

# Annual Weather Review 2010

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## Review of Weather Conditions in 2010

### Northeast Monsoon Season (Jan – March)

2010 started off with a mild Northeast Monsoon, with rainfall well below average for the first two months of the year. Not only was the 2009/2010 Northeast Monsoon unusual in not bringing the monsoon surges typical of the rainy season<sup>1</sup>, the period also saw the occurrence of Sumatra squalls on three almost consecutive days on 4, 6 and 7 January 2010. Sumatra squalls are associated with deep southwesterly winds and are uncommon during the Northeast Monsoon, during which the prevailing winds are predominantly from the opposite direction.

The dry phase<sup>2</sup> of the Northeast Monsoon set in during late January 2010 and extended to March 2010. The dry conditions usually experienced during this period are due to the strong cross equatorial flow induced by the migration of the monsoon rain belt far south of the equator away from Singapore. The absence of sufficient moisture coupled with the presence of strong divergent wind flow at the 700-850 hPa levels, impeded convective activity and suppressed rainfall during this period. In February 2010, the coincident passage of a dry phase of the Madden Julian Oscillation (MJO) and a moderate El-Niño over the maritime continent further exacerbated the dry conditions over Singapore and the surrounding region. As a result, February 2010 was the driest February for Singapore since rainfall records began in 1869, with only 6.3 mm of rainfall recorded at the climate station. Moreover, the dry phase of the Northeast Monsoon in 2010 had only 5 rain days and registered a total rainfall of merely 9.8 mm.

Relatively clear skies led to the hottest day in February since temperature records started (in 1929) being recorded on 26 February 2010. On that day the mercury climbed to 35.2°C at the climate station. The warm and dry conditions persisted till the first week of March. The highest temperature this year was recorded on 6 March 2010, where the dry bulb temperature at the climate station reached a maximum of 35.5°C. This made it one of the 5 hottest days on record since 1983.

### First Inter-Monsoon Season (April - May)

By late March 2010, winds over the region gradually became light and variable with the weakening of the Hadley Circulation and the corresponding transition to Inter-Monsoon conditions. The thunderstorms which are commonly experienced during this Inter-Monsoon period are primarily driven by diurnal variations, with the maximum convective activity occurring in the mid to late afternoon, when the solar irradiation is at a peak and the sea breeze is at its strongest. Moderate to heavy showers induced by such conditions occurred in the afternoon and early evening on about ten days in April 2010 and seven days in May 2010.

The El-Niño weakened considerably from March 2010 to May 2010, restoring rainfall for these months to levels closer to long-term averages (Figure 14). Rainfall at the climate station

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<sup>1</sup> On average two to four monsoon surges occur during each Northeast Monsoon, with each surge event lasting between two to five days.

<sup>2</sup> The Northeast Monsoon usually consists of wet phase and dry phase.

for May was 8% below the long term average of 171.7 mm. Elsewhere, about two-thirds of the island experienced above normal rainfall, with the highest rainfall of 270-300 mm occurring at the western part of the island. This period is traditionally the warmest time of the year as the midday sun moves directly over the equator and light and variable winds inhibit cooling. This was also the case for 2010 and the monthly average maximum temperatures for April and May 2010 was around 33°C.

The onset of the typhoon season in the Western Pacific was delayed in 2010. The absence of any significant tropical storm or typhoon in the South China Sea in April and May 2010 coupled with a weaker Walker Circulation under El-Niño conditions meant that no sustained strong westerly steering winds were present over the surrounding region and no well-organized Sumatra squall lines affected Singapore during this period. The winds gradually turned southwesterly in the first week of June as the monsoon trough began its migration to the Northern hemisphere, marking the start of the Southwest Monsoon season.

### Southwest Monsoon Season (June –October)

The Southwest Monsoon in 2010 turned out to be exceptionally wet for Singapore with the climate station recording 240.5 mm and 298.5 mm of rainfall in June and July respectively (Figure 12). This is 50% above average for June and 80% above average for July. All other parts of the island also received above normal rainfall in June and July 2010. Over a four-week period, Singapore experienced three intense thunderstorm events on 16 June, 25 June and 17 July 2010 which resulted in flash floods over many parts of Singapore.

The event on 16 June 2010 was caused by a particularly intense and slow moving Sumatra squall. The squall line lingered over the city area for over an hour resulting in the worst flooding to occur in the Orchard Road area since 1984. The heavy rains on 25 June were caused by a strong convergence of winds over the region. Of the three events, the heavy rain on 17 July was most intense with a highest total rainfall of 194.8 mm being recorded. This was the heaviest daily rainfall (for any station) recorded in the last three years. On that day, 114.2 mm of rain fell at the climate station. This event was attributed to an intense Sumatra squall possibly induced by Typhoon Conson making landfall near Hainan island the night before. All the three events occurred against a background of La Niña conditions which were rapidly developing over the region in June/July 2010.

Following a brief period of neutral conditions after the dissipation of the 2009/2010 El Nino in April 2010, La Niña conditions developed quickly over the region in June and July 2010. By August 2010, a moderate to strong La Niña had been established (Figure 13). The La Niña was likely to have intensified the heavy rain events as well as contributed to the higher than average rainfall being recorded in Singapore in June and July.

The La Niña also brought generally wet weather conditions to Sumatra during the Southwest Monsoon, despite this being the traditional dry season. However, the wet weather conditions were interspersed with dry periods, particularly in the middle of October. These dry periods coincided with a persistent MJO dry phase which inhibited convection and suppressed rainfall in October. The arid conditions were conducive for burning activities to take place. The hotspot count in Sumatra reached a maximum of 358 on the 18<sup>th</sup> of October. The prevailing southwest to westerly surface winds brought smoke haze from the fires in Sumatra to southern Peninsular Malaysia and Singapore for several days. During this brief haze episode, the air quality recorded on several days over southern Peninsular Malaysia and Singapore deteriorated into the moderate to unhealthy range, with certain places like Muar in Johore reporting air

quality within the hazardous range. The air quality in Singapore also dipped to moderate levels on several days from 16<sup>th</sup> to 24<sup>th</sup> October reaching a peak 24hr PSI reading of 96 on 22<sup>nd</sup> October. The 3hr PSI briefly peaked at 108, in the unhealthy range. Wetter conditions returned to Sumatra and the region on the 23<sup>th</sup> of October, which helped to improve the hotspot and haze situation and restore the PSI to healthy levels.

#### Second Inter-Monsoon Season (late October – mid November)

Uncharacteristically, persistent southwesterly wind flows continued to prevail over the region until late October, only after which did the winds began to show some signs of weakening to become light and variable which is typical during the Inter-Monsoon.

The Inter-Monsoon lasted from late October into the first half of November 2010. The low level winds over the region were generally light and variable. During the first week of November, Singapore experienced mostly localized morning showers with thunder. Towards the middle of the month, scattered showers occurred mostly in the afternoon. The most notable weather events during this period were the intense thunderstorms which are a characteristic of the Inter-Monsoon. In addition to bringing heavy rain, these thunderstorms are often accompanied by strong wind gusts. The thunderstorm on 29 October 2010 resulted in the uprooting of trees and snapping of branches in the Yio Chu Kang area.

The second Inter-Monsoon was relatively short and transitioned to Northeast Monsoon conditions from mid-November 2010.

#### Northeast Monsoon Season (mid November to December)

Following the brief Inter-Monsoon period, winds over the region started to change to a more sustained northwesterly/northeasterly direction in the second week of November. The Northeast Monsoon is usually characterized by the occurrence of several episodes of monsoon surges set in place by the intensification of high pressure systems over Northern Asia. The high pressure systems induce the flow of strong northeasterly winds over the South China Sea that lead to the formation of large rain bearing cloud clusters at the leading edge, bringing widespread prolonged rain to Singapore and the surrounding region.

As of December 2010, the Northeast Monsoon was still relatively subdued as the surge of northeast winds made little headway beyond the Northeastern states of Peninsular Malaysia. Although two weak to moderate monsoon surges occurred over the region from 17-18 December and 27-29 December, the cloud clusters did not move directly over Singapore. This was largely attributed to the presence of a tropical disturbance between Peninsular Malaysia and Borneo which diverted the northeasterly flow to a northwesterly direction and steered the cloud clusters to the sea east of Singapore. As such, much of Singapore and surrounding Johore experienced rainfall that was well below average. The thunderstorms which occurred this month were primarily driven by local effects such as convective heating and sea breeze convergence. For December 2010, the climate station recorded a total rainfall of 181.4 mm, significantly below the long term average of 287.4 mm. All other parts of Singapore registered below average rainfall.

## **Significant Weather Events in 2010**

### Heavy Rain and Flash Floods on 16 June 2010

Thunderstorms started to build up over the Malacca Straits and waters off Singapore in the pre-dawn of 16 June 2010. From 0600 hrs, small patches of weather started to affect Singapore. By 0800 hrs, another spell of weather developed over the southern and central parts of the island, as the main part of a larger squall line began to approach the western edge of Singapore. By 0925 hrs, a squall line, oriented in a southwest-northeast direction had formed over the island. The squall line remained quasi-stationary for close to two hours, depositing heavy rain over a large part of Singapore during the time.

The rain was particularly heavy in the southern and central parts of Singapore with several stations reporting total rainfall in excess of 100 mm. The highest total rainfall of 115.2 mm for that day was recorded in Sentosa. The station at Environment Building in Newton recorded a total rainfall of 111.6 mm for that day, with 81.6 mm of rain falling within the one hour period from 0930-1030 hrs. With the intense heavy rain falling over many parts island, especially over Orchard Road and Scotts Road, the drainage system was overwhelmed and flash floods occurred. The flash floods were primarily in the vicinity of the cross junction around Orchard Road and Scotts Road.

The intense squall was caused by strong convergence of winds over the region, leading to unstable weather conditions. The passage of the wet phase of an MJO cycle could also have intensified the squall. Satellite, radar images and observation data for the event are in Figures 1 to 5.

### Heavy Rain and Flood on 17 July 2010

Singapore was affected by yet another episode of heavy rain and floods on 17 July 2010. The rainfall that fell on that day eclipsed even that on 16 June. On 17<sup>th</sup> July, 194.8 mm of rainfall fell on the Poole Road station with rainfall in excess of 100 mm recorded over half the stations island-wide, indicating that the rainfall that day was not only heavy, but was also widespread.

The heavy deluge was brought about by a Sumatra squall that swept through Singapore in the pre-dawn hours starting from 0400 hrs. The squall line moved from west to east and intensified around 0500 hrs when it moved over the island. The rain over Singapore lasted from till 0900 hrs before slowly petering out. The most intense rainfall that day fell over Thomson and Lower Pierce reservoir in the central catchment area, where 115 mm and 114.2 mm rainfall fell between 0500 and 0600 hrs respectively.

The Sumatra squall was in part triggered by Typhoon Conson which made landfall at Hainan island the night before. The rain-bands from the typhoon extended far south from the main system and could have contributed to the generally wet conditions over the entire region. Furthermore, La Niña conditions were fast developing over the region and could have played a contributory role in enhancing the severity of the event. Satellite, radar images and observation data for the event are in Figures 6 to 10.

## Transboundary Haze in October 2010

During October 2010, a brief period of dry weather over Sumatra led to the escalation of hotspot activities. This dry period in Sumatra coincided with a prolonged period of a MJO dry phase in October which suppressed convective activities in the eastern Indian Ocean. The smoke haze that ensued shrouded Peninsular Malaysia and Singapore towards the middle of the month causing air quality to dip into the moderate range on several days. Wetter conditions which returned on 24<sup>th</sup> October provided a much needed respite and helped to prevent further deterioration of the PSI. Satellite images of the smoke plumes and haze situation are in [Figure 11](#).

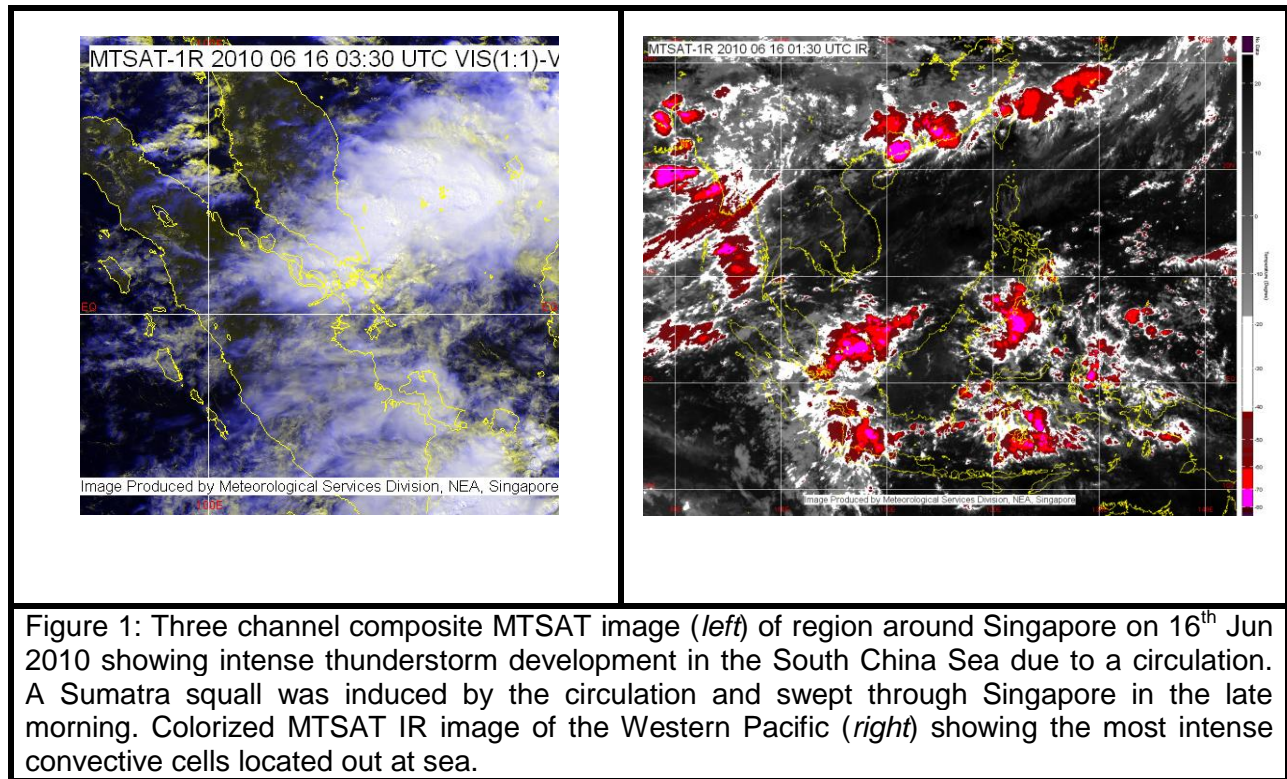
### **Climatic Features**

January and February were exceptionally dry in 2010, while June and July were particularly wet ([Figure 14](#)). Overall, the climate station recorded a total annual rainfall of 2075.1mm which was 11% below the long term average of 2341.1mm ([Figure 17](#)). The moderate El-Niño at the start of the year weakened by April and a moderate to strong La Niña was established by August 2010 ([Figure 13](#)). Their opposing effects on enhancing and diminishing rainfall appeared to have cancelled each other out when the year was taken as a whole. The correlation between percentage deviation of rainfall ([Figure 14](#)) and the Oceanic Niño index was strong in the first half of the year but weakened in the second half. The Oceanic Niño index correlated strongly with the Indian Ocean Dipole Mode Index ([Figure 15](#)) which was positive for the first four months and strongly negative for the remainder of the year. Hence convective activities and rainfall in Singapore was inhibited at the start of the year and enhanced towards the end.

Total rainfall recorded was higher over the North, West and Central parts of Singapore ([Figure 16](#)) and was highest over the central catchment area where the station at Seletar Reservoir recorded more than 3700 mm of rainfall this year. This was largely due to convective rainfall induced by afternoon heating which tend to affect the north, west and central parts of Singapore due to their proximity to the Peninsular Malaysia landmass which acts as a heat source. Moreover, intense thunderstorms which frequently develop on the west coast of Peninsular Malaysia in the afternoon and are advected towards Singapore by northwesterly steering winds, tend to affect these downstream areas more severely. Sumatra squall lines that move from west to east also deposit much of the rainfall over the western parts of the island before petering out as they reached the east. The absence of any significant Northeast monsoon surge events in 2010 (which tend to affect the eastern areas more than the other parts of the island) could have led to the eastern areas recording up to 30% below average annual rainfall ([Figure 17](#)). A particularly strong Southwest monsoon this year also resulted in above average annual rainfall over the north, west and central parts of Singapore.

The 2010 anomalous 850-hPa zonal wind average between 5°N-5°S is shown in [Figure 18](#). At Singapore's longitude (around 100E), it was neutral for most of the year till September when positive anomalies began to arise. The positive anomalies in the last quarter of the year indicate that zonal winds over Singapore were more westerly than usual and could have first contributed to an extended southwest monsoon and subsequently to a mild Northeast monsoon in December, where the monsoon surge was unable to proceed beyond 5°N.

## FIGURES



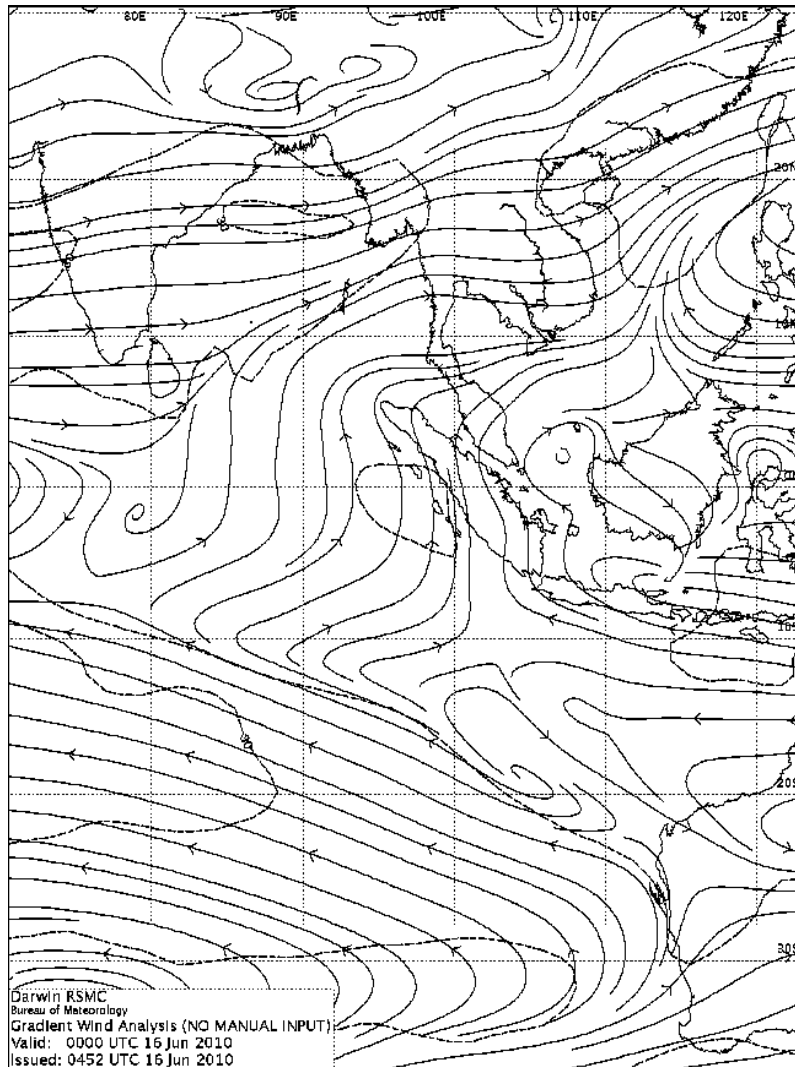


Figure 2: Gradient wind analysis (from Bureau of Meteorology) of synoptic situation in South East Asia region on 16 Jun 2010. The circulation between Peninsular Malaysia and Borneo induced the passage of the Sumatra squall in the late morning. The circulation also hindered the eastward progression of the squall line, causing it to hover over the city area for over an hour.

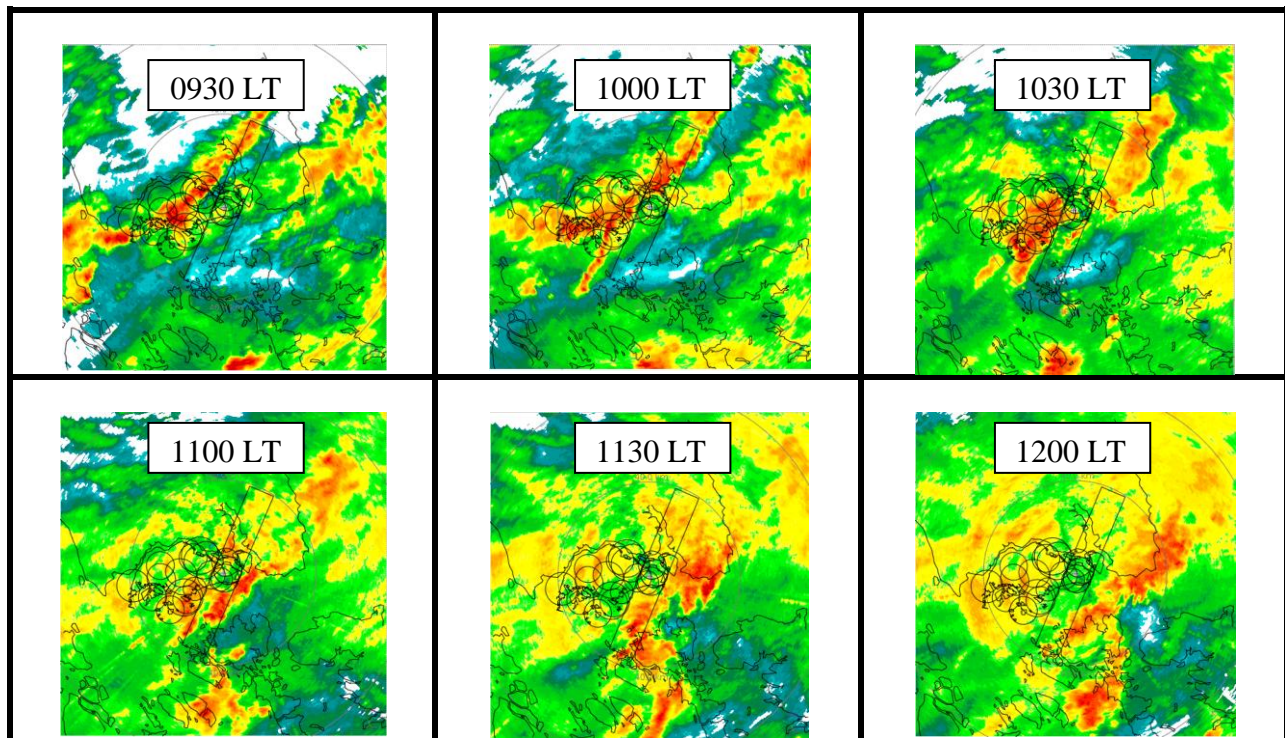


Figure 3: Radar images at half-hourly intervals showing the passage of the Sumatra squall from northwest to southeast. The squall line lingered over the city area in the southeast for over an hour between 0930 and 1030.

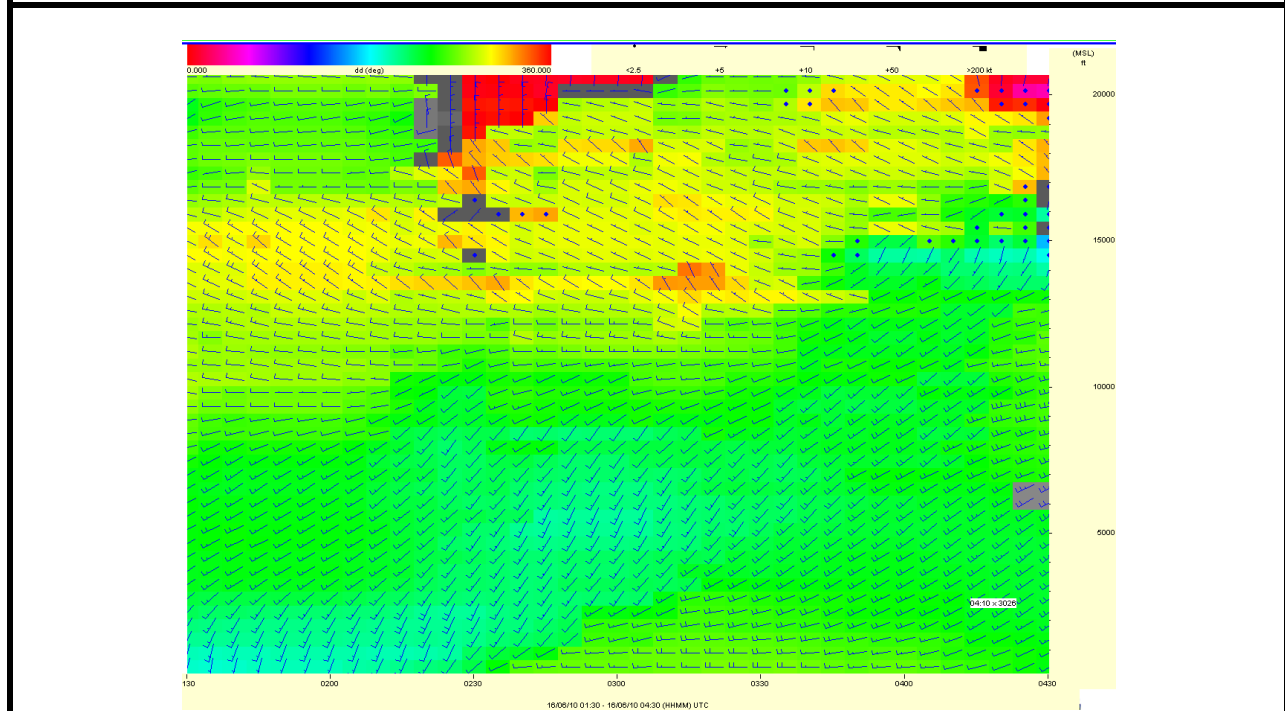


Figure 4: Upper air wind profiles from the wind profiler located at Changi Airport. Time scale on the horizontal axis is in UTC time. As the squall line moved past around 0230UTC, there was a westerly change in the winds close to the surface. This was coupled with a strengthening



of winds up to 10000 ft (700 hPa).

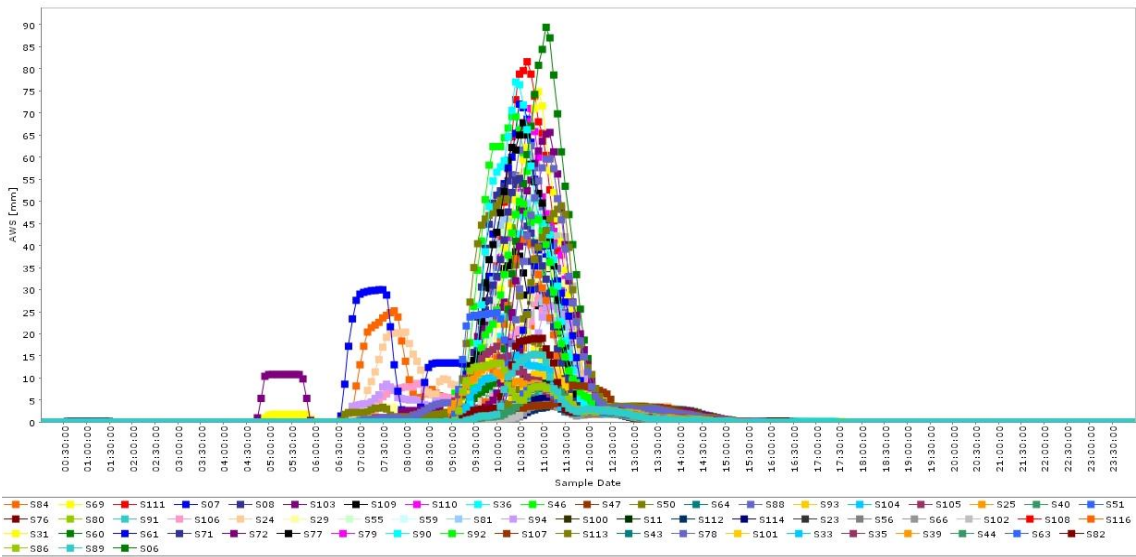
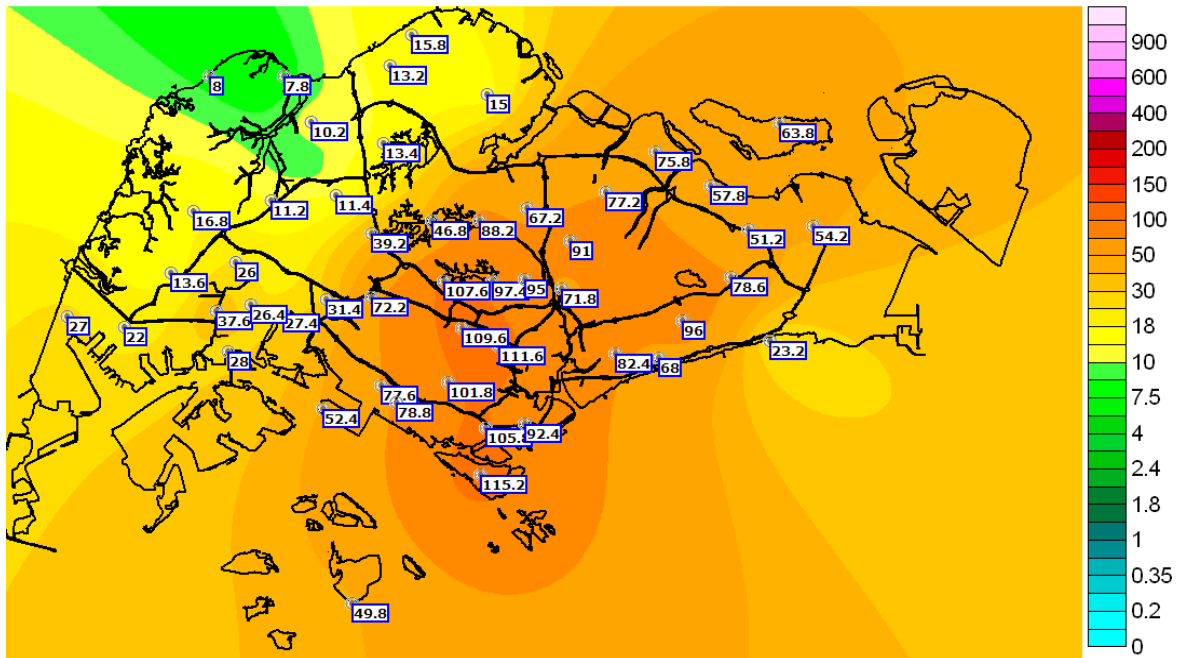


Figure 5: Rainfall data from the automatic weather stations located islandwide on 16<sup>th</sup> Jun 2010. Total rainfall (*top*) and hourly rainfall intensity (*bottom*) for that day.

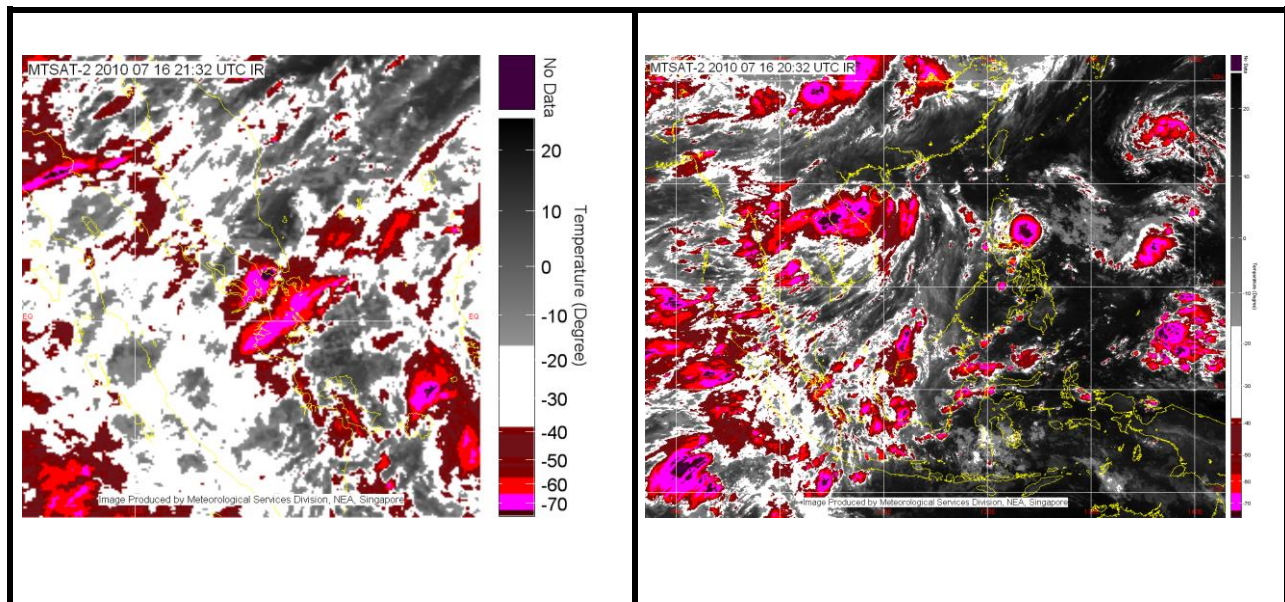


Figure 6: Colorized MTSAT IR image of region over Singapore (*left*) showing a Sumatra squall which swept through Singapore in the pre-dawn of 17 July and intensified over the island. Colorized MTSAT IR image of the Western Pacific (*right*) showing the dissipating Typhoon Conson and the squall line which extended from Myanmar down the entire east coast of Sumatra.

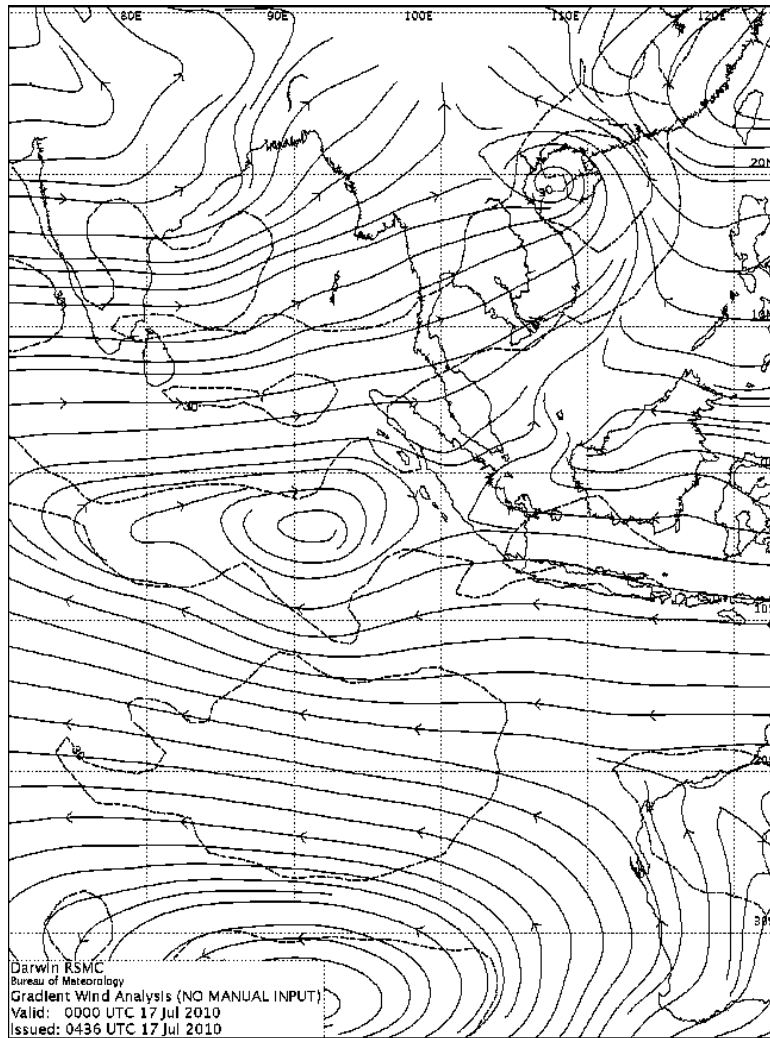


Figure 7: Gradient wind analysis (from the Bureau of Meteorology) of synoptic condition in South East Asia region on 17 Jul 2010. Typhoon Conson made landfall at Vietnam in the early hours and the dissipated energy helped to feed the development of an intense Sumatra squall. An outer band of convergence, originating from Typhoon Conson, extended from the east coast of Vietnam to Singapore.

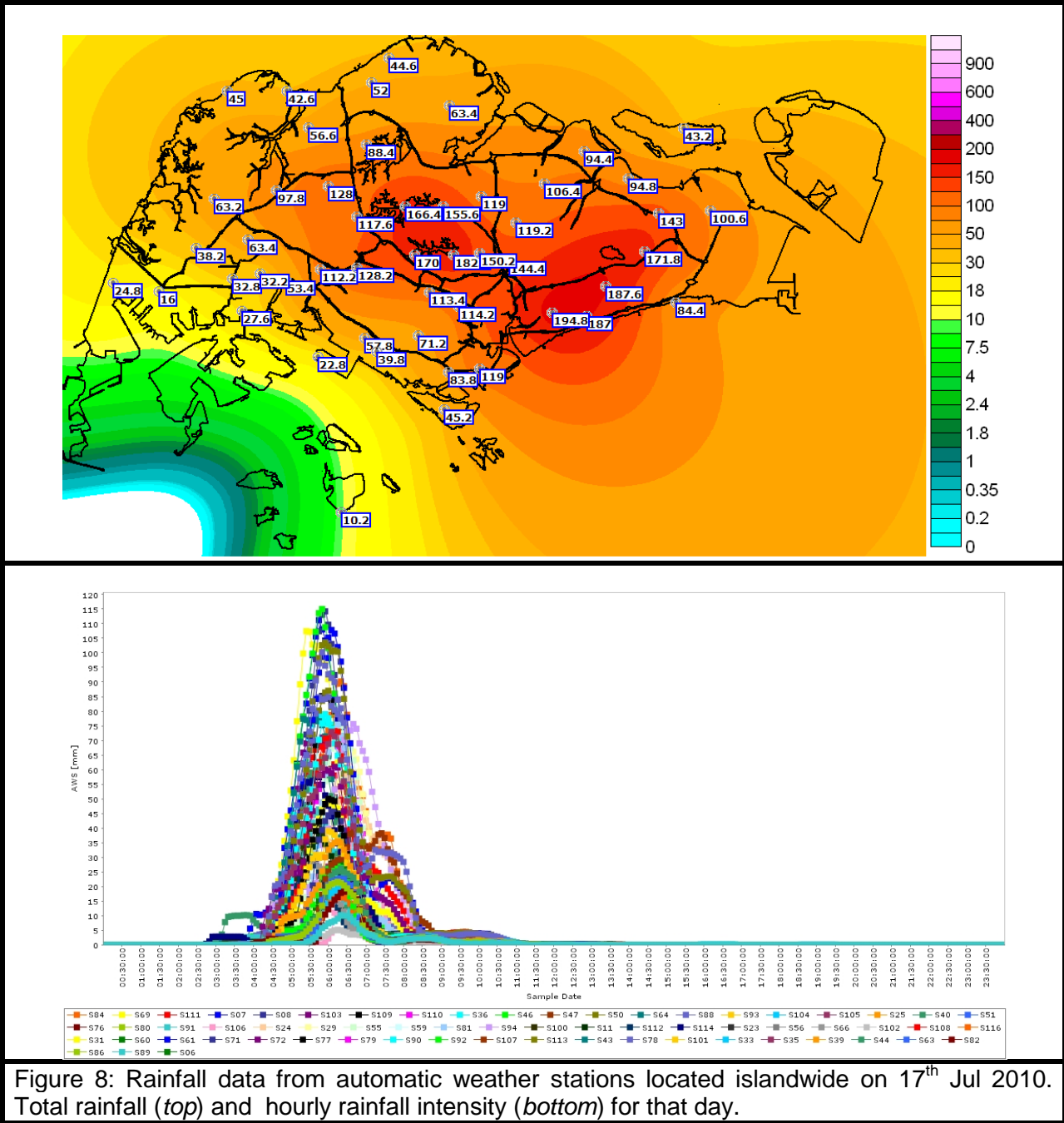


Figure 8: Rainfall data from automatic weather stations located islandwide on 17<sup>th</sup> Jul 2010. Total rainfall (*top*) and hourly rainfall intensity (*bottom*) for that day.

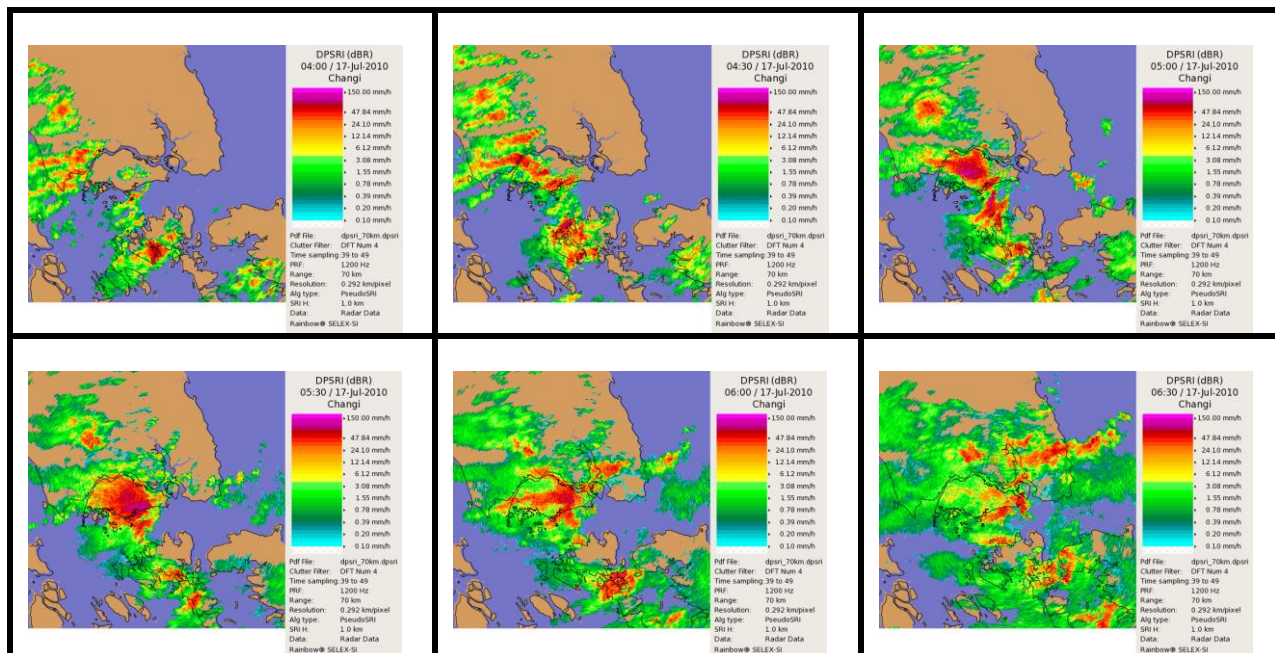


Figure 9: Radar images at half-hourly intervals showing the passage of the Sumatra squall from west to east. Rainfall was most intense between 0500 and 0600 hrs.

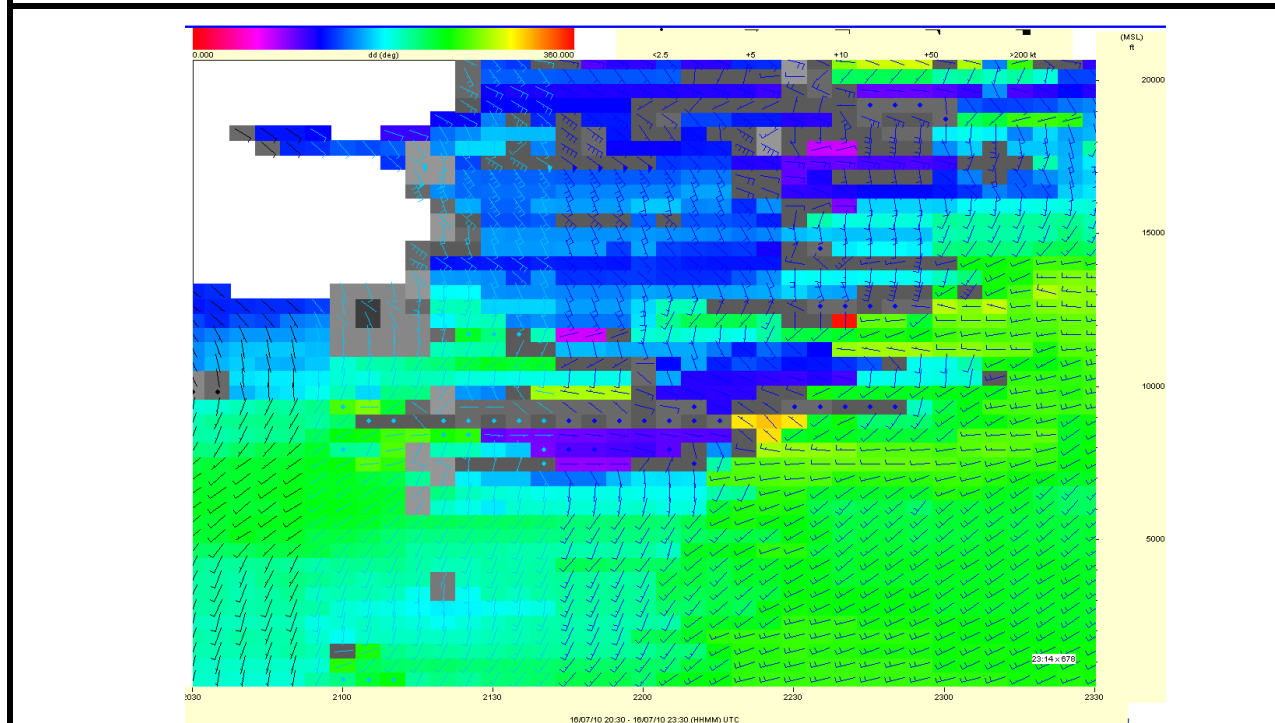
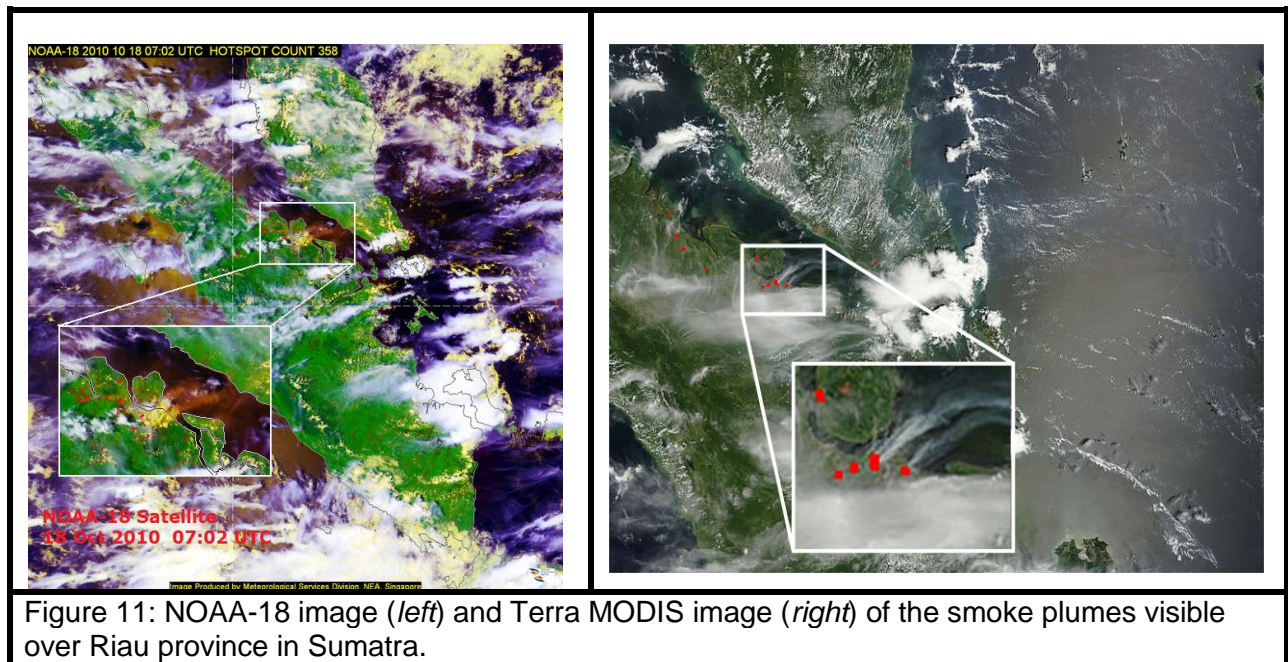


Figure 10: Upper air wind profiles from the wind profiler located at Changi Airport. Time scale on the horizontal axis is in UTC time. Wind barbs in cyan indicate falling precipitation over the wind profiler. As the squall line moved past around 2100UTC, there was a westerly change in the winds close to the surface. This was coupled with a strengthening of winds up to 10000 ft (700 hPa).



## 2010 Monthly Statistics (Climate Station)

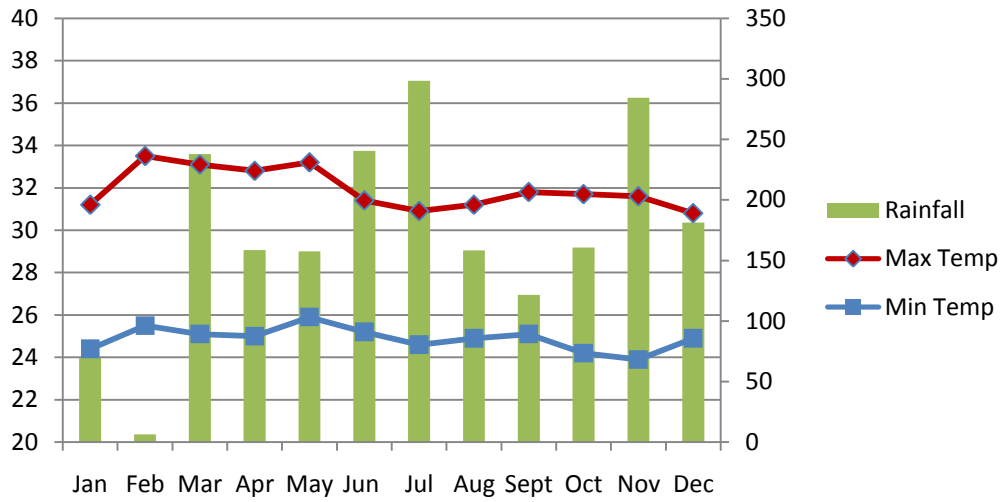


Figure 12: Monthly statistics of rainfall, maximum and minimum temperature at the climate station located in Changi.

## 2010 Oceanic Niño Index (ONI)

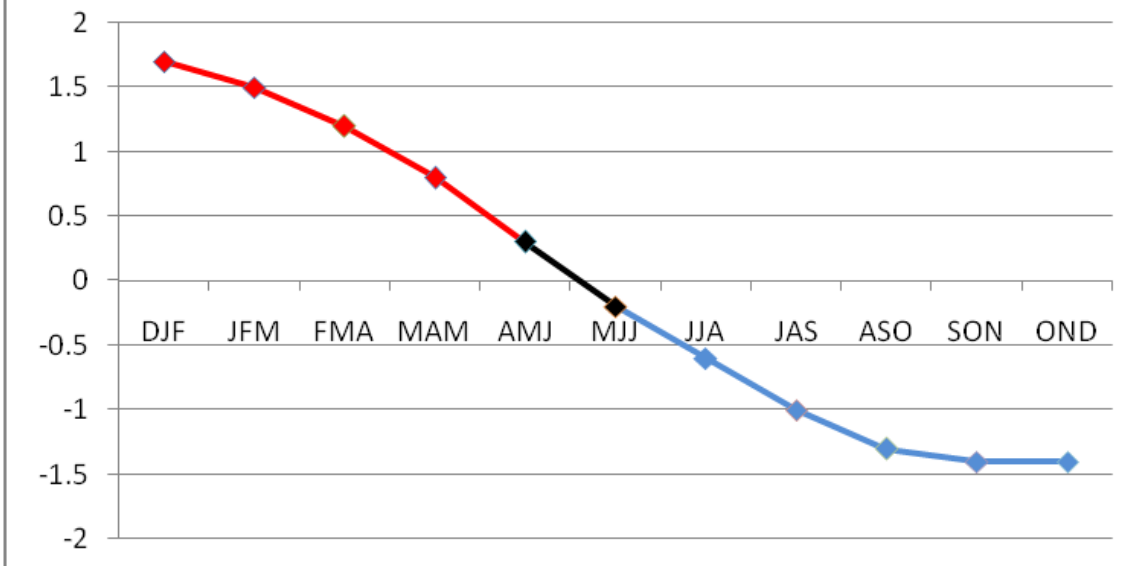


Figure 13: The Oceanic Niño Index for 2010 (Source; NOAA NWS CPC). Red: El Niño conditions; Black: Neutral conditions; Blue: La Niña conditions.

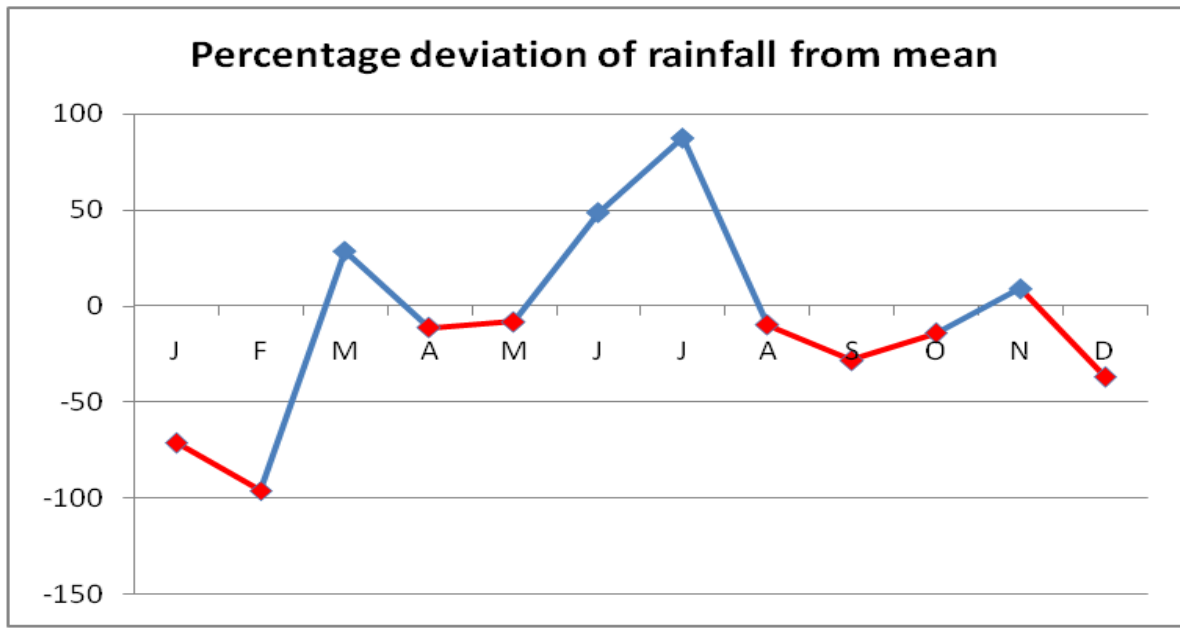


Figure 14: Percentage deviation of rainfall from the mean (1869-2010). The correlation with the Oceanic Niño Index is strong till July but the correlation breaks down in the second half of the year.

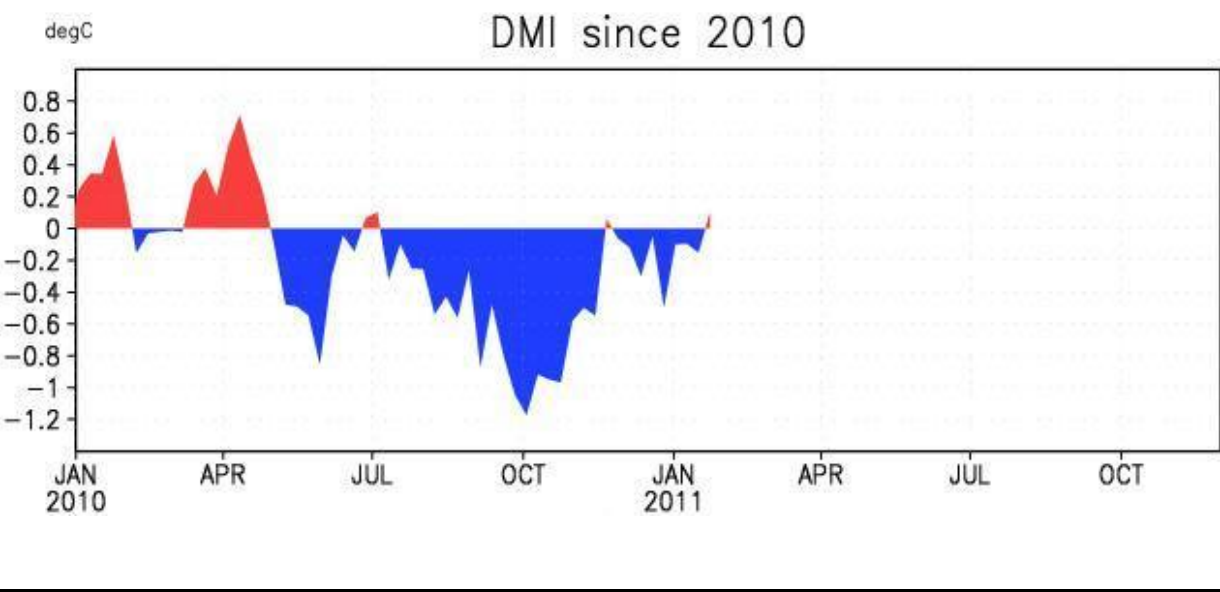


Figure 15: The Indian Ocean Dipole Mode Index (source: JAMSTEC). Positive (red) indicates warmer anomalies in the western Indian Ocean. Negative (blue) indicates cooler anomalies in the western Indian Ocean.



### Annual Rainfall Distribution 2010 (mm)

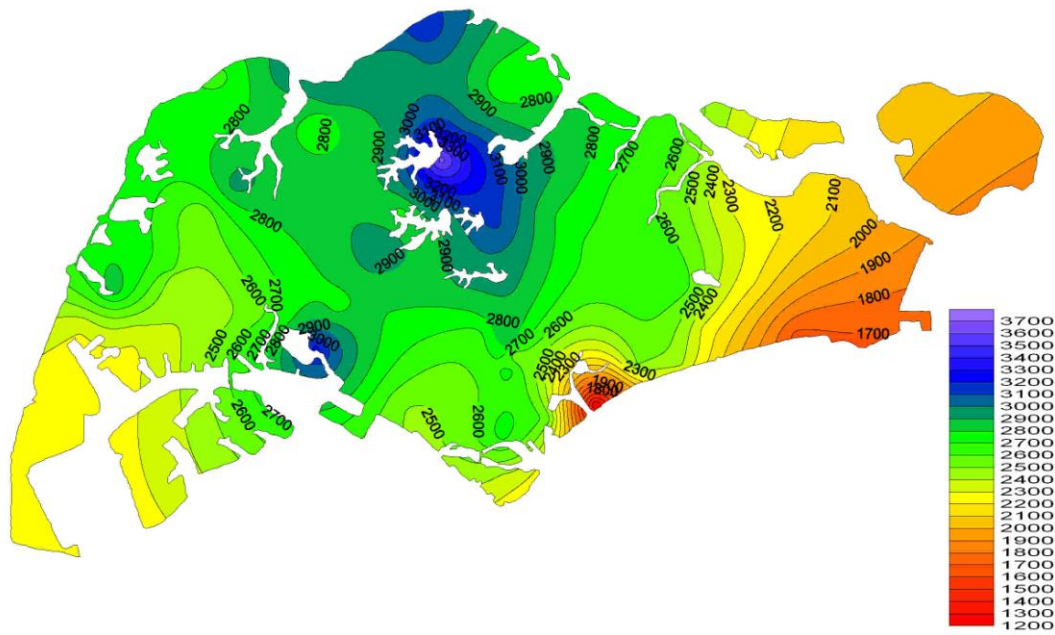


Figure 16: Isohyets of annual rainfall distribution in 2010 for Singapore.

### Annual Rainfall Distribution 2010 (%)

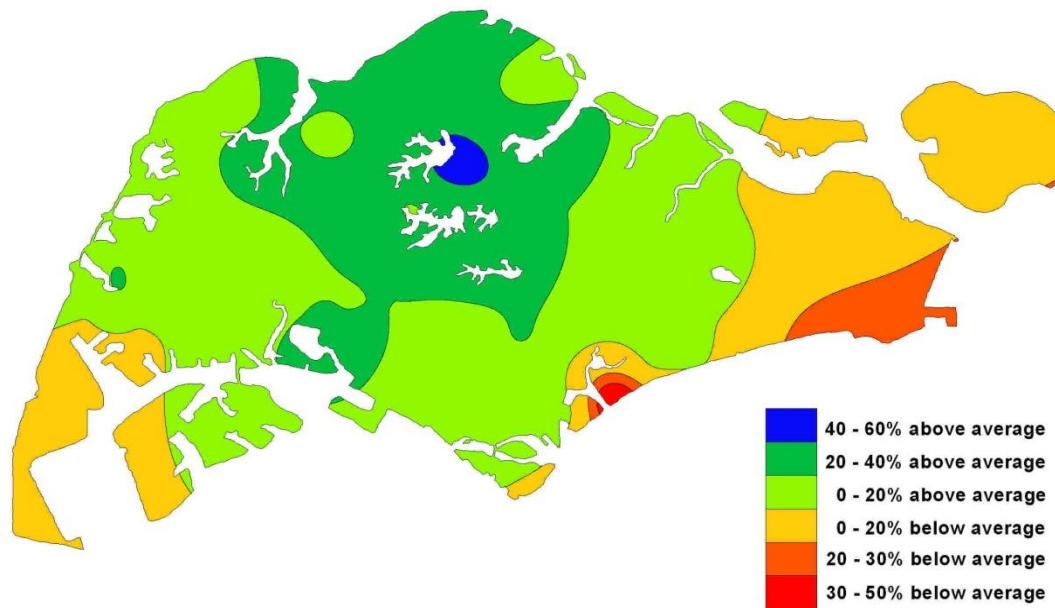


Figure 17: Percent deviation of annual rainfall in 2010 from the long term means for Singapore.

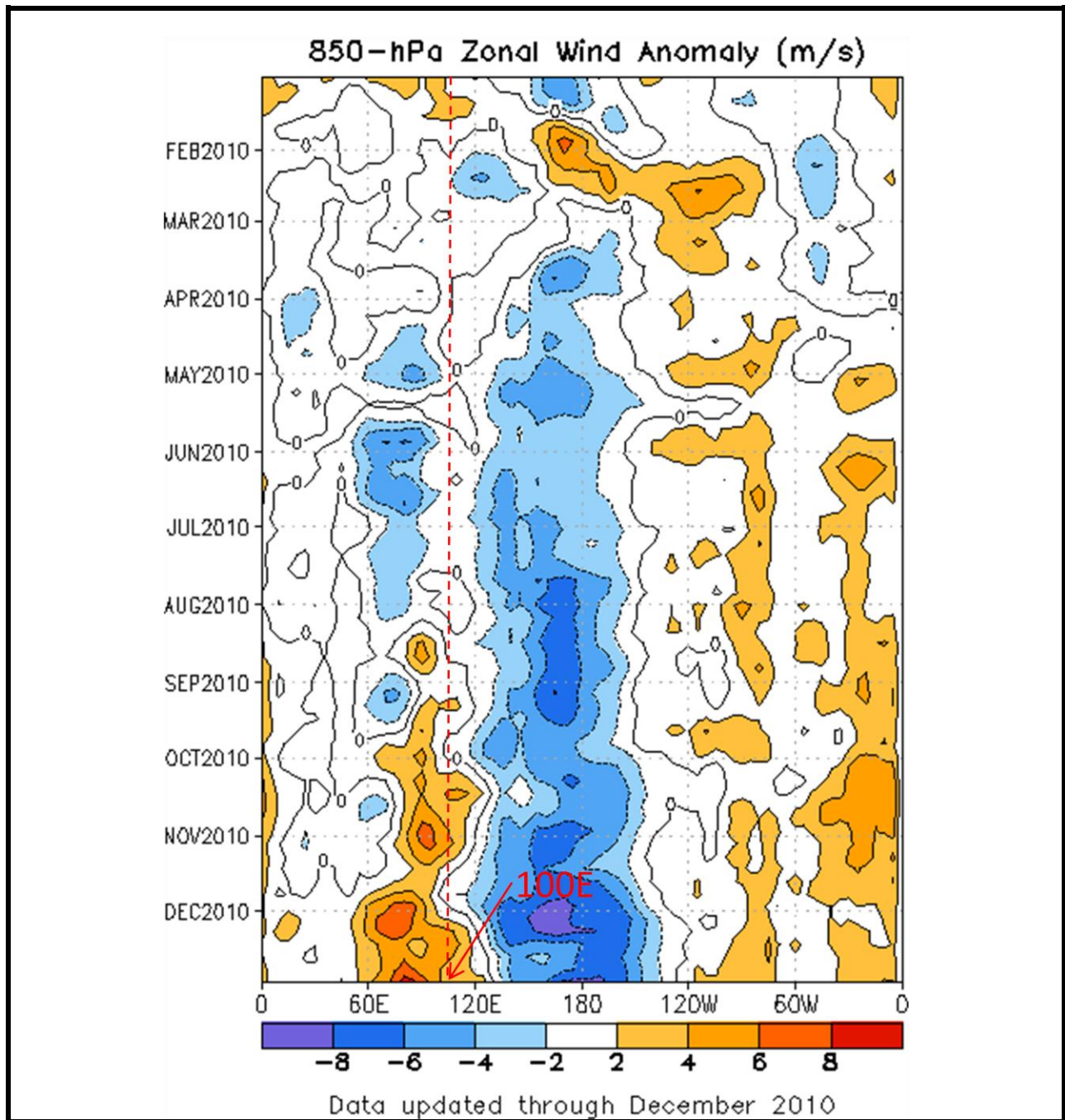


Figure 18: Time-longitude section of anomalous 850-hPa zonal wind averaged between 5N-5S (source: CDAS/Reanalysis). Contour interval is 2 ms<sup>-1</sup>. Anomalies are departures from the 1981-2010 base period pentad means. The data are smoothed temporally by using a 3-point running average. Blue shading and dashed contours indicate easterly anomalies. Orange shading and solid contours indicate westerly anomalies. Singapore is located at approximately 100E.