Annual Weather Review 2013

1. Review of Weather Conditions

1.1 Northeast Monsoon Season (Jan – late March)

Weak to moderate Northeast Monsoon conditions prevailed in January, February and the first half of March 2013, with the low level winds blowing predominantly from the northwest or northeast. January 2013 also saw the wet phase of the Northeast Monsoon reaching its peak, before the season gradually progressing to the drier phase.

Isolated showers occurred on most days in January 2013, mainly in the afternoon and early evening. The heaviest thundery showers occurred on 12 January 2013 where a total of 92.4mm of rainfall was recorded on that day over Scotts Road. The showers were caused by the convergence of winds, coupled with afternoon heating of land areas.

A weak to moderate monsoon surge affected the region between 18 and 21 January 2013 with intermittent rain was experienced throughout the surge period. For January 2013, most parts of Singapore received below average rainfall. The highest rainfall of 271mm to 306mm (15 to 30% above average) fell over the north-eastern and eastern parts of Singapore around Seletar and Pasir Ris. Rainfall was the lowest at southwestern areas over Clementi where 118mm to 153mm (35 to 50% below average) of rain was recorded.

February 2013 was relatively wet as moderate to heavy rainfall affected Singapore in the afternoon on several occasions. The heaviest rainfall occurred on 26 February 2013 where 154.7 mm of rain fell over the central areas near Upper Thomson. A weak monsoon surge also affected the region between 12 and 14 February 2013 resulting in periods of showers throughout the day especially on 14 February 2013.

Above average rainfall was received across Singapore in February 2013 with the highest rainfall of 460mm to 530 mm (200 to 230% above average) fell over the central and southern parts of Singapore mainly around Peirce and Kent Ridge areas. The rainfall was the lowest over Katong and Punggol where 230mm to 280mm (50 to 80% above average) of rain was recorded.

Weak to moderate Northeast Monsoon conditions prevailed in the first half of March 201, and this gradually transited to Inter-Monsoon in the second half of the month. This first half of March 2013 saw a few days of fair and windy conditions due to the strengthening of winds over Singapore.

1.2 First Inter-Monsoon Season (late March – May)

Inter-Monsoon conditions prevailed from the second half of March. The low level winds over the region were generally light and variable in direction. The light winds

coupled with strong daytime heating brought warmer temperatures reaching 35 degrees Celsius on some days.

Short duration thundery showers occurred on several days mainly in the afternoon with the heaviest rain falling in the second half of March 2013. The intense thunderstorms were caused largely by the convergence of winds coupled with the afternoon heating of land areas. About 109mm of rain fell over the Kranji area on 28 March 2013.

Near average rainfall was received across Singapore in March 2013 with the highest rainfall of 350mm to 430mm (80 to 120% above average) over the north-western parts of Singapore around Choa Chu Kang. The rainfall was lowest over the eastern parts of Singapore near Pasir Ris where 30mm to 70mm (60 to 90% below average) of rain was recorded.

In April 2013, Singapore experienced thundery showers mainly in the afternoon and on a few days in the pre-dawn hours. The heaviest downpour took place in the morning of 28 April 2013 when 88 mm of rain fell over the Marine Parade area. The heavy rain, coupled with strong gusty winds was due to large scale convergence of winds that caused widespread thundery showers. Flash floods were reported over Ubi and Chai Chee that day.

For April 2013, most parts of Singapore received average rainfall. The highest rainfall of 330mm to 382mm (90 to 120% above average) fell over the south-western tip of Singapore around Tuas and Jurong Island. Rainfall was lowest over eastern and north-western Singapore around Changi and Lim Chu Kang where 121mm and 174mm (average to 30% below average) of rain was recorded.

Inter-Monsoon conditions continued to prevail in May 2013, and Singapore experienced thundery showers mostly in the late morning and afternoon. The heaviest downpour occurred in the late afternoon of 7 May 2013 where 86.6 mm of rain fell over Yishun. This was due to strong convection coupled with localized sea breeze convergence. This heavy rain episode resulted in flash floods over the northern and central parts of Singapore.

For May 2013, most parts of Singapore received below average rainfall. The highest rainfall of 300mm to 350mm (80 to 110% above average) fell over the north-eastern parts of Singapore around Seletar. The lowest rainfall was recorded over south-eastern and south-western parts of Singapore around Marine Parade and Queenstown where 50mm to 100mm (40 to 70% below average) of rain was recorded.

1.3 Southwest Monsoon Season (June – mid October)

During the first week of June 2013, Inter-Monsoon conditions continued to prevail over Singapore and the region with the Southwest Monsoon conditions gradually becoming established in the second week of the month. With the low level winds over the region blowing predominantly from the southeast or southwest, coupled with strong daytime heating, and drier weather conditions, Singapore experienced warm temperatures of up to 35 degree Celsius on a few days of June 2013.

Thundery showers mostly in the late morning and afternoon affected the island in June 2013 with the heaviest downpour occurring in the late afternoon of 5 Jun 2013. 68.6 mm of rain fell over the Bukit Timah area that day.

Towards mid-June 2013, a period of extended dry weather conditions in the region exacerbated the transboundary smoke haze situation causing hazy conditions to affect Singapore with the air quality reaching the hazardous range on a few occasions.

For June 2013, most parts of Singapore received below average rainfall. The highest rainfall of 202mm to 234mm (25 to 45% above average) fell over the north-eastern parts of Singapore around Seletar. The lowest rainfall fell over the south-western and southern parts of Singapore around Tuas and Marina South where 40mm to 73mm (40 to 70% below average) of rain was recorded.

Southwest Monsoon conditions continued to prevail in July 2013 with Singapore experiencing thundery showers on most days occurring mostly during the morning and early afternoon. The heaviest downpour occurred in the pre-dawn and again in the early afternoon of 9 July 2013 where a total of 118mm of rain fell over Lornie Road area. This heavy rain was attributed to the broad scale convergence of winds in the region.

For the July 2013, about two-thirds of Singapore received below average rainfall. The highest rainfall of 176mm to 207mm (15 to 35% above average) fell over the central and north-eastern parts of Singapore around Thomson and Punggol areas. Rainfall was lowest largely over the western parts of Singapore where 23mm to 54mm (65 to 85% below average) of rain was recorded.

Weak Southwest Monsoon condition in August 2013 brought about a few spells of Sumatra squalls affecting Singapore during the first half of the month. The squall that occurred on the morning of 10 August brought 67.0 mm of rainfall to the Jurong area.

Rainfall in August 2013 was slightly below average with the highest rainfall of 220mm to 250mm (25 to 40% above average) fell over the central parts of Singapore around Bishan. Rainfall was lowest over the eastern parts of Singapore around East Coast Park where 90mm to 110mm (35 to 50% below average) of rain was recorded.

Southwest Monsoon prevailed in the first half of September 2013. Singapore experienced generally wet weather conditions, and the heaviest downpour occurred in the morning of 5 September 2013 where a total of 122mm of rain fell over the Orchard area. In the last week of September, Singapore again experienced wet conditions due to the occurrence of Sumatra squalls.

Many parts of Singapore received above average rainfall in September 2013. The highest rainfall of 380mm to 440mm (125 to 150% above average) was recorded over the central parts of Singapore near Pandan. The lowest rainfall was over western parts of Singapore near Jurong Island where 160mm to 200mm (average to 25% above average) of rain was recorded.

The Southwest Monsoon conditions continued to prevail in the first half of October 2013 before gradually weakened around the middle of the month as the Inter-Monsoon conditions set in over the region.

During October 2013, Singapore experienced several Sumatra squalls in the pre-dawn hours. A severe squall that occurred on 6 October 2013 in the predawn hours brought gusty winds of up to 78 km/hr around the West coast Road area. Several episodes of heavy thundery showers coupled with flash flooding also occurred during the month. The Sumatra squall in the predawn hours of 15 October 2013 resulted in the highest daily rainfall of 129.6mm for October 2013. Flash floods were also reported in Changi and Tampines during this heavy rain event.

For October 2013, most areas of Singapore received above average rainfall with the highest rainfall of 393m to 449 mm (110 to 140% above average) fell over the eastern parts of Singapore around the Marine Parade area. The rainfall was the lowest mainly over the western parts of Singapore around Jurong Island where 112m to 187mm (average to 40% below average) of rain was recorded.

1.4 Second Inter-monsoon Season (end October – mid November)

The Inter-Monsoon conditions prevailed from end October 2013 to the first half of November 2013. Surface winds were generally weak and variable in direction. The rain band was positioned over the equatorial region during this period, resulting in wetter weather conditions over our region.

During the first fortnight of November 2013, Singapore experienced thundery showers mainly in the afternoon, largely due to convective heating and instability induced by the monsoon rain band. The highest one-day rainfall of 87.4mm was recorded on 4 November 2013 over the Clementi area. The heavy rainfall was brought about by the intense thunderstorms that developed due to the convergence of winds over our region coupled with convective heating. Flash floods were reported over several places during this heavy rain episode.

For the first half of November 2013, most parts of Singapore received above average rainfall. The highest rainfall of 353mm to 407mm (195 to 240% above average) fell over the north-eastern parts of Singapore around Seletar area. The rainfall was lowest over the south-eastern parts of Singapore around Kallang area where 84mm to 1200m (average to 30% below average) of rain was recorded.

1.5 Northeast Monsoon Season (late November – December)

Inter-Monsoon conditions gradually transitioned to Northeast Monsoon in the late November 2013 with prevailing low level winds blowing from the northwest or northeast. On several days, Singapore experienced widespread moderate to heavy thundery showers accompanied by gusty winds mainly in the predawn hours and morning.

Most parts of Singapore experienced above average rainfall in November 2013. The highest rainfall of 500mm to 556mm (80% to 100% above average) of rain fell over the north-eastern parts of Singapore around Seletar. The areas over central and eastern Singapore experienced slightly below average rainfall (0 – 20% below average).

The Northeast Monsoon conditions prevailed over the region in December 2013 with the low level winds blowing predominantly from the northeast.

A strengthening of north-easterly winds over the South China Sea, also known as the monsoon surge, affected the region on 1-3 December and again on the 19-21 December 2013. The first surge brought rainy and cool weather conditions to Singapore on these few days. In the second surge, Singapore was fortunately not affected as a shift in the wind direction confined the monsoon rain mostly to the South China Sea areas east of Singapore.

For the rest of December 2013, Singapore experienced mainly short-duration showers in the afternoon and early evening.

Slightly more than half of Singapore received above average rainfall during December 2013. The highest rainfall of 430mm to 510mm (55 to 80% above average) of rain was recorded over the central parts of Singapore near Woodleigh area. The rainfall was lowest over the southern parts of Singapore near Bukit Merah where 170mm to 200mm (25 to 40% below average) of rain was recorded.

2. Significant Weather Events

2.1 Severe Transboundary Smoke Haze in June 2013

Between June and early October 2013, the Southeast Asian region experienced the Southwest monsoon season; with the low level prevailing winds blowing form the southeast or southwest. This is typically the traditional dry season in the southern ASEAN region which includes Singapore, Malaysia and Indonesia.

During the Southwest Monsoon season, smoke haze that originated from the widespread land and forest fires is a perennial problem that affected many areas of the southern Southeast Asia. The resulting smoke is blown by the prevailing winds towards other parts of the region including Singapore, and is visible as moderate to dense haze.

Although in past years Singapore was usually affected by transboundary smoke haze episodes in September and October, Singapore and its surrounding region were blanketed by transboundary smoke haze from forest fires in the Indonesian island of Sumatra over a two-week period in June 2013. Many of the fires occurred on the peat lands along the eastern areas of central Sumatra. The smoke haze episode that occurred in Singapore was exceptional for both its severity and timing. It occurred in the month of June 2013 during a non-El Nino year and in Singapore, the 3-hour Pollutant Standard Index (PSI) reached a record high of 401 on 21 June 2013 (a record reading that is deemed “hazardous” to human health) while the 24-hr PSI

reached a record high of 246 on 22 June 2013, making this the worst transboundary smoke haze occurrence ever experienced in Singapore.

In the second week of June 2013, the 850hPa monthly mean winds showed a belt of anomalous westerly winds over the equatorial region of Southeast Asia (Fig. 1). These westerly winds were further strengthened by the presence of two tropical storms in the South China Sea on 17 – 23 June 2013. The extended dry weather coupled with the westerly winds provided the right conditions for the escalation in fire hotspots mainly in central Sumatra to be blown towards Singapore and Peninsular Malaysia.

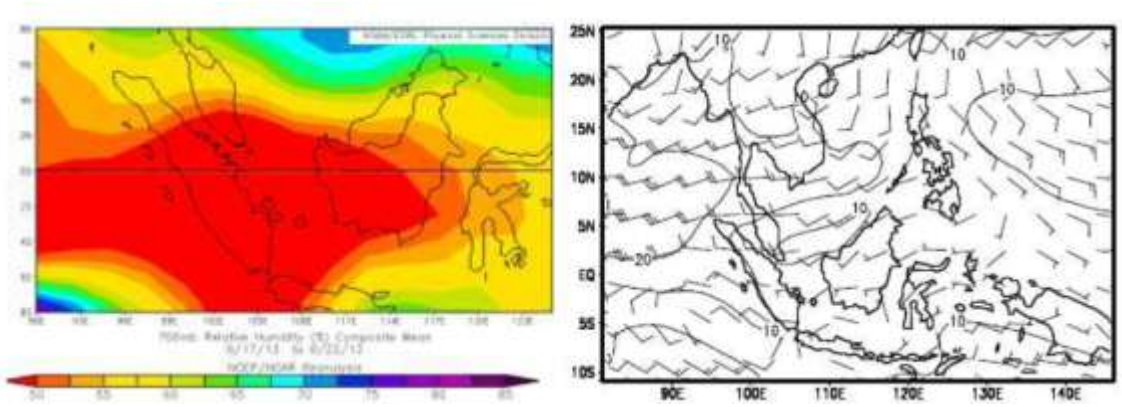

Fig.1: Relative Humidity at 700hPa (17-22 June 2013) over the southern ASEAN (NCEP Reanalysis data) and the 850hPa monthly mean wind for June 2013

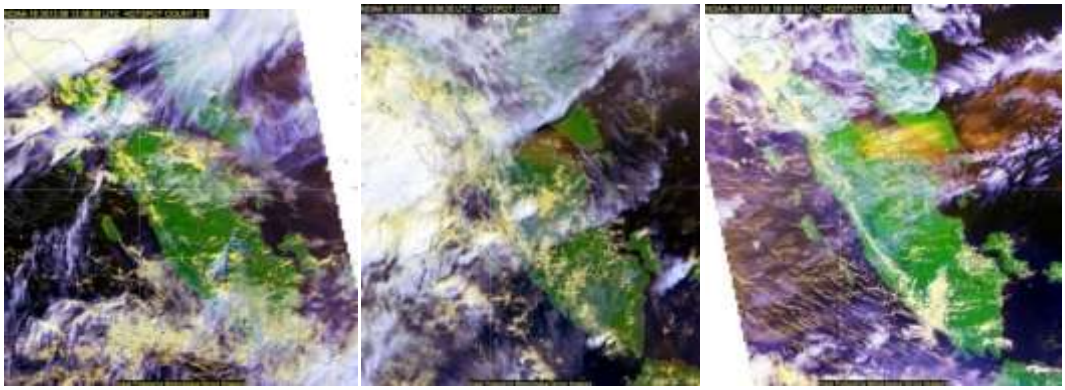

Fig.2: NOAA-18 satellite images on the 13, 16 and 18 June 2013 showing an increase in the number of hotpots counts over Sumatra

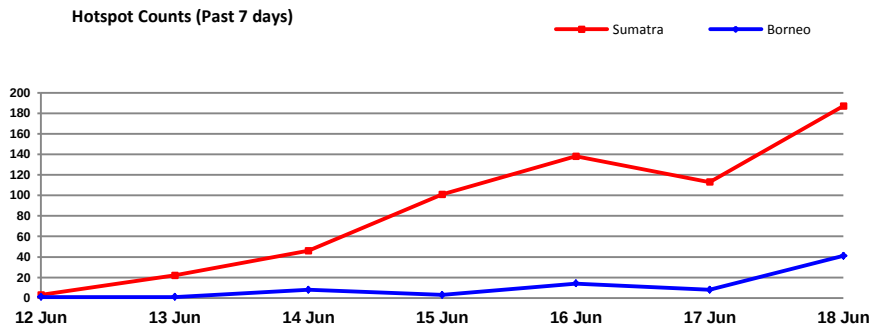

Fig.3: Hotspot Counts over Sumatra and Borneo for the period 12 – 18 June 2013

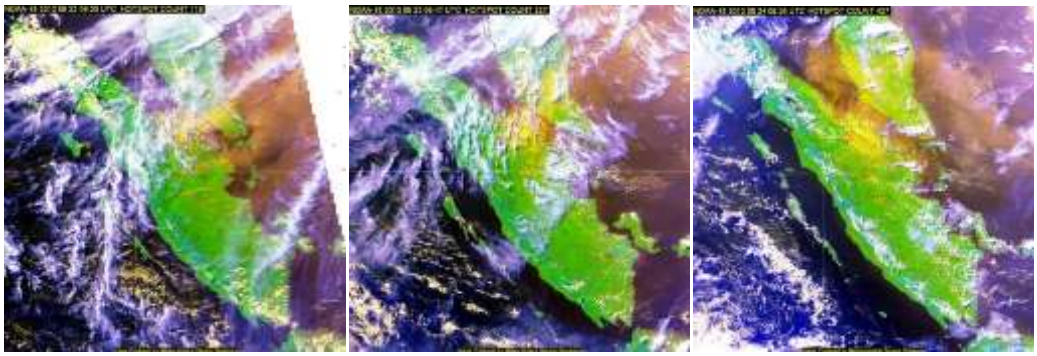

Fig.4: NOAA-18 satellite images on the 22, 23 and 24 June 2013 showing an elevated increase in the number of hotpots counts over Sumatra over the duration of three days.

Singapore started to experience slightly hazy conditions between 13 and 16 June 2013 and the 24-hr PSI was in the moderate range during this period. However, the hazy conditions deteriorated rapidly from 17 June 2013, with an escalation in the number of hotspots over Sumatra (Fig.2 and 3) and a strengthening in the prevailing westerly winds which blew the dense haze from the fires in Sumatra toward Singapore (Fig. 4). The 24-hr PSI between 17 and 23 June 2013 was in the unhealthy to very unhealthy range.

However, as a tropical storm in the South China Sea made landfall over Hanoi, the low level winds over Singapore shifted from the south-southwest and south-southeast on 24 June 2013. This shift in the wind direction brought an improvement to the haze situation in Singapore from 25 June 2013 but worsen the haze situation over southern Peninsular Malaysia as the dense haze that had earlier affected Singapore was now blown northwards. At around the same time, more rain clouds started to develop over the region including Sumatra. The rain helped to subdue the forest fires in central Sumatra leading to an improvement to the overall haze situation in the region over the next several days including Singapore (Figures 5, 6, 7 and 8).

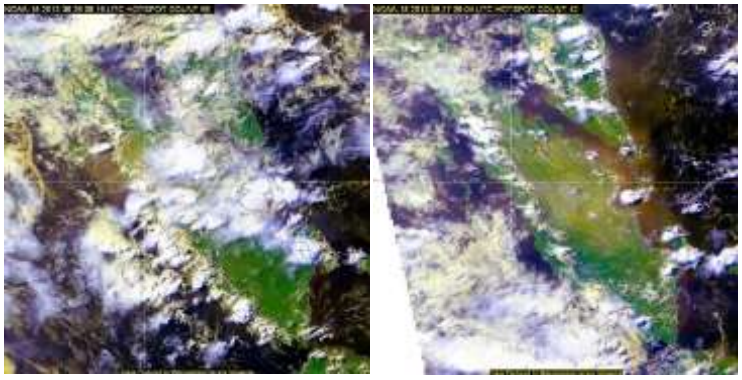

Fig.5: NOAA-18 satellite images on the 26 and 27 June 2013 showing a decrease in the number of hotpots counts as rain cloud started to develop over Sumatra and eventually subdue the forest fires leading to an overall improvement of the haze situation in Singapore.

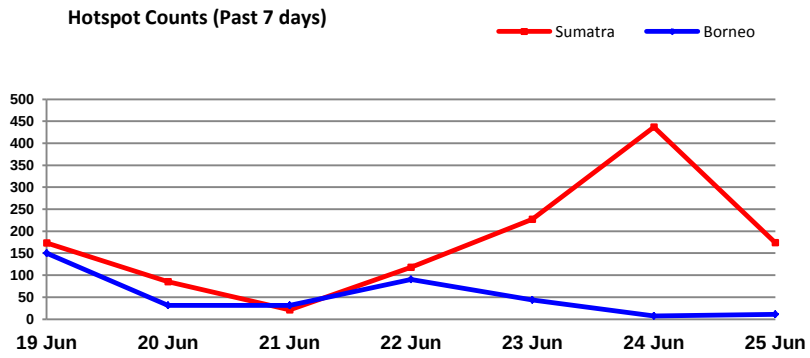

Fig. 6: Hotspot Counts over Sumatra and Borneo for the period 19 to 25 June 2013, showing the decrease of the hotspot counts after 24 June 2013.

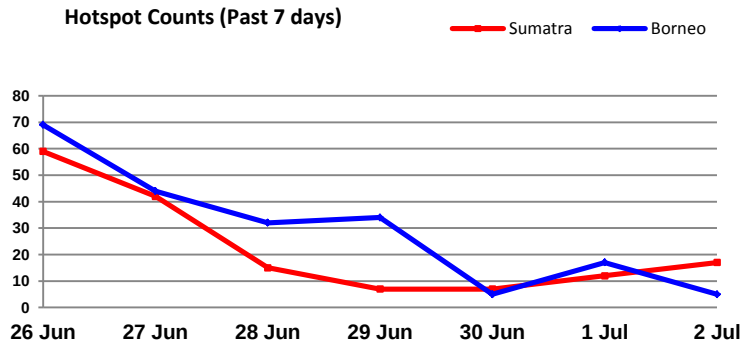

Fig. 7: Hotspot Counts over Sumatra and Borneo for the period 26 June to 02 July 2013, showing a definite decrease of the number hotspot in Sumatra and Borneo too.

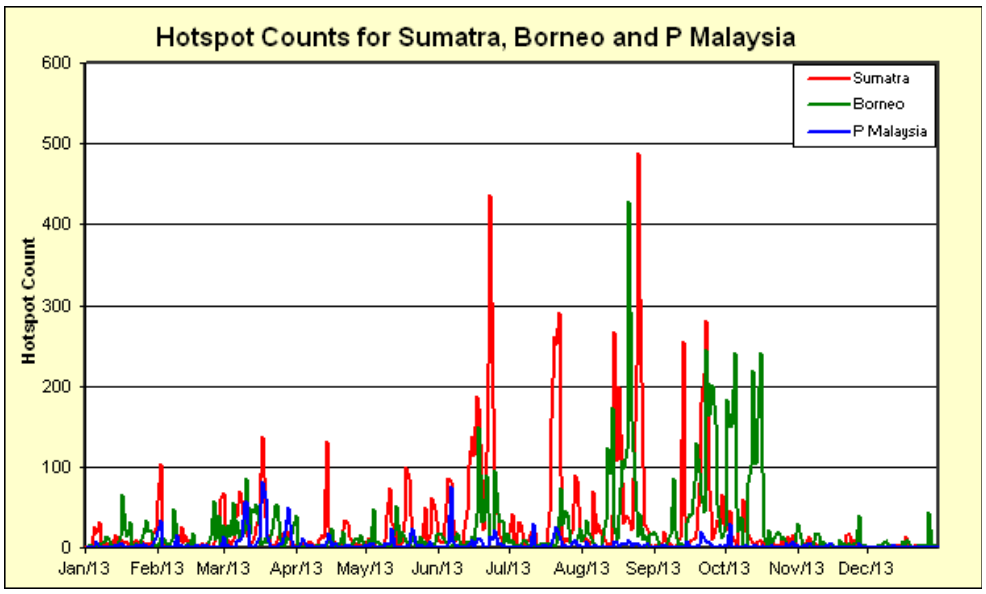

Fig. 8: Cumulative hotspot counts for Sumatra, Borneo and Peninsula Malaysia for 2013

2.2 Heavy rain and hail over Jurong and Choa Chu Kang - 25 June 2013

In the afternoon of 25 June 2013, East–West low level wind convergence was observed in the western parts of Singapore. This led to the development of showers and eventually heavy thunderstorms mainly in the southern and western parts of Singapore (Fig.9 and 10). Gusty winds accompanied these heavy thundery showers while hail was also reported in the vicinity of Jurong, Bukit Batok and Clementi.

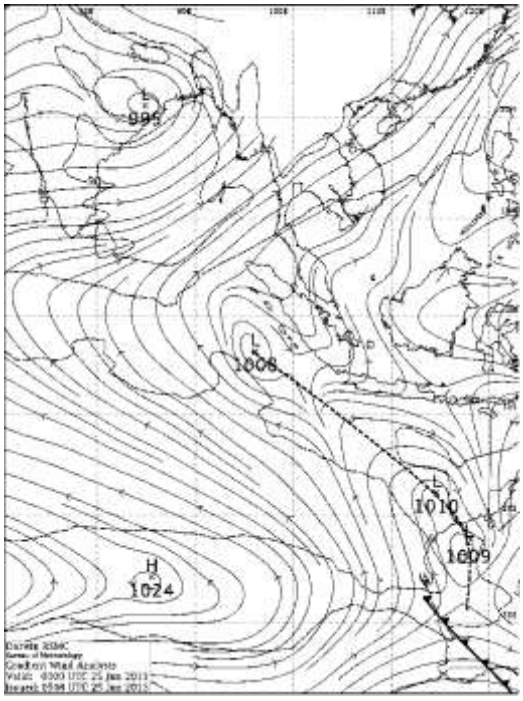

Fig. 9: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 25 June 2013. Low level wind convergence coupled with afternoon heating led to the development of thunderstorms in the afternoon. Hail with gusty winds was also reported during the thundery showers on that day.

Fig. 10: Radar images at different intervals showing the development of the thunderstorm cells with gusty winds over western and southern parts of Singapore where hail was also reported.

2.3 Heavy rain and flash flood over Orchard and Ayer Rajah Expressway (AYE) - 5 September 2013

Singapore experienced generally wet weather conditions with the Southwest Monsoon conditions prevailing with the heaviest downpour occurred in the morning of 5 September 2013 resulting in a total of 122mm of rain over Orchard area.

Due to east-west convergence of winds (Fig.11), Singapore experienced heavy thundery showers in the early morning. The heavy downpour in the southern and central Singapore resulted in flash flooding especially over large section of AYE near Clementi, National University of Singapore, Commonwealth Avenue, Tomlinson Road and Alexandra area (Fig.12). This led to a complete closure of a section of AYE towards the city. The rain did not ease off throughout the day with some thunderstorm building up throughout the afternoon over northern and western parts of Singapore.

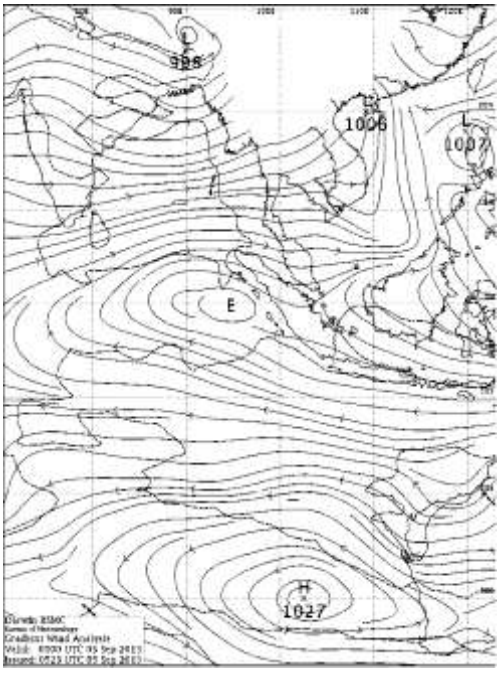

Fig. 11: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 05 September 2013. South-westerlies with convergence of winds triggered the build-up of Sumatra Squall along the Straits of Malacca. The thunderstorms brought heavy rainfall in the early morning on that day.

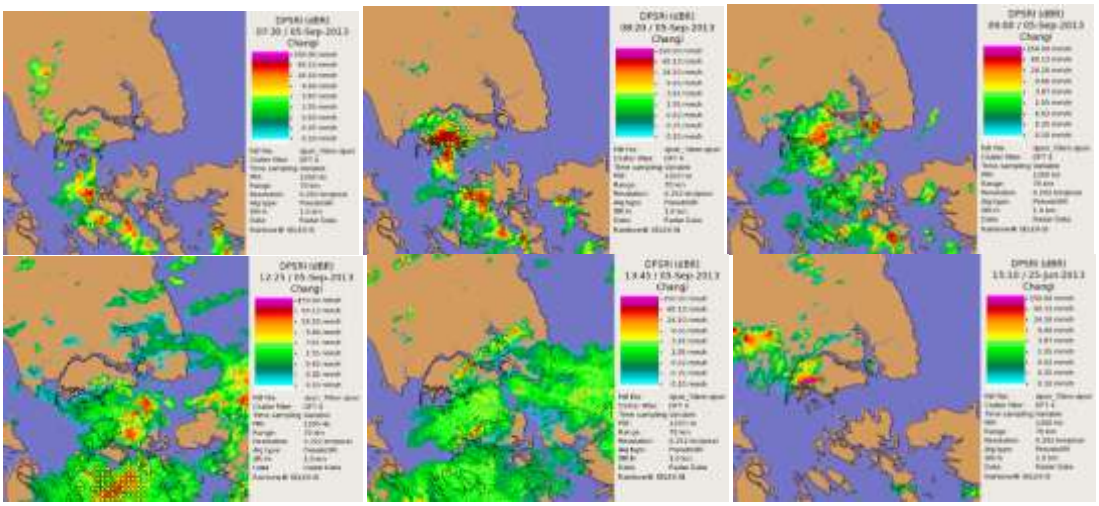

Fig. 12: Radar images at different intervals showing the development of the thunderstorm cells southern and centrals parts of Singapore initially in the early morning and again in the afternoon of 05 September 2013.

2.4 Typhoon Usagi and Sumatra Squall – 25 and 26 September 2013

Typhoon Usagi was a violent tropical cyclone which affected Taiwan, the Philippines, China and Hong Kong in September 2013. Developing into a tropical storm east of the Philippines on 16 September 2013, Usagi began explosive intensification on 19 September and ultimately became a violent and large typhoon. At 18UTC of 19 September 2013, Usagi reached its peak intensity with 10-minute maximum sustained winds at 205 km/h and the atmospheric pressure at 910hPa. Eventually the system weakened slowly, crossed the Bashi Channel on 21 September (Fig. 13). On September 22, Usagi's eye resurged, allowing the typhoon maintaining intensity when approaching the coast of China, and finally made landfall over Guangdong, China on 22 September 2013 with 10-minute maximum sustained winds at 155 km/h. The system subsequently dissipated during September 24, 2013 (Fig. 14). In the path of Usagi's wrath, at least 50 people have died in Asia and of this number, 30 deaths alone occurred in Guangdong province of south China.

With the dissipation of Usagi, Singapore experienced a few consecutive days of Sumatra squalls bringing thundery showers with gusty winds in the early hours on 25 and 26 September 2013 (Fig. 15).

In the early hours of 25 September 2013, a line of thunderstorm cells started to form over East Sumatra and the Strait of Malacca moving southeastward towards Singapore and southern Peninsular Malaysia. Johor and many areas in Singapore were affected by the Sumatra squall in the late morning and early afternoon with the highest rainfall of 74.8mm was recorded over Kim Chuan Road and strong winds of 35.4 knots was recorded at Woodlands Avenue 9. By noon, the Sumatra Squall moved eastwards out of Singapore with light to moderate rain clearing in the early afternoon (Fig 16).

Again in the early hours of 26 September 2013, isolated thunderstorm cell formed over the eastern Sumatra which intensified over the Straits of Malacca in the pre-dawn hours. The Sumatra Squall then moved along the western coast of Malaysia towards Singapore before becoming more organized just west of Singapore. Due to convergence of the downdraft and the surface winds over the western part of Singapore, the Sumatra Squall further intensified over land and many parts of Singapore experienced moderate to heavy thundery showers with gusty winds followed by light to moderate rain in the early afternoon (Fig. 17). The highest rainfall of 78.2mm was recorded at the Dairy Farm Road.

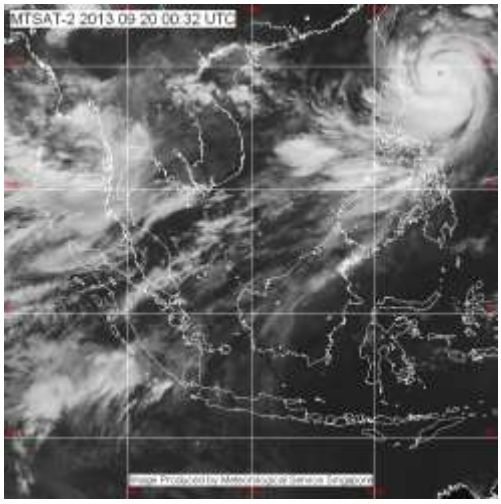

Fig. 13: The MTSAT colour satellite images showing Typhoon Usagi undergoing rapid intensification on the early morning of 20September 2013, moving towards the Bashi Channel.

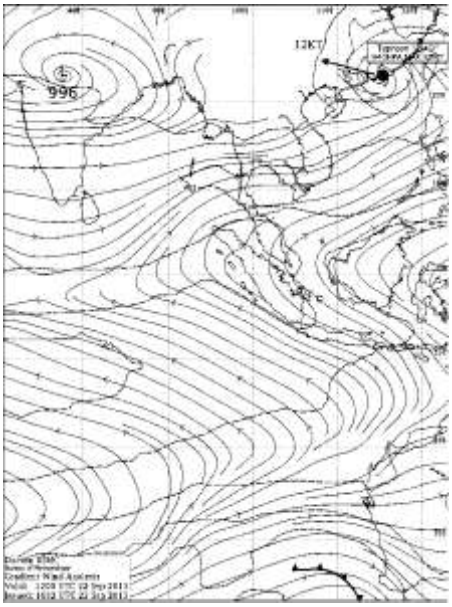

Fig. 14: Left: Gradient wind analysis (from Bureau of Meteorology) of synoptic situation in South East Asia region on 22 September 2013 showing Typhoon Usagi making landfall over Guangdong China.

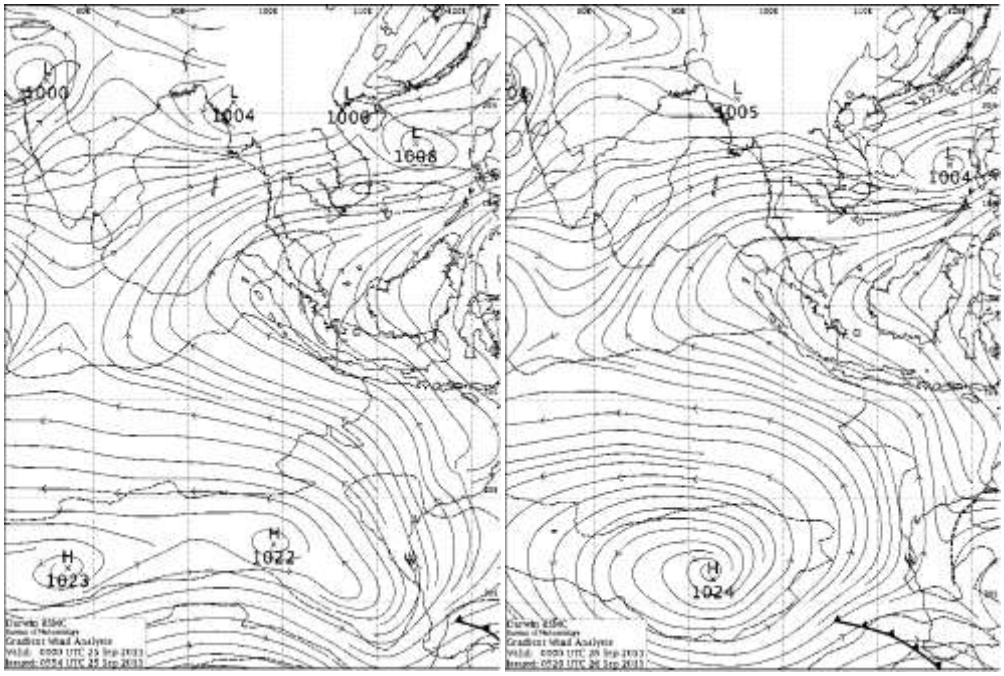

Fig. 15: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 25 and 26 September 2013. South-westerlies with convergence of winds triggered the build-up of Sumatra Squall along the Straits of Malacca..

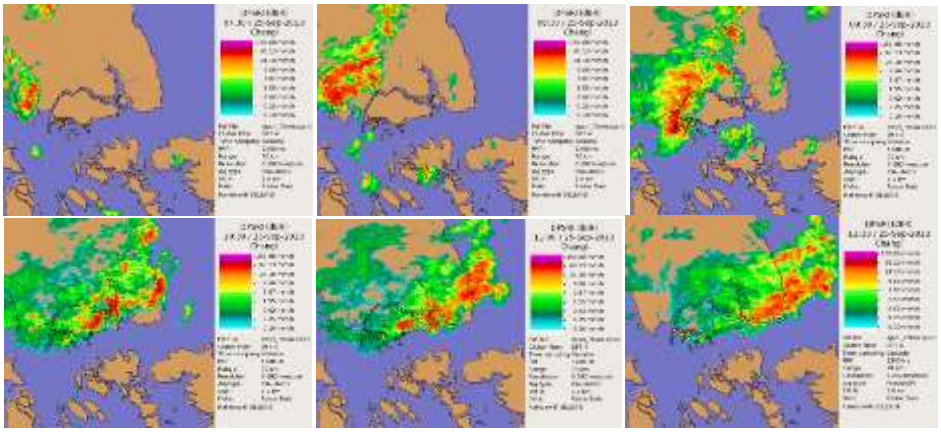

Fig. 16: Radar images at different intervals between 0730 – 1130hr on 25 September 2013, showing a line of thunderstorms cells off the west parts of Singapore in the early morning which swept across the island.

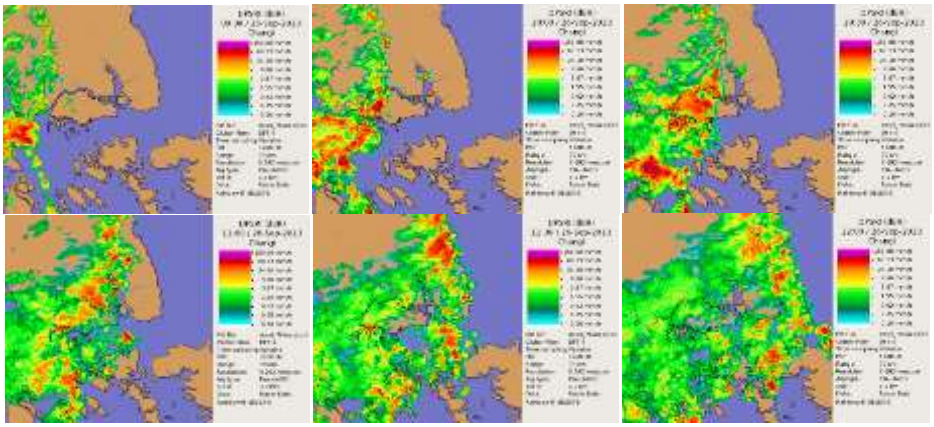

Fig. 17: Radar images at different intervals between 0930 – 1200hr on 26 September 2013, showing a line of thunderstorms cells off the west parts of Singapore, with the Sumatra Squall sweeping across Singapore by late morning.

2.5 Sumatra Squalls – 15 October 2013

In October 2013, Singapore experienced several Sumatra squalls in the pre-dawn hours. The Sumatra squall on 15 October resulted in the highest daily rainfall of 129.6mm for October 2013. Flash floods were reported in Changi and Tampines during this heavy rain event.

With Typhoon Nari making landfall over central Vietnam in the early hours on 15 October 2013 (Fig. 18), the thunderstorm cells that developed over Sumatra moved to south of Singapore and eventually intensified into a Sumatra squall in the predawn hours. Heavy rainfall was reported over many areas in Singapore including flash floods over Tampines and Changi.

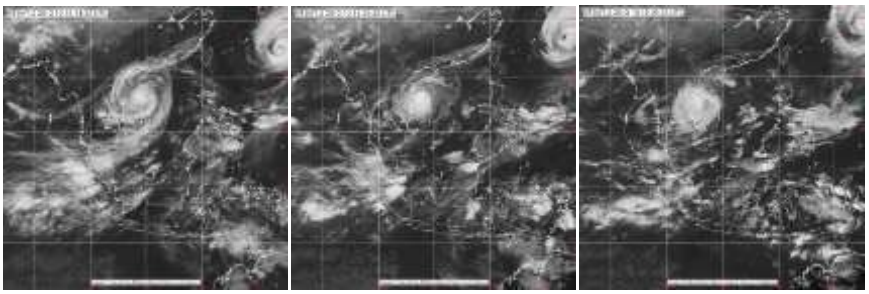

Fig 18: The MTSAT IR satellite images in the early hours, morning and early afternoon of 15 October 2013, showing Typhoon Nari making landfall over central Vietnam and also the development of the Sumatra Squall line.

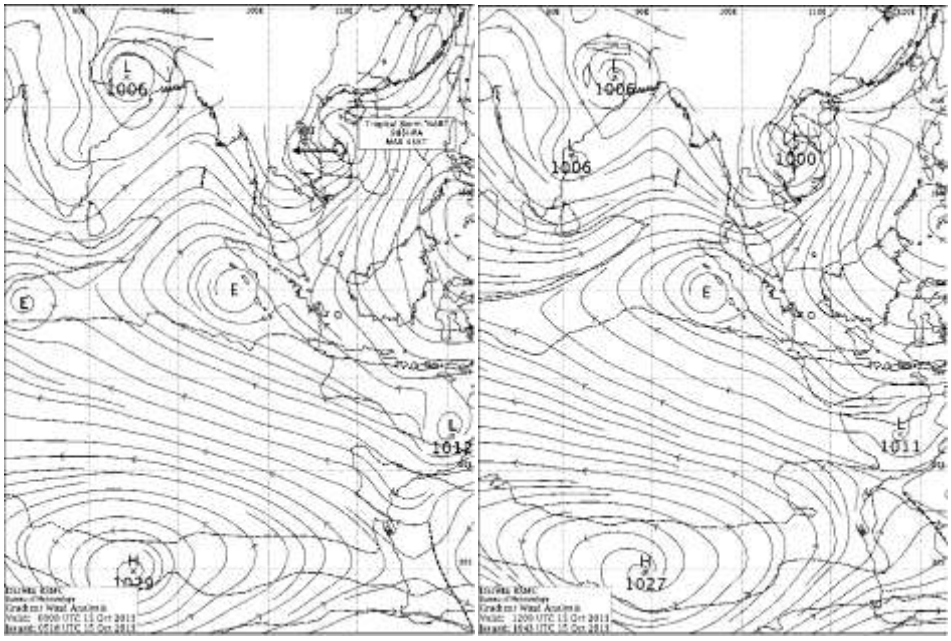

Fig. 19: Gradient wind analysis (from Bureau of Meteorology) of synoptic situation in South East Asia region on 15 October 2013. Tropical Storm Nari made landfall in central Vietnam in the early hours and this led to the development of a Sumatra squall. Due to mesoscale convergence, the region remained active leading to heavy downpour over Singapore in the early morning.

After the development of this moderate to heavy thundery shower in the predawn hours, the region remained active due to mesoscale convergence. Convergence between westerly and southwesterly winds gave rise to another spell of thundery showers mainly in the south, east and central Singapore in the early morning. The total rainfall on this day was quite significant due to the mesoscale convergence (Fig.19) and the two spells brought about heavy downpours on the eastern parts of Singapore (Fig.20). The Sumatra squall in the predawn hours and early morning of 15 October resulted in the highest daily rainfall of 129.6mm for the month of October 2013.

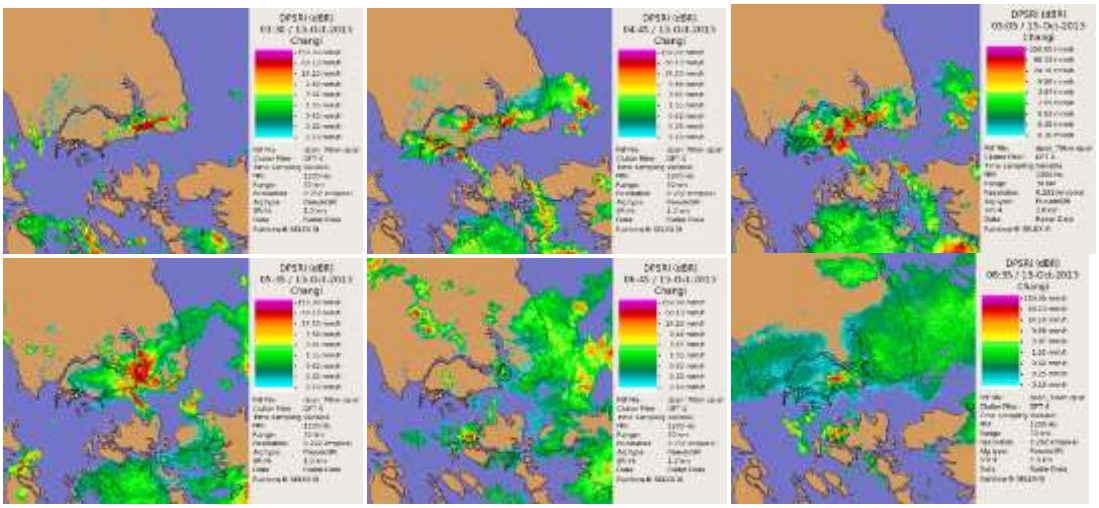

Fig. 20: Radar images at different intervals showing the passage of the Sumatra squall line firstly in the pre-dawn hours, and then in the early morning of 15 October 2013

2.6 Flash floods over Chai Chee – 28 and 30 October; 03, 05 and 24 November2013

On 28 October 2013, convective heating coupled with localized convergence of winds (Fig. 21) resulted in moderate to heavy thundery showers over many areas of Singapore in the afternoon. The heavy rainfall was over the northern, western and eastern areas from 3pm to 4.30pm (Fig. 22, 23 and 24). The highest rainfall of 79.2mm was recorded over Marine Parade from 4.05pm to 5.05pm. Flash flood was reported at junction of New Upper Changi Road and Chai Chee Road making them impassable to traffic.

Due to convective heating coupled with localized convergence of low level winds (Fig 19 and 20), many areas of Singapore experienced thundery showers with moderate to heavy rainfall in the early afternoon of 30 October 2013 (Fig. 21 and 22). Flash floods occurred at the junction of Chai Chee Road and New Upper Changi Road, the same junction that saw flash floods on the 28 October 2013.

On the 03, 05 and 24 November 2013, the junction of Chai Chee Road and New Upper Changi Road experienced heavy rain that caused flash floods in the afternoon due to convective heating (Fig. 25, 26, 27, 28, 29, 30, 31, 32 and 33). Heavy rainfall on the afternoon of 24 November 2013 resulted some vehicles to be stranded over at this very same junction (Fig. 34 and 35).

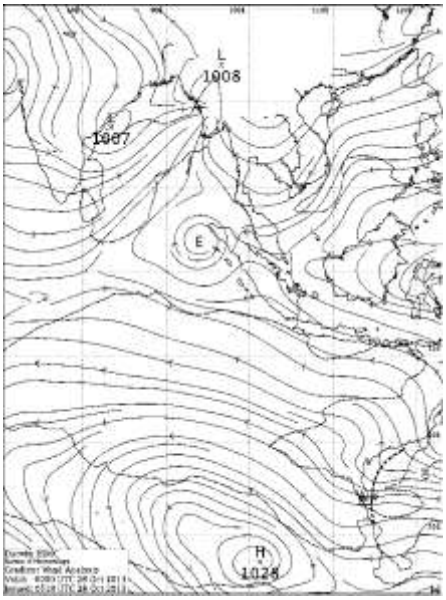

Fig. 21: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 28 October 2013. Low level wind convergence coupled with convective afternoon heating led to the development of thunderstorms in the afternoon.

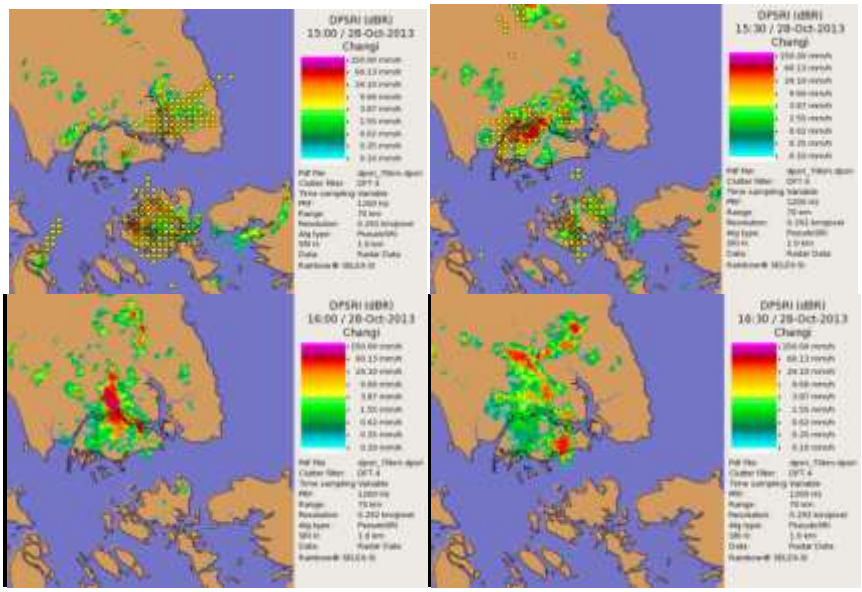

Fig. 22: Radar images at half-hourly between 1500 to 1630hr on 28 October 2012 showing a locally developed thunderstorm over the southeastern Singapore in the afternoon.

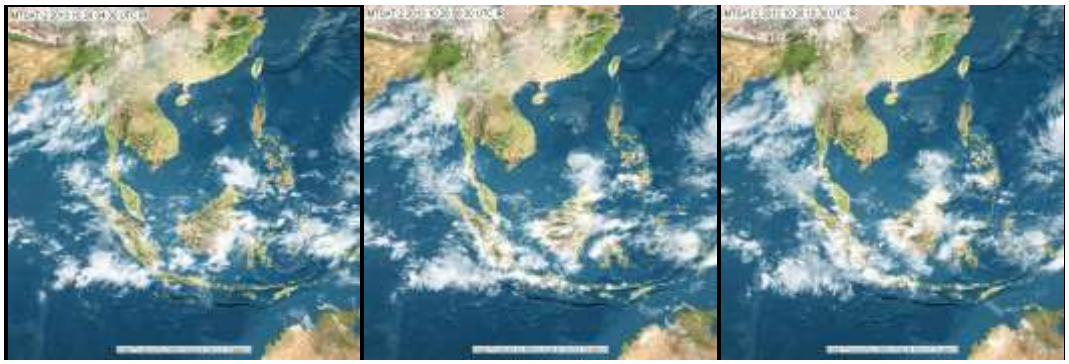

Fig. 23: The MTSAT colour satellite images in the early hours and morning of 28 October 2013, showing a localized thunderstorms cell developing in the Singapore region.

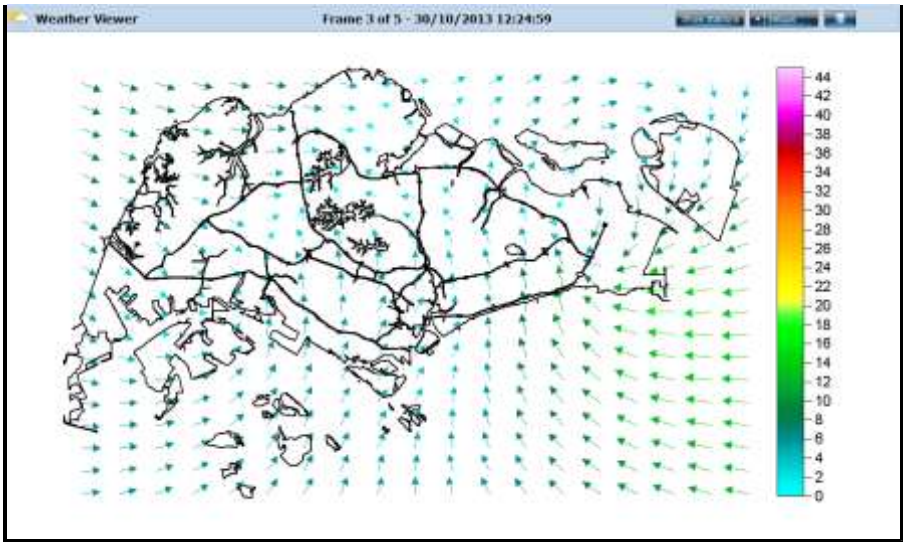

Fig. 24: Wind vector data from the automatic weather stations located island wide on 12.24pm, 30 October 2013, showing a definite low level wind convergence over eastern part of Singapore and coupled with intense convective heating lead to the development of heavy thundery showers in the afternoon.

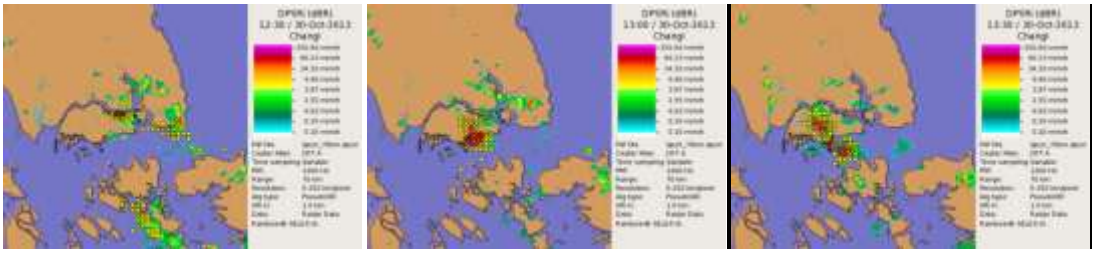

Fig. 25: Radar images at half-hourly between 12.30pm to 2pm on 30 October 2013 showing a locally developed thunderstorm over the southeastern Singapore in the afternoon.

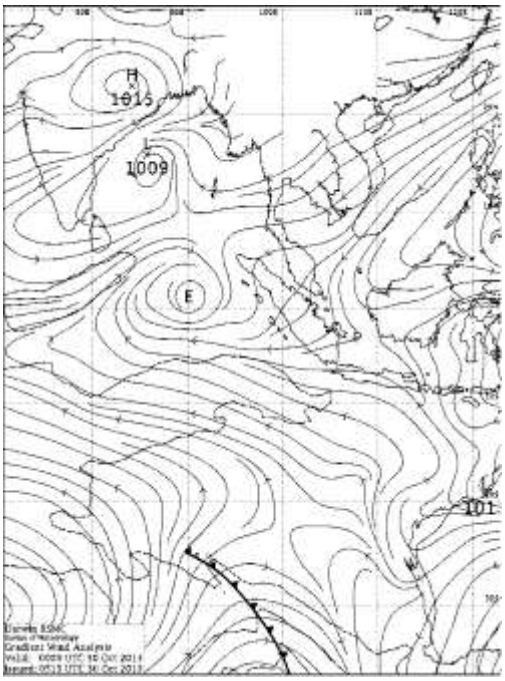

Fig. 26: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 30 October 2013. Low level wind convergence coupled with convective afternoon heating led to the development of thunderstorms in the afternoon.

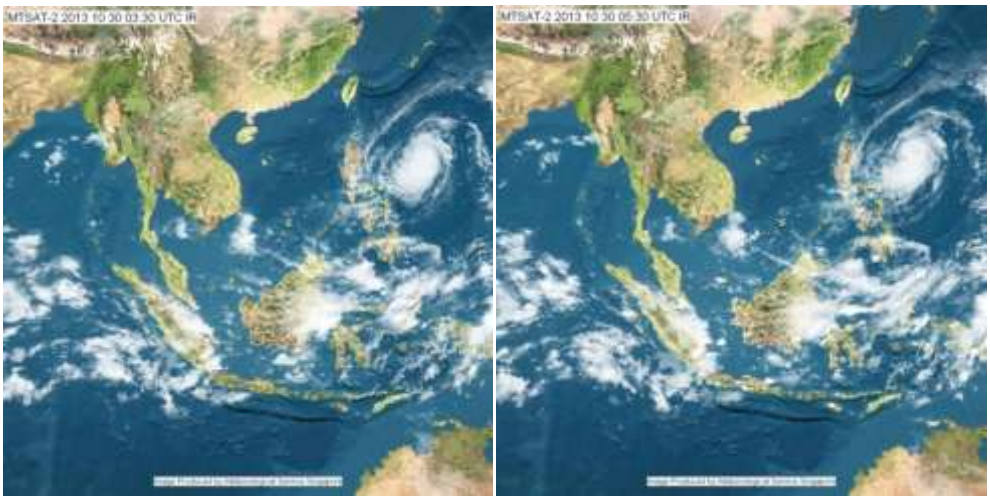

Fig 27: The MTSAT colour satellite images in the late morning and early afternoon of 30 October 2013, showing a localized thunderstorms cell developing in the Singapore region.

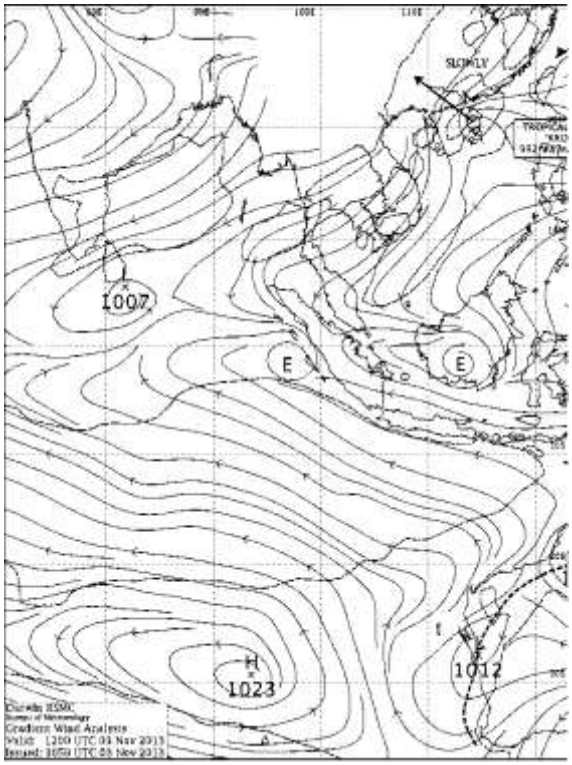

Fig. 28: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 03 November 2013. Low level wind convergence coupled with convective afternoon heating led to the development of thunderstorms in the early afternoon.

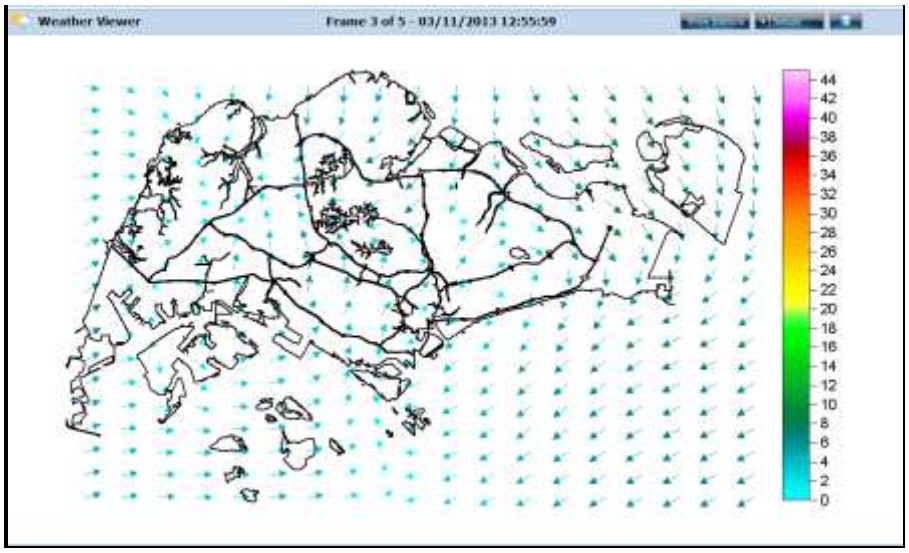

Fig. 29: Wind vector data from the automatic weather stations located island wide at 12.55pm, 03 November 2013, again showing a definite low level wind convergence of eastern part of Singapore and coupled with intense convective heating lead to the development of heavy thundery showers in the early afternoon.

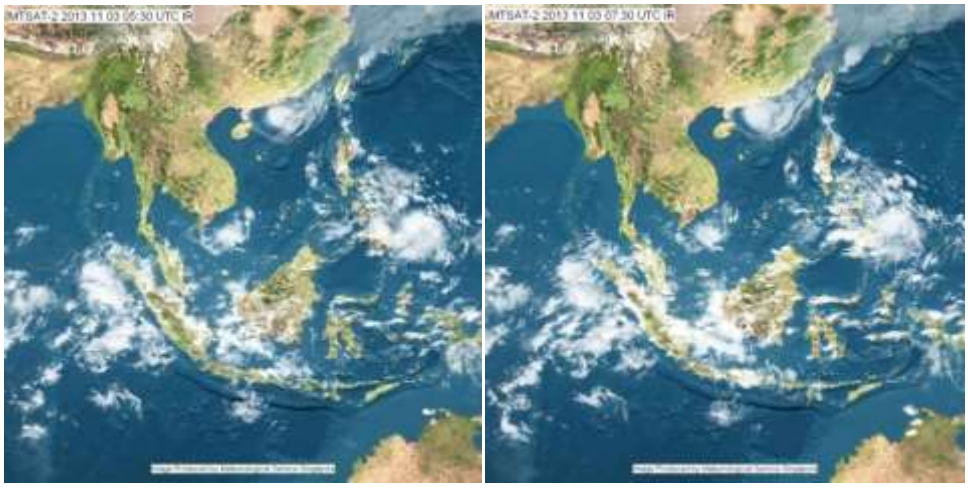

Fig. 30: The MTSAT colour satellite images in the early afternoon of 03 November 2013, showing a localized thunderstorms cell developing in the Singapore region.

Fig. 31: Radar images at half-hourly between 3.30pm to 5pm on 03 November 2013 showing a locally developed thunderstorm cell over the southeastern Singapore in the late afternoon.

Fig. 32: The MTSAT colour satellite images in the afternoon and early evening of 05 November 2013, showing a localized thunderstorms cell developing in the Singapore region.

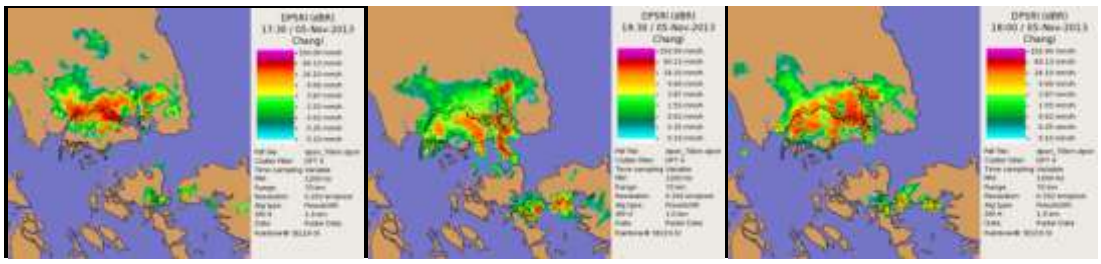

Fig. 33: Radar images at half-hourly between 5.30pm to 7pm on 05 November 2013, showing the late afternoon thunderstorms moving towards southeast of Singapore.

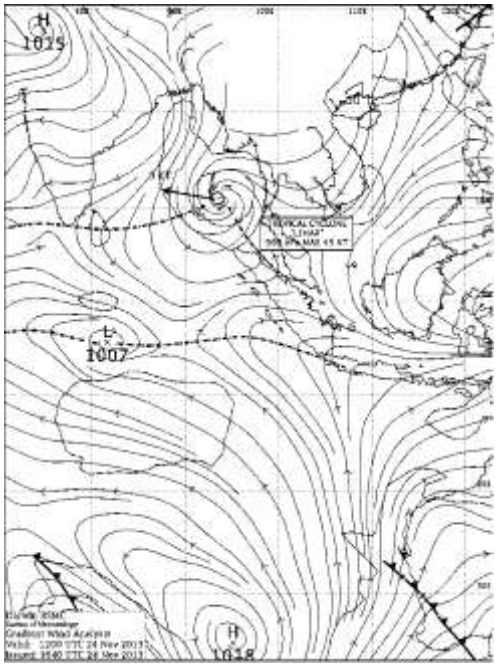

Fig. 34: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 24 November 2013. Low level wind convergence coupled with convective afternoon heating led to the development of thunderstorms in the afternoon.

Fig. 35: Radar images at half-hourly between 1.30pm to 2.30pm on 24 November 2013, showing the development of the thunderstorms mainly over the eastern and southeastern of Singapore in the afternoon due to convective heating.

2.7 Typhoon Haiyan and Sumatra Squall – 12 November 2013

Typhoon Haiyan was an exceptionally powerful tropical cyclone that devastated portions of Southeast Asia, particularly the Philippines in November 8, 2013. It was the deadliest Philippine typhoon on record, killing at least 6200 people in that country alone.

Haiyan originated from an area of low pressure several hundred kilometers east-southeast of Pohnpei in the Micronesia on November 2, 2013. Tracking westward, this low pressure system favoured tropical cyclogenesis development and eventually developed initially into a tropical depression then a tropical storm and eventually after a period of rapid intensification, Haiyan became a typhoon at 1800UTC on 5 November 2013. By November 6, the Joint Typhoon Warning Centre (JTWC) assessed the system to be a super typhoon.

On 1800 UTC 07 November 2013, the JTWC estimated the system's one minute-sustained winds to 315 km/h, unofficially making Super Typhoon Haiyan the strongest tropical cyclone ever observed based on wind speed.

Several hours later, the eye of the Typhoon Haiyan made its first landfall in the Philippines at Guiuan, Eastern Samar. Gradually weakening, the storm made five additional landfalls in the country before emerging over the South China Sea (Fig. 36). Turning northwestward, the typhoon eventually struck northern Vietnam as a severe tropical storm on November 10 and eventually dissipated as a tropical depression the following day (Fig. 37).

During this period of intensification and landfalls by Typhoon Haiyan, Singapore experienced a few cases of Sumatra Squalls notably on the early hours and pre-dawn period of 06, 08, 10, 11, 12 and 14 of November 2013. The most significant Sumatra Squall occurred on the 12 November 2013.

A Sumatra Squall line developed from the south to southwest of Singapore, which eventually brought heavy thundery showers to many areas in Singapore in the early morning of 12 November 2013. After the line of thunderstorms passed through Singapore, light to moderate intermittent rain condition persisted till the early afternoon keeping the temperature for the day low with the maximum temperature of 29 degree Celsius only (Fig. 38, 39 and 40).

Fig. 36: The MTSAT colour satellite images showing Super Typhoon Haiyan moving westward towards the Philippines and making landfall on the early morning of 08 November 2013 before moving westward towards northern South China Sea and Vietnam from 08 to 10 November 2013.

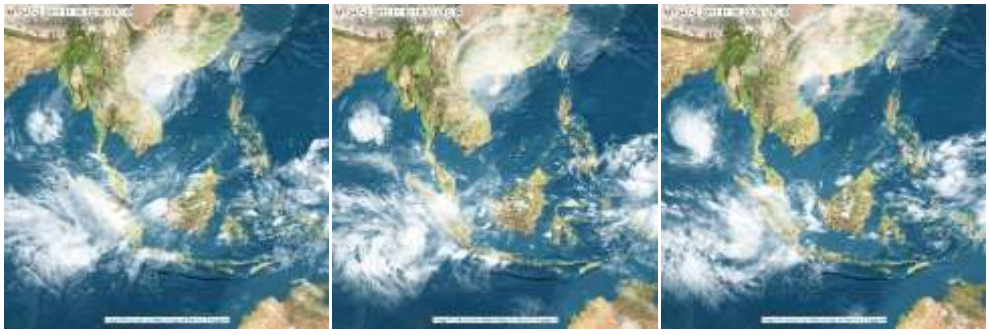

Fig. 37: The MTSAT colour satellite images showing Tropical Storm Haiyan moving westward and making landfall in northern Vietnam on the early hours of 11 November 2013.

Fig. 38: The MTSAT colour satellite images showing the development of the Sumatra Squall in the early hours of 12 November 2013 before sweeping across Singapore in the early morning.

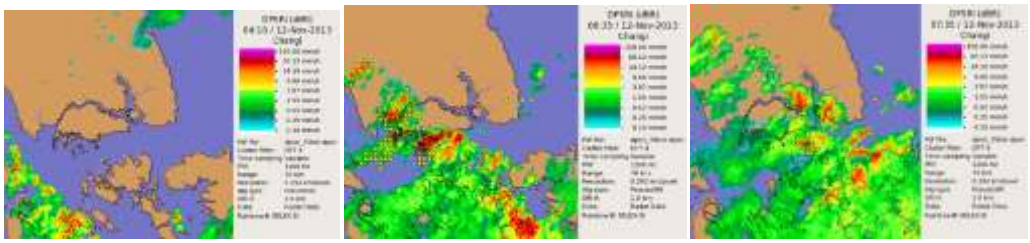

Fig. 39: Radar images at different intervals between 4am – 7.35am on 12 November 2013, showing a line of thunderstorms cells off the southwestern coast of Singapore in the early hours which swept across the island in the early morning.

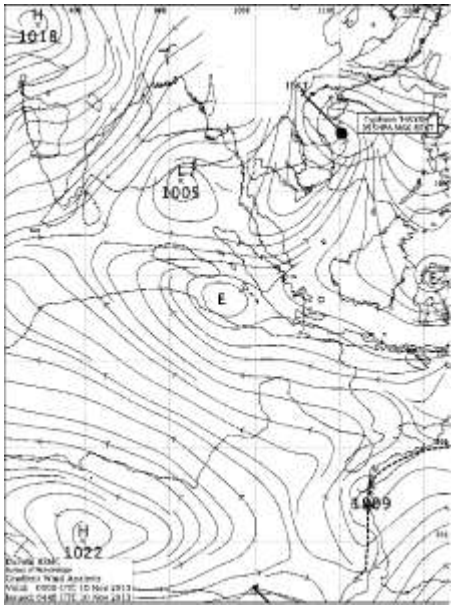

Fig. 40: Left: Gradient wind analysis (from Bureau of Meteorology) of synoptic situation in South East Asia region on 10 November 2013, showing Tropical Storm Haiyan made landfall in northern Vietnam.

2.8 Heavy rain and waterspout in Woodlands - 18 December 2013

Mesoscale convergence coupled with strong heating during the day brought unstable weather conditions over the region (Fig. 41). Heavy thunderstorms over Singapore in the late afternoon.

The late afternoon thunderstorms that developed over Johor moved southwesterly across Singapore in the late afternoon and evening. The intense thundery showers affected the whole of Singapore in two spells with the first spell between 6.15pm and 8.30pm and the second spell from 9.30pm to 11.00pm (Fig. 42). A waterspout was also sighted over the northwest areas of Singapore around Woodlands (Fig. 43).

The first spell brought 67.4mm/hr of rainfall to Sembawang. Wind gust of 58.7 knots was reported at Jurong. The second spell brought moderate rain across the island until the late evening after which only light to moderate rain continued into the early and pre-dawn hours.

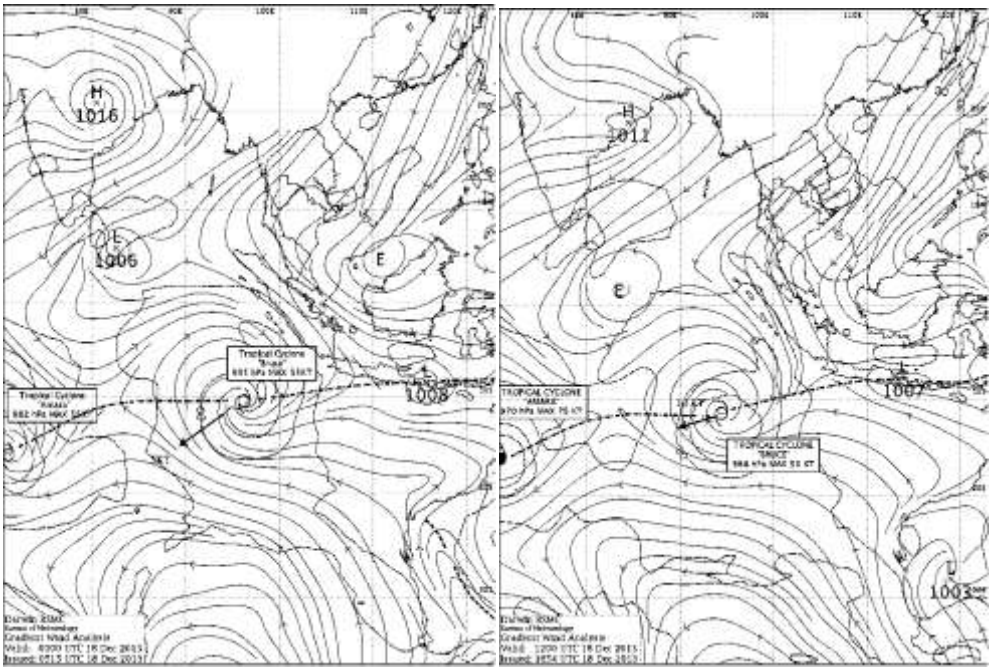

Fig. 41: Gradient wind analysis (from Bureau of Meteorology, Australia) of synoptic situation in South East Asia region on 18 December 2013. Low level wind convergence coupled with convective afternoon heating led to the development of thunderstorms in the afternoon.

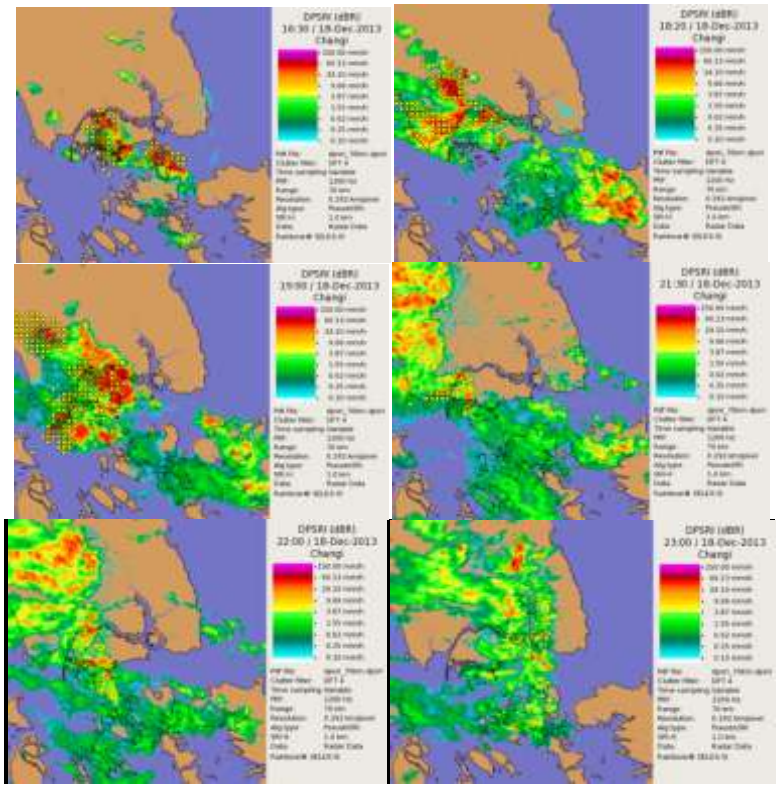

Fig. 42: Radar images at different intervals between 4.30pm – 11pm on 18 December 2013, showing the development of the thunderstorms in the late afternoon and again in the night. The first spell brought intense, heavy rainfall with gusty winds while the second spell brought moderate rain across the island that cleared in the late evening.

Fig. 43: A waterspout was sighted over the northwest part of Singapore in the late afternoon of 18 December 2013.

3. Climatic Features

Since the second quarter of 2012, El Niño-Southern Oscillation (ENSO) indicators in the tropical Pacific (e.g. tropical Pacific sea surface temperatures, sea level pressure, cloudiness and trade winds) have generally been at neutral levels, indicating that neither El Niño nor La Niña conditions have been present.

The Indian Ocean Dipole Mode Index (DMI) (Fig. 44) is largely negative during 2013 except for January and March. Negative DMI would likely enhance convective activities and had contributed to wetter weather conditions during these two months. The percentages of 2013 monthly rainfall difference from mean for climate station

Changi (Fig. 45) also indicated a wetter 2013. They displayed good correlation for 2013 as a whole although monthly correlation was not strong.

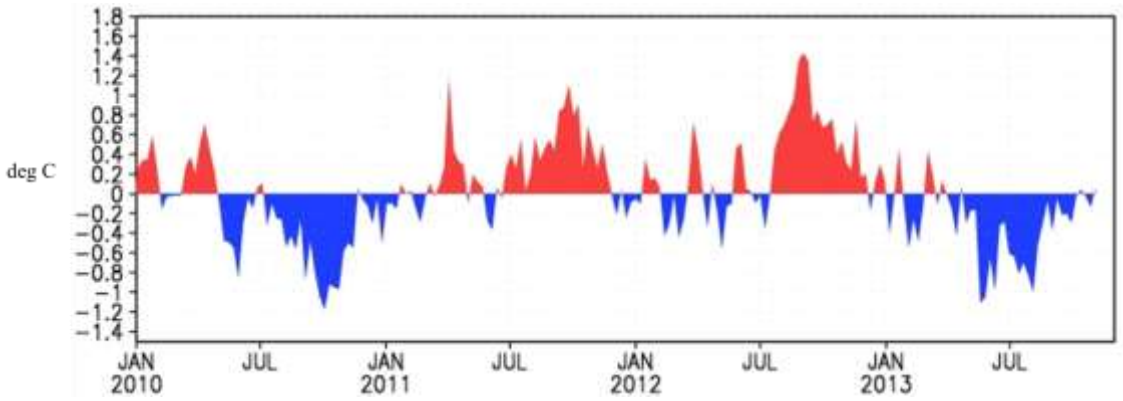

Fig. 44: The Indian Ocean Dipole Mode Index (source: JAMSTEC). Positive (red) indicates warmer anomalies in the western Indian Ocean and cooler anomalies in the eastern Indian Ocean. Negative (blue) indicates cooler anomalies in the western Indian Ocean and warmer anomalies in the Eastern Indian Ocean.

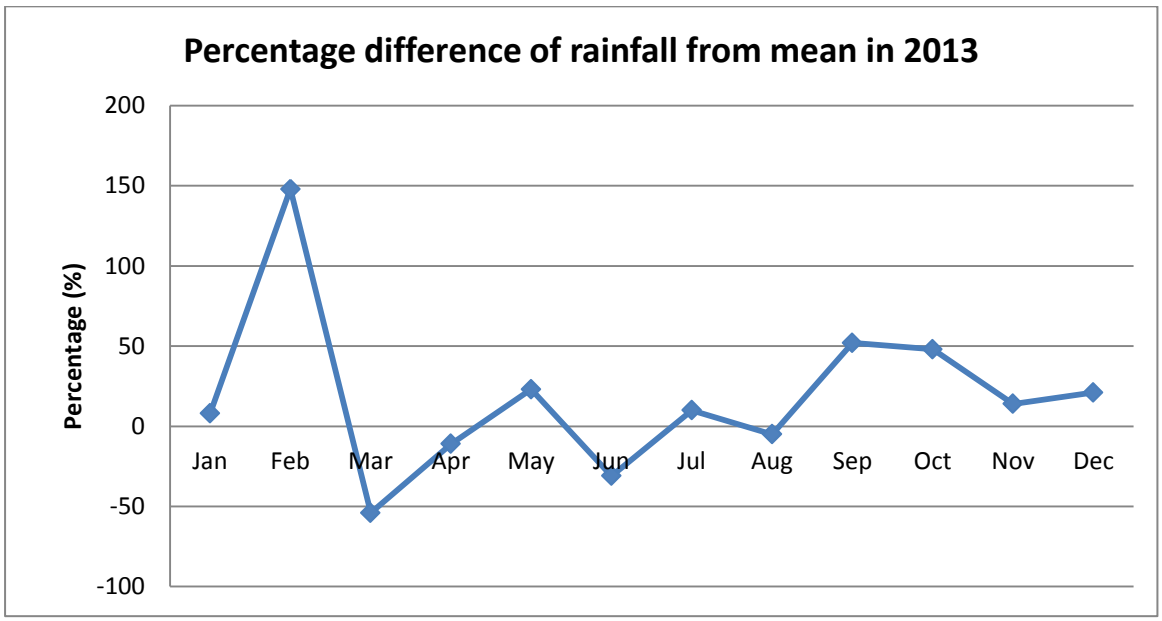

Fig. 45: Percentage difference of 2013 monthly rainfall from the mean (1869-2012) for the climate station at Changi

The passage of intense Madden-Julian Oscillation (MJO) (Fig. 46) dry phase in March and June 2013 may have had a suppressing effect on the convective activities around Singapore. This could have resulted in monthly rainfall that was lower than the long-term average. In February, Singapore saw enhanced convective activities and above average rainfall brought forth by the MJO wet phase.

The 2013 anomalous 850-hPa zonal wind averaged 5N and 5S (Fig. 47) did not show any significant anomaly except for October and November 2013 which indicated an easterly anomalies. This occurred during the beginning of the Northeast Monsoon which gave rise to higher than average rainfall.

Broadly speaking, in 2013, rainfall was above average for most parts except the western and eastern ends of the island (Fig. 48 and 49). The highest rainfall of more than 2900mm (25% - 35% above the average) fell mainly over the northern and part of central Singapore. A total rainfall of 2748.4mm was recorded at the climate station of Changi, which was 17.3% above the long-term average of 2344.0mm. February and December were wettest with monthly rainfall at 395.2mm and 348.2mm respectively (Fig. 50).

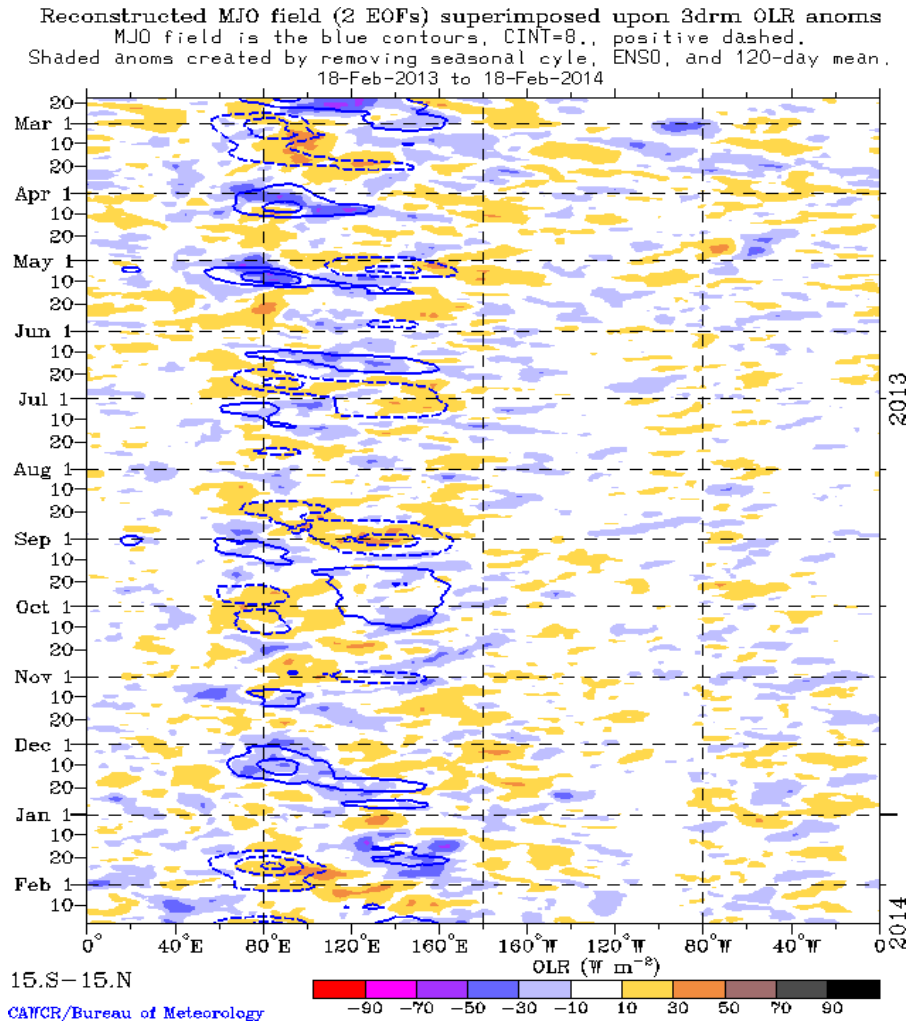

Fig. 46: MJO fields (bold and dotted lines) superimposed on Outward Long wave Radiation (OLR) anomalies. Bold blue lines indicate a wet phase of MJO while dotted lines indicate a dry phase of MJO. Blue contours indicate negative OLR anomalies while orange contours indicate positive OLR anomalies.

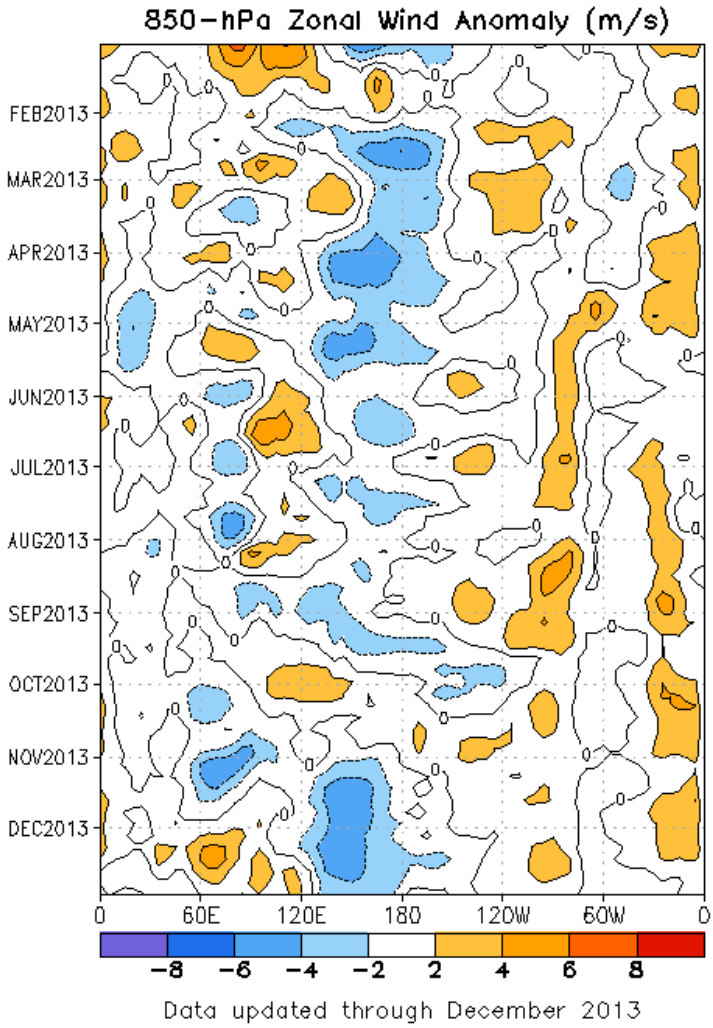

Fig. 47: Time-longitude section of anomalous 850-hPa zonal wind averaged between 5N-5S (source: CDAS/Reanalysis). Contour interval is 2 ms^{-1}. Dashed contours indicate negative anomalies. Anomalies are departures from the 1981-2010 base period pentad means. The data are smoothed temporally by using a 3-point running average. Blue shading and dashed contours indicate easterly anomalies. Singapore is located at approximately 100°E.

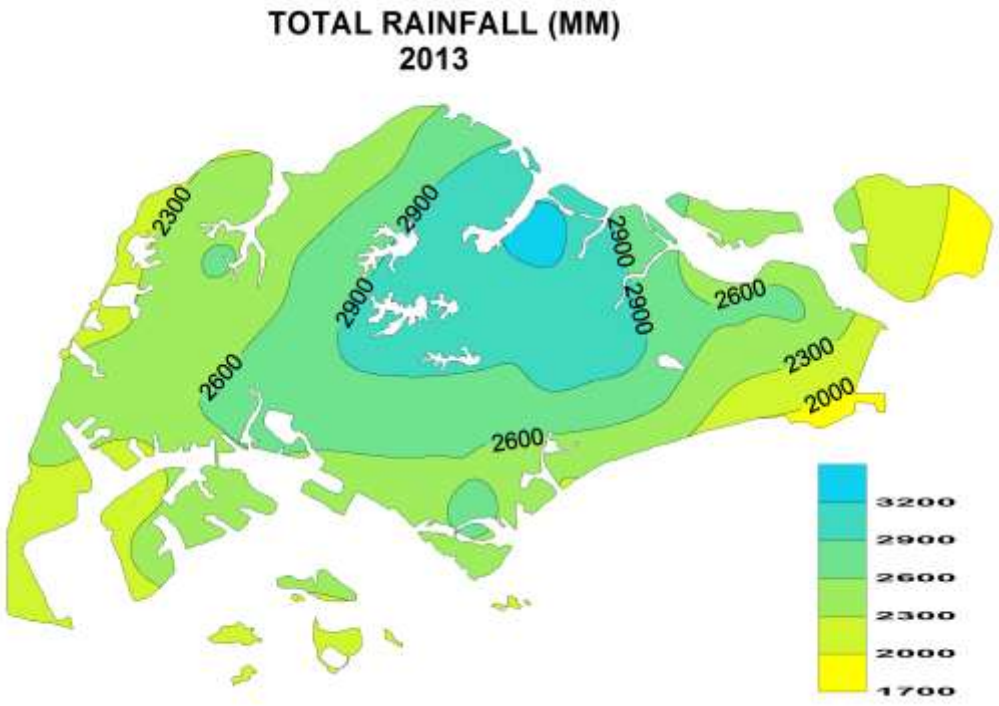

Fig. 48: Isohyets of annual rainfall in 2013 for Singapore.

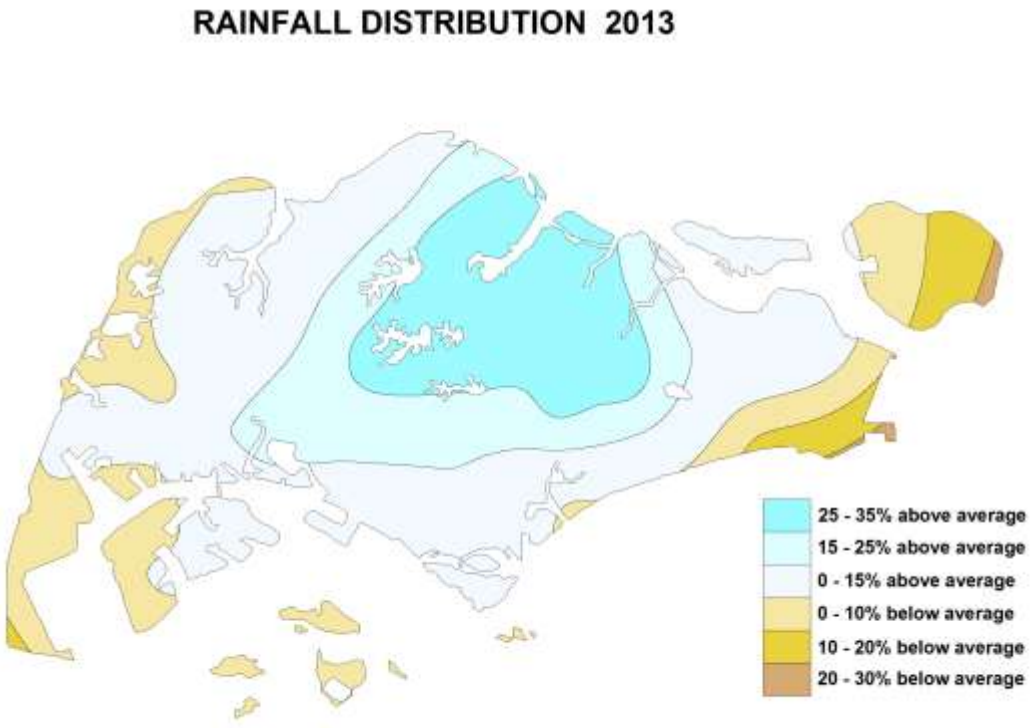

Fig. 49: Percentage difference of annual rainfall in 2013 from the long-term means for Singapore.

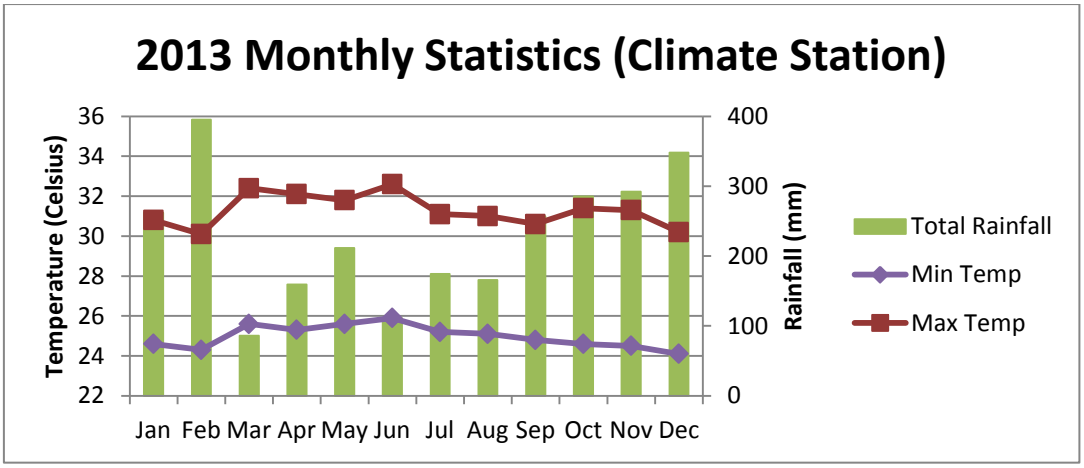

Fig. 50: Monthly statistics of rainfall, maximum and minimum temperature at the climate station located at Changi.

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