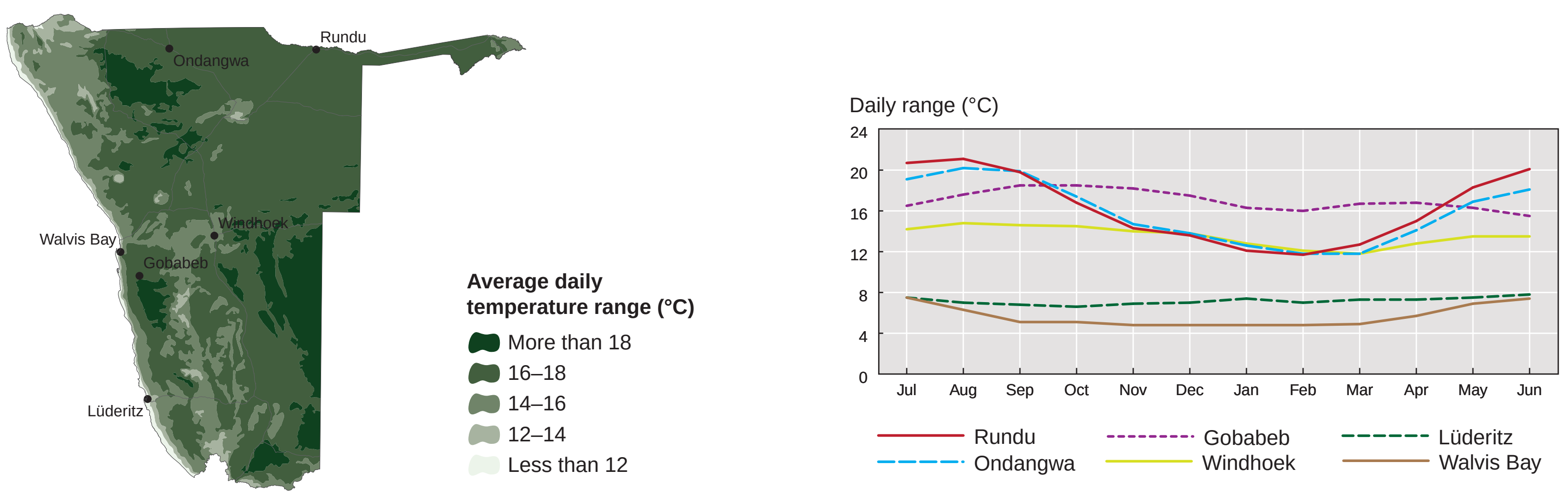
The small map on the right shows the difference between the average maximum and average minimum temperature maps. The northern Namib and coastal strip of the southern Namib experience the smallest range in annual temperature of 22 degrees Celsius or less. The greatest range in temperature – above 32 degrees Celsius – occurs in the southeastern parts of the country around Karasburg and near the Botswana border.



3.16 Temperatures at selected locations[26]

Inland temperatures vary most significantly in the minimums and ranges of temperatures recorded in the winter months. At the coast there is a much greater, yet opposite, seasonal shift in temperature from the cooler summer months to the highest average temperatures in April, May, June and July when hot East Winds are frequent.

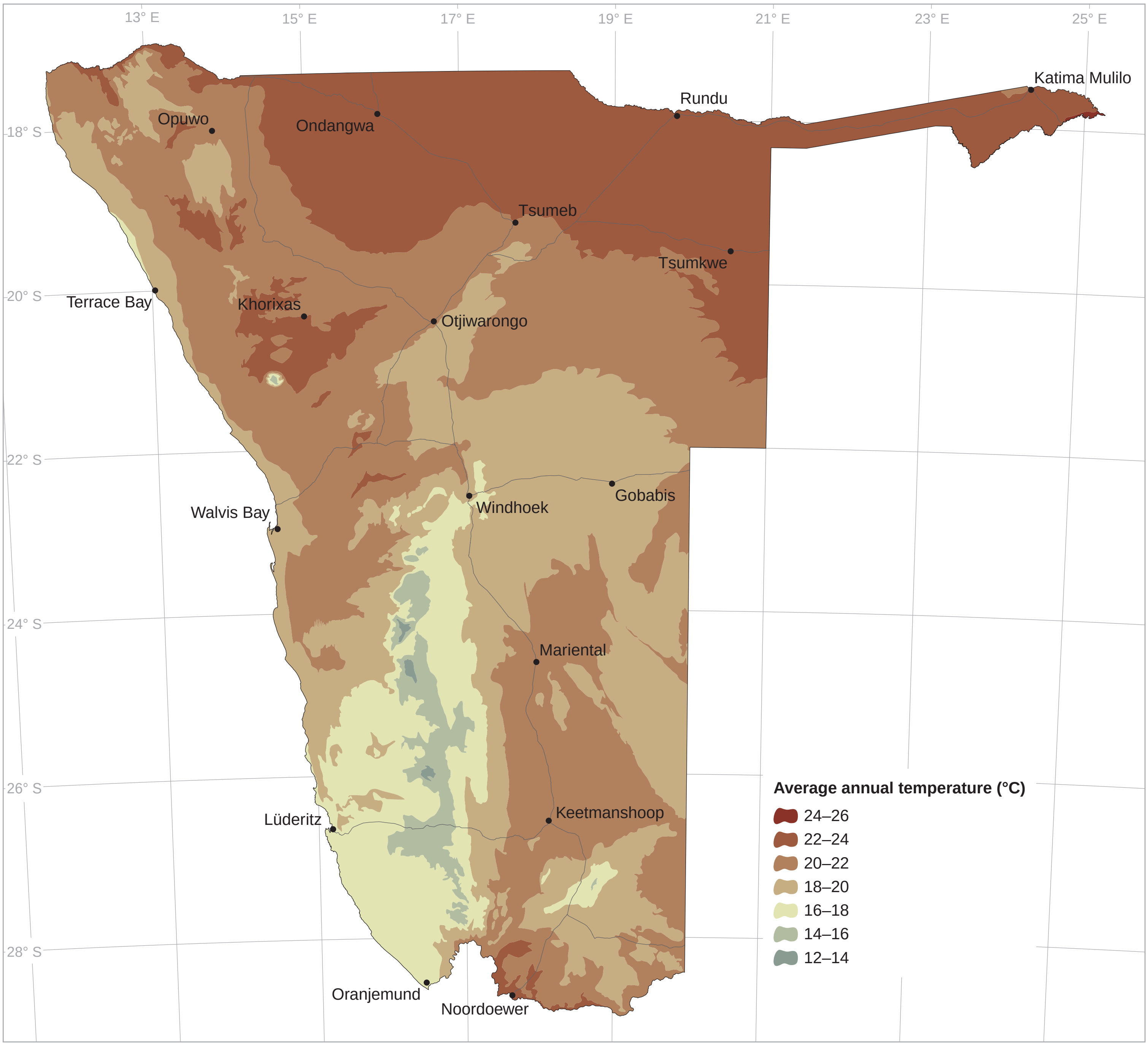
Gobabeb in the Namib Desert experiences little seasonal variation in temperature. Although it is located at the eastern edge of the coastal fog belt (figure 3.06), Gobabeb lies in the sector of the country that receives some of the highest levels of solar radiation (figure 3.14). It experiences high temperatures all year round and holds claim to an official maximum record for Namibia of 45.5 degrees Celsius (in March 2013).[27]



3.17 Daily temperature range[28]

The average daily temperature range is calculated as the difference between mean maximum and minimum daily temperatures in each month. This differs from the annual temperature range map (figure 3.15) which is a measure of the difference between the maximums and minimums of the hottest and coldest months.

Average daily temperature ranges are lowest at the coast and highest in the northern escarpment area, the northeastern Namib Sand Sea and in southeastern Namibia. Towns at the coast experience an average daily range of less than 10 degrees Celsius. This is quite consistent throughout the year. Windhoek's temperature range of about 15 degrees Celsius also varies little during the year. Larger seasonal differences in daily temperature range are felt elsewhere. For example, Ondangwa and Rundu have a daily temperature range of 18–20 degrees Celsius in the dry, winter months, but the range drops to around 12 degrees Celsius when clouds moderate heat loss and gain during the peak rain months.

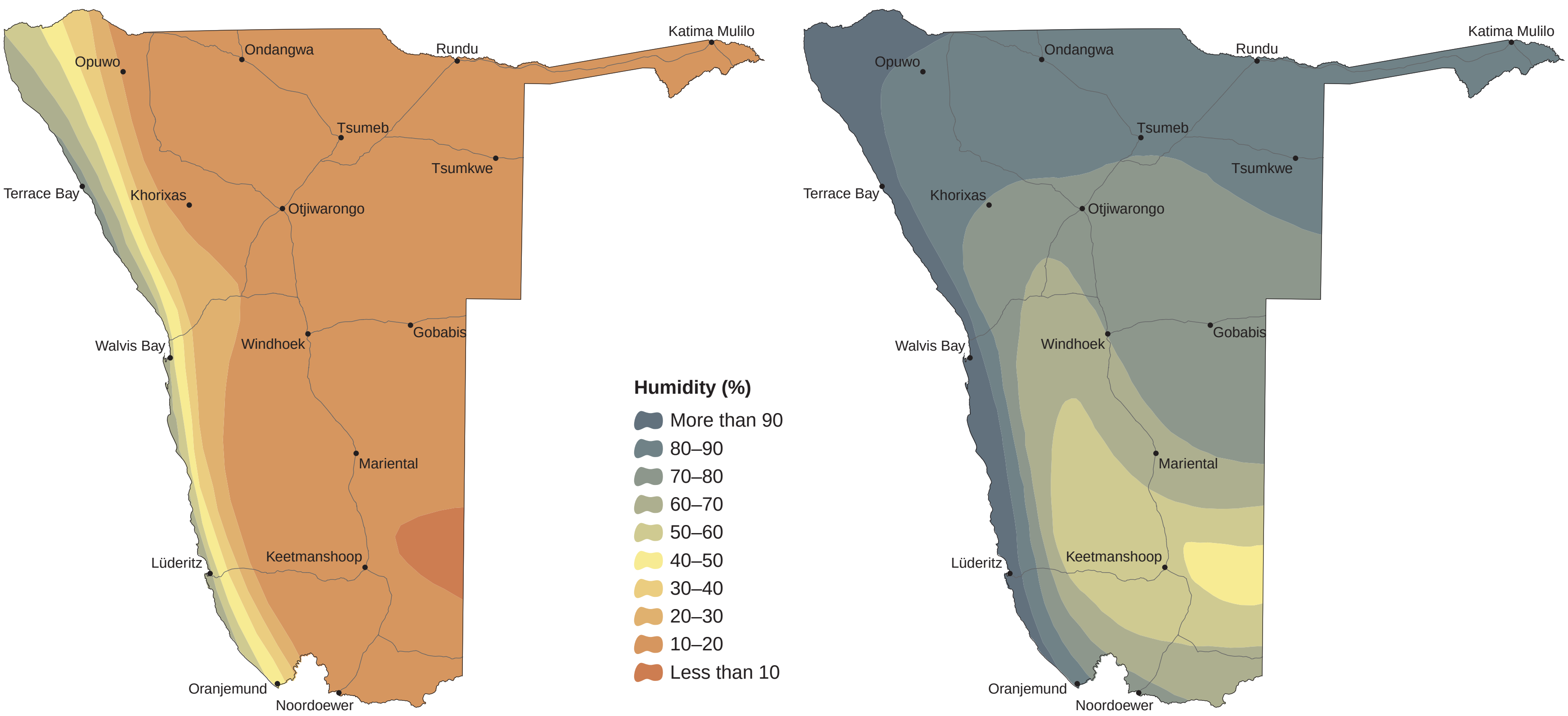


3.18 Average annual temperature[29]

The average annual temperature for each year is calculated from the average of each day's maximum and minimum temperatures. The central northern and northeastern areas along the northern escarpment of the country have the highest annual average temperatures. Moist, humid air absorbs and retains heat longer than dry air and so the greater levels of moisture during the rainy months, and the insulating effects of clouds, help maintain warmth day and night. In addition, the more vegetated Acacia and Broadleaved Tree-and-Shrub Savanna habitats (figure 6.02) insulate the land and help retain heat. Similarly, where humidity remains high along the coast, cool onshore winds and persistent fog or low cloud keep temperatures mild for most of the year, with averages below 20 degrees Celsius. The lowest average temperatures occur in the southern Namib and around the southern escarpment. Although the western desert belt receives high levels of solar radiation during the day (figure 3.14), the generally dry air (figure 3.19) over these bare surfaces loses heat rapidly at night.

Humidity

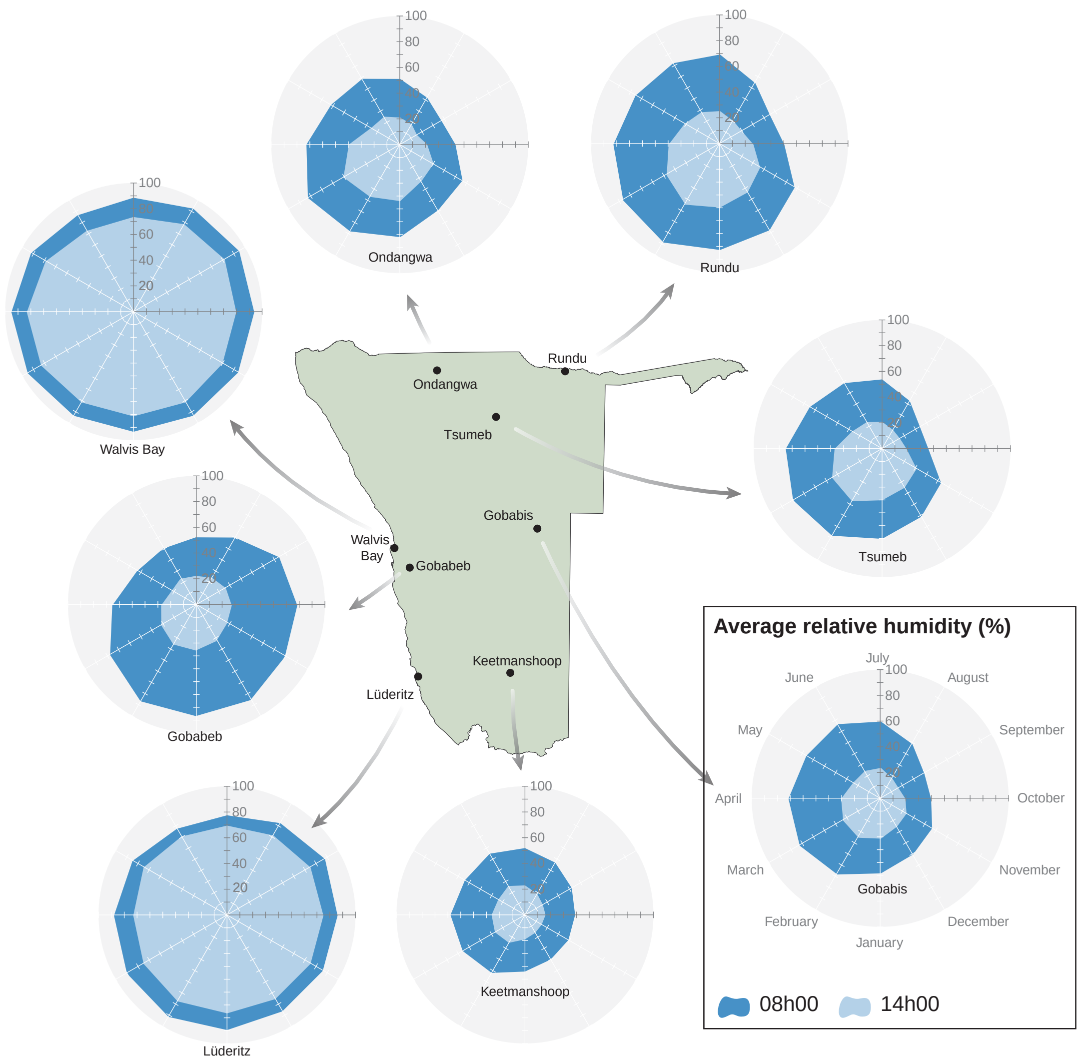
Air moisture content – or humidity – is a measure of the amount of water vapour present. The temperature of the air affects its humidity since cold air can hold less water vapour than warm air before it condenses. Relative humidity is thus the amount of water in the air in relation to what it can hold at a given temperature, and it is this percentage saturation that is used to compare air moisture levels. Relative humidity values are usually highest early in the morning when the air is coldest.



3.19 Relative humidity during the least (left) and most (right) humid months[30]

Over most of Namibia, average relative humidity values vary a great deal between the driest and wettest months. The exception is the narrow belt along the entire coast that experiences moist maritime air throughout the year. During the least humid months, humidity east of the escarpment is generally less than 20 per cent. By contrast during the most humid months, values are around 80 per cent in northern Namibia and 50–60 per cent in the south. Humidity values in the driest months are measured at 14h00 while those in the most humid month are taken in the morning at 08h00, as these are the times when the lowest and highest values, respectively, are recorded.

The typical blue skies of winter are replaced in summer with convective cloud formation following the influx of moist air from the north and east.

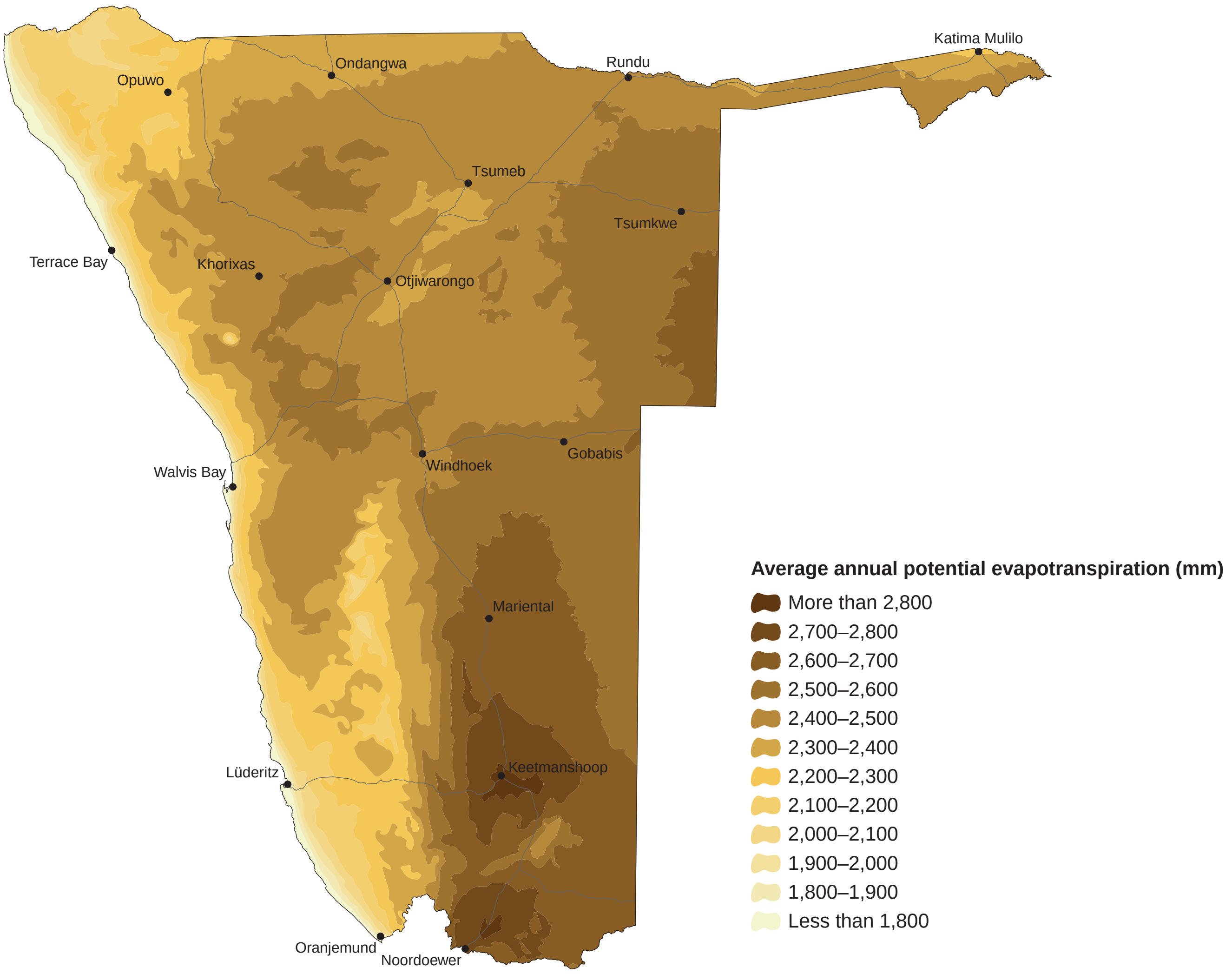


3.20 Changes in relative humidity during the year[31]

When interpreting differences in relative humidity between months, bear in mind that values are influenced both by air moisture and air temperature. At the same moisture levels, cold air will be closer to saturation than warm air. For most inland locations, the months with the lowest average humidity values are August, September and October because the change from winter to spring brings warmer temperatures, but moisture levels in the air are still low. The daily temperature range (figure 3.17) is reflected in the much higher humidity levels recorded in the morning compared to those in the early afternoon at these locations. Rundu, for example, has humidity levels in the morning (08h00) that range between 50 and 70 per cent while at 14h00 they range between 20 and 40 per cent. By contrast, the coastal towns of Lüderitz and Walvis Bay have consistently high humidity values throughout the year (70–90 per cent) and only vary a little between morning and afternoon. The lowest humidity values throughout the year are recorded in the southeast where solar radiation and temperatures are high, but rainfall is low.

Areas close to the coast, in contrast to the interior, have consistently high relative humidity levels throughout the year and frequent fog. This saturated air often extends further east from the coast, especially along lower-lying ephemeral river valleys. Here it casts an eerie grey backdrop over the wildlife supported by this river course.

Evaporation and aridity

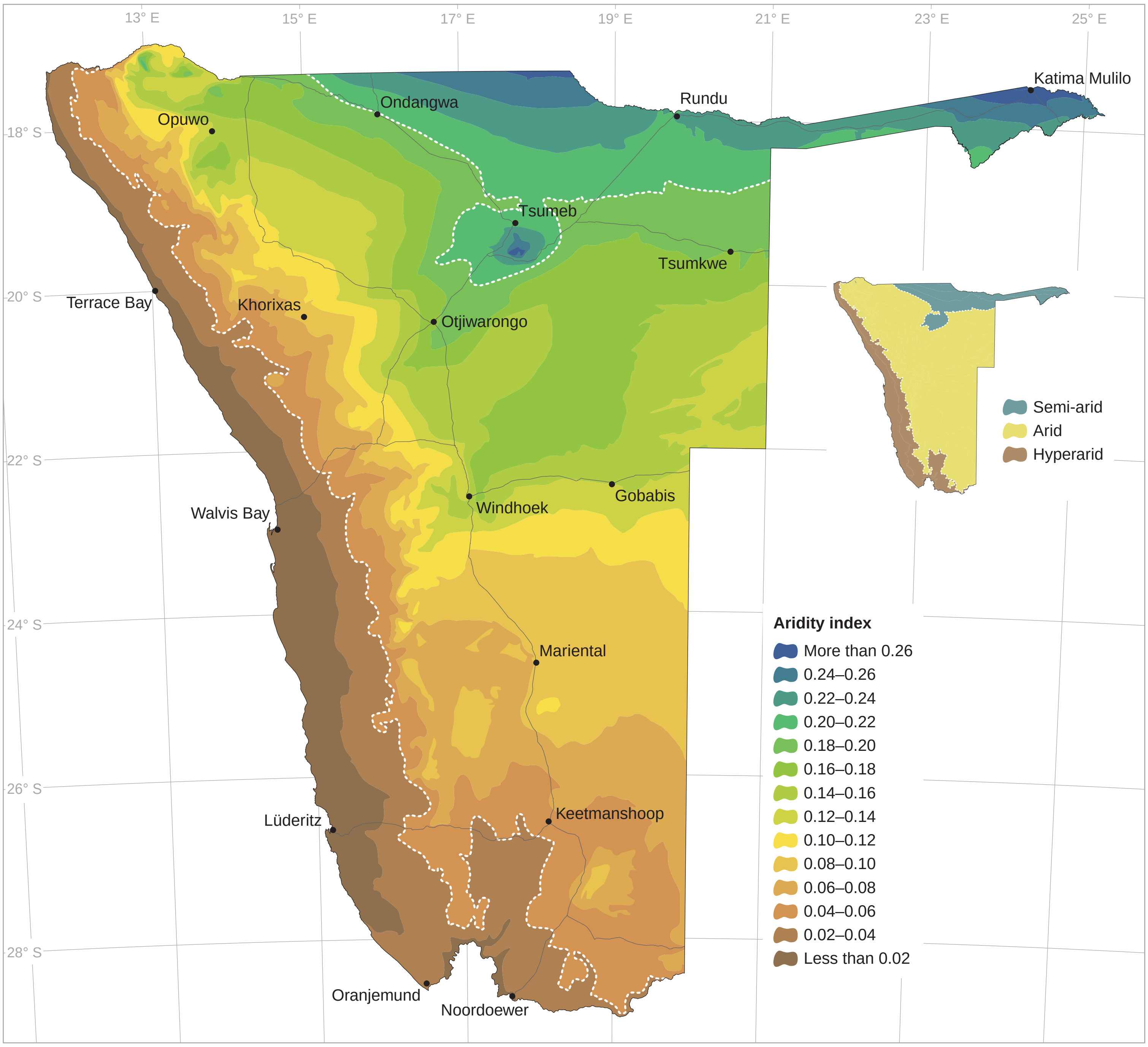


3.21 Annual potential evapotranspiration[32]

Evapotranspiration is measured as the amount of moisture released to the atmosphere through evaporation from surfaces such as the soil, wetlands and standing water combined with transpired moisture lost from plants via their leaves, stems and flowers during photosynthesis. Potential evapotranspiration is a measure of the ability of the atmosphere to remove water through evapotranspiration processes. Using potential rather than actual evapotranspiration provides a means of determining the water balance of a particular area as it indicates the amount of evaporation that would occur if sufficient water were available. The calculations make use of several parameters including rainfall, average temperature, daily temperature range and extraterrestrial radiation.

In arid areas, potential evapotranspiration exceeds annual precipitation and this is depicted clearly in this map where the average values in most areas are an order of magnitude higher than the average levels of rainfall received (figure 3.07). To put this in context, all the water in a full, uncovered, average size public swimming pool would evaporate before a year has past. The parts of the country with the greatest potential for evapotranspiration are in the east and southeast, which are also the areas that experience the greatest annual and daily temperature extremes (figures 3.15 and 3.17).

The water deficit makes cattle farming a hazardous exercise, particularly if faced with consecutive years of low rainfall that result in heavy losses.



3.22 Namibia's aridity index[33]

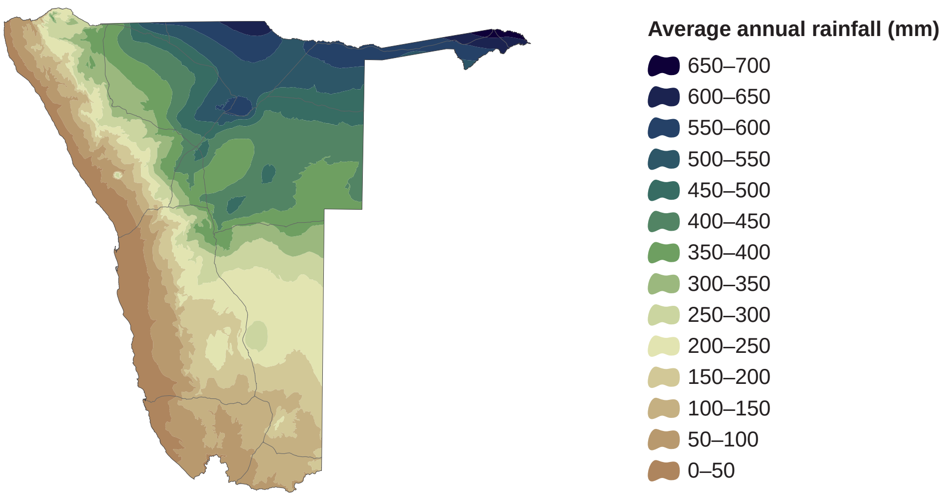
The Global Aridity Index is the ratio between rainfall and potential evapotranspiration. Consequently, an index value of 1 would mean that the amount of potential moisture lost is exactly offset by the amount of rainfall received. This classification system considers values above 0.5 as increasingly humid, while values below 0.5 represent more arid conditions.

In Namibia, the highest index values of 0.20 or more occur along the far northern and northeastern margins of the country, and in the Tsumeb area. In terms of the Global Aridity Index these areas are considered semi-arid. The bulk of the rest of the country has an index of 0.02–0.20 and is considered arid, while the entire coastal belt is hyper-arid. It is of no surprise therefore that much of the country is ill-suited for many forms of livestock or crop farming, especially in combination with Namibia's poor soils (figure 5.17).

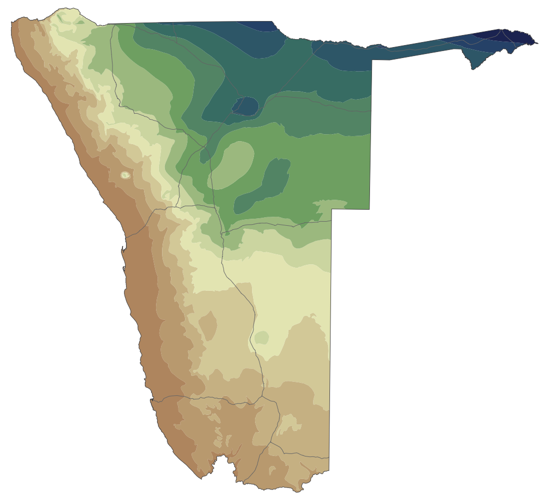
Climate change

Two aspects of climate change are definite. First, the earth has been getting hotter and sea levels have been rising. Those trends are certain to continue. Second, the exact effects of climate change on other aspects of the weather and environment are hard to project. This is not to deny the many possible and damaging effects of climate change, and thus the urgent need to reduce human-induced global warming.

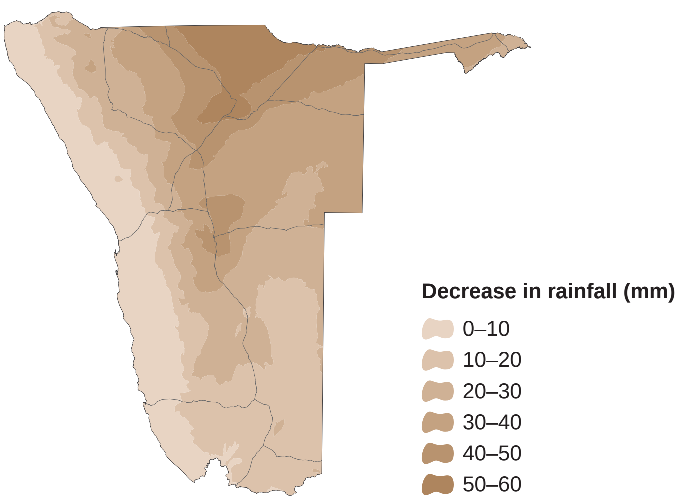
Rainfall, 1960–1990

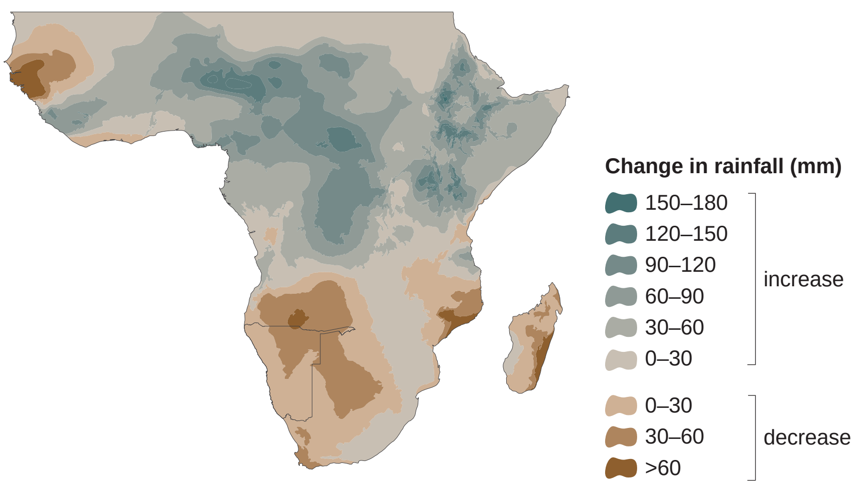


Projected rainfall, 2040–2060



Projected change in average annual rainfall



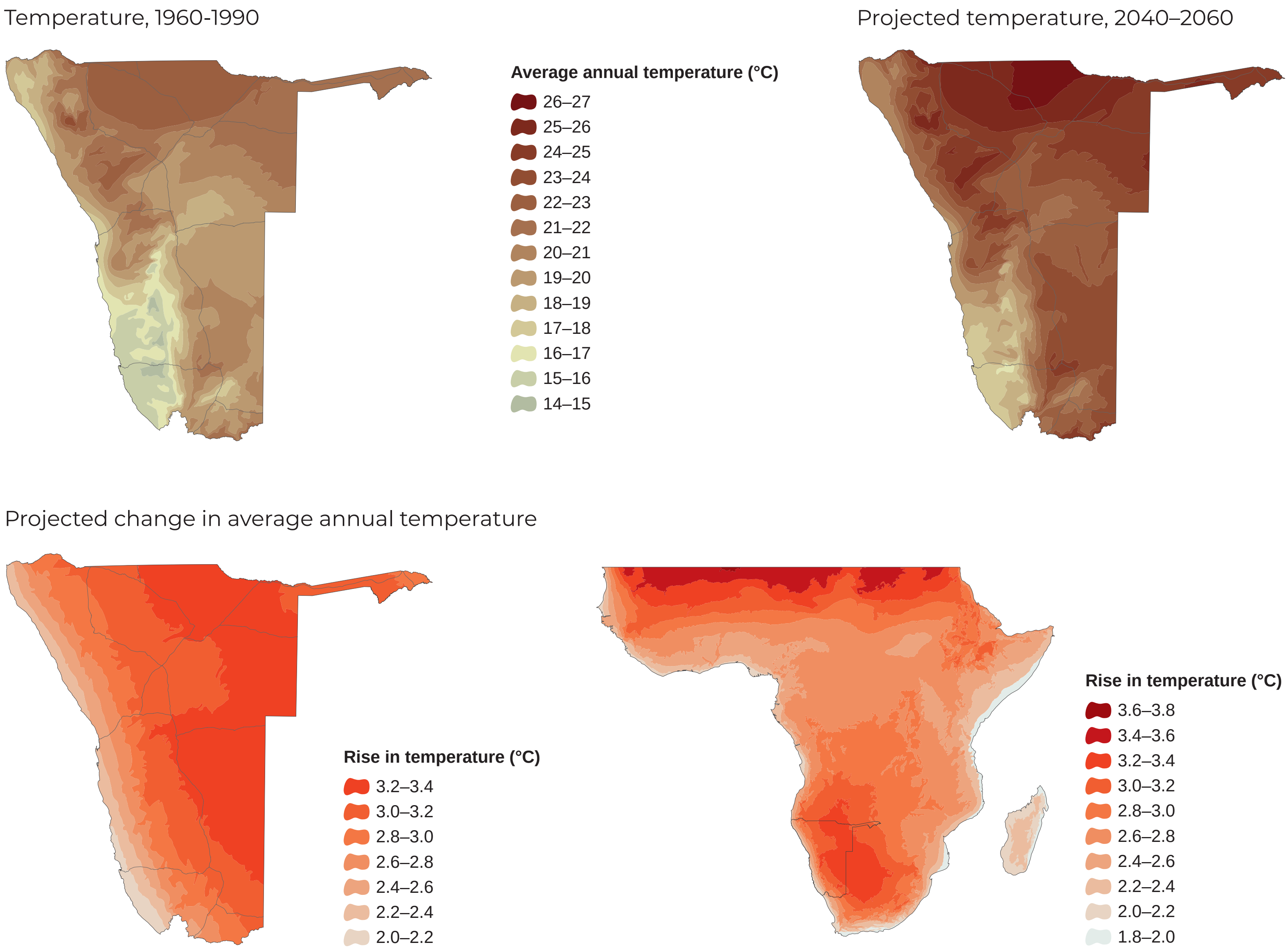


3.23 Projected changes in rainfall by 2060[34]

Total annual rainfall across Namibia, for the period 2040–2060, is expected to decrease by nearly 9 per cent relative to historical (1960–1990) rainfall. All months of the year are expected to be drier, with rainfall in the rainy season (October to April) expected to drop by 8 per cent and in the dry season (May to September) by 20 per cent.

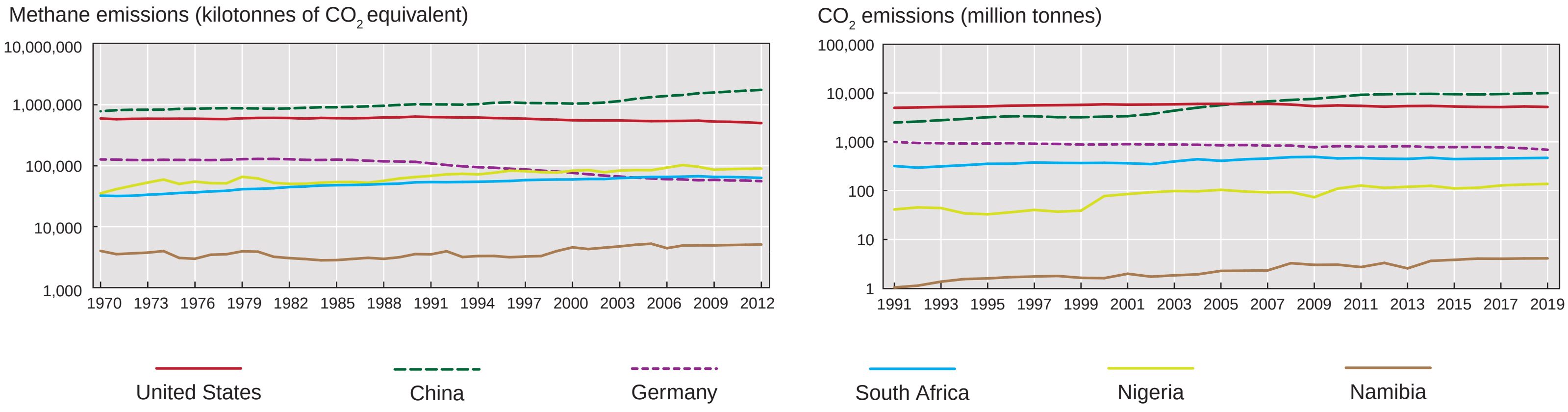
Much of the African continent, however, is expected to receive higher rainfall than it currently does. Substantial changes in rainfall over the East African Rift Valley could have serious implications. For example, Lake Victoria that feeds (and is the source of) the Nile River, receives more than 85 per cent of its water directly from precipitation; with an increase in rainfall, floods would become a serious risk.

Representative Concentration Pathway (RCP) scenarios are used to project changes to the climate. These models assess the influence of different greenhouse gas levels on radiant energy received by, and radiated from, the earth. The maps below depict Scenario 8.5 of the RCP. This scenario assumes that the current rate at which greenhouse gas emissions increase each year will continue throughout the twenty-first century.



3.24 Projected changes in temperature by 2060[35]

Temperatures are expected to increase progressively as one moves eastwards from the coast. Mean annual temperature across Namibia is projected to increase by 3 degrees Celsius, with all months of the year becoming substantially warmer. Increases in temperature across central Africa are projected to be more moderate, while the greatest increases in temperatures across Africa are expected to occur in the Saharan region where they might increase by as much as 3.8 degrees Celsius.



3.25 Greenhouse gas emissions and renewable energy opportunities[36]

The main greenhouse gases contributing to climate change are carbon dioxide, methane, nitrous oxide and fluorinated gases. Carbon dioxide and methane gases generated from human activities come largely from combustion, especially of fossil fuels, solid waste and vegetation. Methane, considered a more potent greenhouse gas than carbon dioxide, is produced by the livestock industry and is a very significant contributor to emissions in countries such as the United States of America and China.

In the global context, Namibia's contribution to greenhouse gas emissions is insignificant. Its carbon dioxide emissions are hundreds of times lower than those of countries with the highest emissions, and its methane production is thousands of times lower. Namibia's relative contribution to global climate change is thus minimal (note the logarithmic scale of the y-axis in the graphs above).

High levels of solar radiation and powerful coastal winds provide Namibia with the opportunity to become a frontrunner in green energy production. For example, a 100-hectare solar park built near Mariental in 2019 generates 45 megawatts of electricity which feeds into the NamPower grid and is sufficient to supply electricity to 70,000 homes. In the urban setting, many shopping malls and other buildings in Windhoek and elsewhere now have their rooftops decked with solar panels. Independent power producers across the country already make a significant contribution to the generation of energy and this is expected to increase as more solar power plants are constructed (page 347). Similarly, the energy from Namibia's strong winds, particularly those in the southern Namib Desert, is being harnessed through the wind turbines of newly constructed wind farms, such as the Ombepo Wind Farm positioned south of Lüderitz, further enhancing the national energy mix (figure 10.20). It is expected that in coming years there will be four wind farms with a total of 98 wind turbines located in the extreme southwestern reaches of the country. By 2030 NamPower expects that 70 per cent of Namibia's electricity requirements will be generated from renewable sources. Renewable energy generation, however, also comes at some cost, and there has been conflict between the energy and environmental sectors as many of the prime locations for wind farms are in highly sensitive habitats.

The roof of Maerua Mall (left), one of Windhoek's largest shopping centres, is installed with panels of photovoltaic cells that convert energy from the sun to electricity; they are able to produce at least 1,800 megawatt-hours of electricity per year. Wind along Namibia's southern coast (right) has great potential for generating electricity and is expected to make a significant contribution to Namibia's energy mix by 2030.

Key points

- Namibia's climate is dominated by two anticyclonic air systems, and the cold Benguela Current. Seasonal changes occur as the two anticyclones move in relation to the advancing and retreating Intertropical Convergence Zone, which is a band of warm, humid air. The influence of frontal weather systems is largely limited to the southern parts of the country during the winter months.

- The cold ocean current and its associated upwelling centres result in mild sea surface temperatures throughout the year with the lowest temperatures recorded between the months of July and September.

- Winds at the coast are persistently strong and predominantly from a southerly direction. Wind speeds in the afternoon are stronger than in the morning and evening, and are lower and more variable further inland. In winter, hot, dry easterly winds are common; wind speeds usually build up from the small hours, peak in the late morning and subside in the afternoon.

- Fog occurs frequently along the coast and can extend more than 100 kilometres inland. Fog occurs when a layer of moist air is trapped between subsiding anticyclonic air and the cold ocean surface. It usually forms at night and dissipates during the day.

- Average annual rainfall ranges from less than 20 millimetres in the west to more than 650 millimetres in northeastern Namibia. The extreme southwestern parts of the country receive very little rainfall, which can fall at any time of the year. The eastern parts of Namibia receive heavier and more frequent falls of rain than the rest of the country.

- In all, except the extreme southern parts of the country, rain is strongly seasonal with most falling between November and April. Peak rain months vary across the country between January in the east and March in the west.

- Rainfall seasons are highly variable both in total amounts of rain received and the spread of rainfall during the season. The highest variability in annual rainfall is seen in the northwestern and central-western areas of Namibia, where average annual rainfall is low (<100 millimetres). Although rainfall is similarly low in southern Namibia, variability here is moderated by rain from frontal weather systems.

- Coastal areas experience an average of 5–7 hours of sunshine per day as a consequence of fog and cloud. Most inland areas experience more than 8 hours of sunshine per day. The difference in day length between the shortest and longest days is about two hours in the north and three-and-a-half hours in the south of the country.

- The southern and western parts of the country, with the exception of the coastal margin, receive the most direct solar radiation.

- Average maximum temperatures range from 22 degrees Celsius to more than 36 degrees Celsius with the highest average maximum temperatures recorded in the east. Some of the coldest temperatures are recorded in the south of the country, particularly along the southern escarpment where average minimum temperatures drop below 2 degrees Celsius.

- Average annual temperatures are highest in the north and northeast, and are lowest along the southern escarpment and in the southern desert areas. Average daily temperature range at the coast is less than 10 degrees Celsius throughout the year, but inland it can be greater than 20 degrees Celsius in the winter months. Average annual temperature can be misleading as it is moderated by large diurnal and seasonal temperature ranges which are experienced across much of the country.

- Close to the coast relative humidity is high and fairly consistent throughout the year due to the prevalence of fog. Further inland, however, relative humidity is generally less than 20 per cent in the dry season in the afternoon increasing to over 70 per cent in the wet season early in the day.

- The potential water loss through evapotranspiration far exceeds the amount of water received through annual rainfall. As a consequence, the far northeastern areas of the country are considered semi-arid, other areas east of the escarpment are considered arid and areas west of the escarpment and the southwest corner of Namibia are considered hyper-arid.

- Projected changes in rainfall over the next 40 years suggest a 9 per cent decrease across the country. Average temperatures are expected to increase, more so in the eastern parts of the country (by more than 3 degrees Celsius) than in the west.