MALAYSIAN METEOROLOGICAL DEPARTMENT (MMD)
MINISTRY OF SCIENCE, TECHNOLOGI AND INNOVATION (MOSTI)

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Diagnoses of The Major Rain Events Occurred in Northwest Peninsular Malaysia in 2012

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Abstract

8 major rain events were determined based on the combined daily rainfalls in 2012 of Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas meteorological stations in northwest Peninsular Malaysia. Each of the rain events was studied by examining the hourly rainfall distributions, satellite images, radar echoes, upper air winds charts, mean sea level pressure charts, cold surge, tephigrams, stability indices, El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Madden-Julian Oscillation (MJO).

1.0 Introduction

The long lasting and/or high intensity rain of major rain events occurring in any year can result in extremely large amounts of rainfall over a rainfall region like northwest Peninsular Malaysia. Such rainfall events can also cause flash floods, strong winds and landslides, which in turn can result in loss of lives, damages to crops and properties. Hence, it is vital to improve our knowledge on such major rain events by studying them in details. Such knowledge will be beneficial to forecasters in anticipating and monitoring such rain events in future. 8 major rain events were determined based on the combined daily rainfalls in 2012 of Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas meteorological stations in northwest Peninsular Malaysia. Each of the rain events was studied by examining the hourly rainfall distributions, satellite images, radar echoes, upper air wind charts, mean sea level pressure charts, cold surge, tephigrams, stability indices, El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Madden-Julian Oscillation (MJO).

2.0 Data

The tephigrams, radar and satellite images, hourly rainfall data of Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas meteorological stations in 2012 were from Malaysian Meteorological Department (MMD). The maps on upper winds and isotachs, and Mean Sea Level Pressure; Southern Oscillation Index (SOI) values for El Nino Southern Oscillation (ENSO), Madden-Julian Oscillation (MJO) and DMI values for Indian Ocean Dipole (IOD) were from NOAA National Centers for Environmental Prediction (NCEP). The stability indices were obtained from the University of Wyoming, USA.

3.0 Analysis

3.1 Identification Of Major Rain Events

The showery nature of the tropical rainfall meaning that it should be treated with area integrals of rain rather than with individual station data (Riehl, 1954). 8 major rain events were identified based on the top combined observed daily rainfall amounts of Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas meteorological stations in northwest Peninsular Malaysia in 2012.

3.2 Hourly And Daily Rainfall

Graphs were plotted to show the hourly distribution of rainfall amounts of all the four stations for all the major rain events identified. Such analyses aim to give an indication of the temporal and areal rainfall distributions. Tables were also used to summarize / show the hourly rainfall distributions and daily rainfall amounts of all the major rain events.

3.3 Satellite Images

For each of the major rain events, a series of IR satellite imageries of selected hours were used to identify the cloud clusters that produced heavy rain.

3.4 Radar Echoes

Radar echo displays of selected hours were examined to reveal the areal extent and intensity of rain during the major rain events. In particular, the displays would be helpful to reveal the association among the thunderstorm cells, squall-lines and their movements. A squall-line is a moving line of thunderstorms, usually hundreds of kilometers long and lasts for several hours. Squall-lines are common along the west coast of Peninsular Malaysia during the southwest monsoon (Azizan A.S. & Lim, J.T., 2004).

3.5 Upper Air Winds

Reanalysed upper air wind charts of 850 and 200 hPa levels were examined to determine the existence of significant synoptic features such as near equatorial trough, cyclonic vortex, tropical cyclone, low-level convergence, upper-level divergence etc. which might have contributed to the occurrence of the major rain events.

3.6 Mean Sea Level Pressure

The mean sea level pressure (MSLP) over the Peninsular Malaysian region was examined to determine the existence of a low pressure area or a tropical cyclone which might have directly contributed to the occurrence of any of the major rain events.

3.7 Cold Surge

All the major rain events during the northeast monsoon were examined for the existence of cold surge that might have contributed to the occurrence of the rain events.

3.8 Tephigrams

Tephigrams of Bayan Lepas were provided to examine the characteristics and changes in the vertical temperature and humidity profiles of the atmosphere associated with the major rain events.

3.9 Stability Indices

The Showalter Index (SI), lifted index (LI), Total totals Index (TTI), Level of Free Convection (LFC), Convective Available potential Energy (CAPE) and Convective Inhibition (CIN) were included to examine the static stability of the atmosphere, intensity and possibility of thunderstorms associated with the major rain events. Values of the indices were computed from three upper air radiosonde ascents at 8.00 a.m. or 8.00 p.m. of Bayan Lepas for each of the major rain events.

CIN in J/kg greater than -50 is considered as weak (inhibition can be overcome by surface heating), while that of -200 to -50 is moderate (overcome by strong heating / synoptic scale forcing), and a strong inhibition of less than -200 impedes thunderstorm development (**Webpage 1**).

3.10 ENSO, IOD and MJO

The SOI for monitoring ENSO, DMI for IOD, and MJO values were obtained to find out whether conditions favouring strong convection or precipitation existed over northwest Peninsular Malaysia during the main rain events.

4.0 Results and Discussion

4.1 Identification of Major Rain Events

Of the eight major rain events, four occurred on 1 January, 7 March, 4 November and 24 November during the northeast monsoon, three occurred on 22 August, 8 and 13 September during the southwest monsoon while one occurred on 5 October during the inter-monsoon season (**Table1**).

4.2 Hourly and Daily Rainfall

Table 2 summarized the hourly rainfall distributions of the four meteorological stations during the major rain events.

From **Table 1**, the combined daily rainfall of the four stations was the highest (232.8 mm) on 8 September, and the lowest (148.0 mm) in 22 August. Seven out of the eight major rain events had the daily rainfall amounts unevenly distributed among the four stations. The highest daily rainfall in each of the major rain events ranged from 53.8 mm on 5 October in Chuping to 138.4 mm on 8 September in Alor Setar while the lowest ranged from 0 mm on 1 January in Bayan Lepas to 5.00 mm on 13 September in Chuping.

4.3 Satellite Images

In the 8 September major rain event, a large cluster of cumulonimbus clouds centred over the east coast of north Sumatra at 12.00 LT. Three and four hours later, the cluster brought heavy rain to Perlis, north Kedah and adjacent sea (**Fig.1a**).

On 5 October and at 2.00 LT, a large cloud cluster was present over northern Straits of Malacca. The cloud cluster was weakening and moving northwestwards in the subsequent five hours (**Fig.1a**).

In the event on 24 November, large cloud clusters are present at 11.00 LT over the northeast coast of Peninsular Malaysia, east coast of southern Thailand and northern Straits of Malacca. By 14.00 LT, the cloud cluster over the Straits had strengthened while the reverse had occurred in other cloud clusters. In addition, a cluster of cumulonimbus clouds was present over Perlis, north Kedah and adjacent sea. An hour later, the cloud cluster showed development and covered Penang and south Kedah (**Fig.1b**).

On 13 September, no cloud cluster was visible at 00.00 LT and 01.00 LT. However, at 16.00 LT two relatively small and elongated cloud clusters appeared over north Kedah and adjacent sea (**Fig.1b**).

At 04.00 LT in the 1 January event, a large cluster with cumulonimbus clouds was over north Peninsular Malaysia and south Thailand. At 08.00 LT, the cloud cluster over north Peninsular Malaysia seemed to have moved northwestwards and intensified. By 10.00 LT, the cloud cluster over northwest of the peninsula and adjacent sea had weakened significantly (**Fig. 1c**).

In the 4 November event and at 17.00 LT, a cloud cluster with cumulonimbus was over northern Straits of Malacca and coastal region of northwest Peninsular Malaysia. An hour later, a significant intensification of the cloud cluster was evident along the coast of Perlis and north Kedah, and adjacent sea. By 20.00 LT, the same cloud cluster had weakened and left the coast (**Fig. 1c**).

At 18.00 LT and 19.00 LT on 7 March, cloud clusters with cumulonimbus were present along Straits of Malacca and coastal areas of northwest Peninsular Malaysia and southern Thailand. The cloud cluster over coastal areas of northwest Peninsular Malaysia and adjacent sea was gone by 21.00 LT (**Fig. 1d**).

In the 22 August major rain event, a large cloud cluster with cumulonimbus was over Penang and south Kedah, and adjacent sea at 19.00 LT. By 23.00 LT, the cloud cluster had weakened very significantly (**Fig. 1d**).

4.4 Radar Echoes

In the major rain event on 8 September and at 12.00 LT, two large patches of rain echoes with slight intensity were located mainly over the Straits of Malacca while the one nearer to the coast brought rain to part of Penang and south Kedah (**Fig. 2a**). At 15.00 and 16.00 LT, the rain echoes were located further north with one patch over land bringing heavy rain to north Kedah and Perlis.

In the 5 October major rain event, a large patch of rain echoes with heavy intensity was located just off the Kedah coast at 02.00 LT. Two hours later, a larger area of stronger echoes indicating very heavy rain was over the north Kedah coast and the adjacent sea. By 19.00 LT, the same patch of rain echoes had weakened and the heavy rain area was then over Perlis (**Fig. 2a**).

At 11.00 LT on 24 November, a large patch of rain echoes with heavy rain was over the sea off the Kedah coast. The patch of rain echoes over the sea dissipated while a new patch with heavy rain was then over Perlis and north Kedah at 14.00 LT. One hour later, the rain echoes showed a weakening except in central Kedah where the reverse had occurred (**Fig. 2b**).

In the 13 September event, the rain echoes showed two narrow lines parallel to each other at 00.00 LT. Heavy rain due to one of the lines was evident over north Kedah. An hour later, one line had broken up while the other one intensified and brought heavy rain to the coastal region of central Kedah. At 16.00 LT, the line appeared to have shifted north causing heavy rain in Perlis (**Fig. 2b**). The lines of rain echoes were probably squall-lines as thunderstorms were reported in all the stations (**Table 5**).

On 1 January, a large patch of slight to moderate rain echoes was over Perlis and Kedah at 04.00 and 08.00 LT. By 10.00 LT, the rain echoes had weakened significantly with slight rain continuing (**Fig. 2c**). This was the only major rain event where no thunderstorm was reported by the stations (**Table 5**). The patches of rain echoes here looked more uniform compared to the other major rain events, and this was consistent with widespread continuous rain (no thunderstorm) reported by all the four stations. Most probably the rain was the stratiform type falling from the nimbostratus clouds (against the convective type from active cumulus and cumulonimbus clouds). Stratiform and convective precipitation show contrasting radar-echo structures. (**Webpage 4**).

In the major rain event on 4 November and at 17.00 LT, moderate to heavy rain occurred mainly over the coastal region of north Kedah while rain echoes also present over the adjacent sea. An hour later, the rain echoes intensified significantly and increased in area causing heavy rain in Perlis. Seemingly, the thunderstorm cells organized into lines with one east-west orientated while another north-south. At 20.00 LT, the rain echoes weakened significantly and the organized structure of thunderstorm cells was gone (**Fig. 2c**).

On 7 March and at 18.00 LT, intense rain echoes showing thunderstorm cells were over Perlis and its adjacent sea, and northern border of Kedah. An hour later, the thunderstorm cells formed a line, most probably due to the orographic effect. At 21.00 LT, the line of thunderstorm cells dissociated while a new line was formed over the sea off the Kedah coast (**Fig. 2d**).

The 22 August event was the least significant among the eight and this was reflected in the rain echoes which were mostly weak (**Fig. 2d**). However, heavy thunderstorms were reported by Pulau Langkawi at 20.00 LT (**Table 5**).

4.5 Upper Air Winds

At 850-hPa level, the near equatorial trough (NET) / cyclonic vortex (3 events on 24 Nov., 1 Jan., & 7 Mar.) and strengthening of the westerly prevailing winds (3 events on 5 Oct., 13 Sep. & 22 Aug.) were the two most common synoptic features over Peninsular Malaysia associated with the main rain events, followed by convergence (1 event on 4 Nov.) and slight variable winds associated with ridge (1 event on 8 Sep.) (**Fig. 3a – 3h** & **Table 3**). As strong synoptic winds suppress local circulations (Azizan A.S. & Lim, J.T., 2004), the slight winds associated with ridge over northwest Peninsular Malaysia in the 8 September major rain event could have favoured daytime heating and convection. In fact, most of the rainfall on that day occurred in the afternoon.

At 200-hPa level, divergent flows existed in most (7) of the major rain events (**Fig. 3a – 3h)** & **Table 3**).

4.6 Mean Sea Level Pressure

No tropical cyclone existed over the Peninsular Malaysia region that might have contributed to the occurrence of any of the major rain events (**Webpage 3**). However, northwest Peninsular Malaysia was within a low pressure area (1004 - 1005 hPa) during the 7 March major rain event (**Fig. 4d**). The low pressure was consistent with the existence of a cyclonic vortex (**Fig. 3g** & **Table 3**).

4.7 Cold Surge

Based on the criteria for cold surge in Weather Forecasting Guidelines, out of the 4 major rain events during the northeast monsoon, only one (1 January) event involved a cold surge.

4.8 Tephigrams

Comparing to the tephigram 12 hours earlier, the available tephigram just before the peak rainfall period of each of the major rain events showed clearly the narrowing between the vertical air temperature and dew point temperature profiles (increased moisture and high relative humidity), particularly from the middle to the upper troposphere (**Fig. 5(a – d**). The increased moisture and high relative humidity mentioned indicated the existence of deep convection, cloud development and precipitation. The reversal occurred in the tephigram just after the peak rainfall period.

4.9 Stability Indices

For SI, all except one (13 September) major rain events had values (-4<SI≤1) interpreted as thunderstorms possible or more probable (**Webpage 2 & Table 4**). The SI value for the exception was interpreted as showers possible with other source of lift.

The most unstable (negative) LI values of the major rain events on 8 September, 13 September and 22 August were -6.0, -4.8 and -4.7 respectively, interpreted as severe thunderstorms while those on 5 October, 24 November, 1 January, 4 November and 7 March were -3.7, -3.3, -2.8, -3.4 and -2.4 respectively, interpreted as thunderstorms more probable (**Webpage 2 & Table 4**).

The TTI values for all the major rain events ranged from 40.7 (13 September) to 48.7 (8 September) (**Table 4**). TTI of at least 44 are needed for moderate thunderstorms to occur while at least 50 for heavy thunderstorms (**Webpage 2**). There were five major rain events with TT values for the occurrence of moderate thunderstorms. The major rain events with TT less than that for moderate thunderstorms to occur were on 24 November and 13 September. For the event on 7 March, one TT value was not available, so no evaluation possible.

The lowest LFC in each of the rain events ranged from 952 hPa (4 November) to 662 hPa (5 October) (**Table 4**).

All the CAPE values (below 2,500) were indicating slightly to moderately unstable atmosphere except that on 13 September, which was very unstable (**Webpage 2 & Table 4**).

Weak inhibition (CIN greater than -50) was present at some stage in each of the major rain events (**Webpage 2 & Table 4**).

4.10 ENSO, IOD and MJO

The monthly SOI values were positive (La Nina) in seven major rain events and negative (El Nino) in one, and they were small (0.2 to 1.1), meaning that the ENSO conditions were very weak or near neutral (**Table 6**). It is noted that the ENSO conditions were found to have no significantly effect on the occurrences of extreme rainfall event in northwest Peninsular Malaysia (Phang and Shaari, 2011).

The weekly DMI values associated with all the major rain events were found to be positive (warm IOD, i.e. cooler than normal SST in equatorial eastern Indian Ocean) (**Table 6**); this was consistent with the finding (Phang and Shaari, 2011) that the positive DMI values of IOD tended to favour the occurrences of extreme daily rainfall in northwest Peninsular Malaysia.

The pentad MJO values were negative (enhanced convection) in six of the eight major rain events and positive (suppressed convection) but small (0.30 and 0.34) in two (**Table 6**). This was also consistent with the finding that extreme daily rainfall events were more likely to occur when the MJO index values were negative (Phang and Shaari, 2011).

5.0 Conclusion

Of the 8 major rain events, 4 occurred during the northeast monsoon, 3 during the southwest monsoon, and 1 during the inter-monsoon season.

Generally, both the satellite imageries and radar rain echoes revealed the existence of large cloud clusters with cumulonimbus over northern Straits of Malacca for events during the southwest monsoon, and in addition to that, over the South China Sea adjacent to south Thailand and north Peninsular Malaysia for events during the northeast monsoon season, prior to the occurrences of heavy rain over northwest Peninsular Malaysia.

At 850-hPa level, the near equatorial trough (NET), and strengthening of westerlies were the two most common (3 events each) synoptic features associated with the main rain events, followed by convergence, and light variable winds associated with ridge (1 event each). At 200-hPa level, divergent flows prevailed.

Only one of the four major rain events during the northeast monsoon season was associated with a cold surge. No tropical cyclone existed over the Malaysian region that might have contributed to the events but northwest Peninsular Malaysia was in a weak low pressure area during one of the events.

Available tephigram just before the peak rainfall period of each of the major rain events showed increased moisture and high relative humidity especially from middle to upper troposphere, and the reverse was true. The stability indices were more useful in indicating the occurrence of thunderstorms compared to intensity, particularly the SI and LI indices.

References

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Riehl H., 1954. Tropical Meteorology. pp. 93-94.

Webpage 1: Guide to Convective Parameters (wind.mit.edu~btangy/Home/convection.htm)

Webpage 2: Atmospheric Stability Indices (www.srh.noaa.gov/ffc//?n=gloss2)

Webpage 3: 2012 Tropical Cyclone Overview by Hong Kong Observatory (www.hko.gov.hk/informtc/tcReporte.htm)

Webpage 4: SEPARATION OF CONVECTIVE AND STRATIFORM PRECIPITATION IN MESOSCALE SYSTEMS (From Houze, 1977. American Meteorological Society) (www.atmos.washington.edu/~gcg-dlh/mg/PDFs/NOTES_SeparationConvectStrat/Mesoscale.pdf)

Table 1: Daily rainfall and combined daily rainfall (mm) of 4 stations

Major Rain event (Date)	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas	Combined
8 Sep	37.6	8.6	138.4	48.2	232.8
5 Oct	51.4	53.8	49.2	44	198.4
24 Nov	27	41.8	85.2	19.8	173.8
13 Sep	38.8	5	115.6	13.8	173.2
1 Jan	23	101.4	41.2	0	165.6
4 Nov	43.4	18.2	76.8	19	157.4
7 Mar	27.2	76	46.6	1.4	151.2
22 Aug	97.8	10.2	9.8	30.2	148

Table 2a-h: Summarized hourly rainfall distribution of Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas of the major rain events

2a

8 September 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	8	5	5	5
Time (hour) with rainfall ≥ 10 mm	15, 16	None	15	11, 12
Highest hourly rainfall (mm) & hour of occurrence	17.8 (16)	2.8 (19)	125.6 (15)	27.2 (12)

2b

5 October 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	11	6	8	9
Time (hour) with rainfall ≥ 10 mm	7	7	4	2
Highest hourly rainfall (mm) & hour of occurrence	15.6 (07)	43.6 (07)	24.2 (04)	24.4 (02)

2c

4 November 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	8	8	6	6
Time (hour) with rainfall ≥ 10 mm	12	14	14, 15	11
Highest hourly rainfall (mm) & hour of occurrence	11.8 (12)	15.8 (14)	44.4 (15)	16.8 (11)

2d

13 September 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	15	10	16	7
Time (hour) with rainfall ≥ 10 mm	09	none	00, 01, 03, 12, 14	none
Highest hourly rainfall (mm) & hour of occurrence	10 (09)	0.6 (16)	38.4 (00)	6.2 (01)

2e

1 January 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	12	15	10	0
Time (hour) with rainfall ≥ 10 mm	none	03, 04, 07, 08, 09, 10	none	none
Highest hourly rainfall (mm) & hour of occurrence	7 (09)	17.2 (04)	9.6 (08)	none

2f

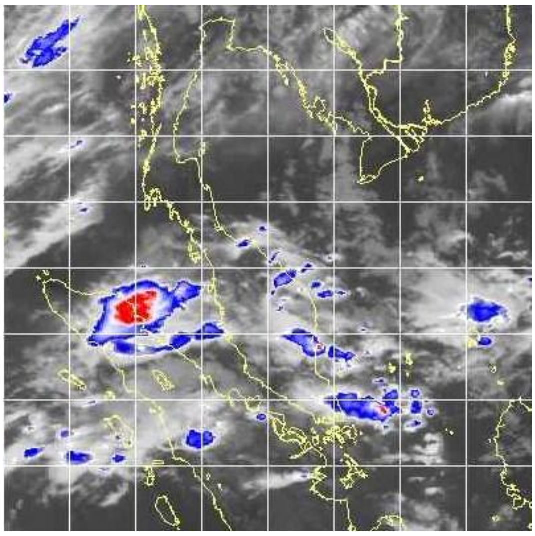
4 November 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	8	2	8	9
Time (hour) with rainfall ≥ 10 mm	17, 18	19	17, 18	20
Highest hourly rainfall (mm) & hour of occurrence	23 (17)	11.2 (19)	55.2 (18)	10 (20)

2g

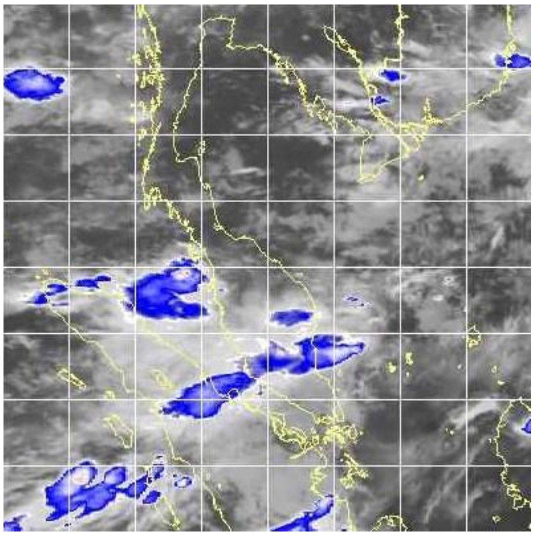
7 March 2012				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	9	5	4	0
Time (hour) with rainfall ≥ 10 mm	21	19, 21	18, 21	none
Highest hourly rainfall (mm) & hour of occurrence	12.8 (21)	60.2 (19)	27 (21)	none

2h

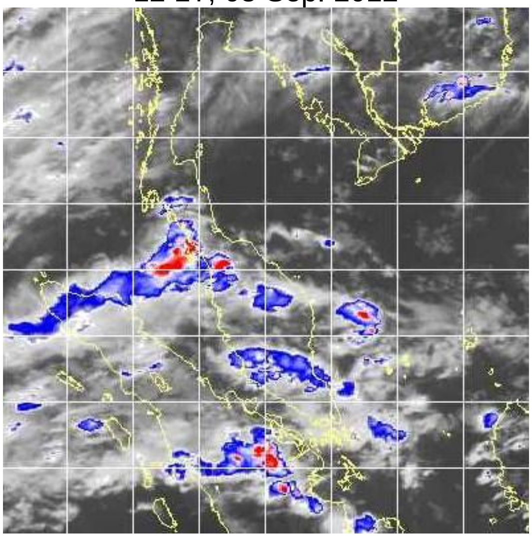
22 Aug				
	Pulau Langkawi	Chuping	Alor Setar	Bayan Lepas
Total no. of hours with rain	8	3	4	5
Time (hour) with rainfall ≥ 10 mm	18, 19, 20	none	none	11, 13
Highest hourly rainfall (mm) & hour of occurrence	40.6 (19)	none	8.2 (19)	11.8 (11)



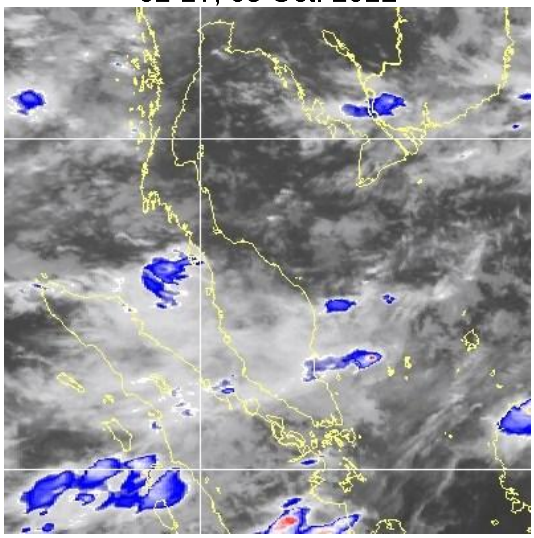
12 LT, 08 Sep. 2012



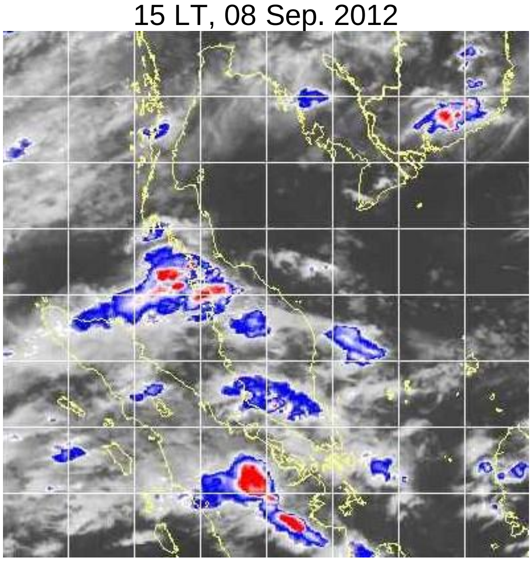
02 LT, 05 Oct. 2012



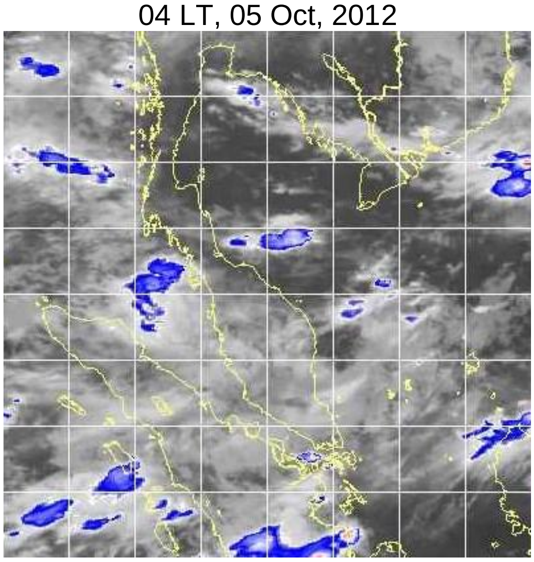
15 LT, 08 Sep. 2012



04 LT, 05 Oct, 2012

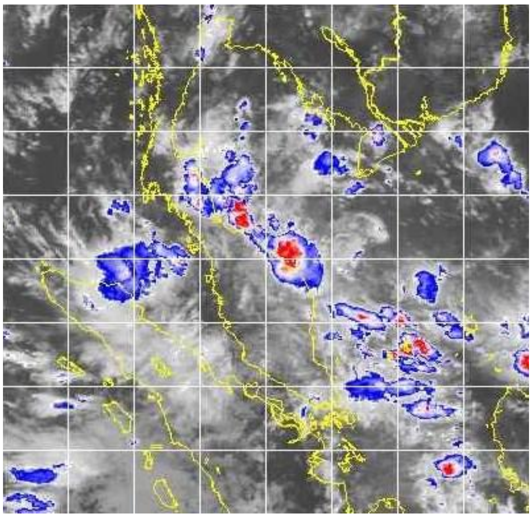


16 LT, 08 Sep. 2012

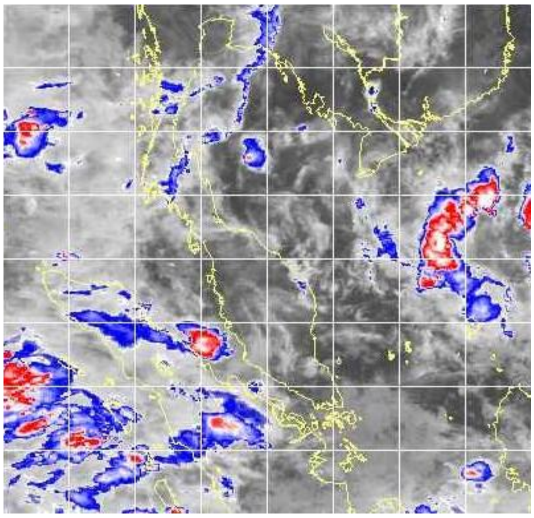


07 LT, 05 Oct, 2012

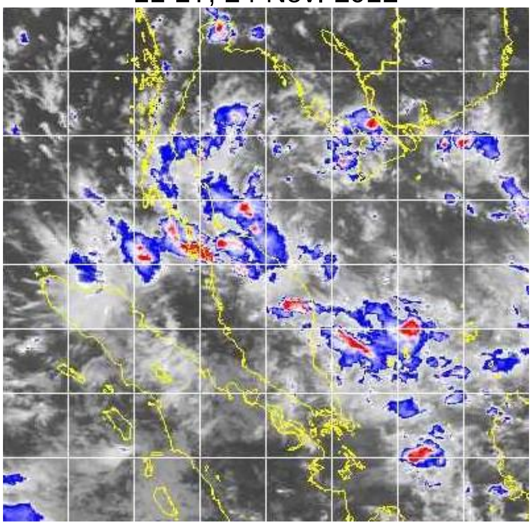
Fig.1a: Satellite imageries on 08 September and 05 October 2012.



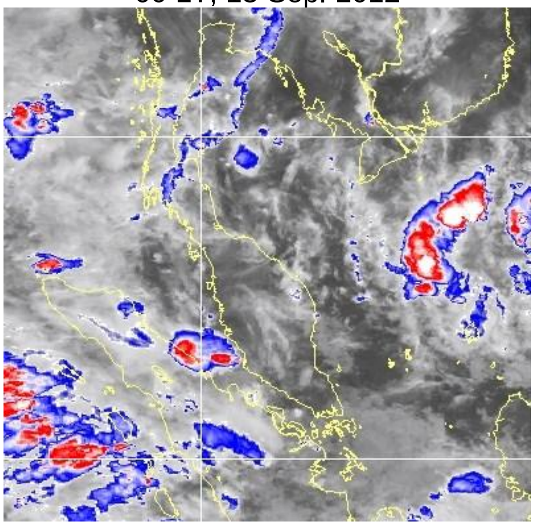
11 LT, 24 Nov. 2012



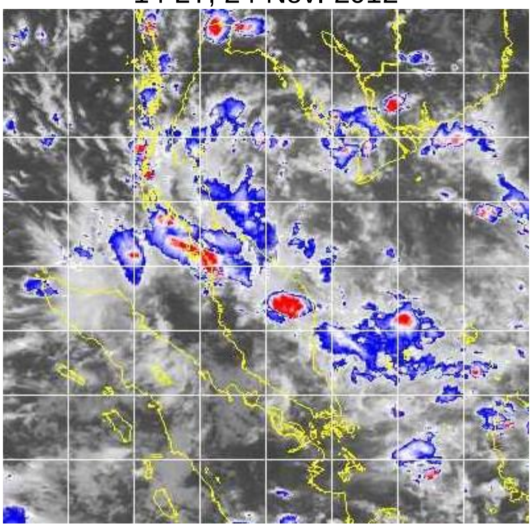
00 LT, 13 Sep. 2012



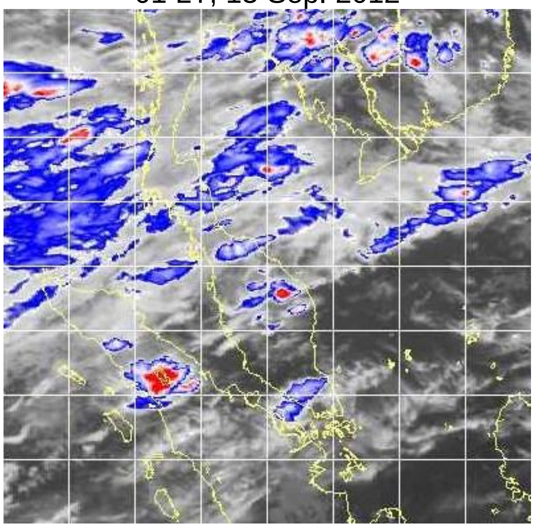
14 LT, 24 Nov. 2012



01 LT, 13 Sep. 2012

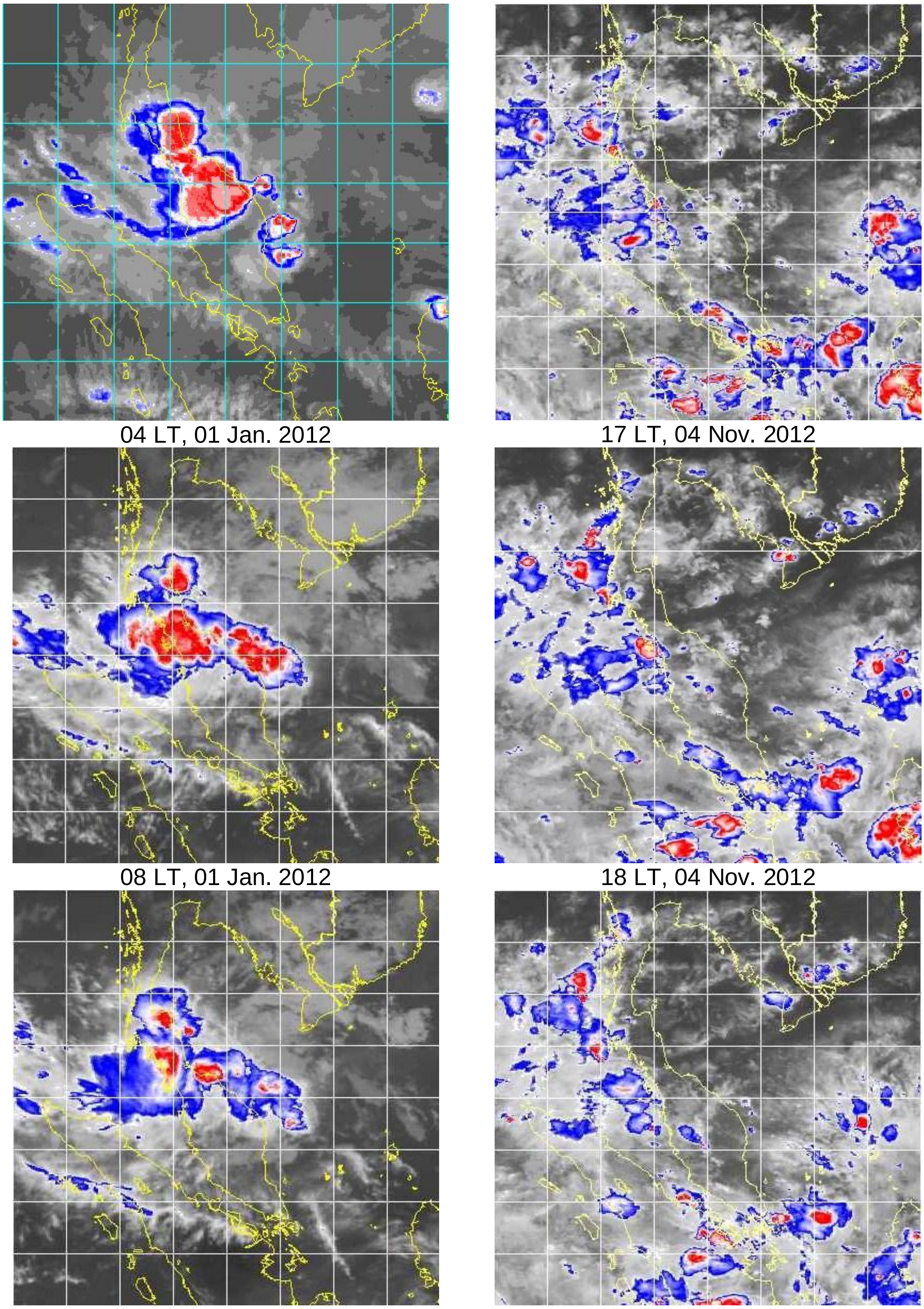


15 LT, 24. Nov, 2012



16 LT, 13 Sep. 2012

Fig. 1b: Satellite imageries on 24 November and 13 September 2012.



04 LT, 01 Jan. 2012

17 LT, 04 Nov. 2012

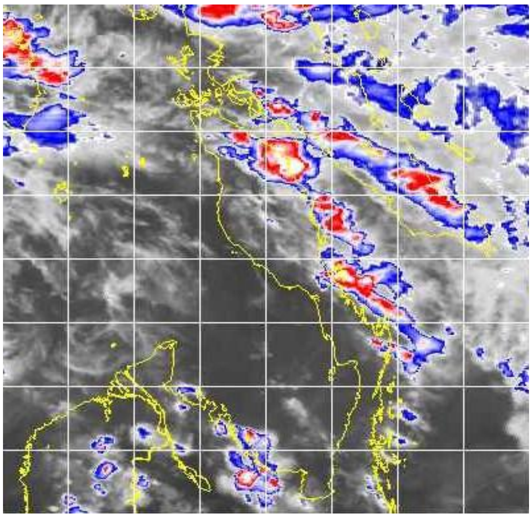
08 LT, 01 Jan. 2012

18 LT, 04 Nov. 2012

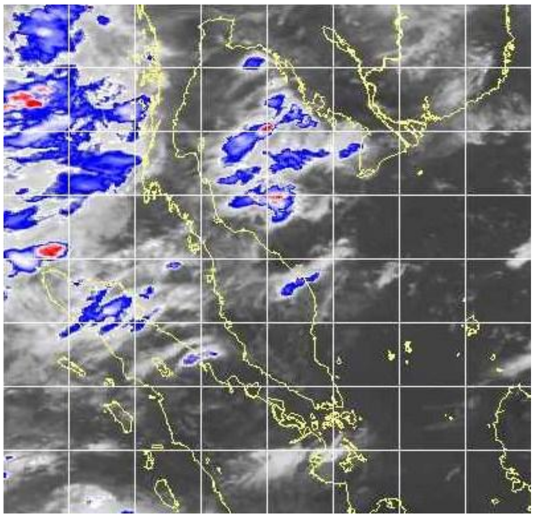
10 LT, 01 Jan. 2012

20 LT, 04 Nov. 2012

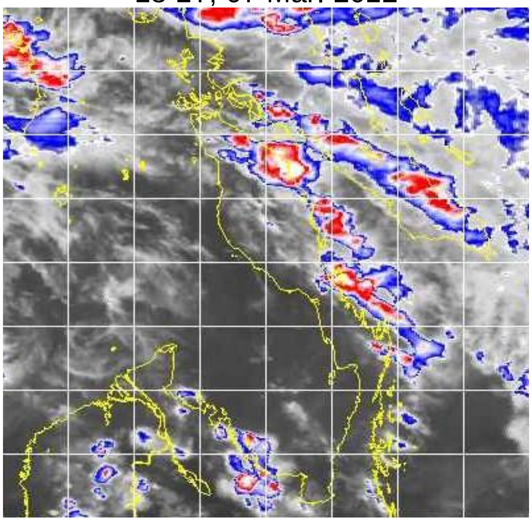
Fig. 1c: Satellite imageries on 01 January and 04 November 2012.



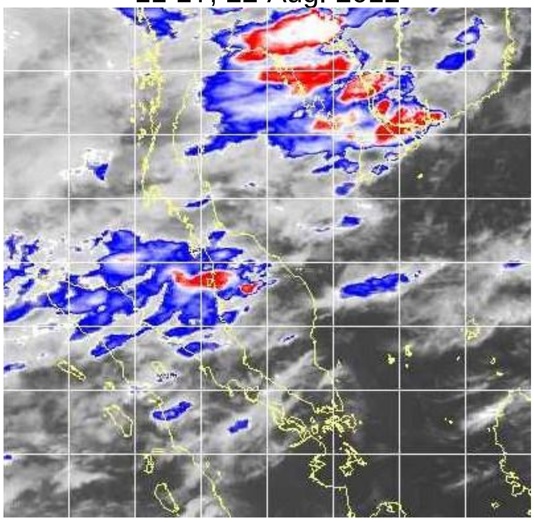
18 LT, 07 Mar. 2012



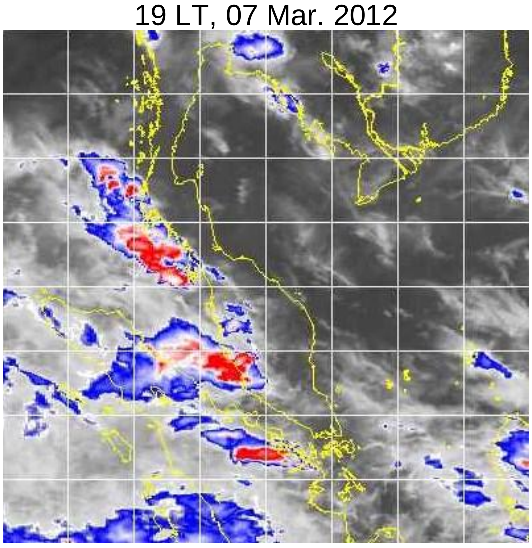
11 LT, 22 Aug. 2012



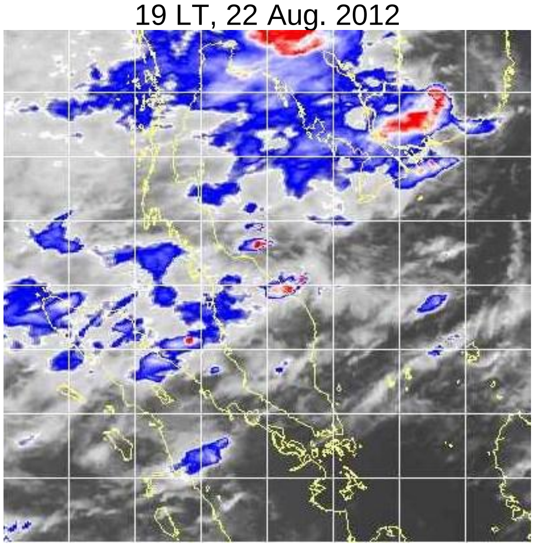
19 LT, 07 Mar. 2012



19 LT, 22 Aug. 2012

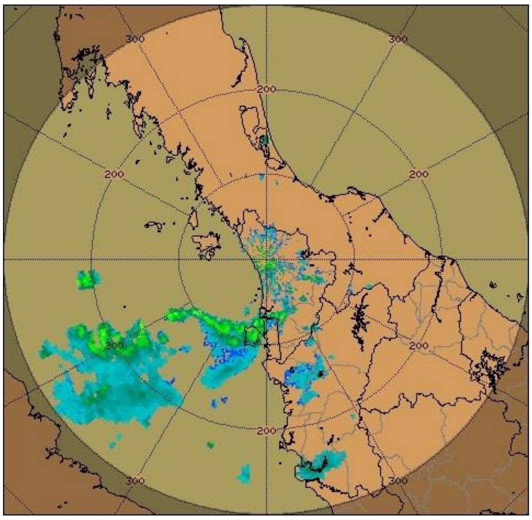


21LT, 07 Mar. 2012

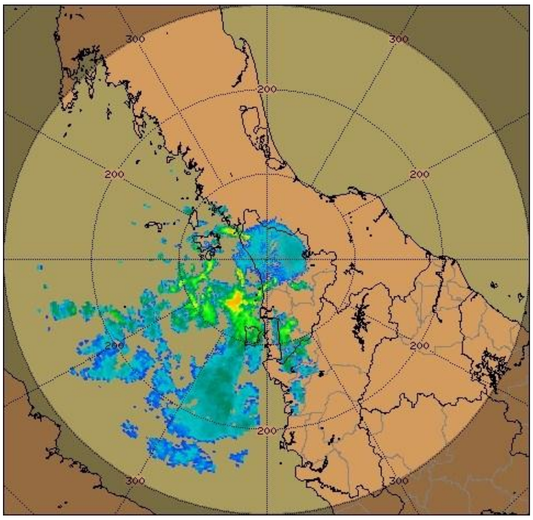


23 LT, 22 Aug. 2012

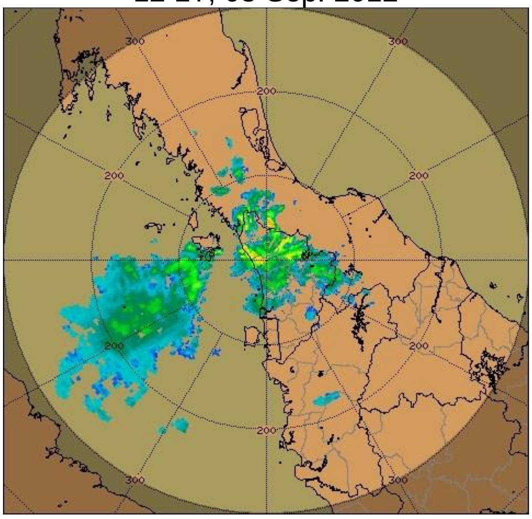
Fig. 1d: Satellite imageries on 01 January and 04 November 2012.



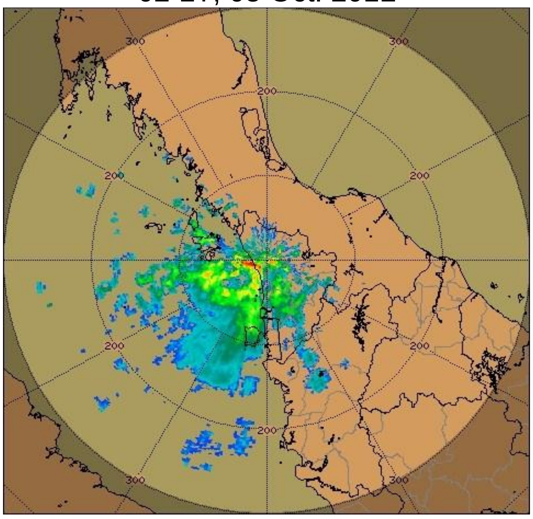
12 LT, 08 Sep. 2012



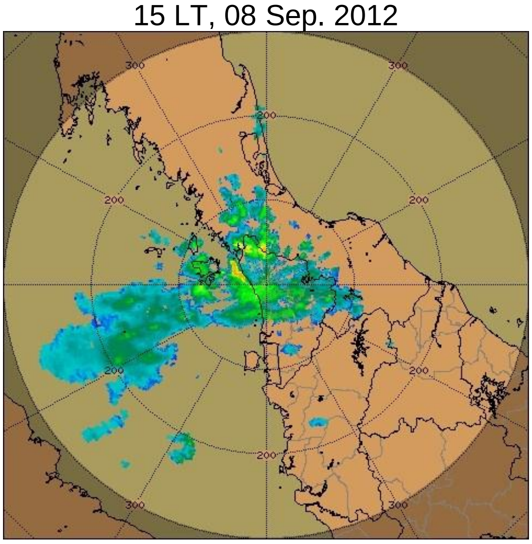
02 LT, 05 Oct. 2012



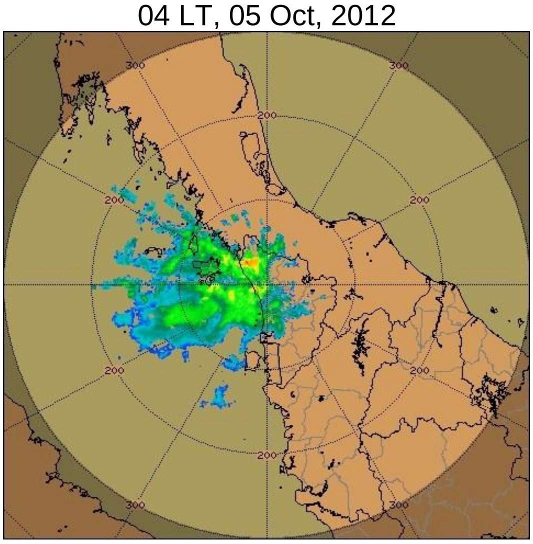
15 LT, 08 Sep. 2012



04 LT, 05 Oct, 2012

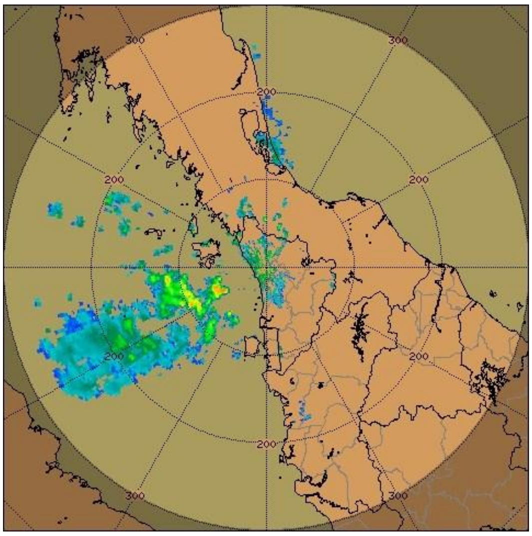


16 LT, 08 Sep. 2012

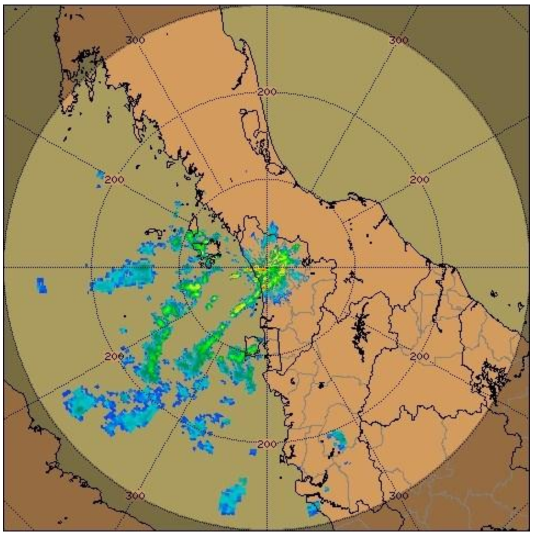


07 LT, 05 Oct, 2012

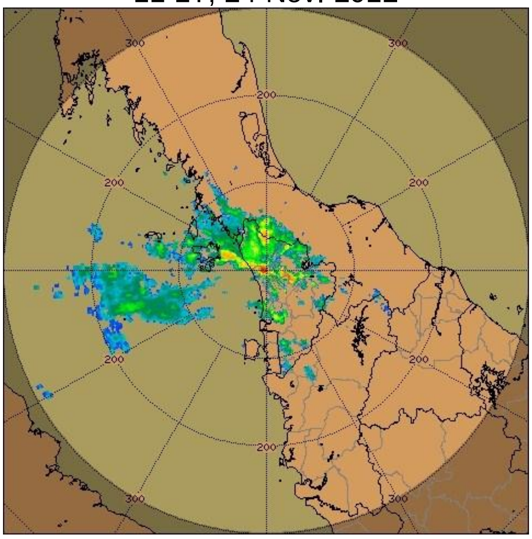
Fig. 2a: Radar displays on 08 September and 05 October 2012.



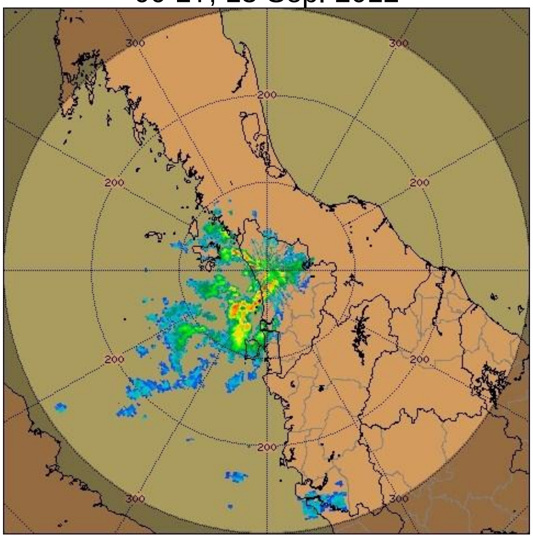
11 LT, 24 Nov. 2012



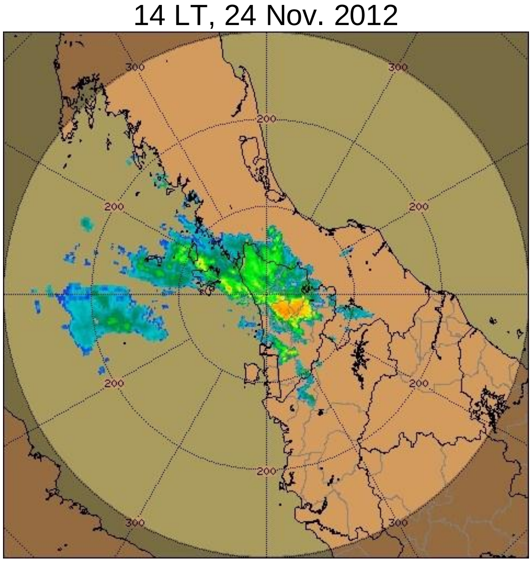
00 LT, 13 Sep. 2012



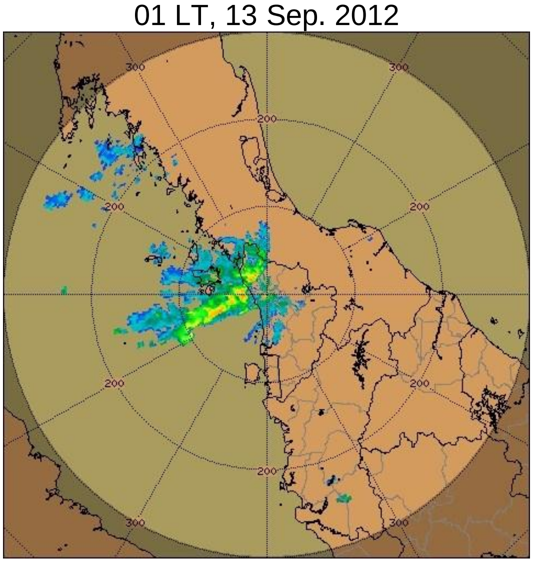
14 LT, 24 Nov. 2012



01 LT, 13 Sep. 2012

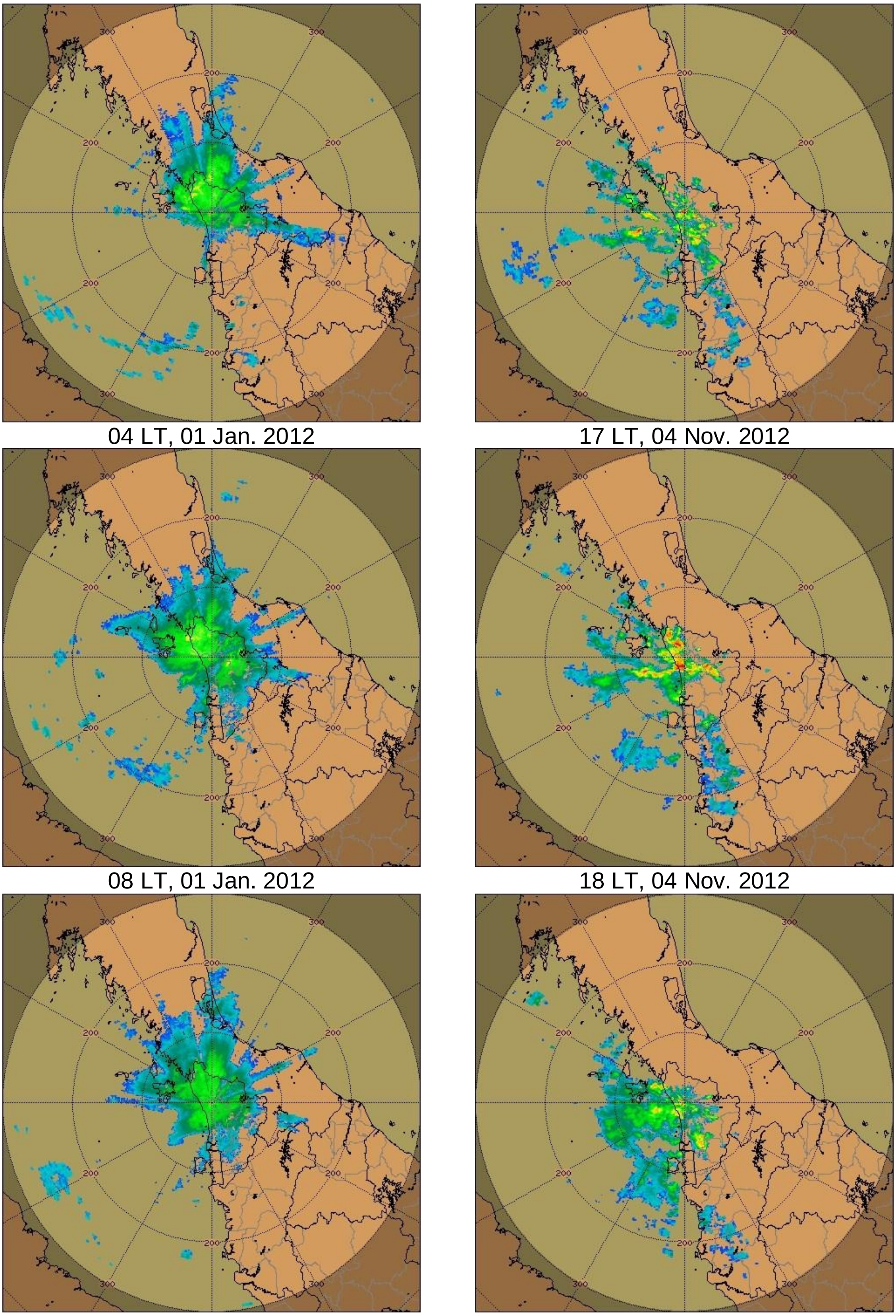


15 LT, 24. Nov, 2012



16 LT, 13 Sep. 2012

Fig. 2b: Weather radar displays on 24 November and 13 September 2012.

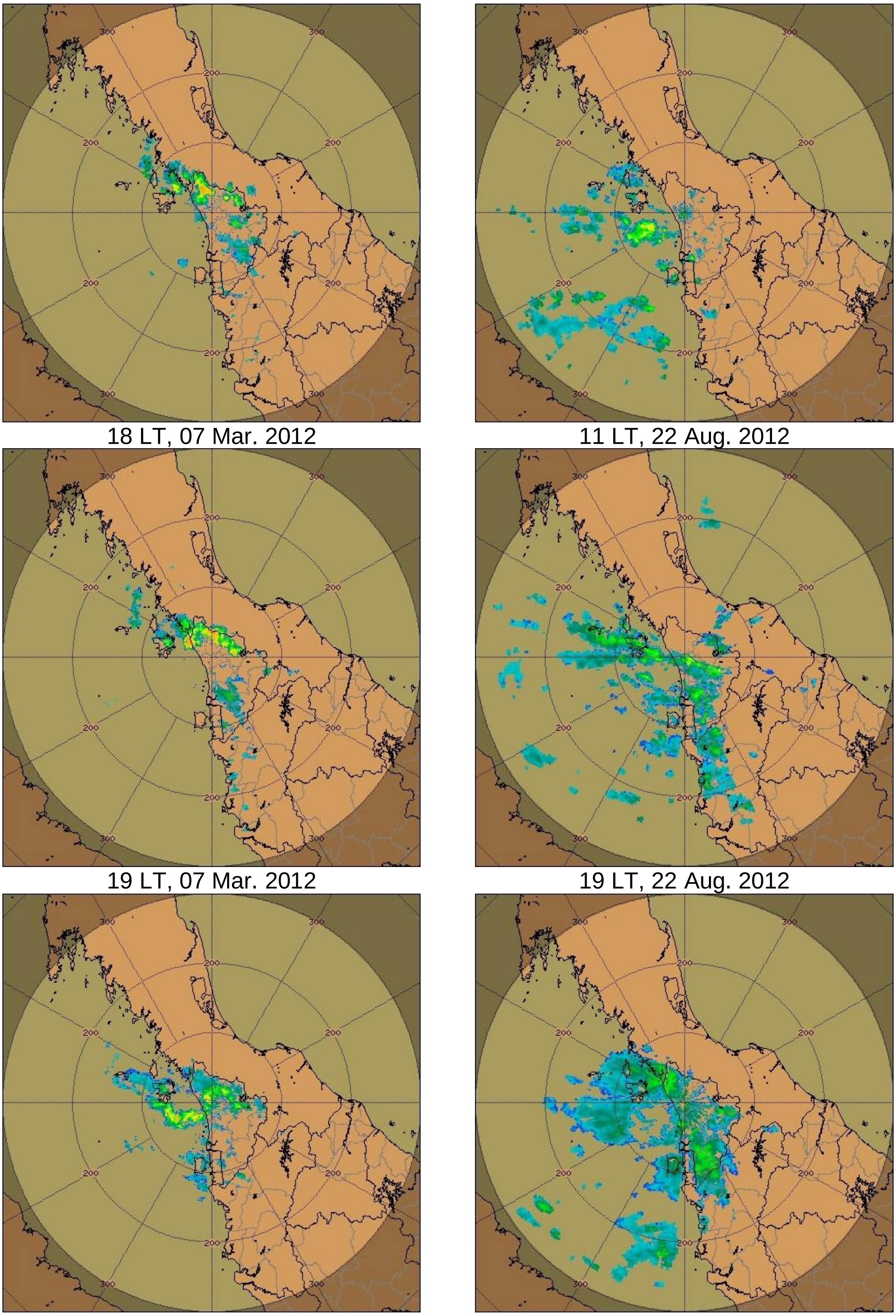


04 LT, 01 Jan. 2012 | 17 LT, 04 Nov. 2012

08 LT, 01 Jan. 2012 | 18 LT, 04 Nov. 2012

10 LT, 01 Jan. 2012 | 20 LT, 04 Nov. 2012

Figure 3: Weather radar displays on 01 January and 04 November 2012.



18 LT, 07 Mar. 2012 | 11 LT, 22 Aug. 2012

19 LT, 07 Mar. 2012 | 19 LT, 22 Aug. 2012

21 LT, 07 Mar. 2012 | 23 LT, 22 Aug. 2012

Fig. 2d: Weather radar displays on 01 January and 04 November 2012.

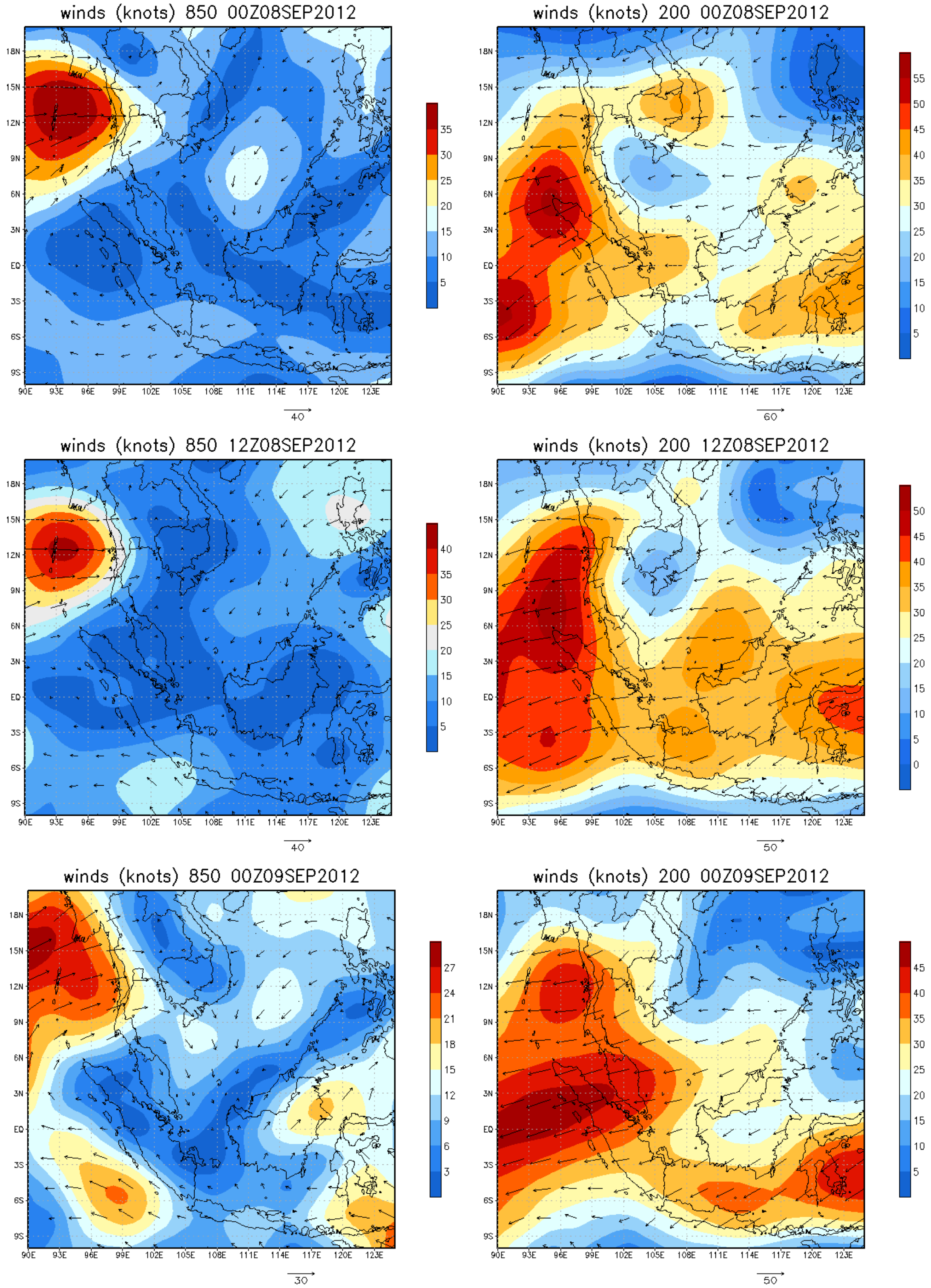


Fig. 3a: Reanalyzed upper air winds and isotachs at 850- and 200-hPa levels from 08 LT, 8 Sep. till 08 LT, 9 Sep. 2012.

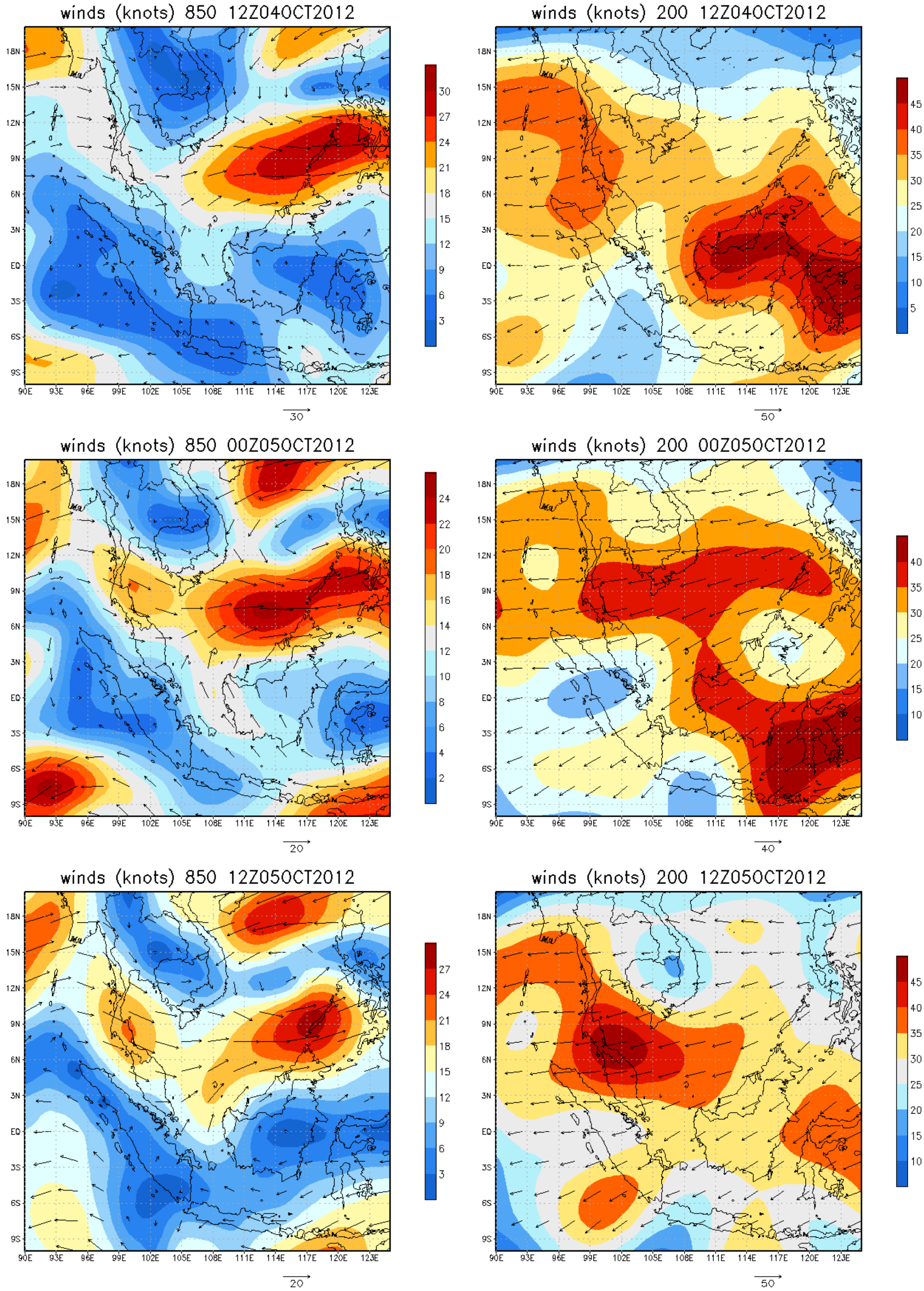


Fig. 3b: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 20 LT, 4 Oct. till 20 LT, 5 Oct. 2012.

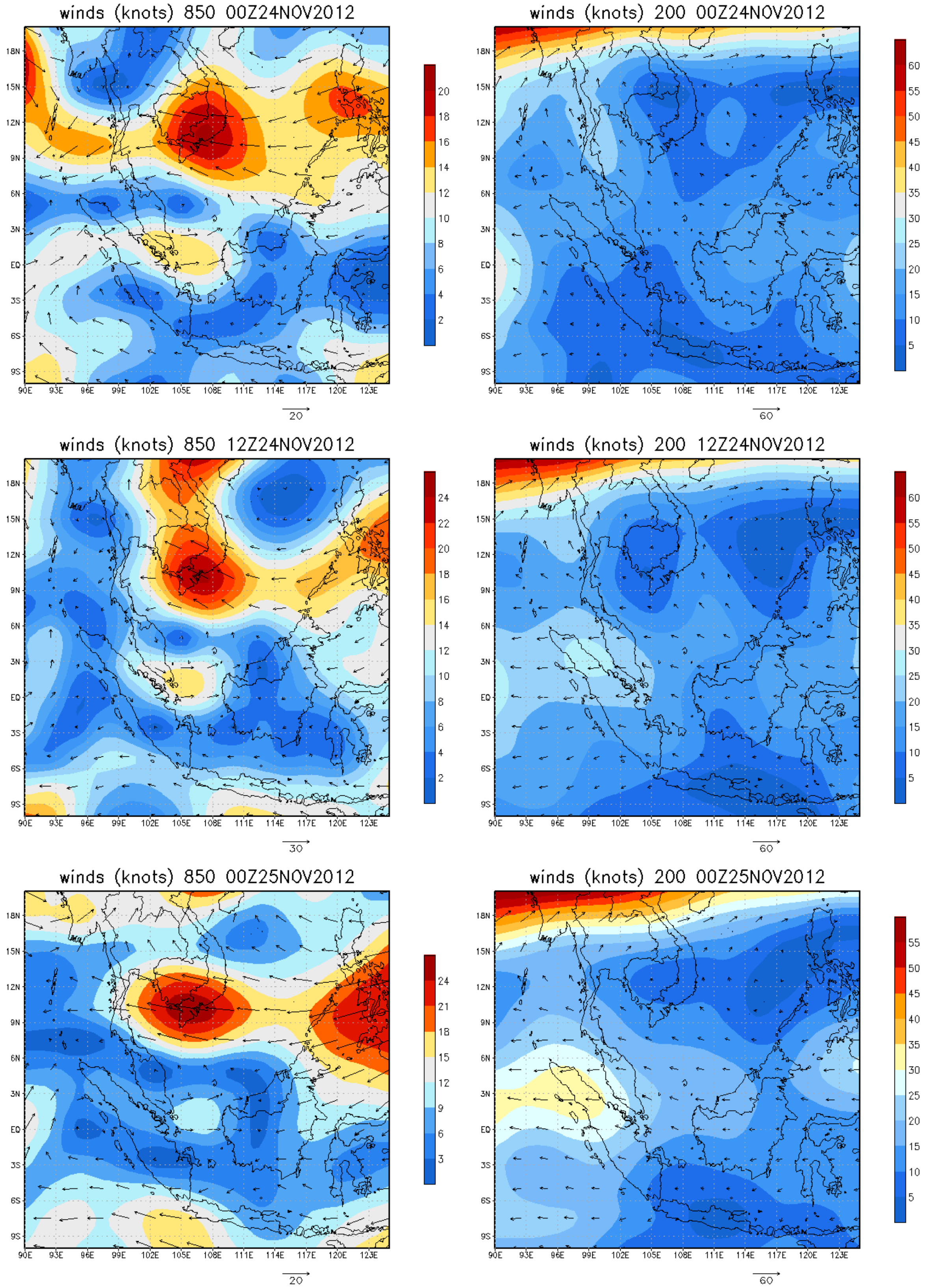


Fig. 2c: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 08 LT, 24 Nov. till 08 LT, 25 Nov. 2012.

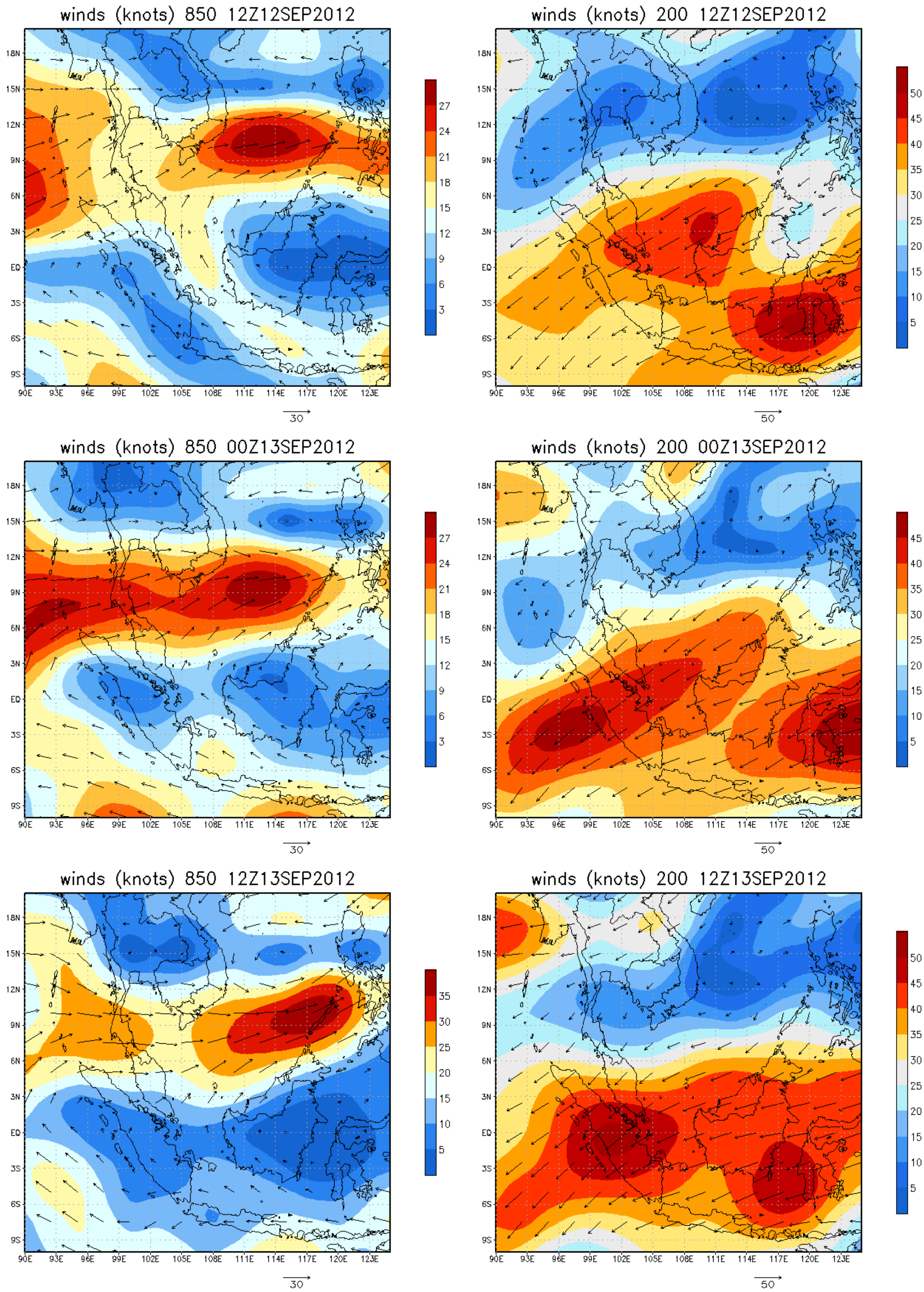


Fig. 4: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 20 LT, 12 Sep. till 20 LT, 13 Sep. 2012.

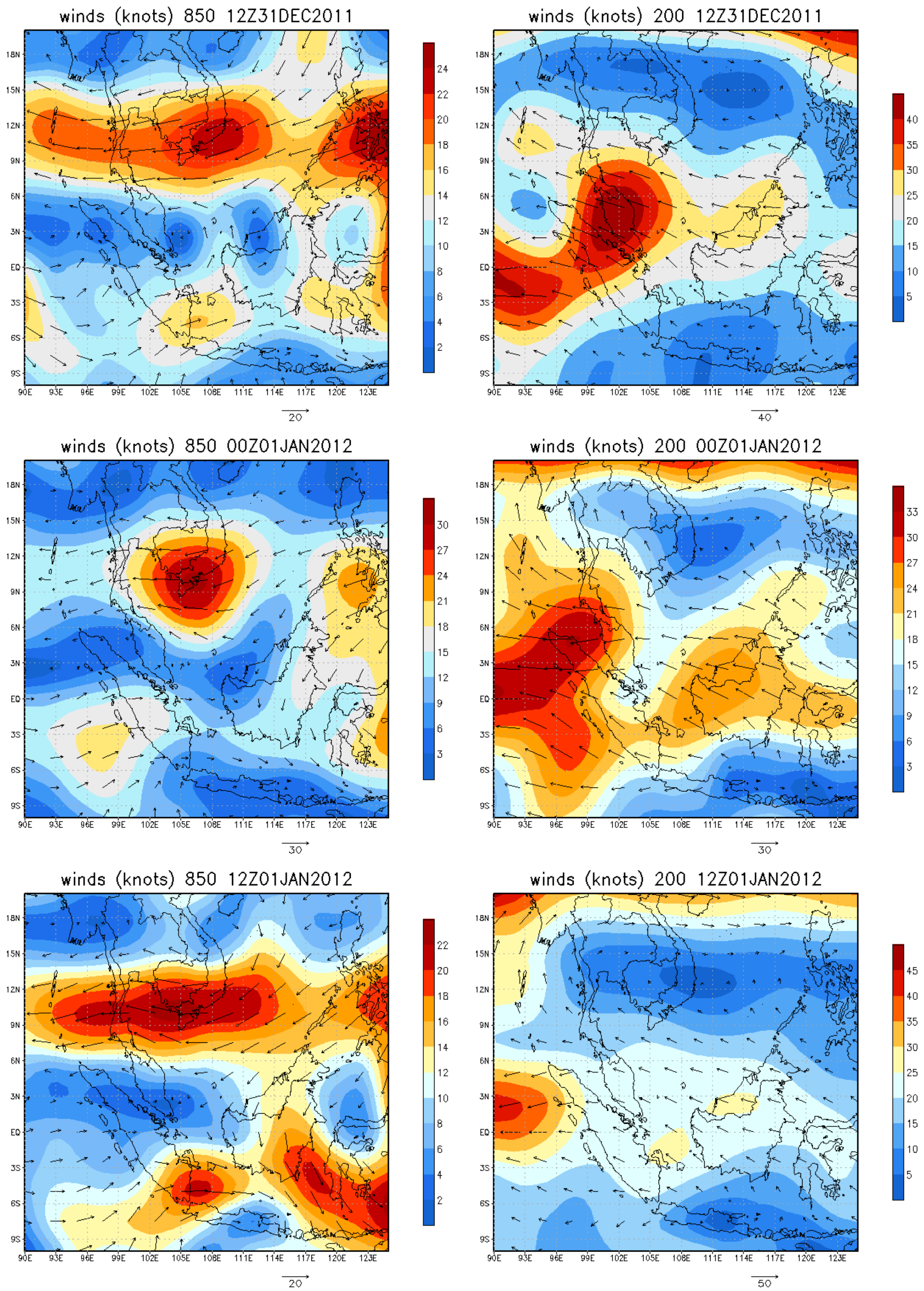


Fig. 3e: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 20 LT, 31 Dec. 2011 till 08 LT, 1 Jan. 2012.

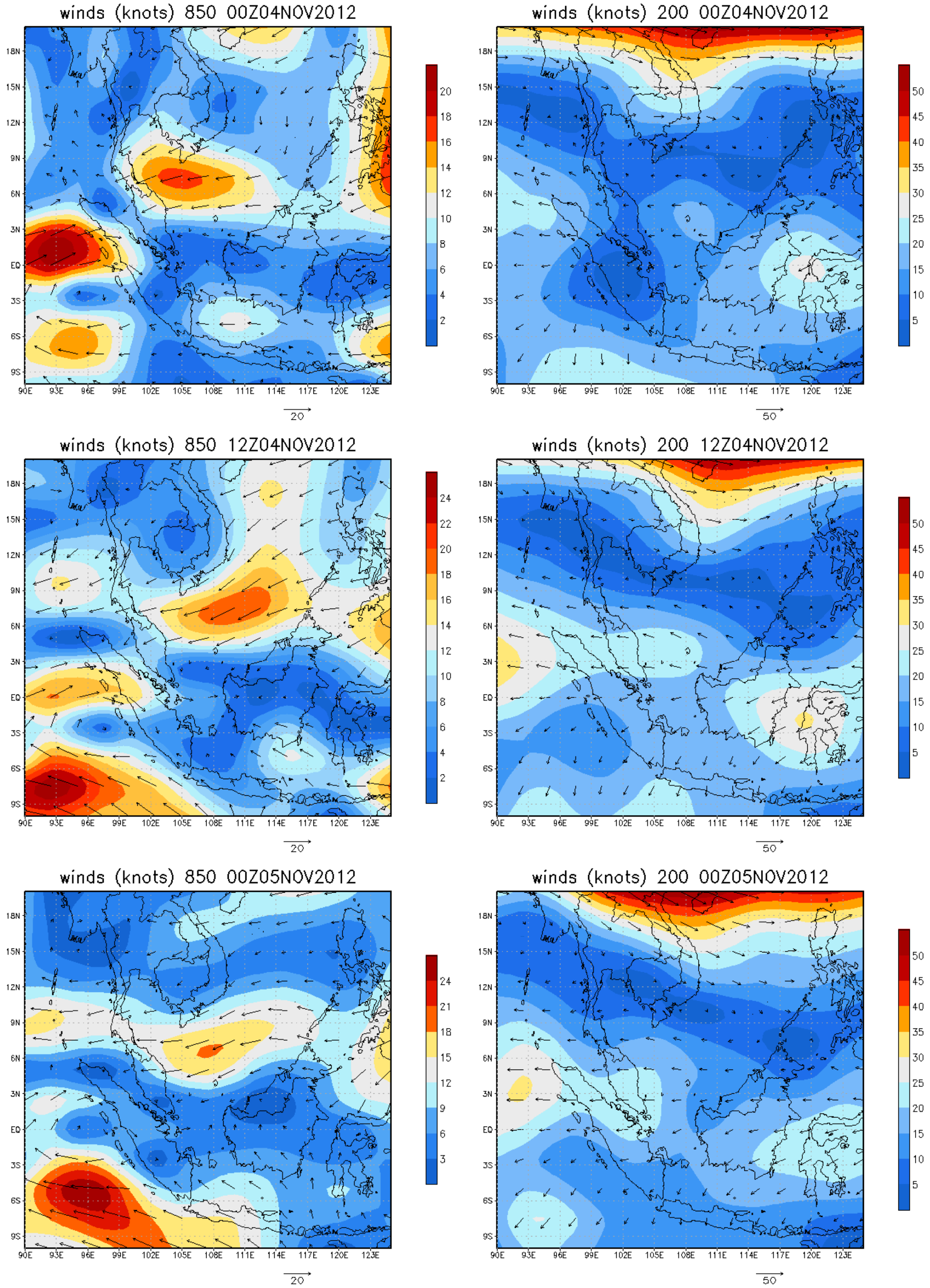


Fig. 3f: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 08 LT, 4 Nov. till 08 LT, 5 Nov. 2012.

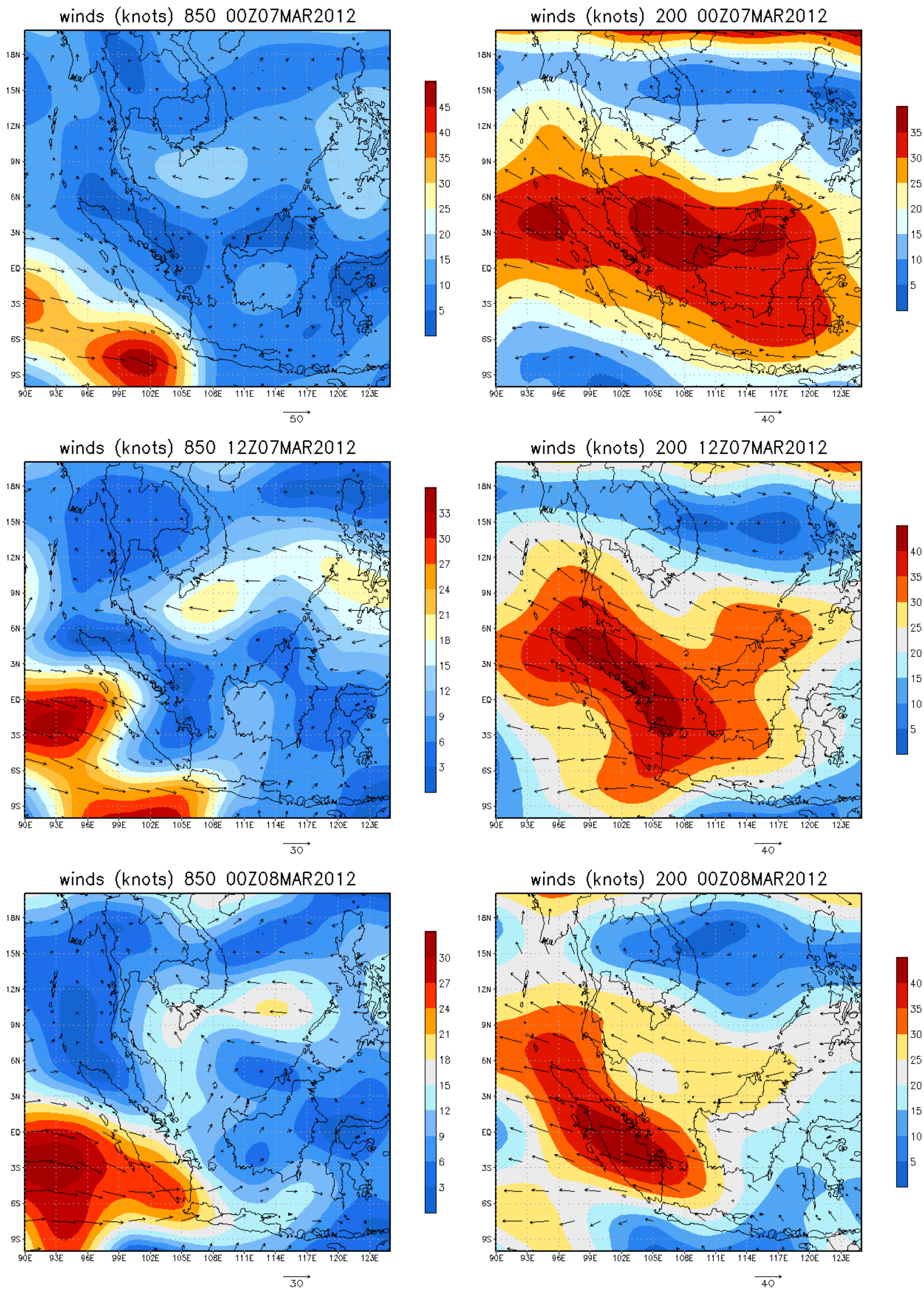


Fig. 3g: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 08 LT, 7 Mar. till 08 LT, 8 Mar. 2012.

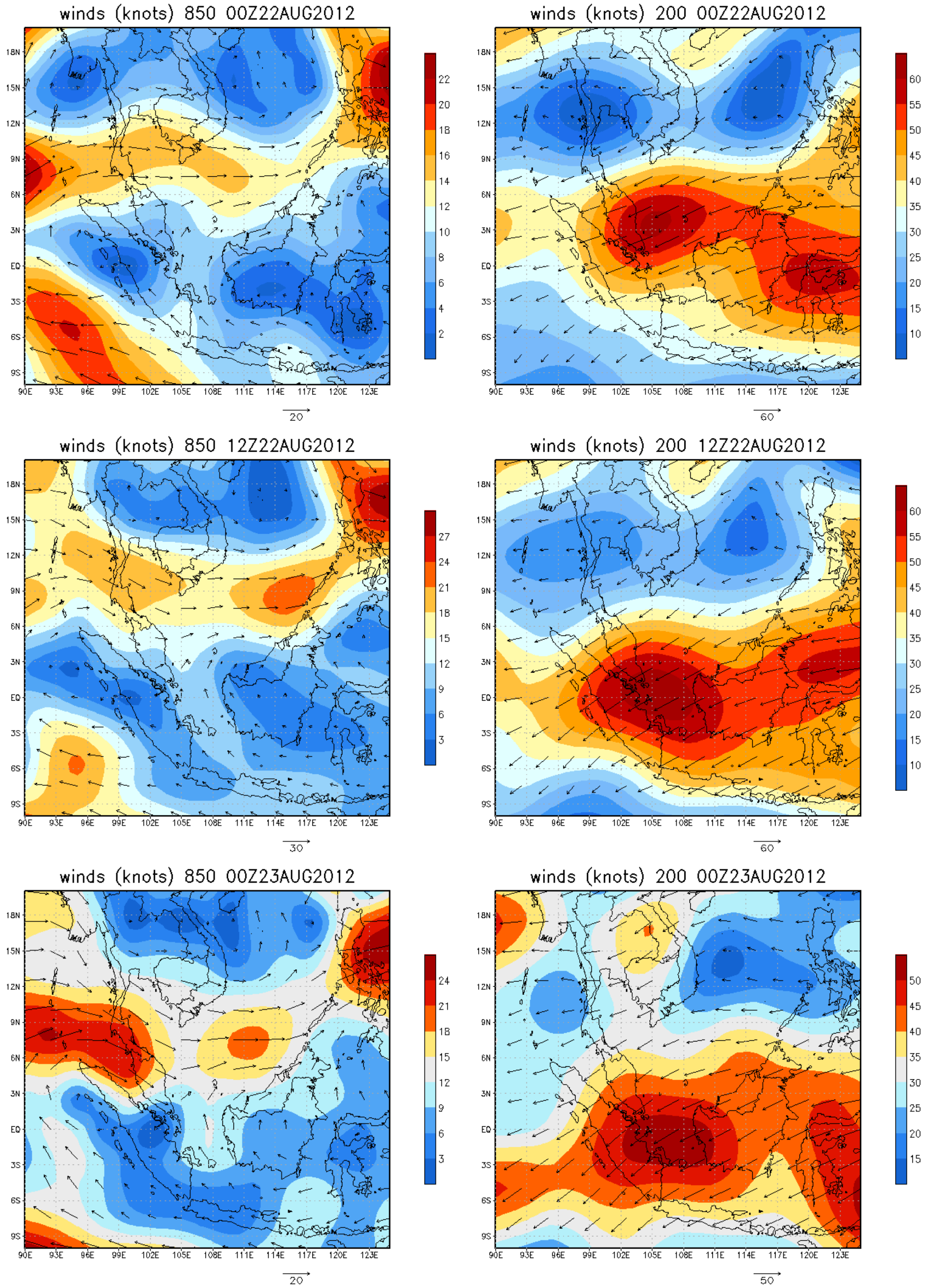


Fig. 3h: Reanalyzed upper winds and isotachs at 850- and 200-hPa levels from 20 LT, 22 Aug. till 08 LT, 23 Aug. 2012.

Table 3: Summarized main synoptic features at 850- and 200-hPa levels.

No.	Major Rain Event	Date & Time	850-hPa Level Winds	200-hPa Level Winds
			Main synotic features	Divergence
1	8 Sep.	8 Sep 08LT	Slight southeasterlies over northwest PM with ridge extending from north Sumatra across Peninsular Malaysia (PM) to Indochina.	Yes
		8 Sep 20LT	As above but with slight southwesterlies	Yes
		9 Sep 08LT	As above but with slight northwesterlies	Neutral
2	5 Oct.	4 Oct 20LT	Slight northwesterlies over northwest PM.	Yes
		5 Oct 08LT	As above but with winds strengthened slightly.	Neutral
		5 Oct 20LT	As above but with winds strengthened further to moderate speed.	Neutral
3	24 Nov.	24 Nov 08LT	Near equatorial trough (NET) over northern PM. Slight northwesterlies over PM.	Yes
		24 Nov 20LT	As above.	Yes
		25 Nov 08LT	As above.	Yes
4	13 Sep.	12 Sep 20LT	Slight southwesterlies over north PM.	Neutral
		13 Sep 08LT	As above but winds became Moderate.	Neutral
		13 Sep 20LT	As above but winds became moderate to strong.	Yes
5	1 Jan.	31 Dec 20LT	NET over central PM. Slight northeasterlies over north PM.	Neutral
		1 Jan 08LT	As above except with slight southeasterlies.	Yes
		1 Jan 20LT	As above except with NET over south PM.	Neutral

6	4 Nov.	4 Nov 08LT	Slight northeasterlies with convergence over northwest PM. NET extending from northern Straits of Malacca (SoM) across central and south PM.	Yes
		4 Nov 20LT	As above	Neutral
		5 Nov 08LT	As above	Neutral
7	7 Mar.	7 Mar 08LT	NET extending from northern SoM with a cyclonic vortex (CV) over PM. Slight southeasterlies over north PM.	Neutral
		7 Mar 20LT	As above except the CV being replaced by trough.	Neutral
		8 Mar 08LT	As above.	Yes
8	22 Aug.	22 Aug 08LT	Slight westerlies over north PM.	Neutral
		22 Aug 20LT	Strengthened slight northwesterlies.	Neutral
		23 Aug 08LT	Moderate northwesterlies.	Neutral

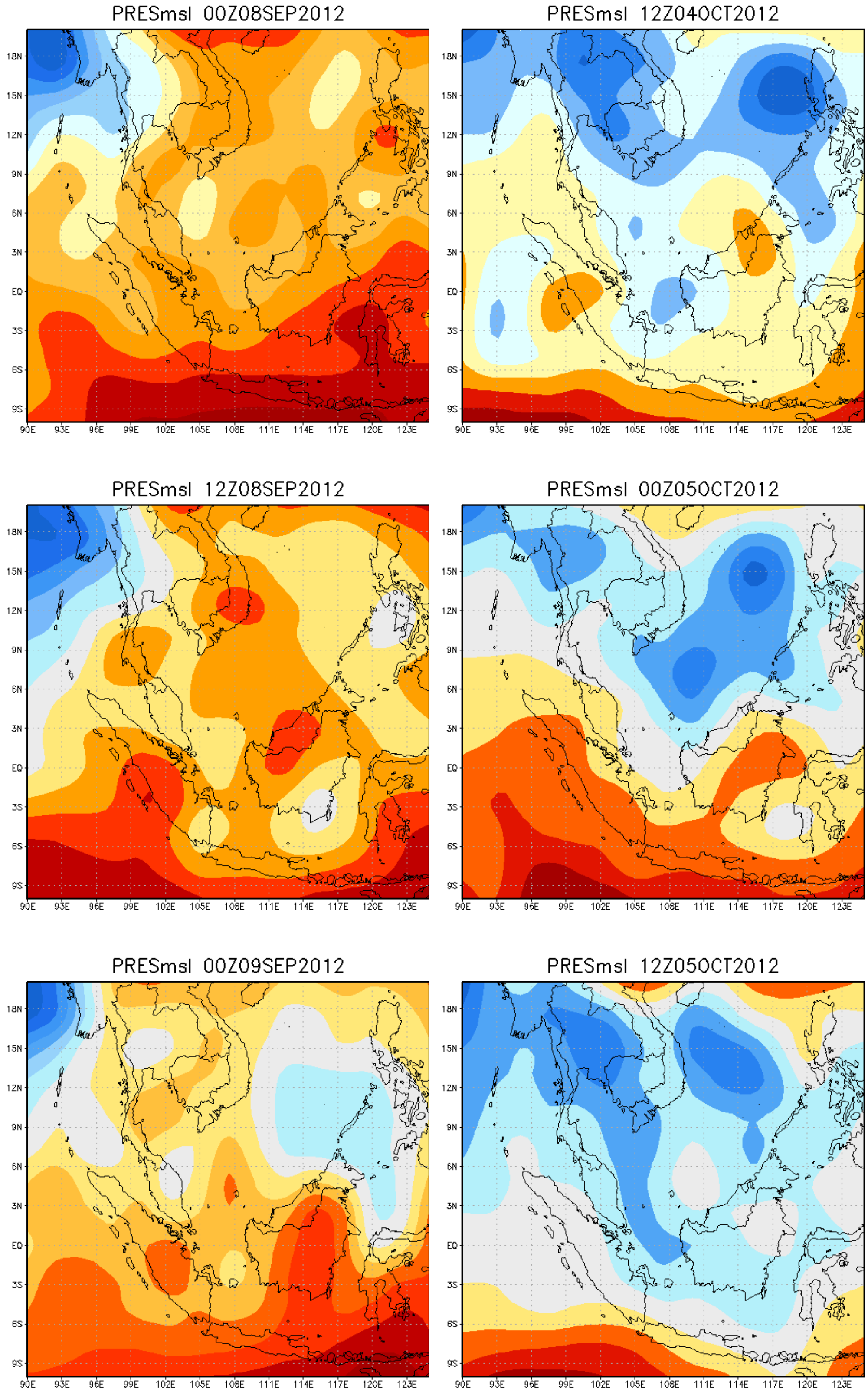


Fig. 4a: Reanalyzed mean sea level pressure from 08 LT, 8 Sep. till 08 LT, 9 Sep. 2012, and from 20 LT, 4 Oct. till 20 LT, 5 Oct. 2012.

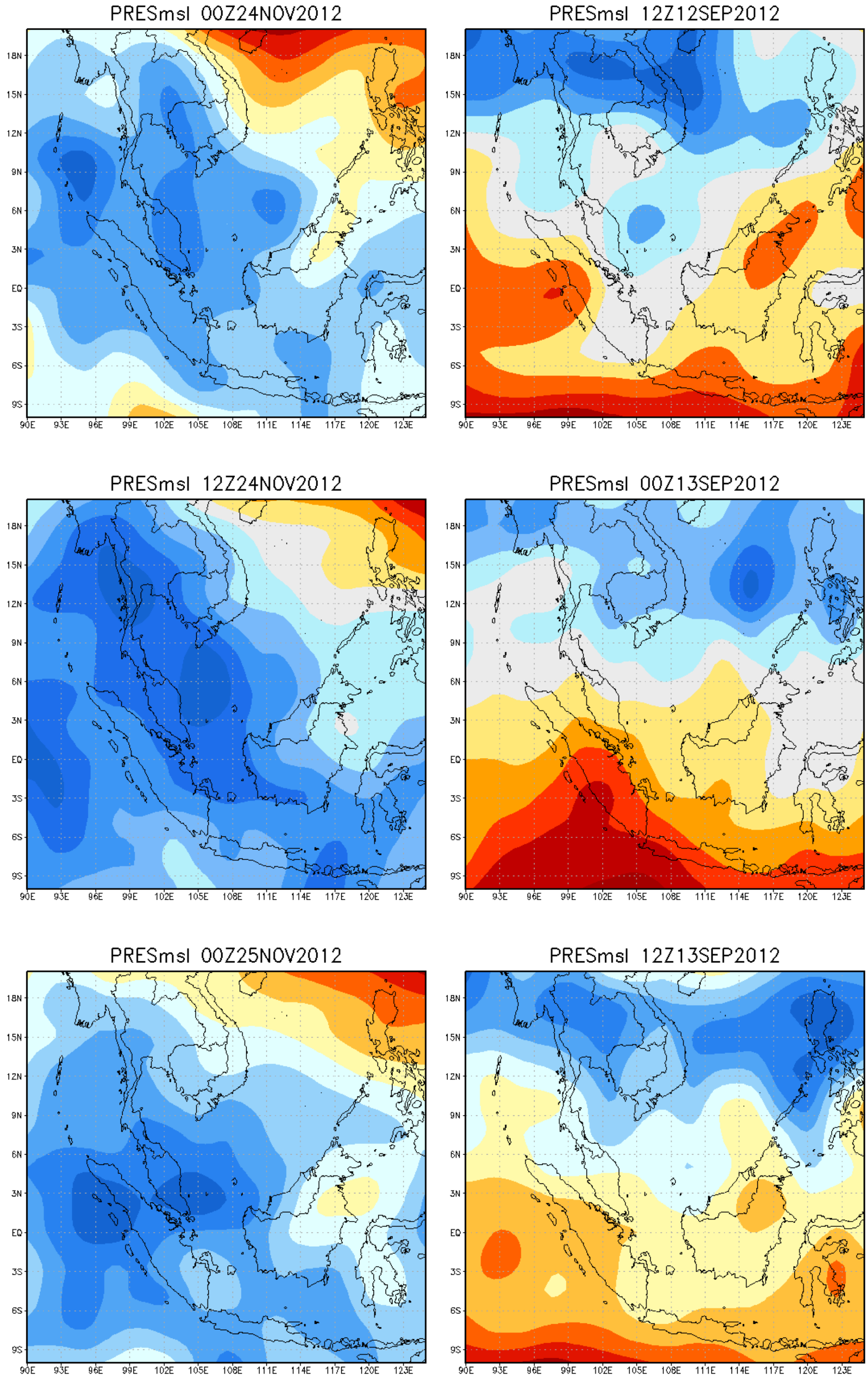


Fig. 4b: Reanalyzed mean sea level pressure from 08 LT, 24 Nov. till 08 LT, 25 November 2012, and from 20 LT, 12 Sep. till 20 LT, 13 Sep. 2012.

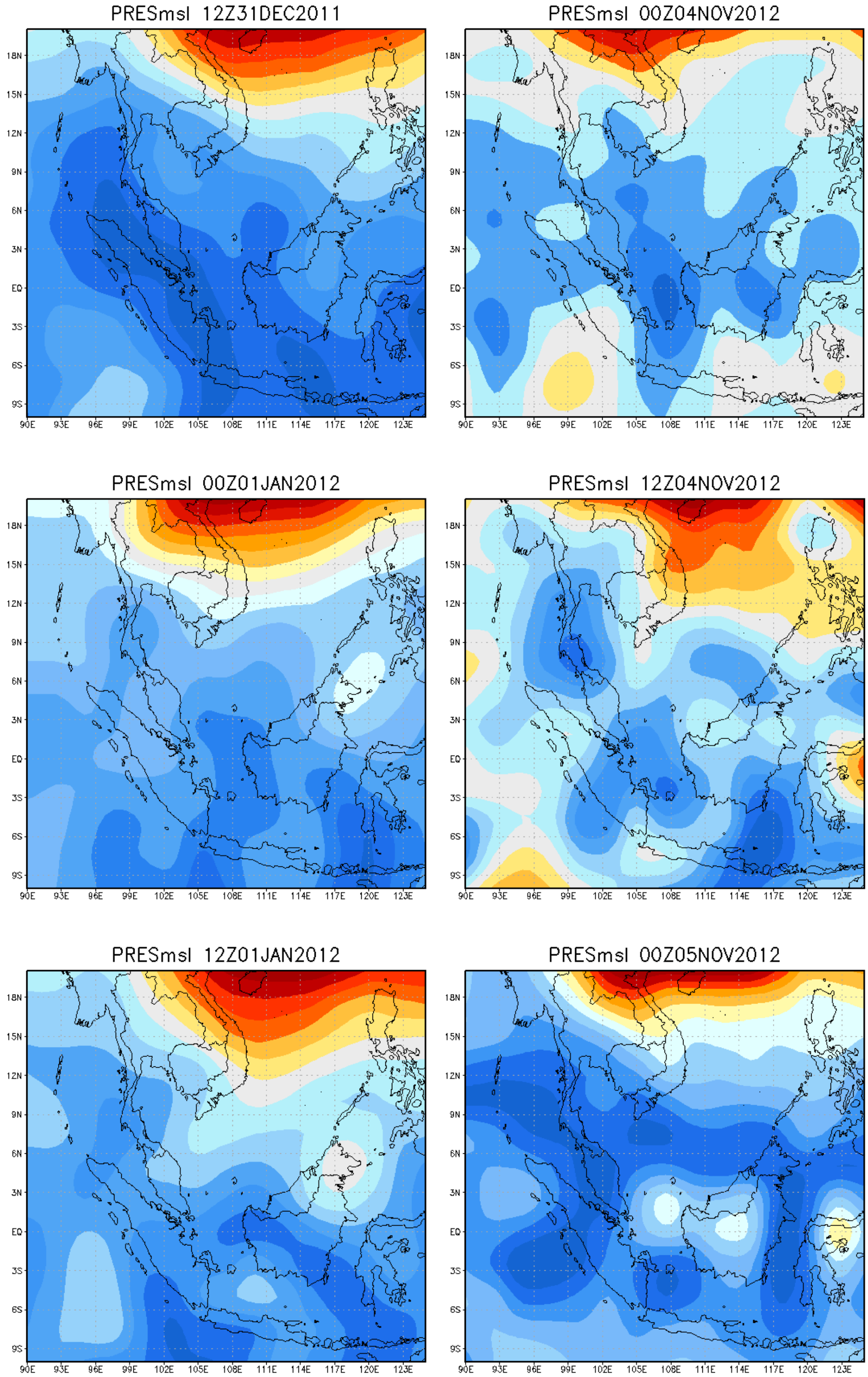


Fig. 4c: Reanalyzed mean sea level pressure from 20 LT, 31 Dec. 2011 till 20 LT, 1 Jan. 2012, and from 08 LT, 4 Nov. till 08 LT, 5 Nov. 2012.

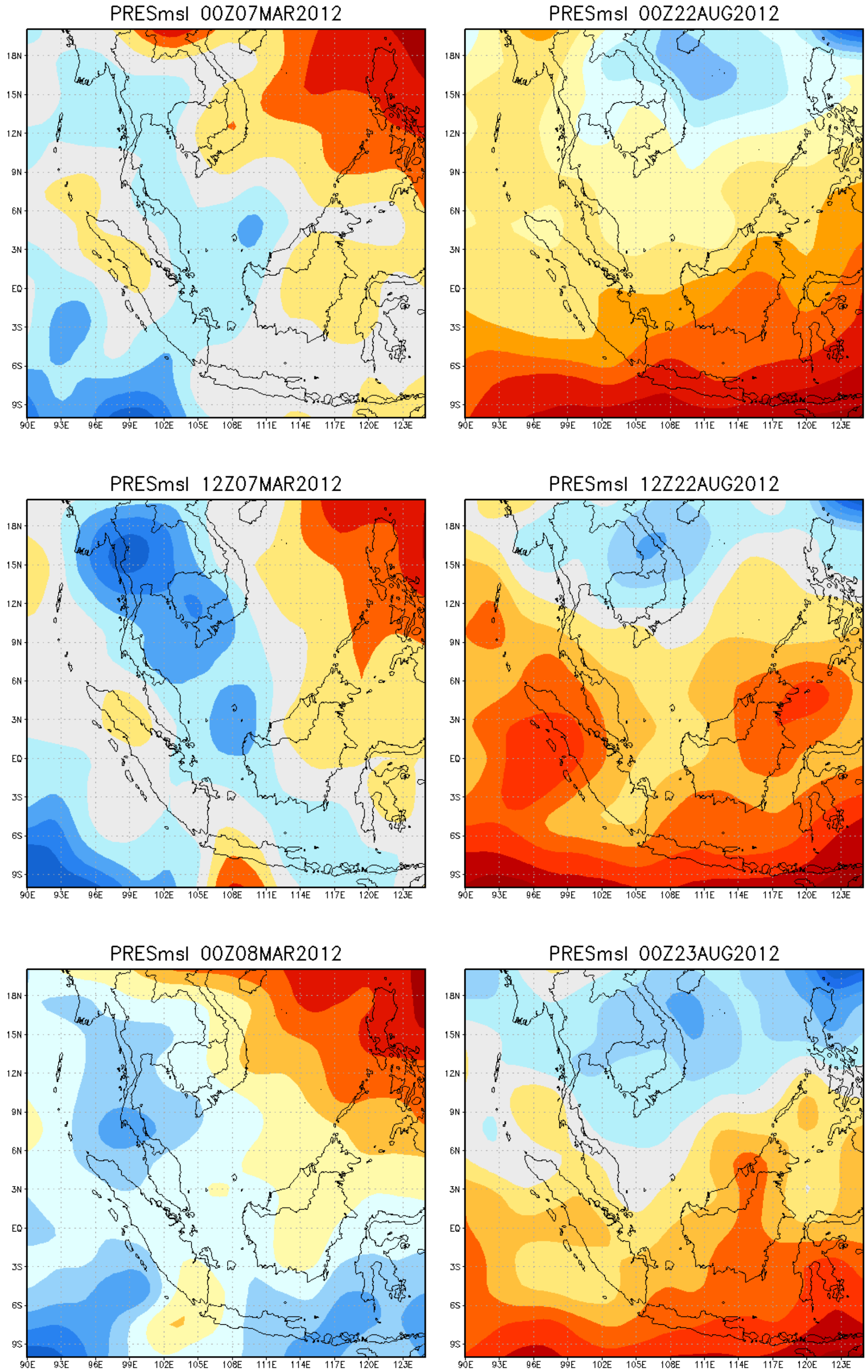


Fig. 4d: Reanalyzed mean sea level pressure from 08 LT, 7 Mar. till 08 LT, 8 Mar. 2012, and from 08 LT, 22 Aug. till 08 LT, 23 Aug. 2012.

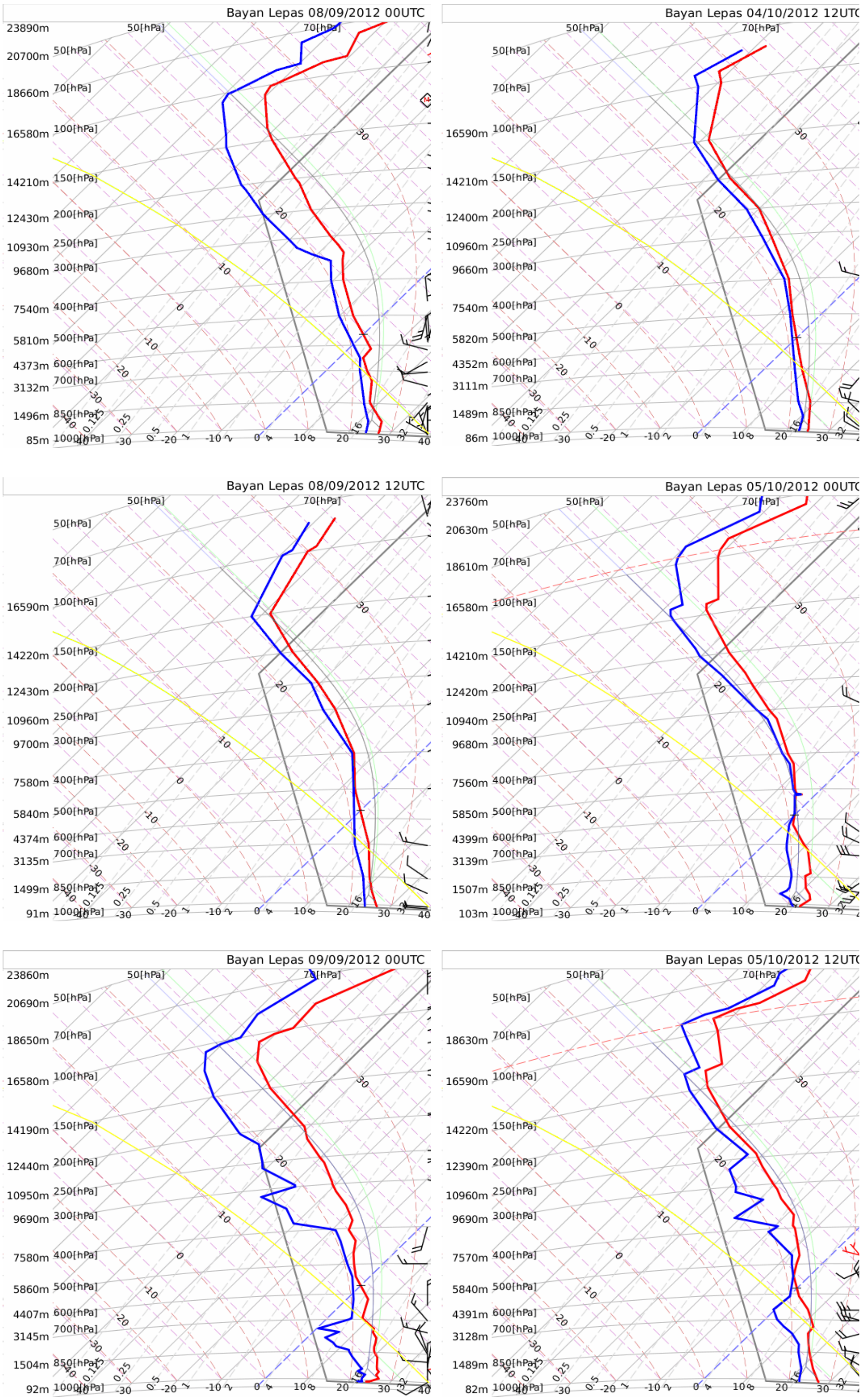


Fig. 5a: Tephigram of Bayan Lepas from 08 LT, 8 Sep. till 08 LT, 9 Sep. 2012, and 20LT, 4 Oct. till 20LT, 5 Oct. 2012.

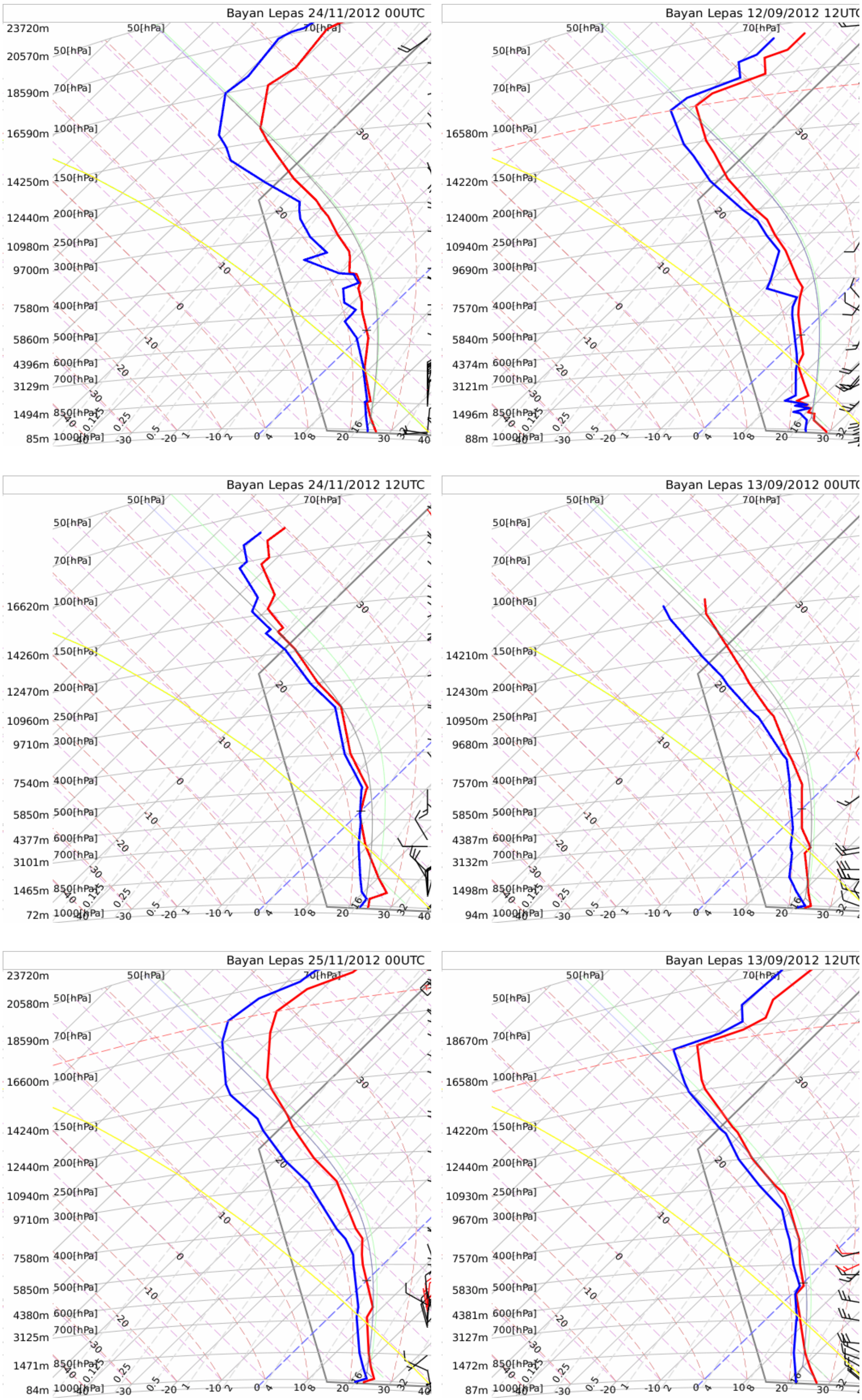
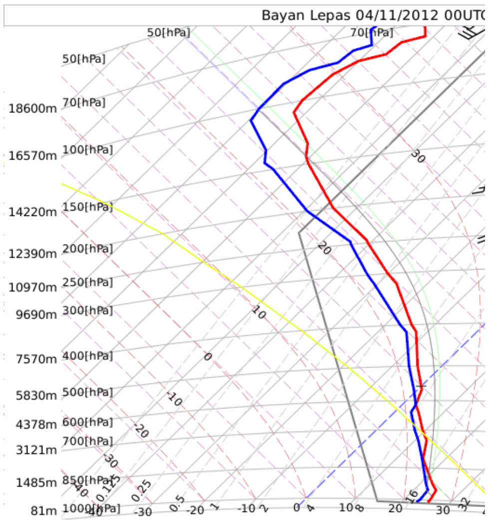
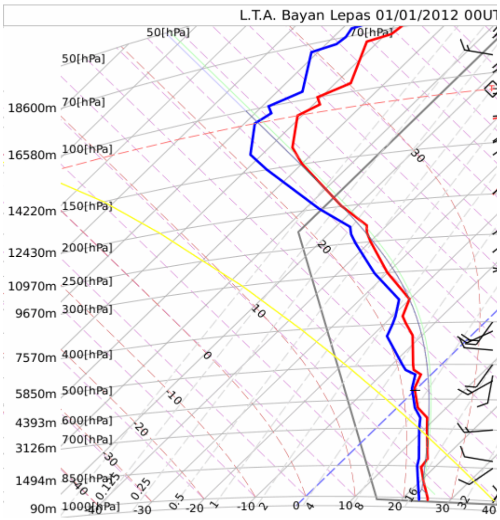
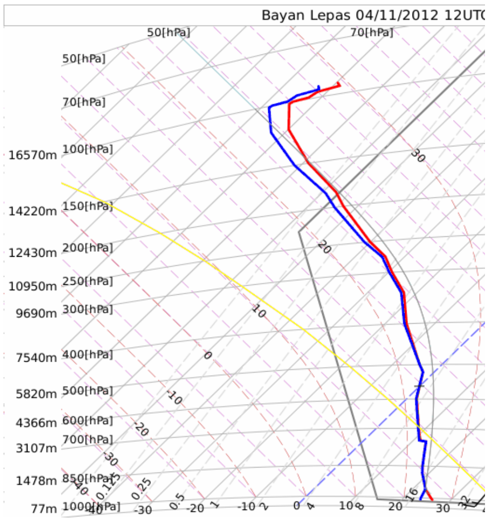


Fig. 5b: Tephigram of Bayan Lepas from 08 LT, 24 Nov. till 08 LT, 25 Nov. 2012, and from 20 LT, 12 Sep. till 20 LT, 13 Sep. 2012

No tephigram data at 20 LT, 31 Dec. 2011







No tephigram data at 20 LT, 1 Jan. 2012.

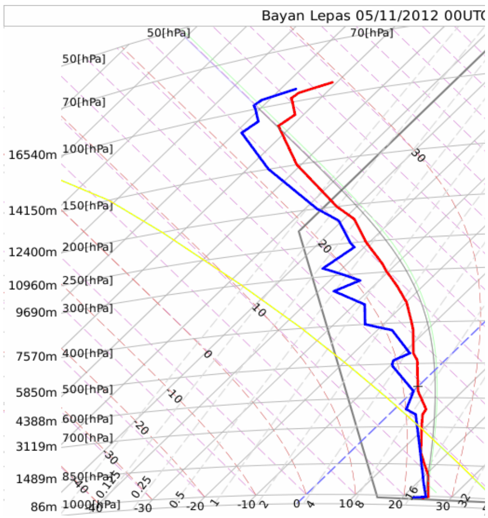
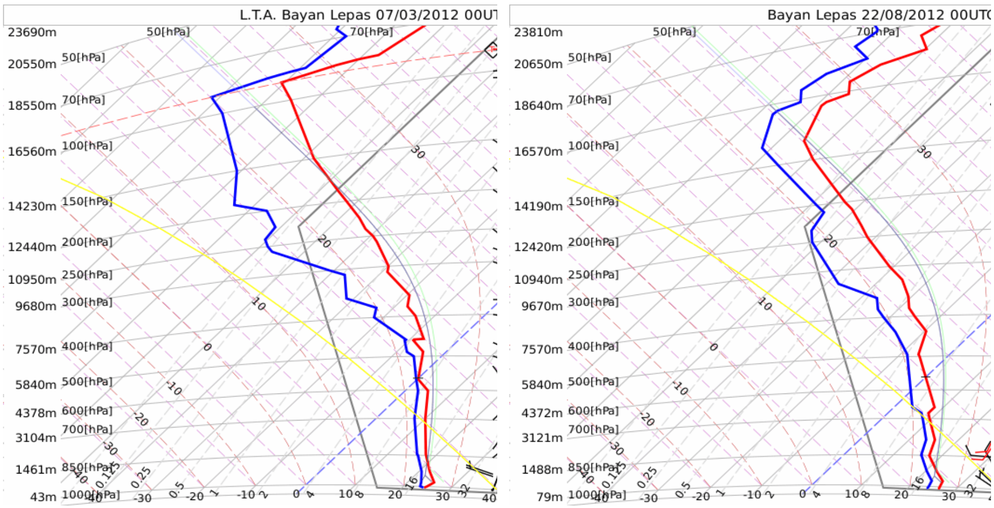
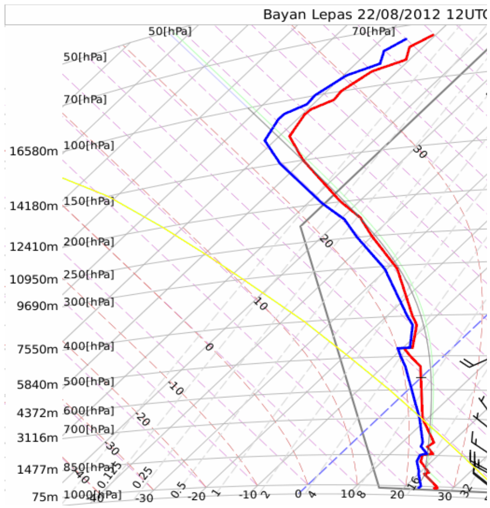


Fig. 5c: Tephigram of Bayan Lepas at 08 LT, 1 Jan. 2012, from 08 LT, 4 till 08 LT, 5 Nov. 2012.



No tephigram data at 20 LT, 7 Mar. 2012.



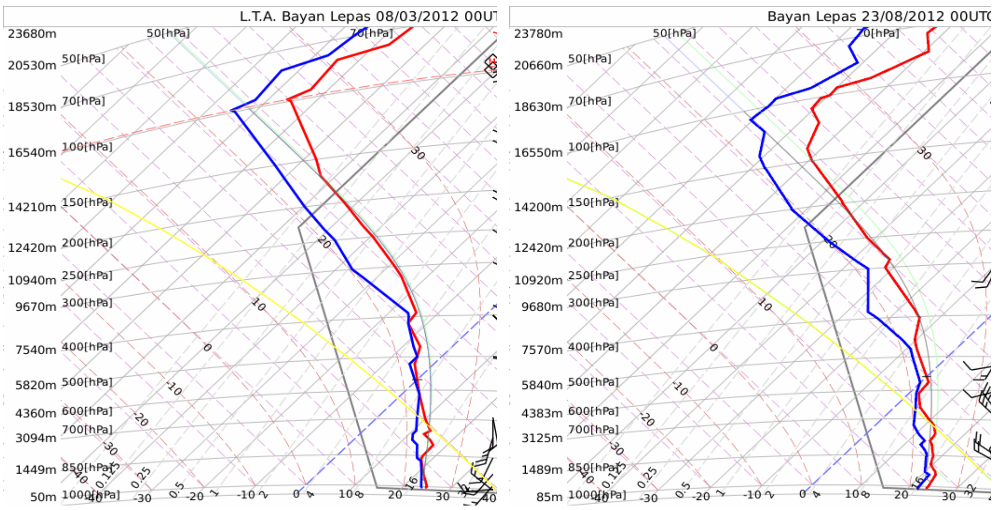


Fig. 5d: Tephigram of Bayan Lepas at 08 LT, 7-8 Mar. 2012, and from 08 LT, 22 Aug. till 08 LT, 23 Aug. 2012.

Table 4: Stability Indices of Bayan Lepas Upper Air Station of the major rain events.

No.	Major Rain Event (Date)	Date & Time	SI (^0C)	LI (^0C)	TTI (^0C)	LFC (hPa)	CAPE (J/kg)	CIN (J/kg)
1	8 Sep.	8 Sep 08LT	-3.0	-6.0	48.7	875	1952	-30.6
		8 Sep 20LT	-2.3	-4.5	47.5	875	1510	-12.2
		9 Sep 08LT	0.1	-4.2	45.8	731	130	-105.0
2	5 Oct.	4 Oct 20LT	-2.0	-3.7	47.7	791	600	-53.7
		5 Oct 08LT	0.8	0.2	43.7	662	49	-225.8
		5 Oct 20LT	-0.9	-3.1	45.6	812	839	-38.1
3	24 Nov.	24 Nov 08LT	-0.6	-3.3	43.7	931	1777	-2.0
		24 Nov 20LT	0.0	-1.1	43.8	756	220	-153.0
		25 Nov 08LT	0.5	-2.1	42.8	864	0	-18.9
4	13 Sep.	12 Sep 20LT	2.2	-4.8	41.0	907	2699	-5.4
		13 Sep 08LT	2.5	-1.9	40.7	856	167	-14.6
		13 Sep 20LT	1.5	-1.0	41.9	828	329	-36.5
5	1 Jan.	31 Dec 20LT	Nil	Nil	Nil	Nil	Nil	Nil
		1 Jan 08LT	-0.8	-2.8	44.8	909	663	-5.2
		1 Jan 20LT	Nil	Nil	Nil	Nil	Nil	Nil
6	4 Nov.	4 Nov 08LT	-1.6	-3.4	45.2	876	490	-22.9
		4 Nov 20LT	-0.7	-2.6	43.4	952	1028	0.0
		5 Nov 08LT	-1.0	-3.3	44.4	902	41	-3.6
7	7 Mar.	7 Mar 08LT	0.5	-1.9	42.1	874	740	-16.8
		7 Mar 20LT	Nil	Nil	Nil	Nil	Nil	Nil
		8 Mar 08LT	0.0	-2.4	43.3	937	720	-0.4
8	22 Aug.	22 Aug 08LT	-0.4	-4.7	44.5	911	1438	-8.5
		22 Aug 20LT	-1.8	-4.1	46.5	940	520	-7.8
		23 Aug 08LT	-2.0	-1.9	46.5	711	56	-76.7

Table 5: Analysis of thunderstorms reported at Pulau Langkawi, Chuping, Alor Setar and Bayan Lepas Meteorological Stations during the major rain events.

No.	Major Rain Event	No. of Stations Reported Thunderstorms & Intensity	Intensity of Thunderstorms Reported in Bayan Lepas
1	8 Sep.	4, Slight to Heavy	Slight to Heavy
2	5 Oct.	3, Slight to Heavy	Slight to Heavy
3	24 Nov.	2, Slight to Heavy	Nil
4	13 Sep.	4, Slight to Heavy	Slight to Moderate
5	1 Jan.	0	Nil
6	4 Nov.	3, Slight to Heavy	Slight
7	7 Mar.	3, Slight to Heavy	Nil
8	22 Aug.	1, Heavy	Nil

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