

A distinction between summer rainy season and summer monsoon season over the Central Highlands of Vietnam

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Abstract The daily rainfall data at 13 stations over the Central Highlands (CH) Vietnam were collected for the period 1981–2014. Two different sets of criteria using daily observed rainfall and 850 hPa daily reanalysis wind data were applied to determine the onset (retreat) dates of the summer rainy season (RS) and summer monsoon (SM) season, respectively. Over the study period, the mean RS and SM onset dates were April 20 and May 13 with standard deviations of 17.4 and 17.8 days, respectively. The mean RS and SM retreat dates were November 1 and September 30 with standard deviations of 17.9 and 10.2 days, respectively. The year-to-year variations of the onset dates and the rainfall amount within the RS and SM season were closely linked with the preceding winter and spring sea surface temperature in the central-eastern and western Pacific. It was also found that the onset dates were significantly correlated with the RS and SM rainfall amount.

1 Introduction

The changes of typical rainfall characteristics such as onset date, retreat date, and total rainfall amount can cause large fluctuations in the water resources of a region, leading to a

significant impact in the field of agriculture and forestry, hydropower, transportation, etc. Therefore, statistical information and forecast of rainfall are of great importance and practical significance.

To date, there have been a number of studies focusing on rainfall over Vietnam and surrounding areas. Generally, the region has a typical summer monsoon rainfall pattern except the eastern coastal Central Vietnam where winter maximum precipitation is observed (Matsumoto 1997; Ngo-Duc et al. 2013; Nguyen-Le et al. 2015; Nguyen-Thi et al. 2012a,b; Yen et al. 2011). Manton et al. (2001) indicated that the number of rain days had decreased significantly during the period 1961–1998, whereas the extreme frequency had increased significantly over two stations located in the north and one station (Pleiku) located in the Central Highlands (CH) of Vietnam. By using the 1950–2000 data from a denser observation network in the Southeast Asian countries, Endo et al. (2009) showed that heavy rainfall decreased and increased in Northern and Southern Vietnam, respectively. Over the CH region, although the number of stations used in their study was limited, Endo et al. (2009) displayed a non-significant increasing trend for heavy rainfall. Villafuerte and Matsumoto (2015) used the Asian Precipitation-Highly Resolved Observational Data Integration Toward Evaluation of Water Resources (APHRODITE; Yatagai et al. 2012) and showed that annual maximum rainfall was significantly increasing in Indochina (including the CH region), and this trend was associated with the rising global mean temperature.

Wang and LinHo (2002) pointed out that the onset and retreat dates of the rainy season (RS) in the Asian monsoon region were not often identified in a consistent way, and the use of different data sources could lead to significant discrepancies. Previous studies often did not really differentiate the RS from the summer monsoon (SM) season because of the typical SM rainfall pattern over most of the Asian

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monsoon area (Matsumoto 1997; Nguyen-Le et al. 2014, 2015). Over South Asia, Stiller-Reeve et al. (2015) stated that different monsoon definitions could lead to different progression of SM or RS. Joseph et al. (1994) used rainfall criteria to show that the long-term mean SM onset over South India varied between May 30 and June 2 with a standard deviation of 8–9 days. Fasullo and Webster (2003) used the vertical integral of moisture transport to show that the mean onset and retreat dates of Indian monsoon for the period 1948–2000 were June 4 and September 7 with standard deviations of 7.4 and 11 days, respectively. Prasad and Hayashi (2005) used the vertical wind shear (between 850 and 200 hPa levels) and the zonal asymmetric temperature anomaly to show that the mean Indian monsoon onset date varied between late May and June, while its mean retreat date varied between late September and October for the 1958–2001 period. Over the Indochina Peninsula, Matsumoto (1997) used pentad rainfall data to investigate the RS onset and retreat dates (hereafter called RSOD and RSRD) of the period 1975–1987 and found that the RSOD occurred in late April to early May, while the RSRD was in late September. Zhang et al. (2002) used a different rainfall criterion and found that the mean SM onset over Thailand during the period 1951–1996 was May 9 with a standard deviation of 12 days. Pham et al. (2010) used combined criteria for both rainfall and 850 hPa wind over the South Vietnam and found that the mean SM onset (hereafter called SMOD) was May 12 with a standard deviation of 11.5 days. Nguyen-Le et al. (2014) showed that the SMOD, based on rainfall criteria, varied considerably among the regions of Vietnam; the earliest onset occurred in the northwestern mountainous area around April 25 and mid-May in the northern and southern plains. Kajikawa et al. (2012) used the criteria of Wang and LinHo (2002) and found an advance of SMOD by 5–10 days over the Indochina Peninsula between the period of 1994–2008 and that of 1979–1993.

The forecasts of onset, retreat dates, and rainfall amount within a RS or within a SM are requested by many civil activities of the region such as agriculture, hydropower, water management, etc. Some previous studies have investigated the predictability of the onset dates. For example, Zhang et al. (2002) found that an early (late) SMOD over Thailand was linked with warm (cold) sea surface temperature (SST) anomalies in the western Pacific and cold (warm) SST anomalies in the central-eastern Pacific in the preceding spring. Nguyen-Le et al. (2015) showed that El Niño–Southern Oscillation (ENSO) had a significant impact on year-to-year variations of the SMOD over the eastern Indochina Peninsula. Pham et al. (2010) pointed out the predictability of the SMOD over Southern Vietnam based on four predictors of the preceding March–April, including sea-level pressure over the East China Sea, southeasterly winds over Southern Vietnam, and deep convection over the Bay of Bengal in early April and over Indonesia at the mid of April.

Located southeast of the Indochina Peninsula, the Central Highlands (CH) Vietnam has a complex terrain comprising of high, medium, and low mountains and hills (Fig. 1). CH is a crucial area of Vietnam for planting coffee, rubber, cocoa, pepper, and other crops. Coffee is the most important crop in CH and produces the great majority of the total coffee yield of Vietnam, the world's second largest exporter after Brazil (Vu et al. 2015). As coffee yield depends much on rainfall (Camargo 2010), rainfall forecast information is of great importance to determine optimal production zones and how these may be changing through climate change. However, to our knowledge, there are no peer-reviewed publications on such a topic for the CH coffee zone.

Therefore, this study attempts to describe first the general rainfall statistics over the CH region. We will also estimate and clearly differentiate the RS, SM onset, and retreat dates based on different sets of criteria introduced in Sect. 2. The paper is expected to serve as a useful reference for future studies as well as for water management purposes over the region.

2 Data and methodology

2.1 Data

Daily rainfall data for the period 1981–2014 have been collected from 13 stations operated by the National Hydrometeorological Service of Vietnam in five provinces (KonTum, GiaLai, DakLak, DakNong, and LamDong) in CH (Fig. 1, Table 1). To avoid possible biases introduced by missing data, monthly (annual average) values at one station could only be estimated if the daily data were available for at least 25 days (330 days) for the respective month (year).

To compute wind index and vertically integrated moisture flux (VMF) over the region, the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data were used (Kalnay et al. 1996). The wind index for a specific year is defined as daily values of 850 hPa zonal wind speed averaged for the domain of [12 N–14.5 N; 107.5–109 E], which covers the CH region. The VMF is given by $\overline{VMF} = \frac{1}{g} \int_{p_{1000}}^{p_{300}} q \overrightarrow{V} dp$, where p_{1000} , p_{300} , q , \overrightarrow{V} , and g represent 1000 hPa, 300 hPa, specific humidity, wind vector, and gravity acceleration, respectively.

The NOAA Optimum Interpolation (OI) SST V2 dataset (Reynolds et al. 2002) was used to estimate SST correlation with rainfall-related quantities over CH (Sect. 3). The SST dataset used in the current study covers the period from December 1981 to December 2014 with a resolution of 1° latitude by 1° longitude.

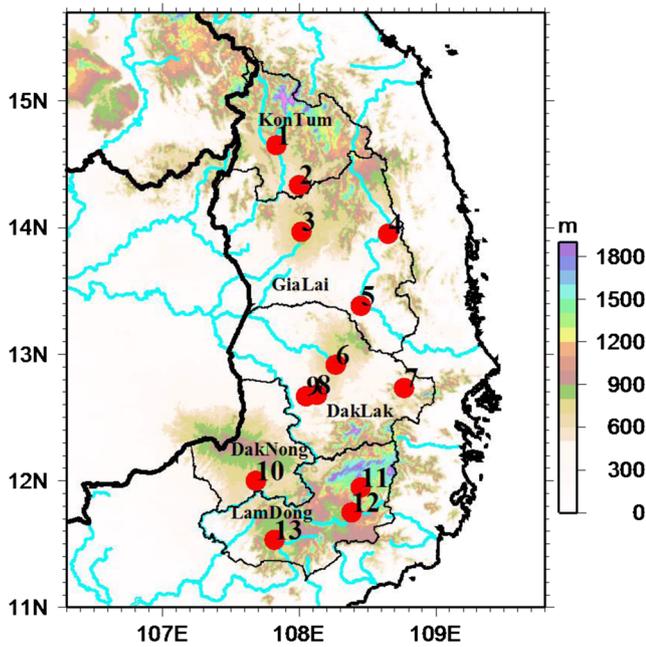


Fig. 1 Locations (red-filled circles) of 13 rainfall stations used in this study in the five provinces (black text) of the Central Highlands. The stations are numbered as specified in Table 1. Terrain height is also displayed. Rivers are marked as light blue

2.2 Trend analysis

To estimate the trend of a given time series (x_1, x_2, \dots, x_n), i.e., a rainfall-related quantity in the current study, the Sen’s slope method (Sen 1968) was used. The Sen’s slope determines the magnitude of the trend and is defined as the median of the sequence series composed of $n(n - 1)/2$ elements ($\frac{x_j - x_k}{j - k}$, $k = 1, 2, \dots, n - 1; j > k$). Then, the non-parametric Mann-Kendall test (Kendall 1975) was used to examine the trend’s statistical significance at the 0.05 level.

Table 1 Locations (longitude, latitude, and height above the mean sea level) of the 13 rainfall stations in the Central Highlands, Vietnam

No.	Station	Lon (E)	Lat (N)	Height (m)
1	Dakto	107.83	14.65	620
2	Kontum	108.00	14.33	536
3	Pleiku	108.02	13.97	779
4	Ankhe	108.65	13.95	422
5	Ayunpa	108.45	13.38	159
6	Buonho	108.27	12.92	707
7	Mdrak	108.77	12.73	419
8	Eakmat	108.13	12.68	516
9	Bmthuot	108.05	12.67	470
10	Daknong	107.68	12.00	631
11	Dalat	108.45	11.95	1509
12	Lienkhuong	108.38	11.75	957
13	Baoloc	107.82	11.53	841

2.3 Criteria for rainy season onset and retreat dates

The method introduced by Zhang et al. (2002) was applied to investigate the RSOD in CH. A rainfall index was first defined as the daily averaged rainfall of 10 stations (the stations listed in Table 1 but without Ankhe, Ayunpa, and Mdrak). Then, a 5-day moving average was applied for the rainfall index time series. The reason for not taking into account Ankhe, Ayunpa, and Mdrak is that those stations are located in the eastern side of CH, having a typical northeast monsoon characteristic with their maxima occurring during the autumn-winter period (Fig. 2b); thus, their rainy seasons are different from that of the remaining 10 stations. One should note that for the same reason, the daily rainfall data at Ankhe, Ayunpa, and Mdrak were also excluded when calculating the mean total rainfall over CH in this study.

The RSOD in CH for each year is identified if the 5-day moving average rainfall index satisfies the two following conditions (Zhang et al. 2002):

- The amount of the daily rainfall index is larger than 5 mm day^{-1} for five consecutive days.
- Within the consecutive 20 days, there must be at least 10 days with rainfall greater than 5 mm day^{-1} .

Zhang et al. (2002) did not specify any criteria for determining RSRD. In the current study, the RSRD in CH is identified for each year by applying the above onset criteria but for the reverse rainfall index time series.

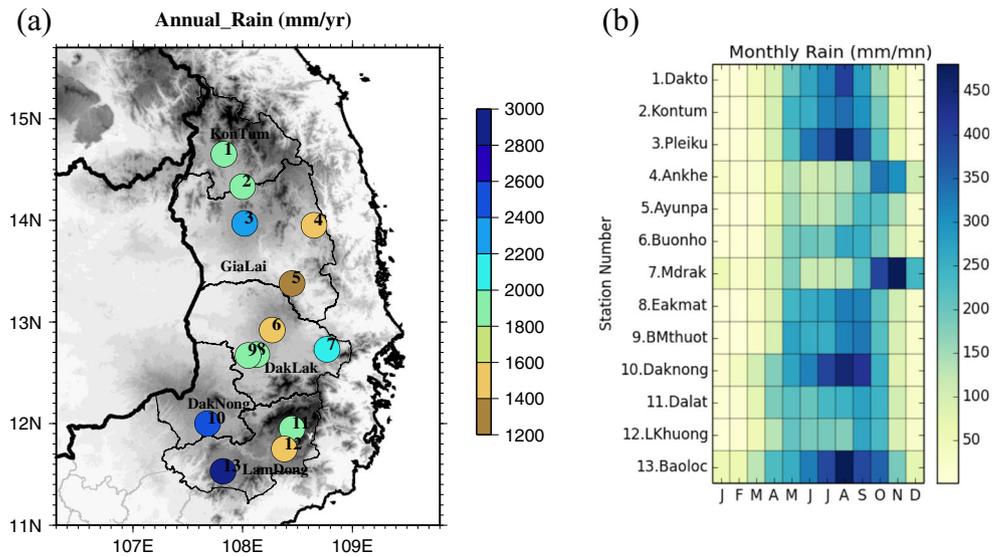
2.4 Criteria for summer monsoon onset and retreat dates

In the next section, it will be shown that the RSOD (RSRD) identified with the above criteria is not simultaneous with the monsoonal wind direction reversal over CH; therefore, it is not identical with the SMOD (SMRD) in the region. To determine SMOD (SMRD), we applied two conditions with the first one being the same with the first criterion for RSOD (RSRD) and the second one being as follows:

- The average daily wind index at 850 hPa is greater than 0.5 ms^{-1} for five consecutive days from SMOD (SMRD) forward (backward).

One should also note that Pham et al. (2010) determined SMOD for Southern Vietnam by using a somehow similar set of criteria described above except the wind index being applied at 1000 hPa and required to be greater than 0.5 ms^{-1} only for the SMOD. As CH has a relatively high elevation (Fig. 1), the current study thus used the wind data at 850 hPa. The threshold of “five consecutive days” was also applied to avoid any localized wind direction reversal over the region.

Fig. 2 **a** Mean annual total rainfall and **b** monthly rainfall over the stations of the Central Highlands for the period 1981–2014



3 Results

Figure 2a, b, respectively, shows the 1981–2014 climatological values of annual and monthly total rainfall at the 13 stations in CH. Depending on the station locations, rainfall in the region may vary from over 1200 to less than 3000 mm year⁻¹. At some stations lying in the summer monsoon windward side (i.e., southwest direction) of high mountainous areas, annual

average rainfall is large and can reach up to 2936 and 2545 mm at Baoloc (station no.13) and at Daknong (no. 10), respectively. In the summer monsoon leeward side, the amount of rainfall is relatively small; for example, Ayunpa (no. 5) has the annual average rainfall of only 1268 mm year⁻¹. Figure 2b indicates the monthly distribution of rainfall throughout the year, showing that rainfall at most stations in the area is concentrated in the summer monsoon period from May to October. However, rainfall at three stations, namely

Table 2 RSOD and SMOD over the Central Highlands for the period 1981–2014

Year	RSOD	SMOD	Year	RSOD	SMOD
1981	Apr. 16	May 15	1998	May 14	May 15
1982	Mar. 23	May 9	1999	Mar. 30	Apr. 23
1983	May 7	Jun. 5	2000	Mar. 30	May 8
1984	Apr. 15	May 18	2001	Mar. 24	Mar. 25
1985	Apr. 19	Jun. 8	2002	May 10	May 22
1986	May 4	May 15	2003	May 1	May 16
1987	May 3	May 19	2004	May 7	May 19
1988	Apr. 18	May 23	2005	Apr. 24	May 22
1989	Mar. 16	May 18	2006	Apr. 25	May 17
1990	May 6	May 23	2007	May 2	May 5
1991	May 15	Jun. 7	2008	Apr. 30	May 1
1992	Apr. 30	Apr. 10	2009	Apr. 11	Apr. 26
1993	May 7	Jun. 9	2010	Apr. 18	May 21
1994	Apr. 7	Apr. 7	2011	May 5	May 23
1995	May 8	May 9	2012	Mar. 19	May 11
1996	Apr. 1	May 10	2013	Apr. 16	Apr. 16
1997	Apr. 6	May 18	2014	Apr. 2	Jun. 9
			Mean	Apr. 20	May 13
			STDV	17.4	17.8

Table 3 RSRD and SMRD over the Central Highlands for the period 1981–2014

Year	RSRD	SMRD	Year	RSRD	SMRD
1981	16 Nov. 16	4Oct. 4	1998	Nov. 28	Sep. 23
1982	9 Oct. 9	Sep. 25	1999	Nov. 7	Sep. 17
1983	3 Nov. 3	Oct. 14	2000	Dec. 9	Oct. 15
1984	20 Oct. 20	Oct. 10	2001	Oct. 24	Sep. 27
1985	17 Oct. 17	Sep. 21	2002	Oct. 21	Sep. 26
1986	24 Oct. 24	Sep. 20	2003	Oct. 22	Sep. 23
1987	27 Nov. 27	Sep. 12	2004	Sep. 22	Sep. 15
1988	9 Nov. 9	Oct. 17	2005	Oct. 25	Sep. 28
1989	15 Oct. 15	Oct. 14	2006	Oct. 14	Oct. 8
1990	14 Nov. 14	Oct. 20	2007	Nov. 12	Oct. 9
1991	16 Oct. 16	Oct. 8	2008	Oct. 31	Sep. 30
1992	30 Oct. 30	Sep. 24	2009	Nov. 5	Oct. 2
1993	11 Dec. 11	Sep. 29	2010	Nov. 5	Oct. 9
1994	29 Oct. 29	Sep. 27	2011	Oct. 21	Oct. 15
1995	28 Oct. 28	Sep. 16	2012	Oct. 8	Sep. 24
1996	18 Nov. 18	Sep. 25	2013	Nov. 17	Oct. 4
1997	4 Nov. 4	Oct. 5	2014	Oct. 28	Sep. 19
			Mean	Nov. 1	Sep. 30
			STDV	17.9	10.2

Ankhe (no. 4), Ayunpa (no. 5), and Mdrak (no. 7), mainly occurs from May to December, in which the largest rainfall amount occurred in October and November due to the influence of northeast winter monsoon (Nguyen-Le et al. 2014, 2015). This is the reason why the rainfall index presented in Sect. 2.3 was defined as the daily averaged rainfall of the stations over CH but without Ankhe, Ayunpa, and Mdrak.

The onset and retreat dates of each year of the period 1981–2014 demonstrate the non-simultaneity for most years of a rainy season identified using the criteria of Zhang et al. (2002) and the respective summer monsoon season over CH

(Tables 2 and 3). The mean RSOD is April 20 with a standard deviation of 17.4 days, whereas the mean SMOD is May 13 with a standard deviation of 17.8 days. The mean RSRD and SMRD are November 1 and September 30 with standard deviations of 17.9 and 10.2 days, respectively.

It is worth to note that previous studies indicated that the SMOD is around May 10 over CH and the surrounding areas (Nguyen-Le et al. 2014, 2015; Pham et al. 2010; Wang and LinHo 2002; Zhang et al. 2002) and the SMRD over eastern Indochina Peninsula is in early to late September (Matsumoto 1997; Nguyen-Le et al. 2014,

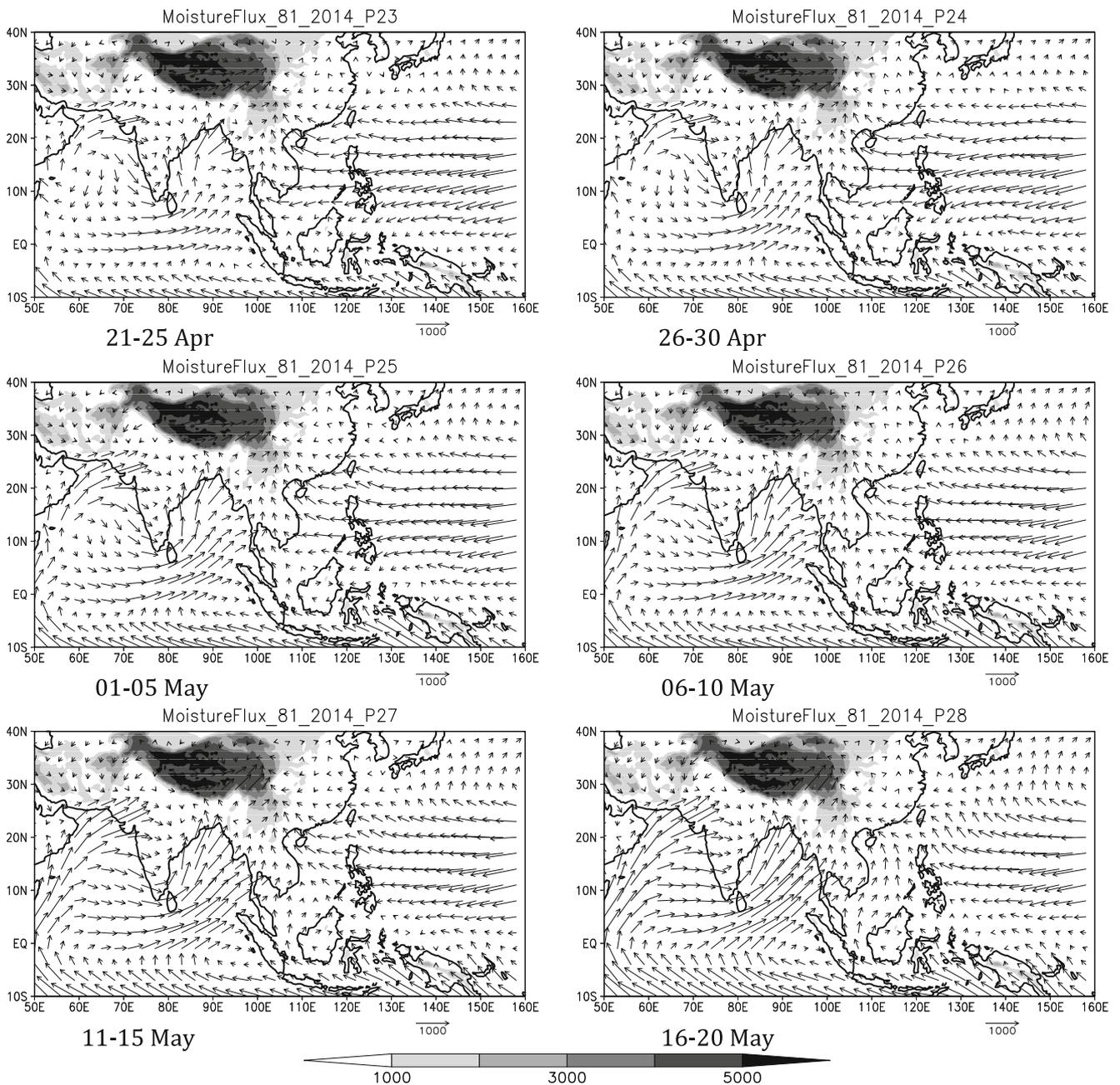


Fig. 3 Year 1981–2014 climatology of vertical integrated moisture flux from pentad 23 (April 20–24) to pentad 28 (May 16–20). Vector’s units in gram per meter per second. Shading indicates altitude of the topography in meters

2015; Zhang and Wang 2008). Zeng and Lu (2004) mentioned that different criteria could lead to very different results of SMRD. The trend analysis shows that RSOD and SMOD are earlier in recent years with the Sen's slope values of -1.79 and -2.5 days per decade, respectively. However, those trends are non-significant at the 0.05 level. The Sen's values of both RSRD and SMRD are 0 day meaning that there is no clear trend for the retreat dates over the period 1981–2014. Kajikawa et al. (2012) also pointed out that the SMOD over the region of the period 1994–2008 was earlier than that of the period 1979–1993.

The non-simultaneity of RS and SM over CH shown in Tables 2 and 3 can be attributed to the fact that rainfall in the region is contributed from different sources, not only from the southwest monsoon system. For example, Nguyen-Thi et al. (2012a,b) pointed out that total rainfall induced by tropical cyclone in CH is approximately $200\text{--}300\text{ mm year}^{-1}$. Kiguchi and Matsumoto (2005) showed the influence of mid-latitude disturbances on the pre-monsoon rainfall over the Indochina Peninsula. Takahashi and Yasunari (2006) and Takahashi et al. (2015) showed the importance of tropical disturbances from the western Pacific on the rainfall over the region.

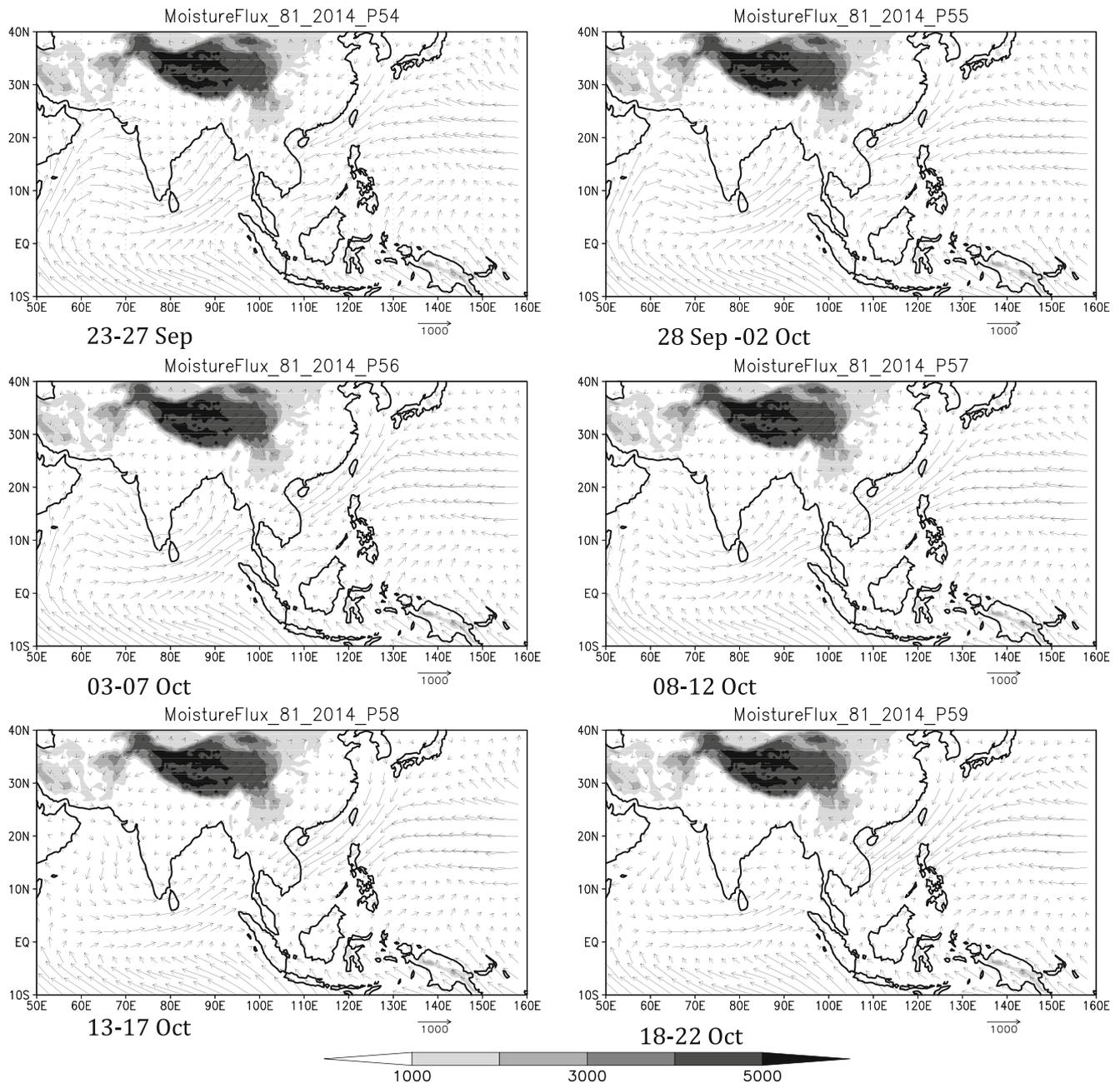


Fig. 4 As in Fig. 3 but for pentad 54 (23–27 Sep.) to pentad 59 (18–22 Oct.). Vector's units in gram per meter per second. Shading indicates altitude of the topography in meters

Fig. 5 Interannual variability of RSrain, SMrain (bars, left axis), and the length of RS and SM season (lines, right axis) over the Central Highlands during the period 1981–2014

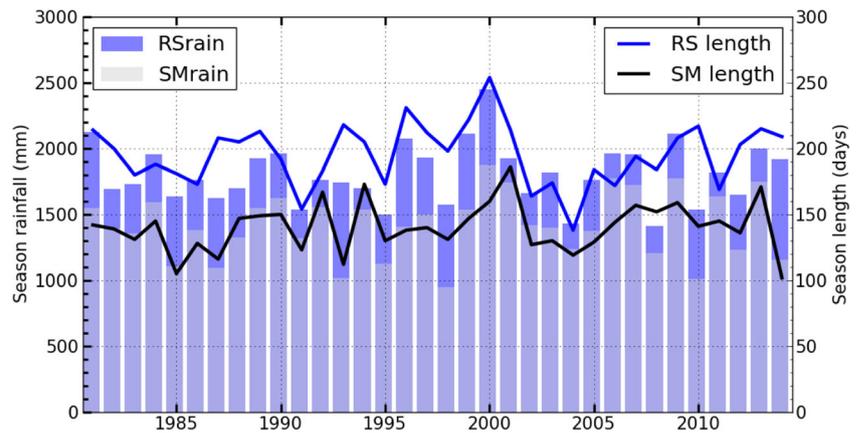


Figure 3 indicates more details of the non-simultaneity between the dry to wet transition and the wind direction reversal over the study area. Before pentad 26 (corresponding to the period before May 5), where the mean RSOD has already occurred (Table 2), the vertical integrated moisture over CH was brought from the South China Sea, which originated from the southern edges of the western pacific subtropical high (WPSH). From pentad 26 (May 6 to May 10), the WPSH gradually weakens and retreats eastward; the moisture over CH originates from the trans-equatorial flow coming from

the south. Also from pentad 27 (May 11 onwards), the southwest moisture flow originating from the Bay of Bengal begins to prevail, marking the start of the summer monsoon in the CH area. The mean SMOD occurred thus around pentad 27.

Figure 4 displays the vertical integrated moisture flux from pentad 54 to 59 (i.e., September 23 to October 22). Overall, the weakening southwest monsoon gave way to winter monsoon in CH from the 55th pentad (i.e., September 28). From pentad 57 (October 8), winter monsoon becomes strongly persistent over CH and the moisture is mainly from the

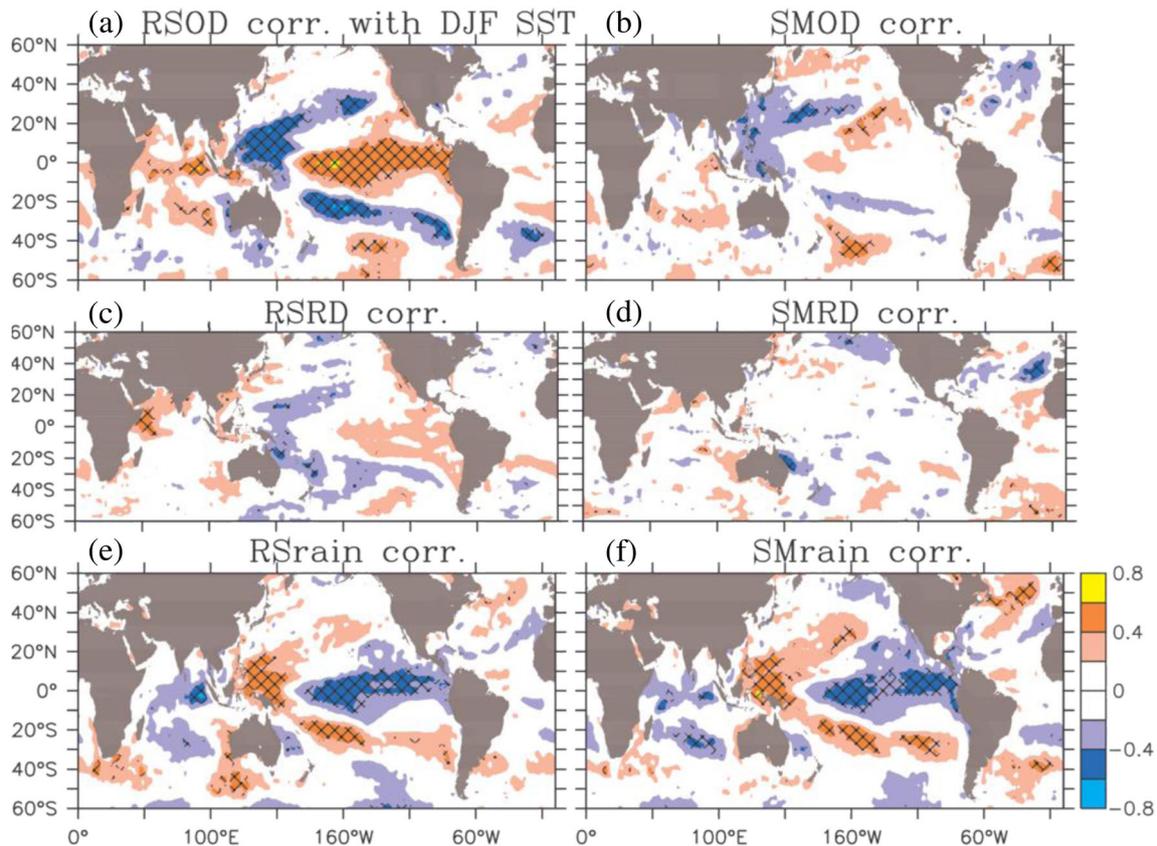


Fig. 6 Correlation between the sea surface temperature of the preceding DJF and the time series of **a** RSOD, **b** SMOD, **c** RSRD, **d** SMRD, **e** RSrain, and **f** SMrain over the Central Highlands for the period 1982–2014. The cross-hatching patterns represent statistically significant areas at the 0.05 level

northeast ocean region. After the summer monsoon season ends (around September 30), moisture over the region is brought from the South China Sea by the northeast monsoon system. Thus, the mean RSRD is around November 1, long after the mean SMRD (Table 3).

Strong interannual variability of the total rainfall within the RS and SM (hereafter called RSrain and SMrain) and of the seasons' lengths is shown in Fig. 5. RSrain varied from less than 1500 mm (in 2004) to more than 2500 mm (in 2000), while SMrain was always smaller than RSrain and varied from less than 1000 mm (in 1998) to more than 1800 mm (in 2000). RSrain and SMrain are significantly correlated with the lengths of the RS and the SM season with the correlation coefficients of 0.62 and 0.72, respectively. The length of the SM season is generally shorter than that of RS by about 54 days. The variations in RS length and associated RSrain show a remarkable change from 2000 to 2004. Such similar swings are likely to cause major difficulties for farmers in the region; thus, to improve understanding of these processes and forecasts is obviously important. It is worth to notice that in the case of Indian monsoon, the onset timing showed no significant correlations with the monsoon seasonal rainfall (e.g., Bansod et al. 1991). Such differences among the different region emphasize the specific characteristics of the CH's monsoon climate.

Figure 6 portrays the correlation between the preceding winter (December–January–February, hereafter called DJF) SST and the annual time series of the onset dates, retreat dates, and rainfall amount within the RS and SM. It is shown that the RSOD over CH is significantly and positively (negatively) correlated with the preceding DJF SST in the central-eastern (western) Pacific (Fig. 6a). A similar pattern of correlation is found for SMOD (Fig. 6b); however, the value is generally not statistically significant at the 0.05 level. The retreat dates of both RS and SM are not clearly linked with the preceding winter SST (Fig. 6c–d). As shown previously, early (late) RSOD and SMOD tend to extend (shorten) the RS and SM, hence to increase (decrease) the total rainfall within the RS and SM (hereafter called RSrain and SMrain), respectively. Consequently, RSrain and SMrain are significantly and negatively (positively) correlated with the preceding DJF SST in the central-eastern (western) Pacific (Fig. 6e–f).

Similar correlation patterns are identified with the preceding spring (March–April–May, hereafter called MAM) SST (Fig. 7). However, the correlation values are lower compared to those with DJF SST. The results of Fig. 7 are consistent with the finding of Zhang et al. (2002) where they discovered that an early (late) SMOD over Thailand was linked with warm (cold) SST anomalies in the western Pacific and cold

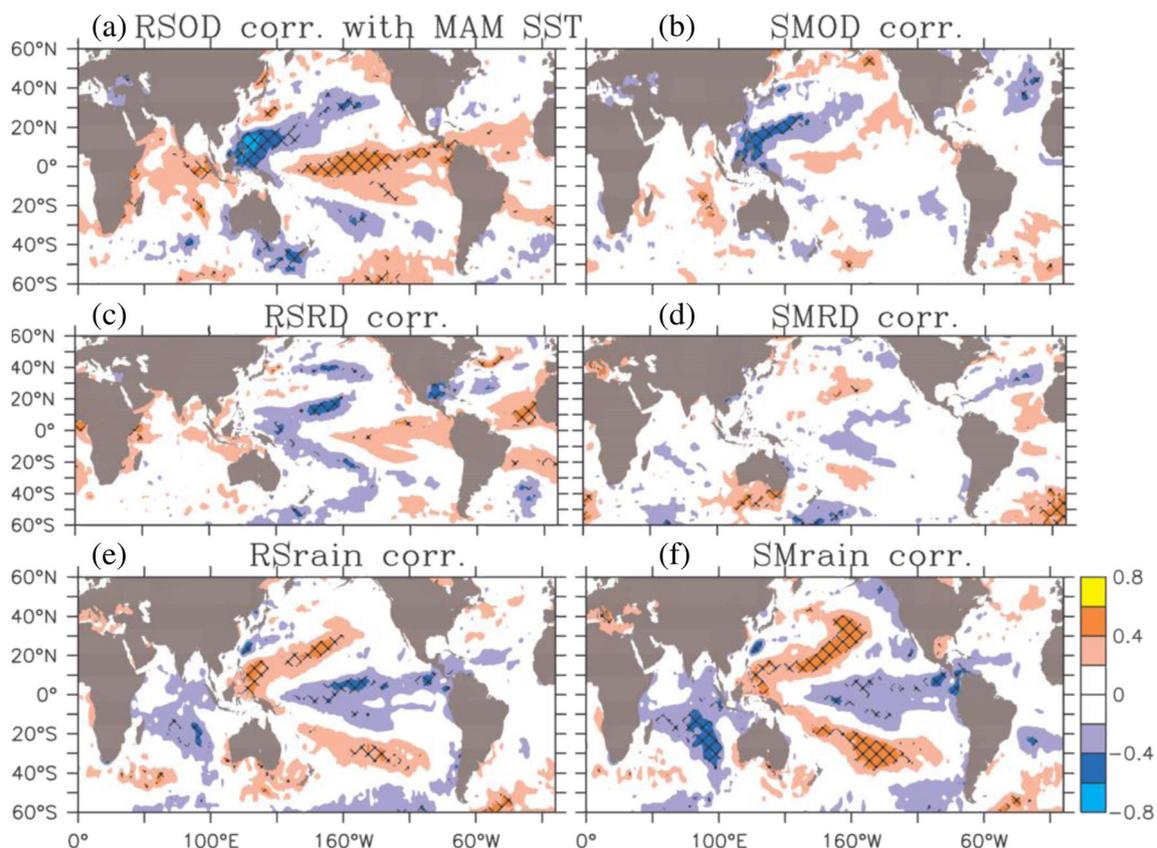


Fig. 7 As in Fig. 6 but for the correlations with the MAM sea surface temperature

Table 4 Correlation between RSOD and SMOD with other rainfall quantities for the 1981–2014 period

	RSRD	SMRD	RSrain	SMrain
RSOD	0.10	−0.03	−0.48	−0.32
SMOD	−0.01	0.16	−0.23	−0.50

Ital values indicate that the correlation is significant for a two-tailed test at the 0.05 level

(warm) SST anomalies in the central-eastern Pacific in the preceding spring.

It is of great interest to note that RMOD and SMOD are significantly correlated with RSrain and SMrain, respectively (Table 4). Therefore, the onset information could be used in the forecast of the respective seasonal rainfall amount. This result is in agreement with Pham et al. (2010), where a significant correlation between SMOD and SMrain was shown for the southern region of Vietnam. Table 4 also shows that there is no significant correlation between the onset and retreat dates of both rainy and summer monsoon season over the CH region, meaning that an advanced onset does not necessarily lead to a respective advanced/delayed retreat and vice versa.

4 Conclusions

It is also important to note that in this study, the rainy season has been well differentiated from the summer monsoon season. The onset (retreat) dates of the rainy season are earlier (later) compared to that of the summer monsoon season. Over the period 1981–2014, the mean RSOD and SMOD are April 20 ± 17.4 days and May 13 ± 17.8 days, respectively. The mean RSRD and SMRD are November 1 ± 17.9 days and September 30 ± 10.2 days. The trend analysis shows that RSOD and SMOD are earlier in recent years by 1.79 and 2.5 days per decade. RSRD and SMRD do not show any trend. All the trends' values are however statistically non-significant at the 0.05 level. The preceding winter and spring SST in the central-eastern and western Pacific are well correlated with the RSOD and SMOD, as well as with the RSrain and SMrain. In addition, the RSOD (SMOD) is significantly correlated with the RSrain (SMrain); thus, the preceding winter and spring SST and the onset information could be good predictors for seasonal rainfall forecasts over the Central Highlands, and this possibility is now being further investigated with relevant coffee stakeholders.

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