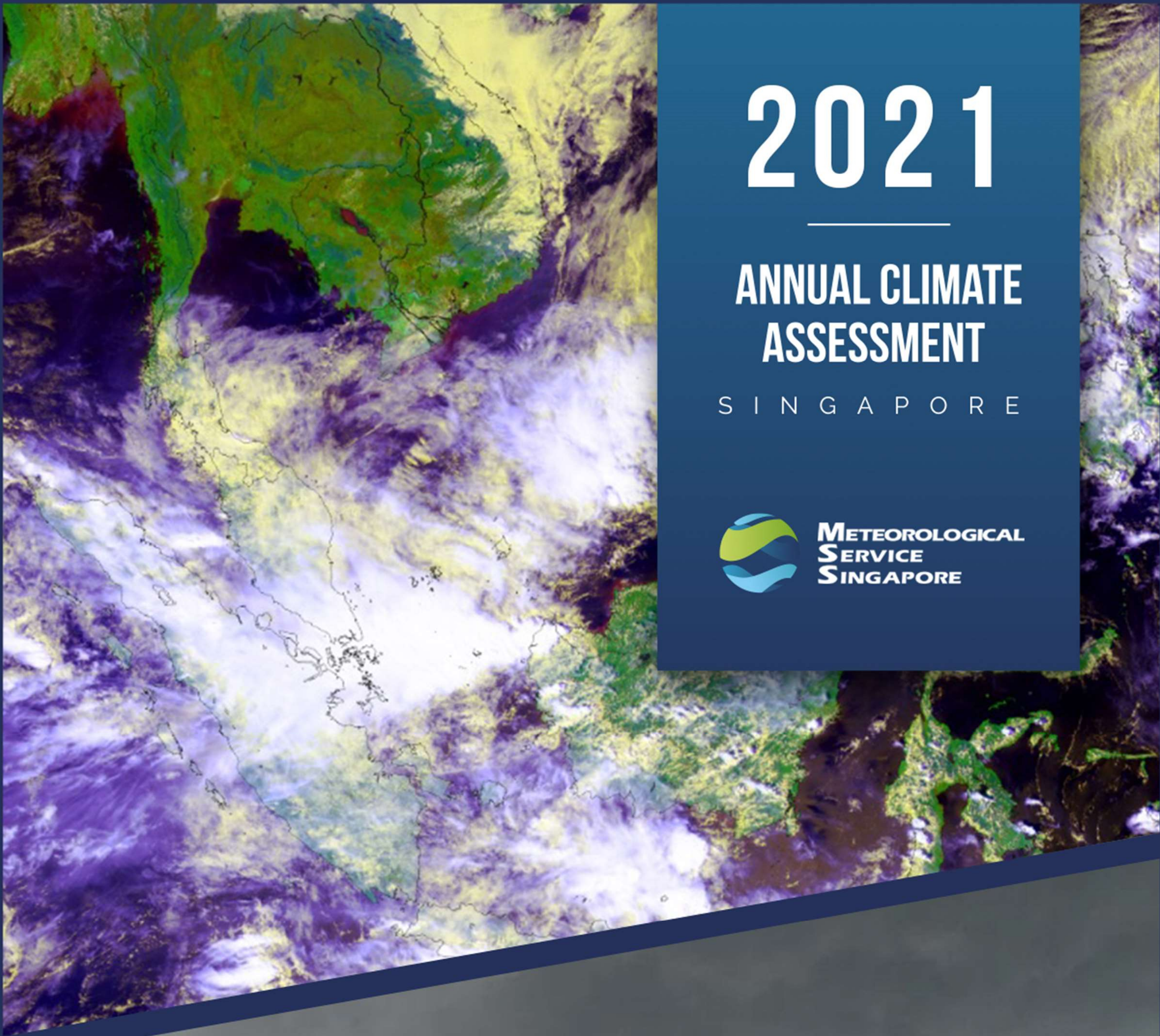
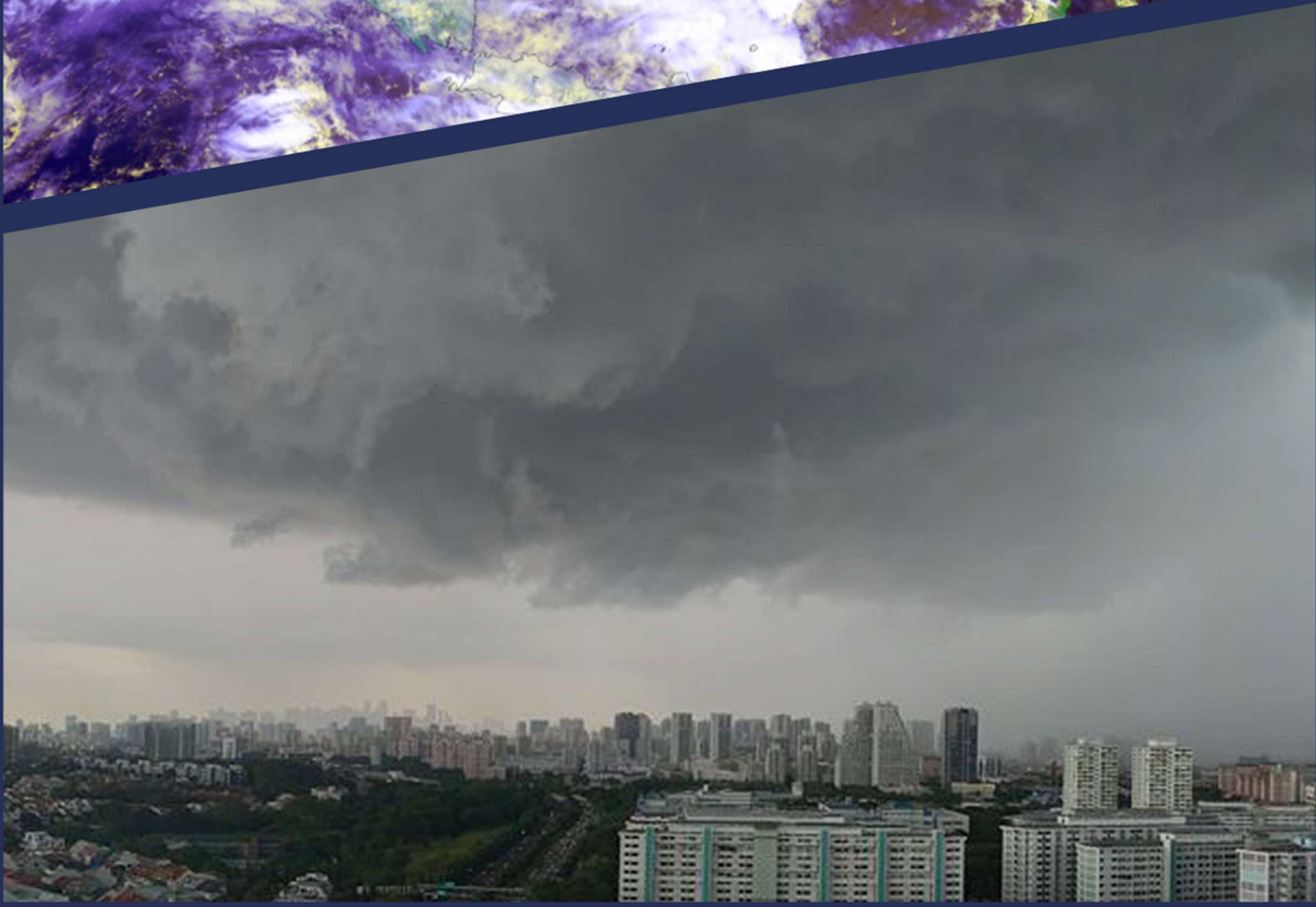


2021

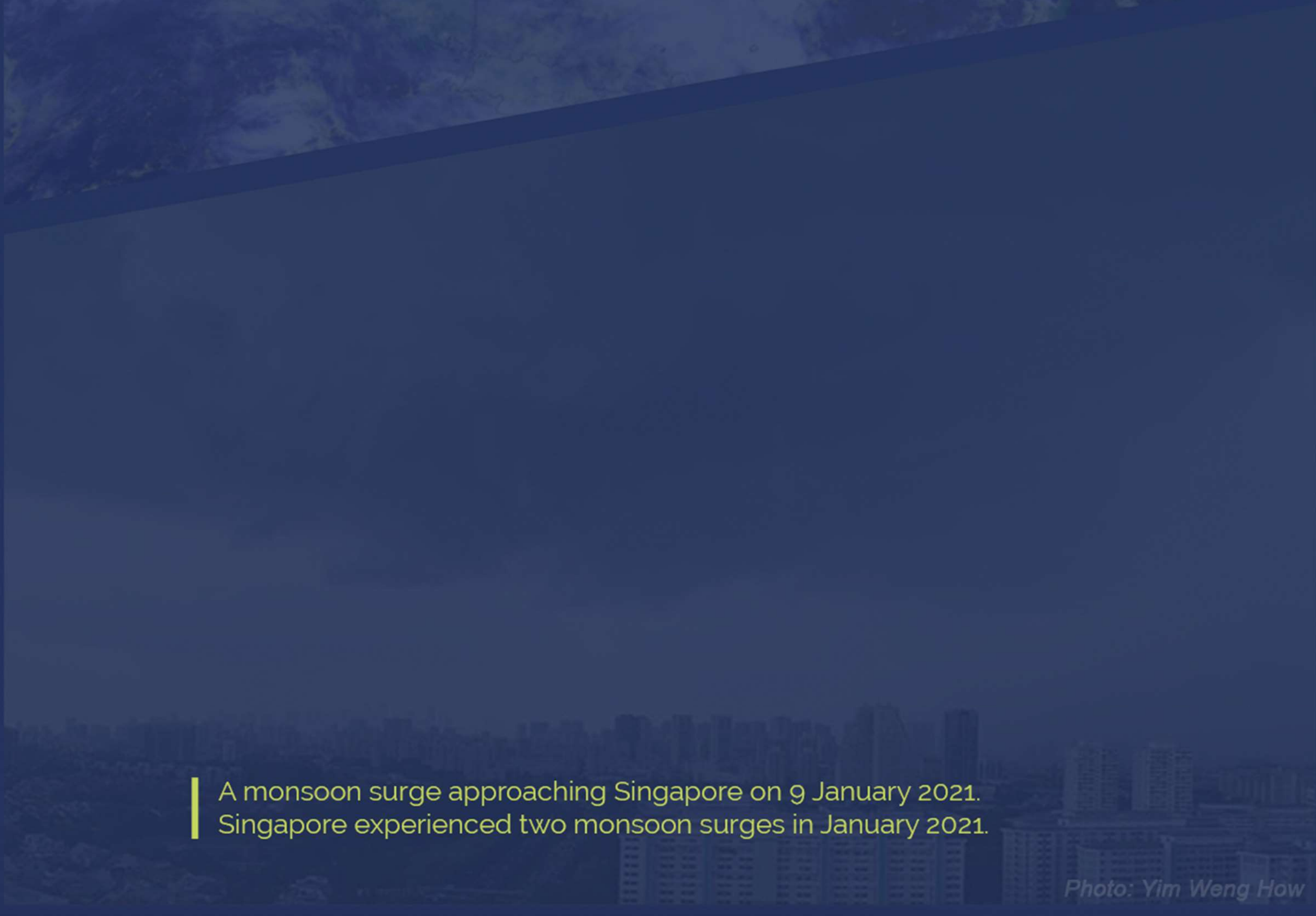
ANNUAL CLIMATE ASSESSMENT

SINGAPORE

Meteorological Service Singapore



Himawari-8 satellite image 9 January 2021, showing a northeast monsoon surge headed towards Singapore from the South China Sea.



A monsoon surge approaching Singapore on 9 January 2021. Singapore experienced two monsoon surges in January 2021.

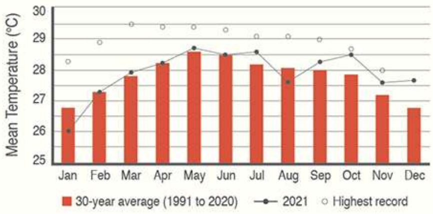
Photo: Yim Weng How

Singapore's Climate in 2021

Decadal mean temperature

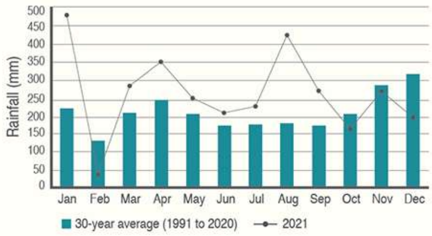
Last 10 years from 2012 to 2021 is Singapore's warmest decade on record, with decadal mean temperature of 27.97°C.

Monthly mean temperature



Warmer-than-average temperature in the second half of the year. December 2021 is the joint warmest December on record.

Monthly total rainfall



Higher-than-average rainfall for most months. 2021 is the second wettest year since 1980, with annual total rainfall of 2809.9mm at the Changi climate station.

NOTABLE WEATHER EVENTS IN 2021

Contrasting January and February

Monsoon surges contributed to the highest January rainfall at the climate station since 1893. It was followed by the second driest February on record – a mere 1.0mm of rain fell over the climate station.

April Sumatra squall

A Sumatra squall brought heavy rain islandwide on 17 April. Ulu Pandan station recorded 170.6mm, the highest daily total rainfall ever recorded in the month of April.

August deluge

August was unseasonably wet. On 24 August, several spells of thundery showers led to a daily total rainfall of 247.2mm at Mandai station, the highest ever recorded in the month of August.

WEATHER EXTREMES IN 2021

Meteorological Service Singapore

Singapore's Climate in 2021

The year 2021 saw significantly wetter-than-average[1] conditions and is Singapore's second wettest year since 1980. The annual total rainfall recorded at the Changi climate station was 33% higher than the long-term average of 2113.3 mm. The wetter conditions contributed to moderating Singapore's overall temperature in 2021. In addition, La Niña conditions prevailed during the first quarter of 2021, returning to neutral El Niño – Southern Oscillation (ENSO) conditions in the second quarter, with La Niña conditions re-emerging in the third quarter of the year.

Temperature

The last 10 years from 2012 to 2021 is the warmest decade on record. The mean temperature from 2012 to 2021 was 27.97°C, 0.02°C higher than the previous record of 27.95°C for the decade from 2010 to 2019.

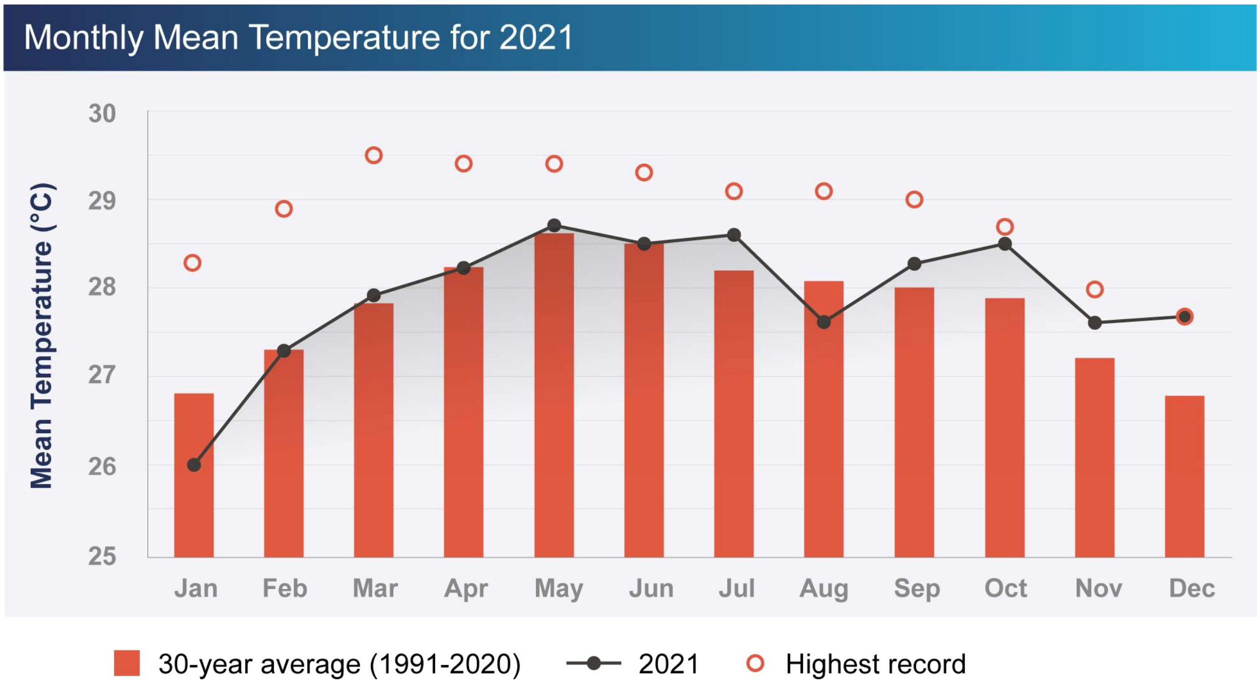


Figure 1: Singapore monthly mean temperature for 30-year average from the Changi climate station (bars, 1991 – 2020) compared to 2021 (solid line). Also shown are the highest recorded monthly values for the historical period prior to 2021 as 'dots'.

In the first half of the year, mostly near-average temperatures were observed while warmer-than-average conditions were observed during the second half of the year. The warmer-than-average temperatures towards the end of the year were associated with relatively drier weather conditions. The annual mean temperature in 2021 was 27.9°C, which is 0.1°C above

[1] According to World Meteorological Organization (WMO) guidelines, the standard climatological normal (derived from meteorological observations) calculated as the average over a 30-year period is updated every 10 years. As year 2021 marked the beginning of a new 30-year climatological period, a new set of climatological normals for Singapore was compiled based on the meteorological data from stations with continuous long-term records from 1991 to 2020.

the long-term average of 27.8°C and the 10th warmest year on record (tied with 2018, 2014, 2009, and 2004).

In January and August, the cooler-than-average temperatures (Figure 1) were associated with significantly higher-than-average rainfall during these two months. The mean temperatures in January and August were 26.0°C and 27.6°C respectively, which are 0.8°C and 0.5°C cooler than their respective long-term monthly averages. Notably, January 2021 is the coolest January in the past 30 years, while August 2021 is the second coolest August in the past 20 years. While no long-term monthly temperature records were broken in 2021, the monthly mean temperature of 27.7°C in December is the joint warmest December (together with December 2015) since temperature records started in 1929.

Rainfall

The annual total rainfall in 2021 was well above average, resulting in the second wettest year since 1980 both at the climate station[2] and for the islandwide average[3]. The annual total rainfall recorded was 2809.6 mm at the Changi climate station and 3167.7 mm when averaged across islandwide stations with long-term records, which was 33% and 25% above their respective long-term annual averages of 2113.3 mm and 2534.4 mm.

Most months in 2021 experienced above-average rainfall. Based on the islandwide average, almost all of these wetter months also rank within the top 10 wettest for the respective months over the past 40 years. In particular, total rainfall in January (480.5 mm) and August (426.2 mm) were at least twice their respective long term monthly averages (Figure 4), resulting in the wettest January and August in the past 40 years. At the climate station (Figure 5), similar significantly above-average rainfall was recorded in January with a total rainfall of 692.8 mm. This makes January 2021 the second wettest January on record after January 1893 (818.6 mm).

Among the few months that showed drier-than-average monthly rainfall in 2021, February had significantly drier conditions. Monthly total rainfall in February both for the islandwide average (35.8 mm) and the Changi climate station (1.0 mm) were about 73% and 99% below average respectively, resulting in the second driest February over the past 40 years, based on the islandwide average, and second driest for the climate station since rainfall records started in 1869.

[2] It is ranked at 21st wettest when compared to the entire climate station record since 1869.
[3] The islandwide average is based on the data from 32 stations across Singapore that have a continuous record from 1991 onwards.

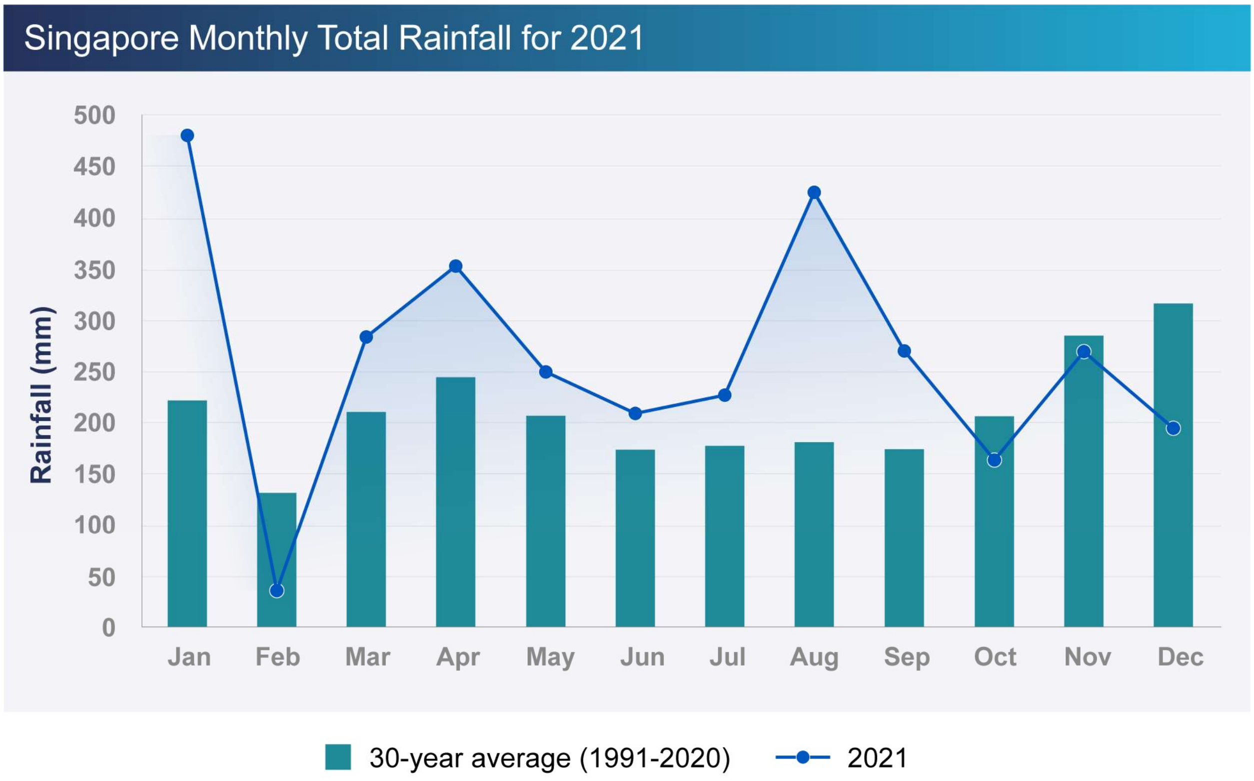


Figure 2: Singapore monthly total rainfall for 30-year average over islandwide stations with long-term records (bars, 1991 – 2020) compared to 2021 (solid line). The annual total rainfall of 3167.7 mm for 2021 was 25% above the long-term annual average of 2534.4 mm.

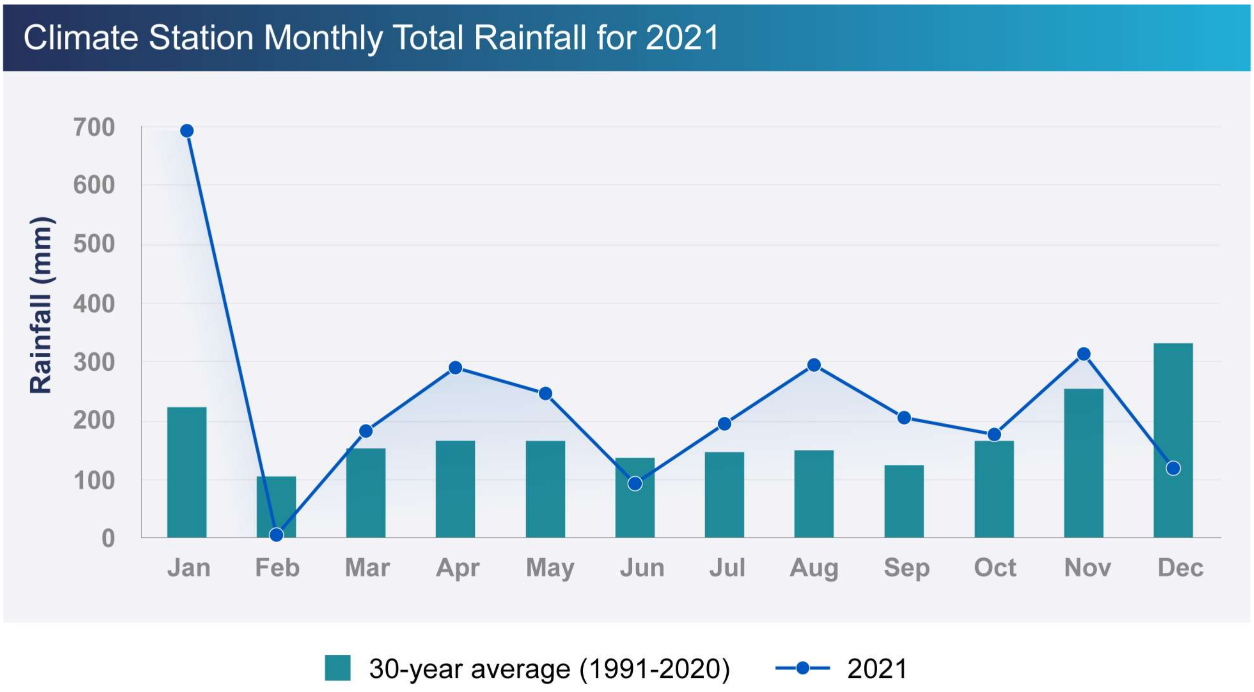


Figure 3: Monthly total rainfall for 30-year average at the Changi climate station (bars, 1991 – 2020) compared to 2021 (solid line). The annual total rainfall of 2809.6 mm at the Changi climate station for 2021 was 33% above the long-term annual average of 2113.3 mm.

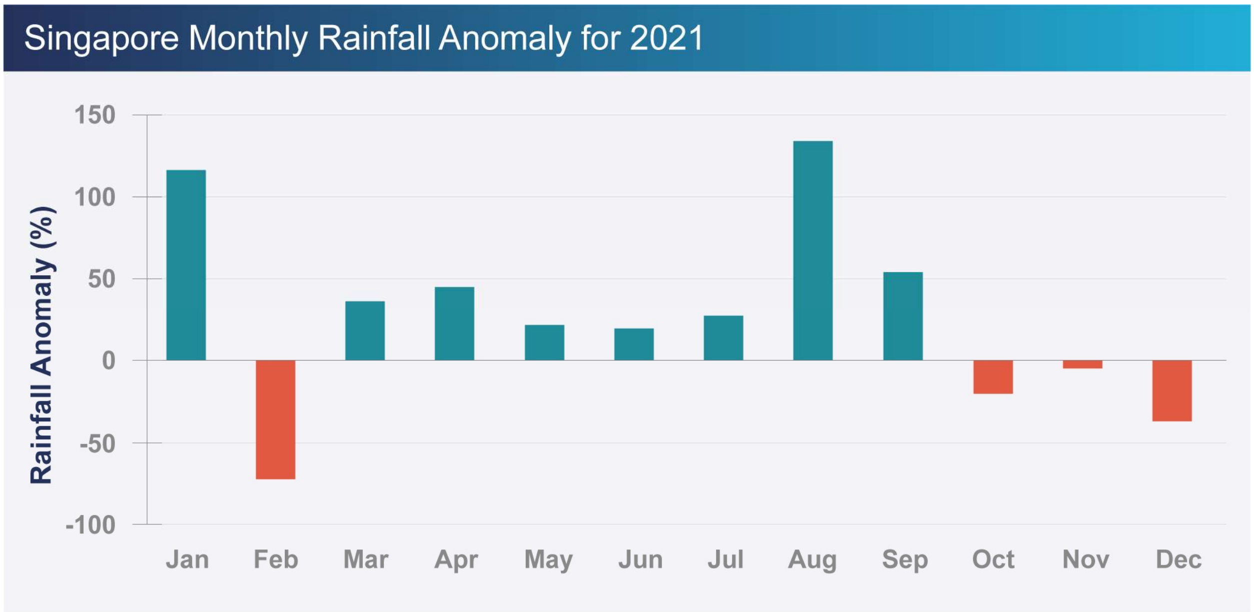


Figure 4: Monthly rainfall anomaly for 2021 averaged over islandwide stations with long-term records. Rainfall was significantly above average in most months of the year especially in January and August. Below average rainfall was observed in February and last quarter of the year.

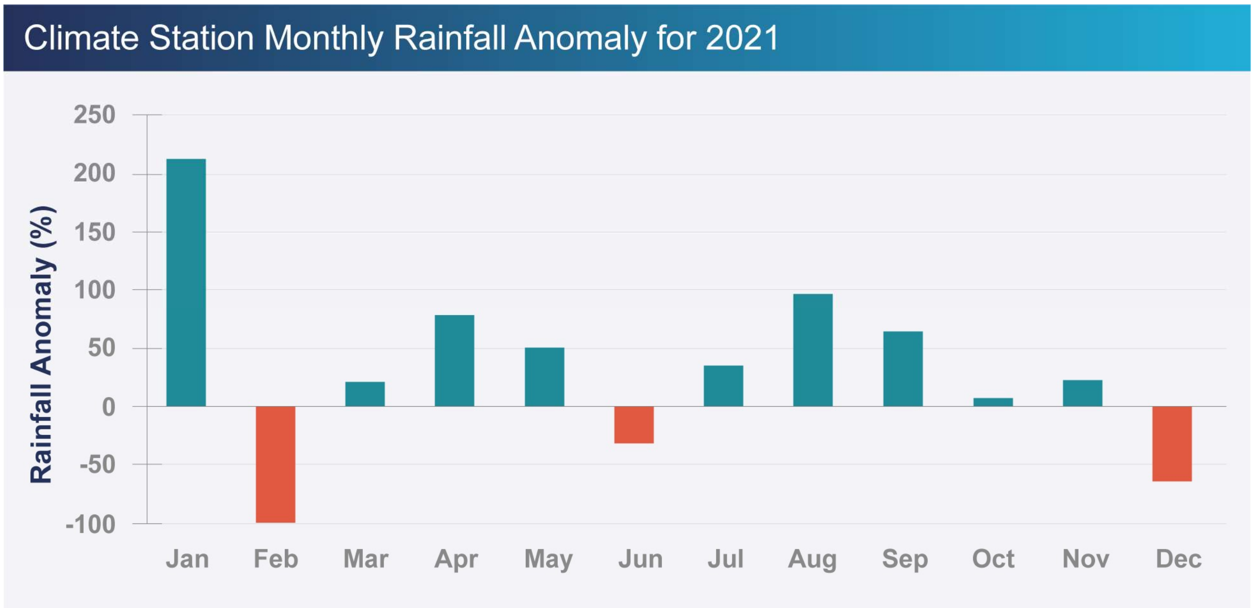


Figure 5: Monthly rainfall anomaly for 2021 at the Changi climate station. Rainfall was significantly above average in most months of the year especially in January and August. Below average rainfall was observed at the climate station in February, June, and December 2021.

La Niña conditions prevailed during the first quarter of 2021, returning to neutral El Niño – Southern Oscillation (ENSO) conditions in the second quarter. After approximately four months of neutral conditions, La Niña conditions re-emerged towards the end of the third quarter. While the La Niña conditions continued to strengthen in the fourth quarter of 2021, the magnitude of the La Niña event was slightly weaker at the end of 2021 compared to the start of 2021. Based on historical observations, La Niña events tend to have the strongest effect on Singapore's rainfall during the Southwest Monsoon season and the weakest effect during the Northeast Monsoon season.

Along with La Niña conditions, a negative Indian Ocean Dipole (IOD) was also present in 2021. In the second quarter of 2021, there were signs of a negative IOD developing with the negative IOD established by the third quarter. The strength of the negative IOD fluctuated considerably during the second half of the year and returned to neutral by the end of 2021. A negative IOD typically results in wetter-than-average conditions over Singapore and the nearby region during the Southwest Monsoon season.

Weather Extremes in 2021

	2021		Since 1869 (rainfall), 1929 (temperature), 1984 (wind)
	All Available Stations	**Climate Station**	**Climate Station Records**
Hottest Day *(°C)*	36.3 2 Apr *Ang Mo Kio*	34.7 2 Apr	**36.0** 26 Mar 1998
Coldest Night *(°C)*	21.1 2 Jan *Newton*	21.7 2 Jan 3 Jan	**19.4** 30 - 31 Jan 1934
Warmest Month *(°C)*	29.6 Jun *Marina Barrage*	28.7 May	**29.5** Mar 1998
Coolest Month *(°C)*	25.5 Jan *Jurong (West)*	26.0 Jan	**24.2** Jan 1934
Wettest Day *(mm)*	247.2 24 Aug *Mandai*	210.6 2 Jan	**512.4** 2 Dec 1978
Wettest Month *(mm)*	692.8 Jan *Changi*	692.8 Jan	**818.6** Jan 1893
Driest Month *(mm)*	1.0 Feb *Changi*	1.0 Feb	**0.2** Feb 2014
Strongest Wind Gust *(km/h)*	87.4 5 Oct *Pasir Panjang*	57.4 15 Aug	**90.7** 29 Nov 2010

Table 1: Temperature, rainfall and wind extremes recorded at climate station in 2021 compared to the historical record; additional information from all available stations provides further context.

Notable Weather Events in 2021

A Wet Start to the Year – Second Wettest January On Record

2021 began on a wet note, with the first half of January experiencing exceptionally wet and cool weather due to the occurrence of a Northeast Monsoon surge. This refers to a strengthening of northeasterly winds blowing from a strong high-pressure system toward the South China Sea, bringing periods of prolonged widespread rain and windy conditions to the surrounding region. The monsoon surge brought continuous widespread rain, at times heavy, over Singapore in the first weekend of the year. The highest daily total rainfall of 210.6 mm was recorded at the Changi climate station on 2 January 2021.

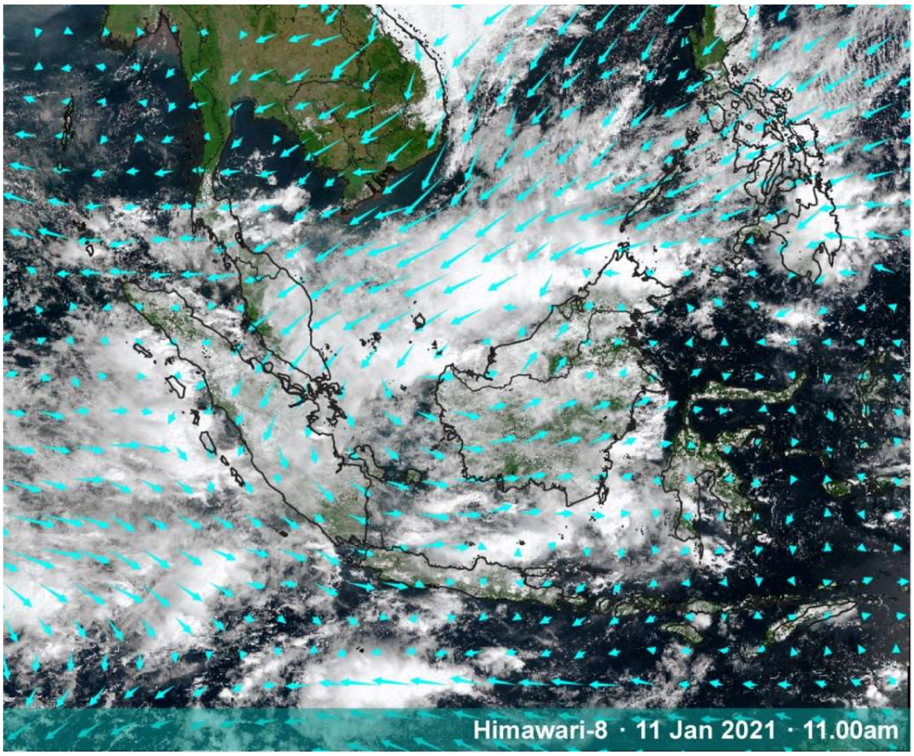


Figure 6: Satellite image on 11 January 2021 showing extensive rainclouds and strong winds (depicted by arrows) from a Northeast Monsoon surge that brought wet weather to Singapore and its surrounding region.

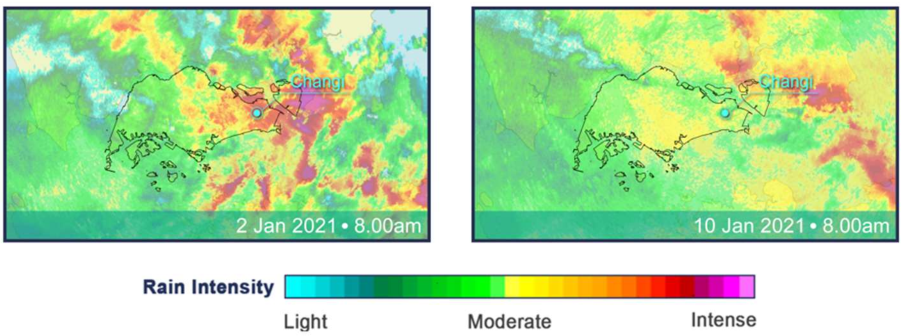


Figure 7: Radar images showing widespread rain over Singapore and the vicinity during the monsoon surge episodes on 2 January 2021 (left) and 10 January 2021 (right).

Another monsoon surge developed about a week later. Strong northeasterly winds coupled with convergence of winds over Singapore and the surrounding region brought windy and rainy weather on 8 – 13 January 2021. Continuous moderate to heavy rain fell across the island on 10 January 2021, resulting in a total daily rainfall of 204.0 mm recorded at Changi, the highest recorded during this surge episode.

The monthly rainfall recorded at the Changi climate station for January 2021 was 692.8 mm, with 648.4 mm recorded in the first fortnight alone. This makes January 2021 the second wettest January since rainfall records began in 1869, exceeding the previous second highest value of 634.5 mm recorded in 1918. The highest ever total rainfall for January recorded at the climate station was 818.6 mm in 1893.

The exceptionally wet weather in January 2021 also brought relatively cool weather on most days. At the Changi climate station, the monthly mean temperature of 26.0°C for January 2021 was the lowest for January in the last 30 years.

A Dry and Windy February – Second Driest February On Record

In contrast to a very wet January 2021, February 2021 was fair and windy on most days, as the dry phase of the Northeast Monsoon season set in over Singapore and the surrounding region. The monsoon rainband remained mostly south of the equator in the vicinity of the Java Sea during this period.

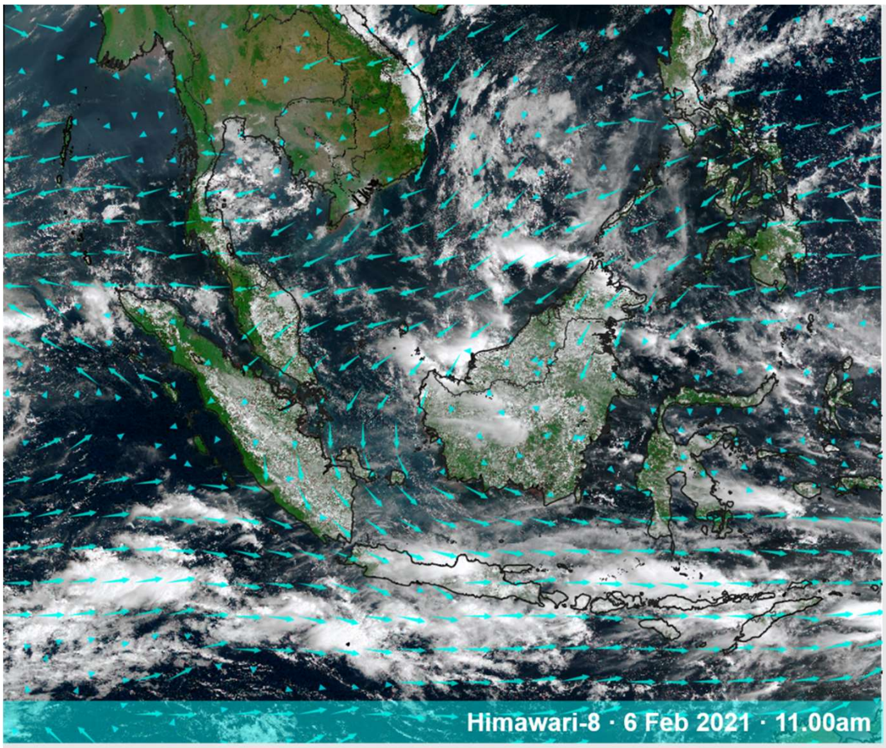


Figure 8: Satellite image on 6 February 2021 showing that the monsoon rainband has now shifted south, so that dry weather prevails over Singapore and its surrounding region. Strong winds (depicted by arrows) are still observed over the South China Sea, bringing windy conditions to Singapore and its surrounding region.

The highest daily total rainfall in February 2021 of only 46.9 mm was recorded at Jurong West on 11 February, while the Changi climate station recorded a mere 1.0 mm for the entire month. February 2021 was the second driest February on record after February 2014 which recorded 0.2 mm of total rainfall. Figure 9 shows the February total rainfall recorded at the climate station in the past 20 years.

February 2021 was also a very windy month, with the Changi climate station recording an average daily wind speed of 13.1 km/h. As a result, February 2021 was the second windiest February since continuous wind records commenced in 1984, behind the 13.7 km/h recorded in February 2014.

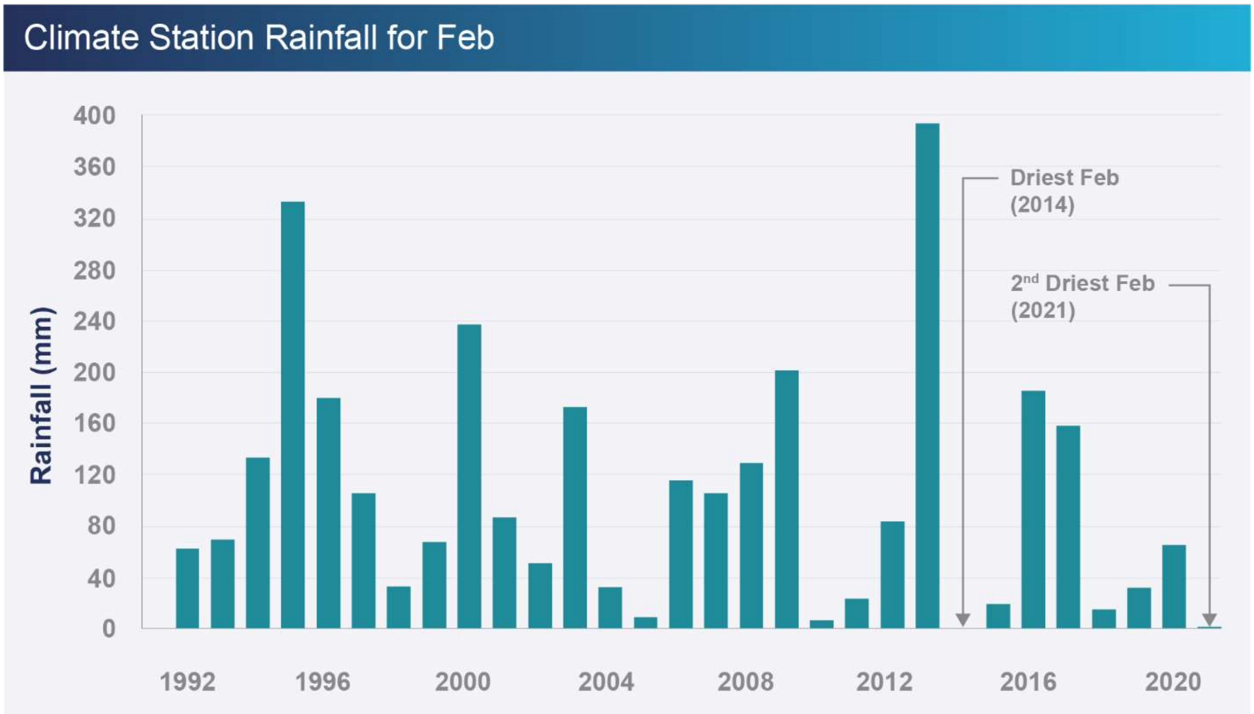


Figure 9: February total rainfall recorded at the climate station between 1992 and 2021. February 2021 was the second driest February after February 2014 since rainfall records started in 1869.

A Sumatra Squall Triggers the Highest Daily Rainfall for April

Although tropical cyclones do not directly affect Singapore, they affect the wind flow and impact the weather in the surrounding region. On 17 April 2021, the convergence of prevailing winds under the influence of Typhoon Surigae in the western Pacific Ocean contributed to the development of a Sumatra squall over the Strait of Malacca in the morning. The Sumatra squall moved eastward to affect Singapore, bringing widespread thundery showers in the afternoon.

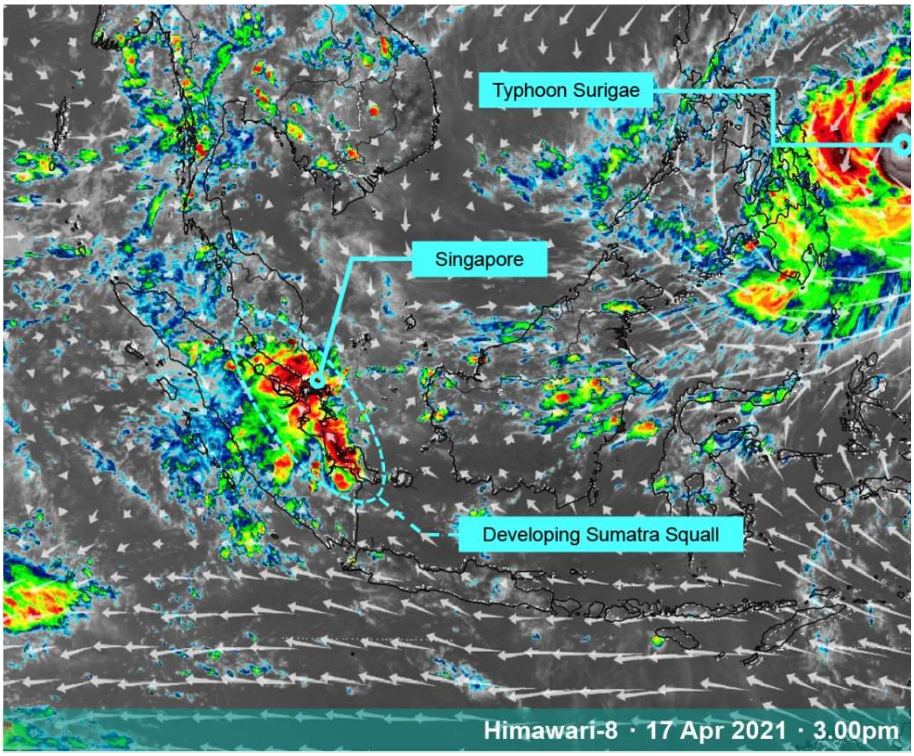


Figure 10: Himawari-8 satellite image at 3pm on 17 April 2021, showing a Sumatra squall line affecting Singapore under the influence of Typhoon Surigae over the western Pacific Ocean.

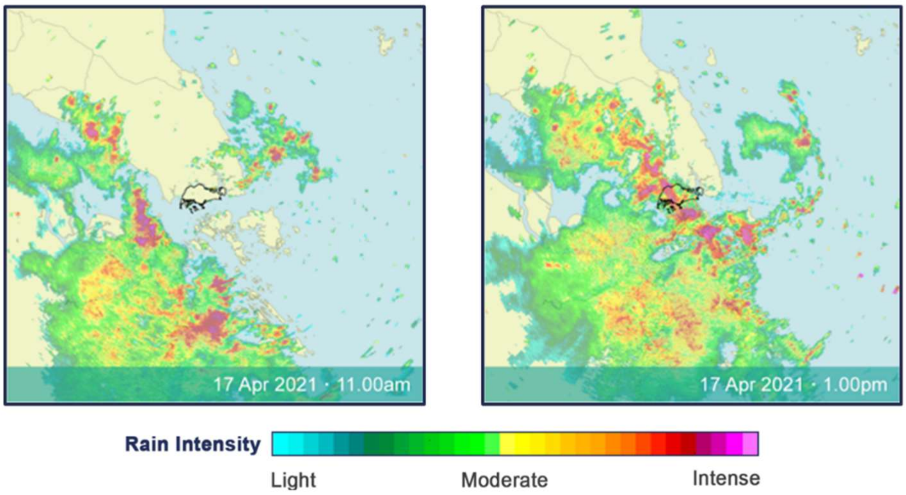


Figure 11: Weather radar images showing an organised line of thunderstorms from a Sumatra squall approaching Singapore (left) and bringing widespread thundery showers in the afternoon (right) on 17 April 2021.

Rainfall was heaviest over the western and southern parts of the island with a number of stations recording over 100 mm of rainfall. Of note was the daily total rainfall of 170.6 mm recorded at Ulu Pandan, the highest recorded for April 2021. It also set a record for the highest rainfall in a day for April, breaking the previous record of 159.9 mm set on 25 April 2007.

Figure 12: Heavy rain from a Sumatra squall led to flash floods along Dunearn Rd on 17 April 2021. (Photo credit: Robin Low)

Unseasonably Wet August

Climatologically, August is among the drier months of the year. However, August 2021 was anomalously wet, with well-above average rainfall recorded across the entire island. There were two days with exceptionally heavy rain that led to flash floods in some areas.

On the morning of 20 August 2021, the convergence of two wind flows from the south and west-northwest of Singapore brought widespread thundery showers to the island and its surrounding vicinity. Rainfall was heaviest over the central, northern, and eastern parts of Singapore, and several areas including Hougang, Choa Chu Kang, Pasir Ris, and Ang Mo Kio recorded more than 100 mm of rainfall.

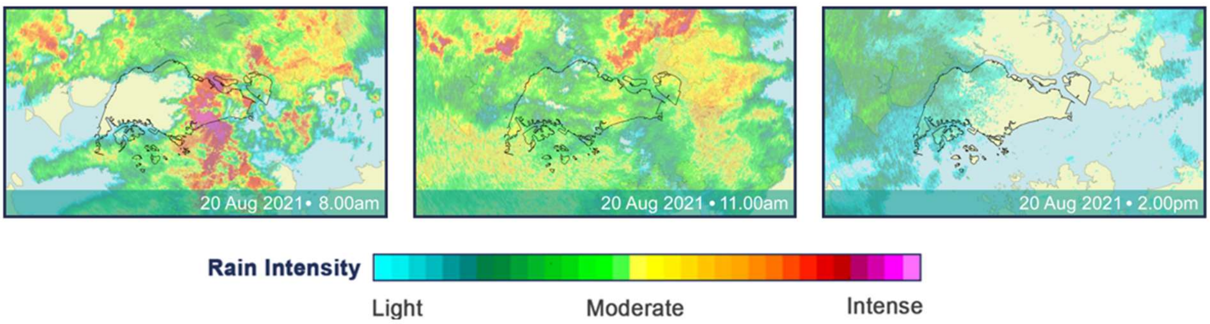


Figure 13: Sequence of weather radar images between 8am and 2pm on 20 August 2021 showing widespread thundery showers affecting Singapore on 20 August 2021.

On 24 August 2021, several spells of moderate to heavy thundery showers, induced by large-scale convergence of winds, fell over the entire island in the pre-dawn hours and morning. The rainfall station at Mandai recorded a remarkable daily total rainfall of 247.2 mm, setting a record for the highest daily total rainfall for August, and far surpassing the previous high of 181.8 mm at Changi on 22 August 1983. It was also the wettest day of 2021.

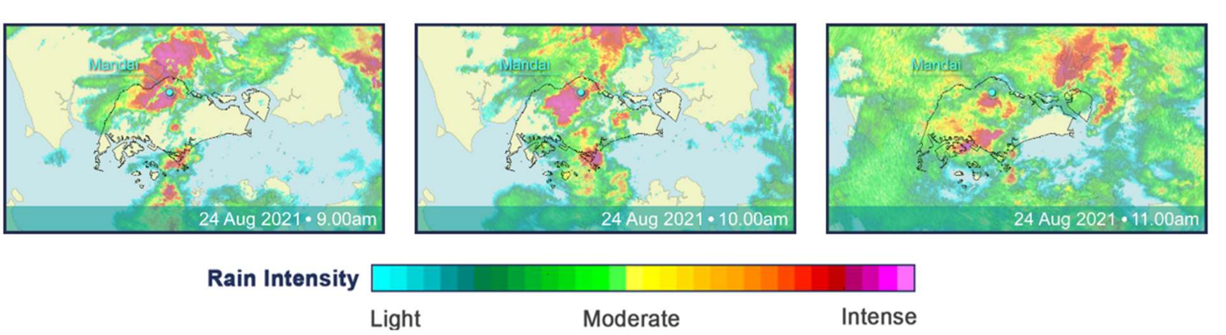


Figure 14: Sequence of weather radar images between 9am and 11am showing multiple spells of widespread moderate to heavy rain on 24 August 2021.

A combination of factors contributed to the exceptionally wet weather in August 2021. These include the influence of the negative phase of the Indian Ocean Dipole (IOD), developing La Niña conditions, and the passage of the wet phase of the Madden-Julian Oscillation (MJO) over the region. Based on the islandwide average, August 2021's total rainfall of 426.2 mm was the highest since 1980, exceeding the previous high of 346.6 mm in 1996.

Large-scale Climate Variability in 2021

The two key climate drivers at the annual scale in 2021 were El Niño – Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). The conditions in both Pacific and Indian Oceans tended to increase the chance of wetter conditions for Singapore — contributing to the wetter-than-average rainfall in 2021. An overview of the climate drivers affecting Singapore and the surrounding region is included below, followed by further details of ENSO, IOD, and Madden-Julian Oscillation (MJO).

Climate Drivers Affecting Weather and Climate in the Region

The major weather and climate features are influenced by climate drivers operating on different temporal and spatial scales, from the seasonal migration of the monsoon (i.e., the Intertropical Convergence Zone (ITCZ), ENSO, IOD, and the MJO), to smaller scale features such as Sumatra squalls, the Borneo Vortex and remote influences from tropical cyclones (see Figure 15). These features, sometimes several occurring at the same time, affect the regional pattern in rainfall, temperature, winds, ocean currents, and many other aspects of the climate and the environment in general.

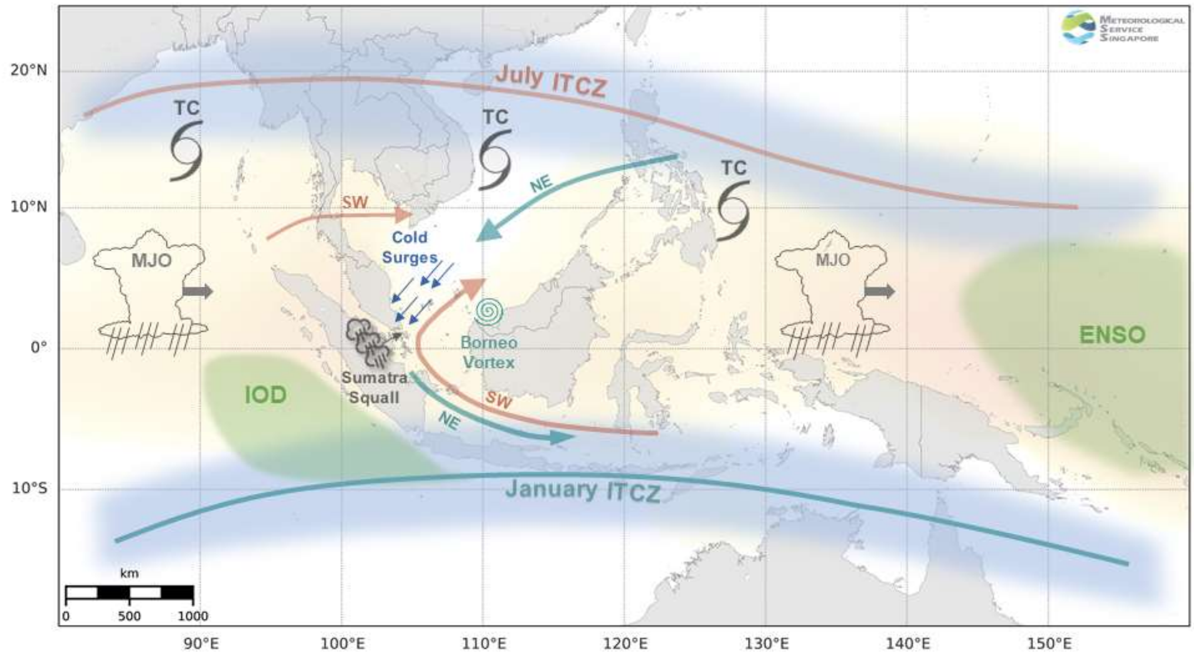


Figure 15: Climate drivers influencing weather and climate for the region around Singapore. Included are the average position of the Intertropical Convergence Zone (ITCZ) in blue indicating the furthest northward and southward extent of the seasonal migration of the regional monsoon system. The green and orange arrows indicate the corresponding Northeast and Southwest monsoonal flows. Against the background of warm ocean waters (soft orange colour indicating regions above 28.5°C), the El Niño – Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) impact the region's rainfall patterns on seasonal and inter-annual timescales, while the Madden-Julian Oscillation (MJO) impacts the region's rainfall at weekly to monthly timescales. At shorter timescales, Sumatra Squalls, Cold Surges and the Borneo Vortex can be sources of strong rainfall events. Further afar, tropical cyclones (TCs) can develop near the ITCZ away from the equator.

Key Climate Drivers

Understanding the large- and small-scale features that influence climate variability across the Maritime Continent[4] is essential in predicting Singapore's weather and climate as well as understanding how the climate may change in the future. Such knowledge[5] helps to inform climate adaptation planning and preparedness and supports resilient development in vulnerable local communities. The provision of reliable scientific information for decision-making enables more effective adaptation planning: an essential requirement for securing sustainable development in the region.

The **El Niño – Southern Oscillation (ENSO)** is the major influence on climate variability in the western tropical Pacific and Maritime Continent. It affects the year-to-year chance of droughts, extreme rainfall and floods, tropical cyclones, extreme sea levels, and coral bleaching. A more detailed description on how ENSO affected Singapore in 2021 is provided on the next page.

The **Intertropical Convergence Zone (ITCZ)** is a persistent east-west band of converging low-level winds, cloudiness, and rainfall stretching across the Maritime Continent into the Pacific Ocean bringing monsoonal rains. It migrates every year southward across the equator and back again, affecting most countries across the Maritime Continent.

Indian Ocean sea surface temperatures impact rainfall and temperature patterns across the Maritime Continent. Warmer than average sea surface temperatures can provide more moisture for weather systems crossing the region. Sustained changes in the difference between sea surface temperatures of the tropical western and eastern Indian Ocean are known as the **Indian Ocean Dipole (IOD)**. The IOD has three phases: neutral, positive, and negative.

The **Madden-Julian Oscillation (MJO)** can be characterized as an eastward moving "pulse" of cloud and rainfall near the equator that typically takes around 30 to 60 days to circle the globe, although the signal of the MJO in the tropical atmosphere is not always present. MJO effects are most evident over the Indian Ocean and the Maritime Continent. Besides influencing the region's wind and bringing more rain, it can also bring periods of drier conditions associated with its dry or 'suppressed' phase.

A **Sumatra Squall** is an organised line of thunderstorm that develops over Sumatra or the Strait of Malacca, and typically moves eastward towards Singapore under the influence of south-westerly or westerly winds. It commonly occurs during the Southwest Monsoon and Inter-monsoon periods, and usually affects Singapore overnight or in the morning, often bringing strong gusty surface winds of 40 to 80 km/h and heavy rain lasting from one to two hours.

A **Borneo Vortex** typically appears off the northwestern coast of northern Borneo. If a monsoon cold surge event coincides with a vortex, Singapore can experience enhanced rainfall as the convection strengthens over northwest Borneo and weakens north of Java. The lifetime of the vortex is typically a few days.

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[4] The Maritime Continent covers the maritime portion of Southeast Asia, including Indonesia, Malaysia, Philippines, and Singapore.
[5] More information is available via http://www.weather.gov.sg/learn_weather_systems/ and http://www.weather.gov.sg/learn_climate/.

Tropical cyclones (TCs) typically form over large bodies of relatively warm water away from the equator. Because of the large-scale spatial extent of some TCs, they can have a remote impact on Singapore's weather.

The El Niño – Southern Oscillation (ENSO) Overview

The key driver from the tropical Pacific Ocean in 2021 was ENSO, with the occurrence of two back-to-back La Niña events. The La Niña conditions from the second half of 2020 continued into the start of 2021, as indicated by the Nino3.4 index in Figure 16. These La Niña conditions steadily weakened and returned to neutral by mid-2021. After around four months of ENSO neutral conditions, La Niña conditions again developed, increasing in strength towards the end of 2021.

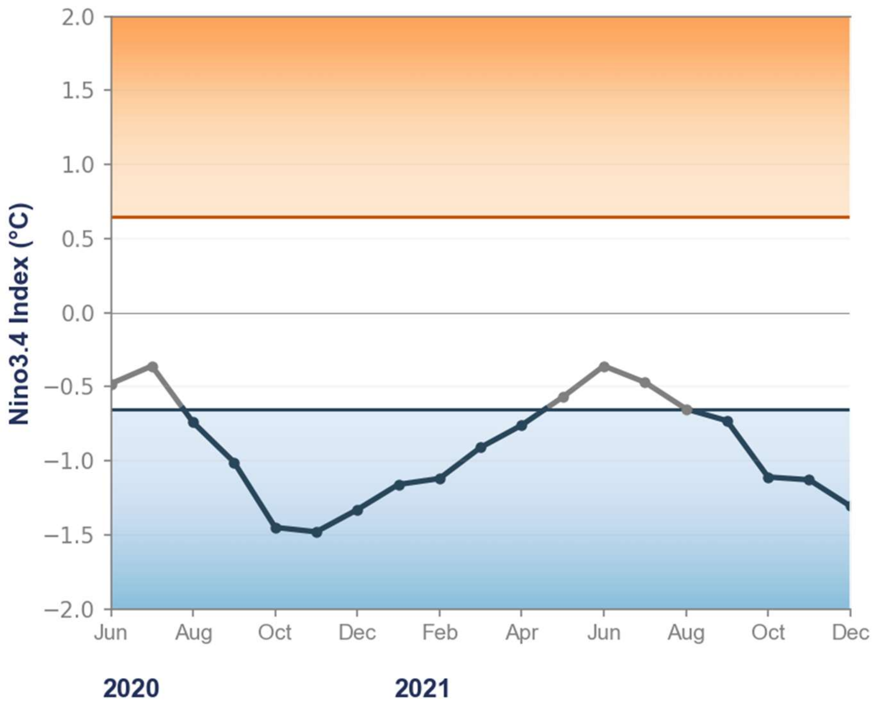


Figure 16: Nino3.4 index from June 2020 to December 2021. The index indicates two periods of La Niña conditions between August 2020 and April 2021, and from August/September 2021 onwards.

Back-to-back La Niña events, or two La Niña events separated by less than a year, are not uncommon. The last time there were back-to-back La Niña events was in 2016 followed by 2017/2018, as well as in 2010/2011 followed by 2011/2012. However, while back-to-back La Niña events are not uncommon, it is unusual to see back-to-back El Niño events.

The Indian Ocean Dipole (IOD) Overview

The IOD refers to a broad pattern of temperature differences in the western and eastern Indian Ocean. The IOD Index measures the difference between the sea surface temperature anomalies in the western and eastern tropical Indian Ocean. Sustained positive (negative) values indicate a positive (negative) IOD event.

In the first half of 2021, the IOD Index fluctuated around neutral. However, towards the middle of the year, there were signs of a negative IOD developing, with the negative IOD established by the third quarter. The strength of the negative IOD varied in the second half of the year: strongest in July 2021, weakening in August, and then strengthening again in September. However, by December 2021 the IOD Index was close to zero, indicating a return to neutral.

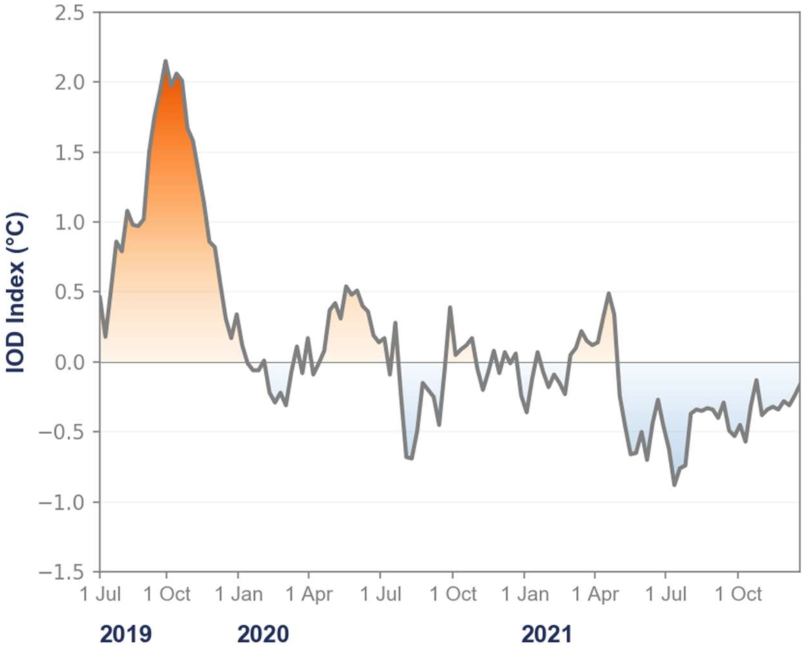


Figure 17: The Indian Ocean Dipole (IOD) Index[6] shows negative values from around June 2021 onwards. However, the magnitude of the negative IOD event is much smaller compared to the strong positive IOD in the second half of 2019.

Negative IOD Events and Their Relationship with La Niña Events

By September 2021, there was a negative IOD event in the Indian Ocean and a La Niña event in the Pacific Ocean. The co-occurrence of negative IOD events and La Niña events is not uncommon, although there are differences in when IOD and ENSO events develop, as well as how long they last for. Since 1960, all negative IOD events have either occurred under ENSO neutral conditions or when a La Niña event has developed or is developing.

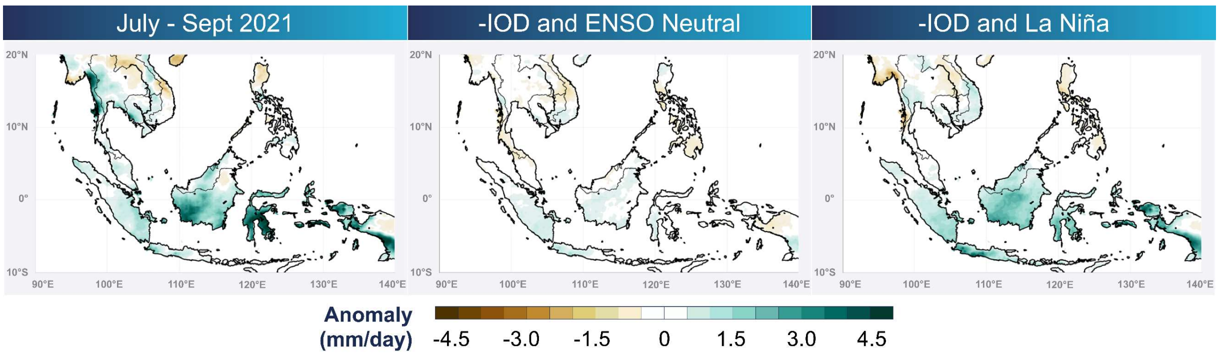


Figure 18: July – September 2021 rainfall anomalies[7] against the 1991 – 2020 climatology (left). This is compared to the four previous negative IOD (−IOD) events when there were ENSO neutral conditions (middle) and four −IOD events when there were La Niña conditions (right). Much of the Maritime Continent experienced wetter than usual conditions in all three cases, although on average the anomalies were larger when a −IOD event co-occurred with a La Niña event.

[6] Data source: Bureau of Meteorology, Australia
[7] Data source: Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)

Negative IOD events and La Niña events both bring wetter than usual conditions to Singapore and the surrounding region, including during July – September (the time when negative IOD events typically peak). While no two negative IOD events, or two La Niña events, are alike, based on past events, Singapore and the surrounding region typically receive more rainfall when both negative IOD and La Niña events are present compared to when there is only a negative IOD event.

The Madden-Julian Oscillation (MJO)

At the subseasonal timescale, the MJO is an important driver for climate variability in Singapore. The MJO's path along the equatorial region is divided into sub-geographical locations, or phases, marked by the location of enhanced/suppressed rainfall or convective activity. While the MJO is not always present, when it does occur, it can provide predictability for rainfall in the coming weeks.

In 2021, there were two notable months for the MJO, which influenced the regional rainfall patterns: February and August (Figure 19). In the first half of February 2021, there was an MJO signal in the Western Pacific (Phases 6 and 7 based on the MJO phase diagram in Figure 19 upper left). While the signal weakened in the second half of the month and was likely influenced by other climate drivers, the slow-moving signal from the first half of the month made an impact on the region's rainfall. Around February, MJO Phase 6 typically brings wetter conditions to the eastern half of the Maritime Continent, while MJO Phase 7 typically brings drier conditions to the western half of the Maritime Continent, including Singapore. This wet/dry pattern is also seen in the rainfall for the region (Figure 19 lower left), with wetter than usual conditions in the eastern half of the region (green) and drier conditions in the western half (brown).

The second notable signal was in August 2021 (Figure 19 upper right). At the start of the month, a weak MJO signal was present in the Western Hemisphere (MJO Phase 8). The signal emerged over the Indian Ocean (MJO Phase 2) in the second week of August, strengthening rapidly coupled with slower eastward propagation. This MJO signal weakened in the second half of August while still over the Indian Ocean. Typically, in August, an MJO signal brings drier conditions to northeastern parts of Southeast Asia, and wetter conditions to the western Maritime Continent. In August 2021 (Figure 19 lower right), parts of northeastern Southeast Asia saw drier than usual conditions (e.g., Viet Nam, northern Philippines), while the western Maritime Continent saw wetter conditions (including Singapore). In fact, the wetter conditions in August 2021 extended to cover much of the Maritime Continent — likely due to both the negative IOD in the Indian Ocean and the developing La Niña conditions in the Pacific Ocean.

During the rest of 2021, the other MJO signals were either much weaker (e.g., July 2021), or propagated faster around the equator (e.g., April, May 2021), with a less pronounced influence on Singapore's and the surrounding region's rainfall.

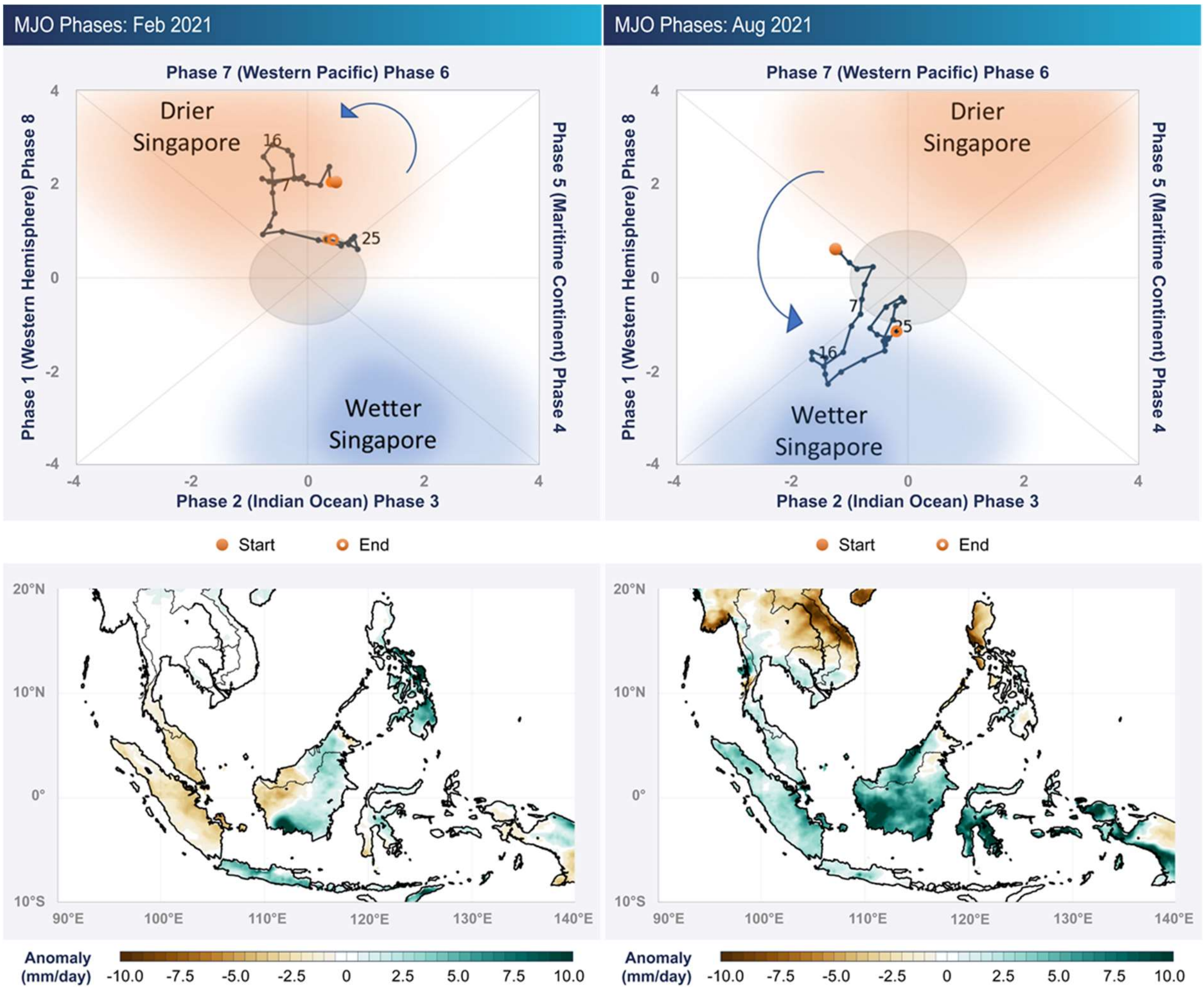


Figure 19: Upper: MJO Phases for February 2021 (left) and August 2021 (right). Lower: Monthly rainfall anomalies for February 2021 (left) and August 2021 (right)[8], with green colours indicating wetter than usual conditions and brown colours indicating drier than usual conditions.

[8] Data sources: CHIRPS (rainfall), Bureau of Meteorology, Australia (RMM values)

Temperature in 2021

2021 was the joint 10th warmest year in Singapore based on temperature records since 1929, along with 2018, 2014, 2009, and 2004. The annual mean temperature in 2021 was 27.9°C, which was 0.1°C above the 1991 – 2020 long-term average of 27.8°C. The last 10 years from 2012 to 2021 is the warmest decade on record.

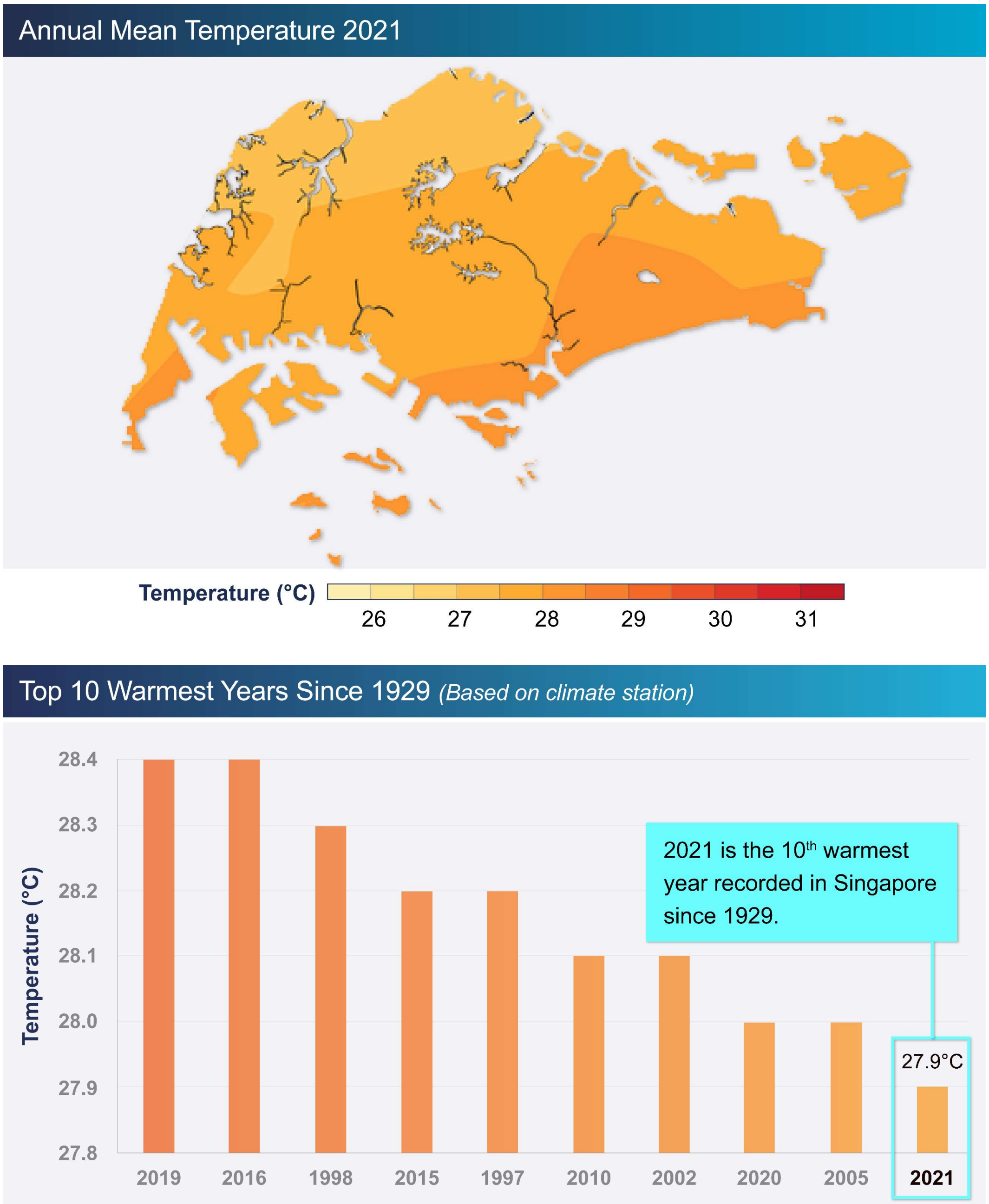


Figure 20: Annual mean temperature across Singapore in 2021 (top) and the top 10 warmest years on record (based on the Changi climate station).

Globally, significant parts of the world recorded above average temperatures (Figure 21). It is expected that the global average temperature for 2021 will be between the fifth to seventh warmest year on record[9]. The global temperature is cooler in 2021 than recent years,

[9] This is based on the WMO State of Global Climate 2021 provisional report, which references several independently maintained global temperature datasets: HadCRUT.4.6 produced by the UK Met Office in

associated with the La Niña conditions that bring a temporary cooling effect, although this does not reverse the long-term warming trend. Globally, 2021 is around 0.18 to 0.26°C warmer than in 2011 (after the previous major La Niña event in 2010/2011). Furthermore, it is likely that the past seven years, 2015 to 2021, will be the seven warmest years on record.

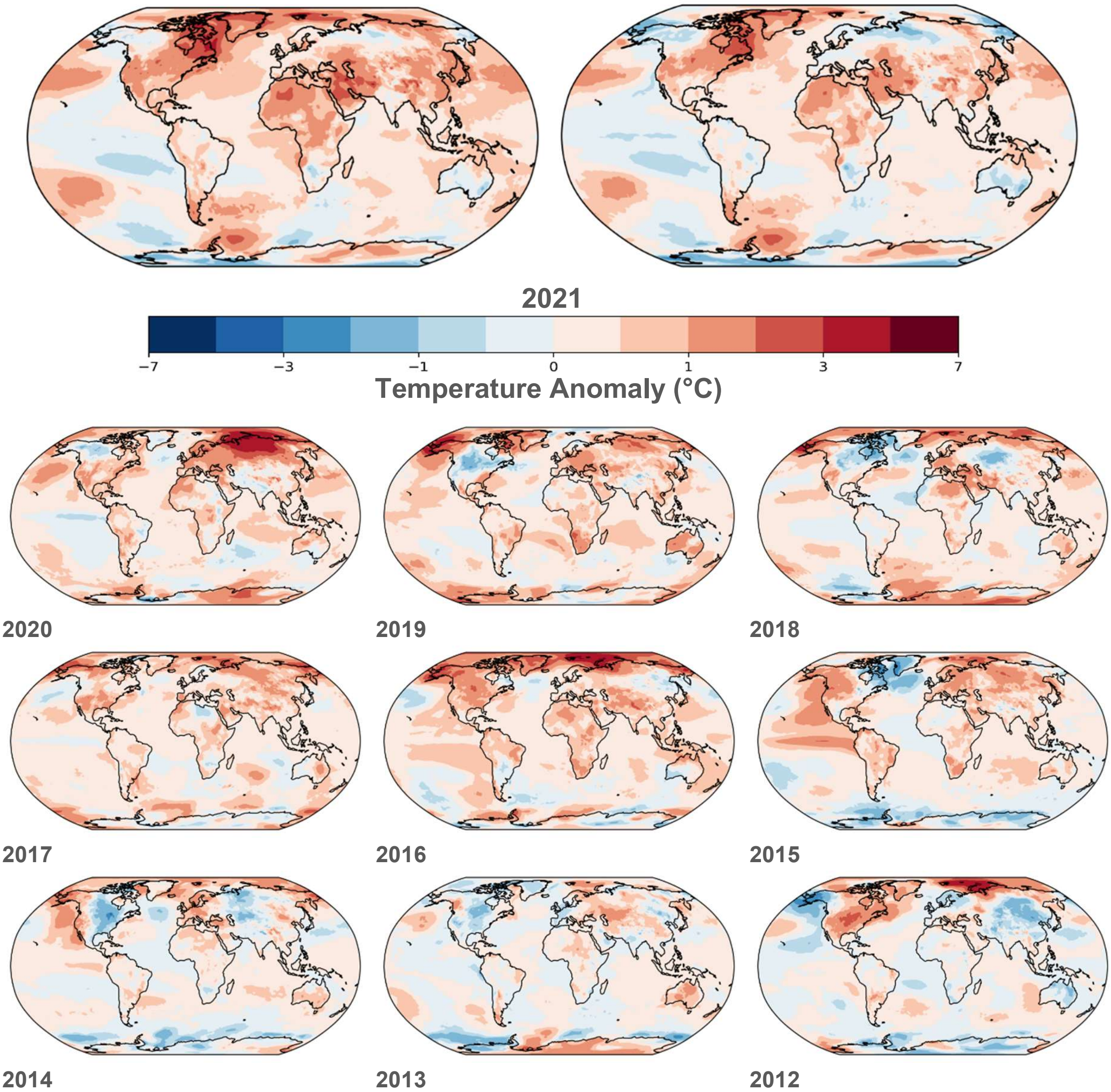


Figure 21: Global annual surface air temperature anomaly for 2021 (top; relative to the old climatological period from 1981 to 2010 on the left and new period from 1991 to 2020 on the right). Subsequent figures show the anomalies relative to the new climatological period from 1991 to 2020 for the past 10 years.[10]

collaboration with the Climatic Research Unit at the University of East Anglia, UK; NOAA Global Temp produced by National Oceanic and Atmospheric Administration, National Centers for Environmental Information, USA; GISTEMP produced by the National Aeronautics and Space Administration Goddard Institute for Space Studies, USA; JRA-55 produced by the Japan Meteorological Agency, Japan; and ERA-Interim produced by ECMWF.

[10] Data source: ERA5

Rainfall in 2021

2021 was quite a wet year and ranked as the second wettest in the past 40 years (Figure 22). The annual total rainfall was above average across Singapore (Figure 23), with an islandwide average annual total rainfall of 3167.7 mm, around 25% above the long-term annual total of 2534.4 mm. Similarly, the annual total rainfall of 2809.6 mm at the Changi climate station was 33% above its long-term annual average of 2113.3 mm.

Considering the individual months, January and August have the highest wet anomalies, followed by April and September (see Figure 24). March, May, June, and July recorded a mix of below and above average rainfall, although overall were wetter than average. While 2021 was a wet year overall, there were also months that were drier than usual. February has the driest anomalies, followed by December. Finally, October and November also recorded a mix of below and above average rainfall, although overall were drier than average.

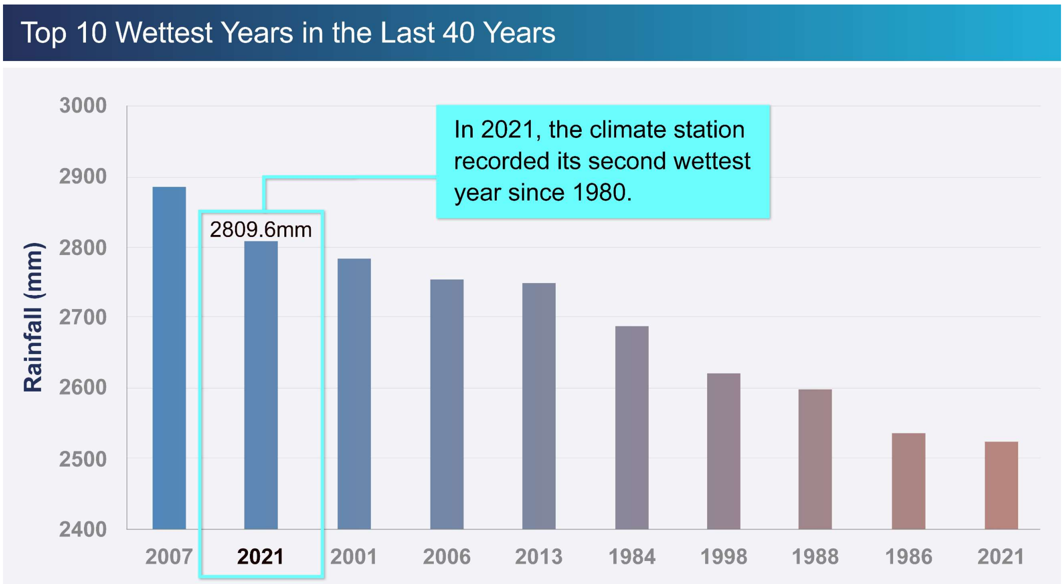


Figure 22: The top 10 wettest years in the last 40 years based on the Changi climate station

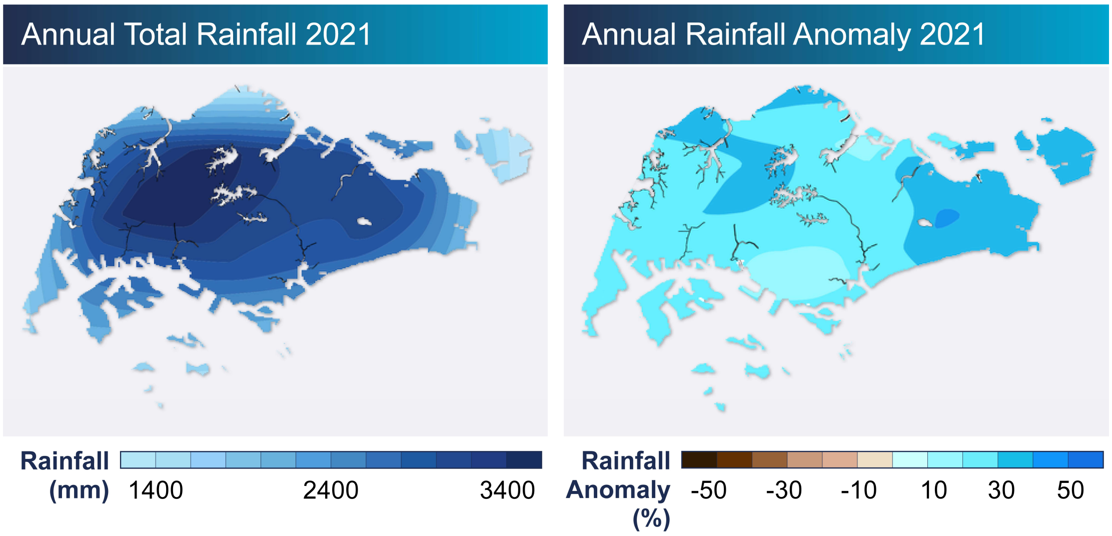


Figure 23: Annual total rainfall distribution across Singapore in 2021 (left), and annual rainfall anomalies (in percentage term) across Singapore in 2021 (right).

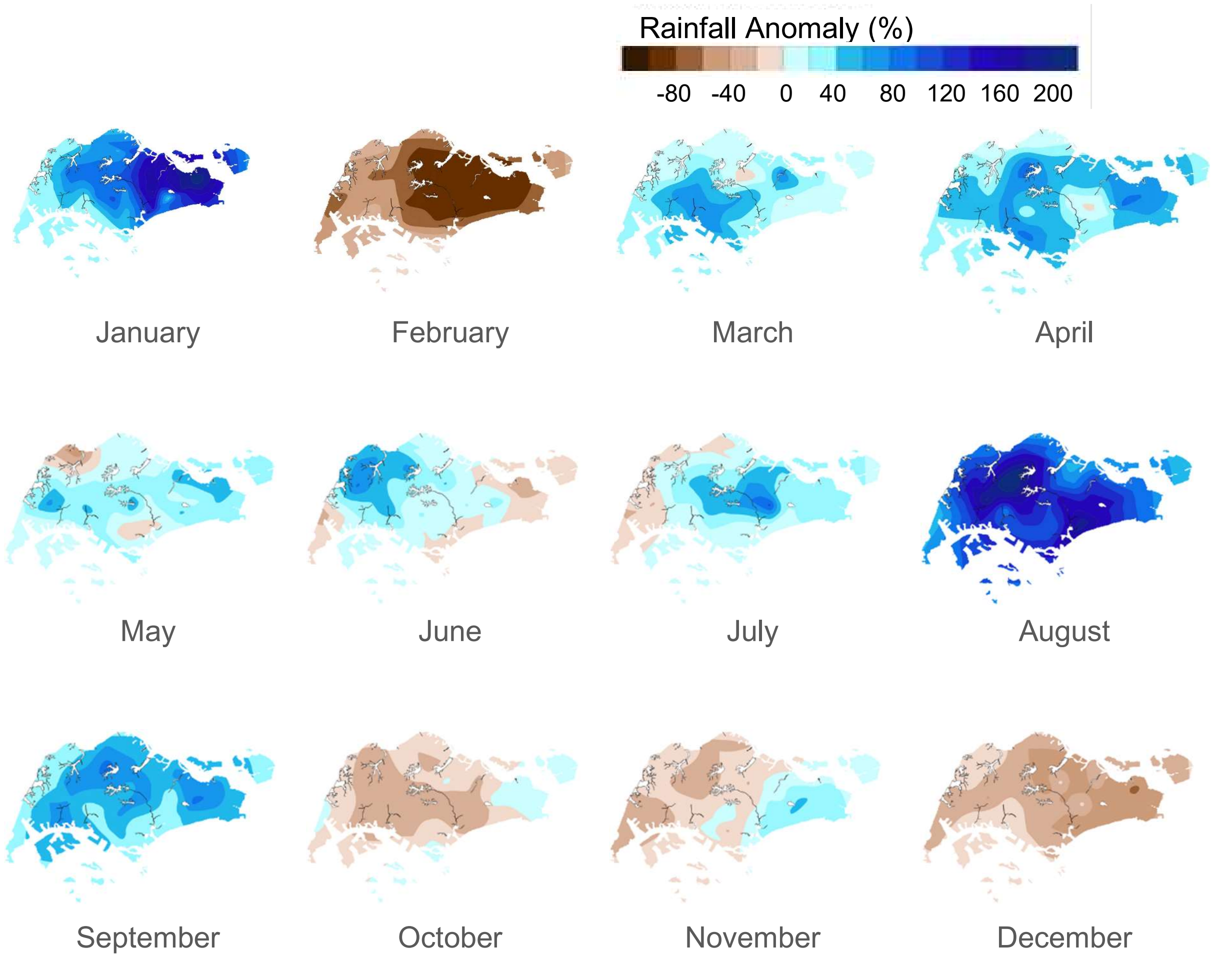


Figure 24: Monthly rainfall anomalies (in percentage term) across Singapore in 2021 (relative to the new climatological period 1991 – 2020 for the particular month).

New Climatological Normals

In 2021, MSS updated the 30-year climatological period to 1991 – 2020, from the previous 1981 – 2010 period. This change means that from 2021, there are updated reference points to compare whether Singapore is warmer, wetter, or windier than usual.

What Are the Climatological Normals?

The climatological normals are based on long-term historical averages, and therefore provide information on what weather conditions typically occur at a particular period of the year at a given location. The normals also provide a basis on which conditions can be compared (e.g., to answer questions such as 'was Singapore wetter than usual?').

A climatological normal is calculated over a 30-year period. For example, the current annual rainfall climatological normal for Singapore is the average annual rainfall between 1991 and 2020. The 30-year period is a reasonable duration to capture the average conditions and minimise the effect of long-term trends that make historical observations less representative of current conditions. Periods shorter than 30 years are not usually recommended as they may be influenced by climate variability, especially climate phenomena such as ENSO.

Why Are the Climatological Normals Updated?

Due to evolving climate conditions, the older climatological normals become less representative of current conditions. Therefore, climatological normal updates are necessary to utilise more recent climate information to provide a more accurate reflection of current typical conditions. The World Meteorological Organization (WMO) guidelines state that climatological normals should be updated every 10 years.

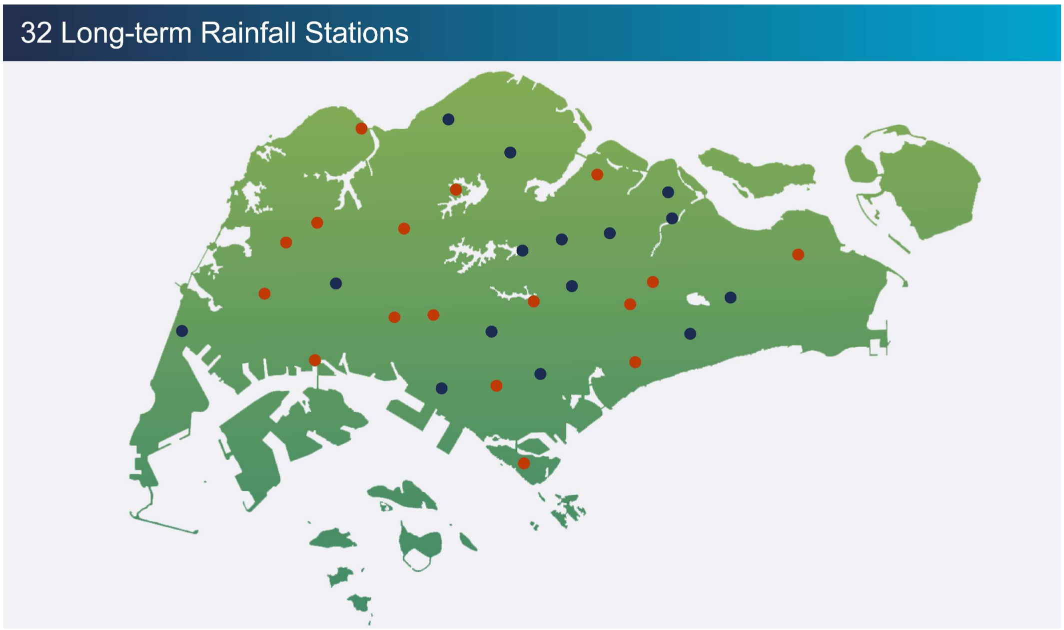


Figure 25: Locations of the 32 rainfall stations for the new climatological normals with continuous long-term rainfall records from 1991 to 2020, which comprise 1) Existing rainfall stations used in the previous 1981 – 2010 climatological normal (red dots), and 2) Newly added rainfall stations (blue dots).

A new climatological period also allows for more observing stations to be included. For the new climatological rainfall normals, the rainfall network has been expanded from 28 to 32 stations with continuous long-term records from 1991 to 2020 (Figure 25). While some of the new stations are replacing old stations that are no longer operational, the new stations also improve the data spatial coverage. Hence, measurements from an updated set of 32 stations are now used to compute the islandwide average for the new 30-year climatological normals.

Are There Any Differences Between the Old and New Climatological Normals?

The new temperature normals are generally warmer than the previous normals. Consistent with global trends, the influence of the long-term warming trend is reflected in the new climatological temperature normal. At the Changi climate station, the new climatological monthly and annual mean temperatures were warmer than the old climatological normals (Figure 26). The new monthly mean temperature is warmer across all months of the year, with the period 1991 – 2020 between 0.2°C and 0.4°C warmer than 1981 – 2010.

For the new annual mean temperature normal, the entire interquartile range (IQR) and its minimum and maximum are also higher than the statistics from the previous climatological normal. Notably, the minimum observed annual mean temperature between 1991 and 2020 is warmer than the lower interquartile range between 1981 and 2010. This means that the coolest year between 1991 and 2020 is still warmer than 25% of the years between 1981 and 2010, which is more remarkable given that the two climatological periods overlap by 20 years.

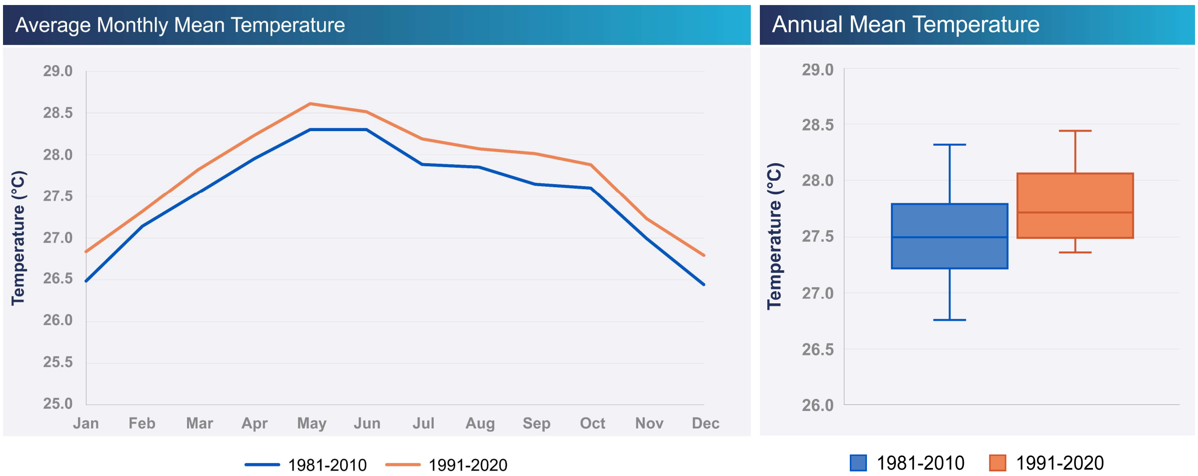


Figure 26: Climatological monthly mean temperature (left) and annual mean temperature[11] variations (right), for climatological period 1981 – 2010 (blue) and 1991 – 2020 (orange) at the Changi climate station.

Taking 2021 as an example, the annual mean temperature was 27.9°C, which is 0.1°C above the new long-term average, but 0.4°C above the old long-term average (based on the 1981 – 2010 base period). The change in climatological period affects the size of differences between any year and the reference period, but long-term trends remain unaffected.

[11] The box plot (Figure 26 right and Figure 27 right) summaries the data in the climatological period: half of the years are within the solid box (the limits of the box are the 25th and 75th percentile values), while the whiskers indicate the maximum and minimum values in the 30-year period. The median, or middle value, is the solid line within the box.

Overall, there is little change in the new climatological rainfall normals (Figure 27). The average monthly total rainfall and annual total rainfall amounts for 1981 – 2010 and those for 1991 – 2020 are similar.

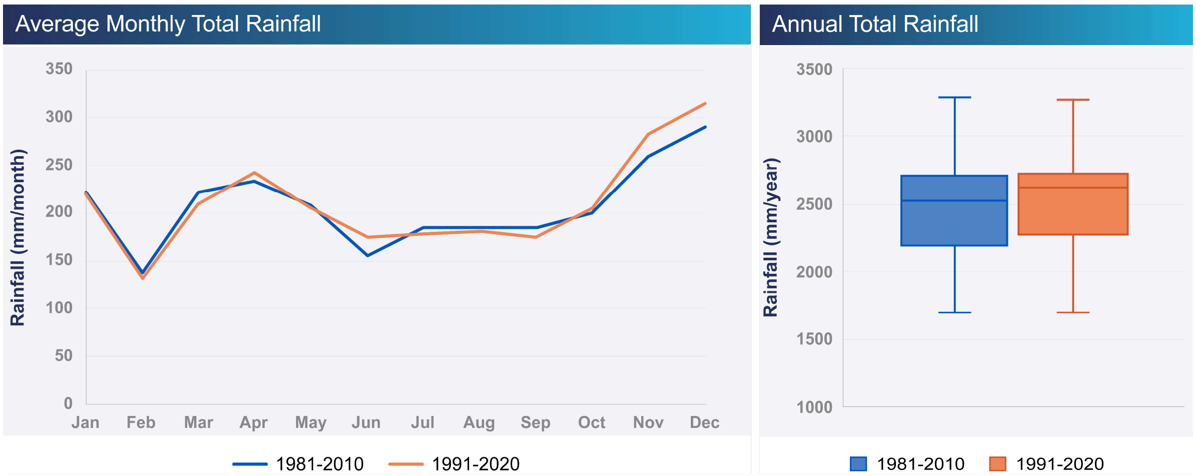


Figure 27: Climatological mean monthly total rainfall (left) and mean annual total rainfall variation[11] (right) for climatological period 1981 – 2010 (blue) and 1991 – 2020 (red).

The spatial distribution of rainfall over Singapore is also similar between the two climatological periods, with the highest rainfall on average recorded in the central and western parts of the island (Figure 28). In the eastern half of Singapore, there is no noticeable difference in the average annual total rainfall, with only marginally higher rainfall over the western half of Singapore observed in 1991 – 2020 compared to 1981 – 2010.

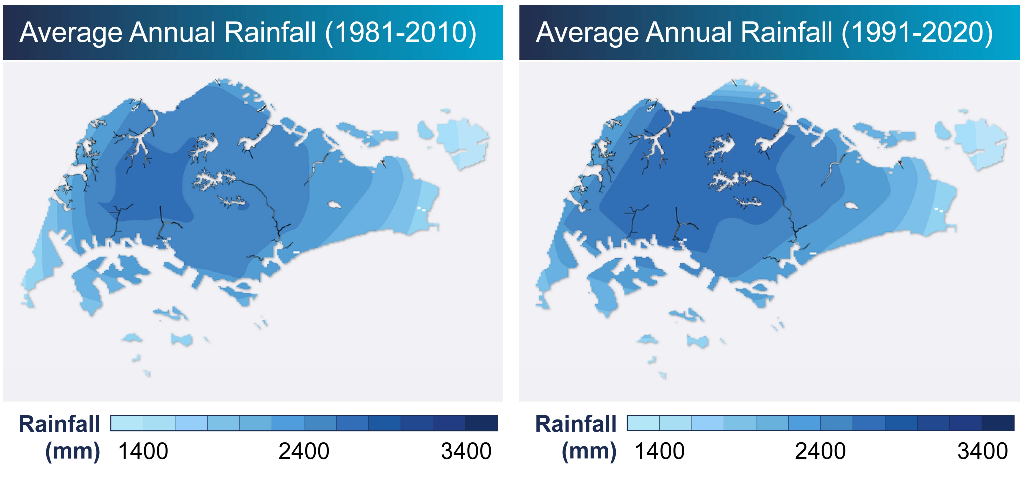


Figure 28: Annual total rainfall distribution across 28 stations for the previous climatological period 1981 – 2010 (left) and new climatological period 1991 – 2020 with 32 stations (right).

General Climate of Singapore

Singapore has a tropical climate which is warm and humid, with abundant total annual rainfall of approximately 2200 mm. Generally, the eastern parts of Singapore receive less rainfall compared to other parts of the island. The winds are generally light but with a diurnal variation due to land and sea breezes.

The temperature variation throughout the year is relatively small compared to the mid-latitude regions. The daily temperature range has a minimum usually not falling below 23–25°C during the night, and a maximum usually not rising above 31–33°C during the day.

Singapore's climate is traditionally classified into four periods according to the average prevailing wind direction:

a) Northeast Monsoon (December to early March).
b) Inter-monsoon (Late March to May).
c) Southwest Monsoon (June to September).
d) Inter-monsoon (October to November). The transitions between the monsoon seasons occur gradually, generally over a period of two months (the inter-monsoon periods). The winds during the inter-monsoon periods are usually light and variable in direction.

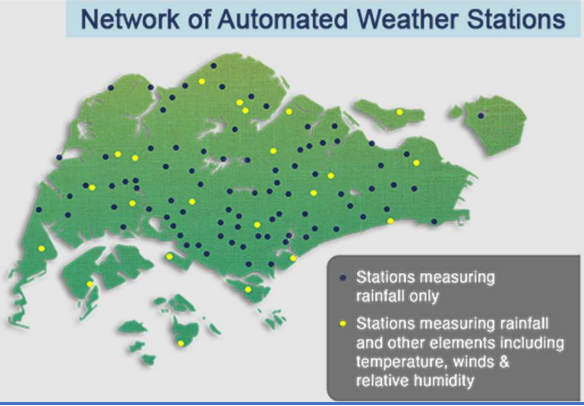
Average Annual Rainfall (1991–2020)
(based on 32 rainfall stations)

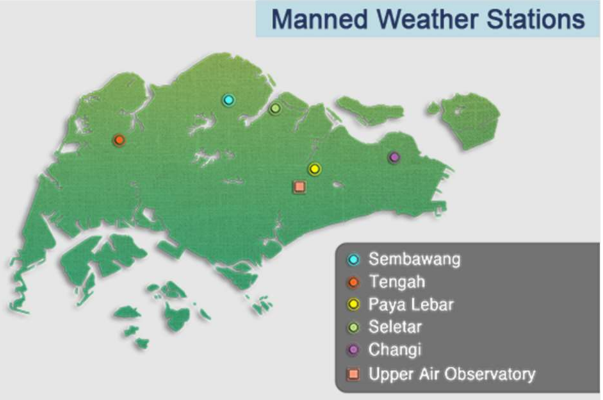
The three main rain-bearing weather systems that affect Singapore are the localised convective showers/thunderstorms, Sumatra squalls, and Northeast Monsoon surges. The convective showers/thunderstorms occur throughout the year while Sumatra squalls commonly occur between April and November. The monsoon surges occur during the Northeast Monsoon season.

Sea Breeze Induced Thunderstorms: Sea breezes are winds formed as a result of temperature differences between the land and the adjoining sea. The sea breeze, carrying a large amount of moisture from the sea, blows inland during the day where the moist air mixes with the rising warm land air and, under unstable conditions, form rain clouds in the afternoon. During the Inter-monsoon periods, when winds are light, sea breezes are more common.

Sumatra Squalls: A Sumatra squall is an organised line of thunderstorm that develops over Sumatra or the Strait of Malacca, often overnight, and moves eastward to affect Peninsular Malaysia and Singapore. In a typical event, the squall line can bring about one to two hours of thundery showers. Often this happens in the predawn or morning hours. Some Sumatra squalls are also accompanied by strong wind gusts with speeds up to 80 km/h (22 m/s) which can uproot trees.

Northeast Monsoon Surges: A Northeast Monsoon surge is a surge of cold air from Central Asia. During the period December through early March, the continental northern Asia including Siberia experiences very low, cold temperatures. From time to time, this cold air surges southward from Central Asia to the South China Sea. This results in a sudden increase in northeasterly winds over the South China Sea blowing toward the warm tropics. The sea warms and moistens the overlaying air and the winds converge to bring widespread rain in the tropics. December and January are usually the wettest months of the year in Singapore. The few widespread moderate to heavy rain spells caused by surges of Northeast Monsoon winds contribute significantly to the rainfall in these months. A typical rain spell generally lasts for a few days.





About the Meteorological Service Singapore (MSS)

The MSS is Singapore's national authority on weather and climate. It is a pillar under the National Environment Agency (NEA).

MSS currently operates a network of five manned observation stations, one upper air observatory and around 100 automatic weather stations. All the automatic weather stations measure rainfall and more than one-fifth of them measure other meteorological elements including temperature, relative humidity, pressure, and wind. This observation network serves as the main source of climate data for this report.

The manned observation station at Changi is MSS's designated climate station. The climate station, first located at Outram in 1869, has moved several times over the years due to changes in local land use, before moving to its current site at Changi. The climate station serves as the reference station where its records are used for tracking the national long-term climate trends. The oldest climate station records are for monthly rainfall (starting from 1869) and temperature (starting from 1929, with a break from 1942 to 1947).

The installation of the automatic weather station network from 2009 greatly expanded the coverage of weather observations across Singapore. Prior to this, there were around 40 manual rainfall stations and just a few temperature stations in Singapore. For the purpose of analysing long-term climate trends and establishing climatological averages, only stations with continuous long-term (at least 30 years) records can be used. This limits the number of stations available for such purpose to 28 stations for rainfall and three stations for temperature.

Singapore is located deep within the tropics where wind and atmospheric conditions evolve rapidly. The twice daily soundings provide the main source of complete upper air information to support operations. In addition to operational purposes, the observation records from the station would also be useful for monitoring of long-term upper air conditions in the equatorial tropics, as the records extend back many decades to the 1950s.

Further Information
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