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Season Onset Prediction Based on Statistical Model for Malang Regency, East Java

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ABSTRACT

Prediction of season onset is important for many sectors, particularly on agricultural practices, as its usage for reducing climate risk and planning activities. Current knowledge on season onset prediction mainly focused on large area, which remains research challenge for local level. This research developed model prediction of season onset for Malang Regency, East Java based on global climate data. The research specifically aimed to: (i) determine the onset date of rainy and dry season, (ii) generate equation for onset date prediction using principal component regression (PCR) approach, and (iii) evaluate the model performance. We depend on statistical model based on a combine of domain time and principal component analysis (PCA) for atmospheric variables, namely sea level pressure, outgoing longwave radiation, and zonal wind. We used the Tropical Rainfall Measuring Mission (TRMM) data for model evaluation, especially for determination of onset date. Based on cumulative anomalies rainfall, the onset date for dry season occurred in the early May, whereas for rainy season it was in early November. The results showed that regression models of the principal components had a good skill to predict onset date for both seasons. It has been confirmed by a low error and a high correlation. Visually, the dynamic of onset dates from model was mostly identical to the observation. The predictive model for rainy season had higher performance compared to the model for dry season. This finding was confirmed by insignificant difference resulted from the independent t-test between model and observed onset dates. The best model for dry season was conducted by domain time of February, whereas for rainy season was domain time of August. This research can be used to complement previous studies regarding season onset prediction in Indonesia.

KEYWORDS
global climate data, linear regression, onset criteria, principal component analysis, rainfall variability

INTRODUCTION

A season onset has different criteria for different regions (Lala et al., 2020; Lisonbee et al., 2020; Pham-Thanh et al., 2020), and it depends on climatic zones which will specify the onset's indicator (Ferijal et al., 2022; Giráldez et al., 2020; Shukla et al., 2021). The onset is also influenced by climate variability, such as El Nino Southern Oscillation (Cao et al., 2019; Hrudya et al., 2020), Indian-Ocean Dipole (Ratna et al., 2021), and Madden-Julian Oscillation (Taraphdar et al., 2018). Prediction for season onset is essential for many sectors, particularly on agriculture (Acharya and Bennett, 2021; Apriyana et al., 2021; Lala et al., 2021). Previous studies have discussed about season onset prediction over Indonesia (Duan et al., 2019; Ferijal et al., 2022; Irsyad and Oue, 2021; Lubis and Saragih, 2021). But, little was known for prediction on district level at Malang.

Information of season onset in Malang Regency is generally important due to its mountainous topography in which most areas are prone to flooding and landslides (e.g. Bachri et al., 2021; Hasyim et al., 2021). The information is mostly needed for agricultural sector since Malang is dominated by agriculture land including paddy fields, and horticulture. The shifting of season onset will affect the production yield of the agricultural commodities. The onset of season prediction information is needed to help farmers plan their agricultural activities (Surmaini et al., 2018).

Season onset may be predicted based on climate variables, such as wind, rainfall, a combination of winds with outgoing longwave radiation (OLR), or cloud cover. There are many methods to identify the criteria of season onset. In Indonesia, BMKG suggests that season onset is based on ten-day rainfall. Rainy seasons initiate when the received rainfall is more than 50 mm in ten days, and this condition occurs 3 times in a row. Meanwhile, dry season onset is technically determined using the same method, yet the ten-day rainfall should be less than 50 mm. In West Africa, rainy season onset was defined when the accumulated five-day rainfall is more than 20 mm, and at least 0.1 mm recorded for each day, followed by a no dry period of seven or more consecutive days (Kumi et al., 2020). In Malaysia, onset of the monsoon was best determined by considering the changing of wind direction at between 850 hPa and 600 hPa height and outgoing longwave radiation (Chenoli et al., 2018). Another season onset criteria is by accumulating daily rainfall anomalies, which was firstly developed by Liebmann et al. (2007). This method was well simulated the onset and ending dates of rainy season in South America with biases of less than 10 days.

This research was performed to develop model prediction of season onset for Malang Regency using global climate data. This research specifically aimed to: (i) determine onset date of rainy and dry season, (ii) develop model using principal component regression (PCR) approach, and (iii) evaluate the model performance. The PCR approach was used to overcome multicollinearity problems, which usually occurred in prediction model using linear regression approach. This research can be used to complement previous studies regarding season onset prediction in Indonesia.

RESEARCH METHODS

Data Sources

This study used two types of data, i.e. station-based and spatial data. All data covered period from 2000 to 2013. To determine season onset date, we used spatial daily rainfall data from the Tropical Rainfall Measuring Mission (TRMM), which has spatial resolution 0.25°. The TRMM data was obtained from IRI/LDEO Climate Data Library[1]. The data was then validated using observed daily rainfall data from Geophysics Karangkates station (8.152°S,112.448°E).

Model prediction for season onset date was developed using four atmospheric variables as predictors, namely outgoing longwave radiation (OLR), mean sea level pressure (MSLP), and zonal wind data at two different altitudes (200 hPa and 925 hPa). The OLR data was daily scale at spatial resolution 1°, which was obtained from National Oceanic and Atmospheric Administration (https://www.ncei.noaa.gov/). The rest of data (MSLP and zonal wind) were downloaded from Europe Center for Medium-Range Weather Forecasting (https://www.ecmwf.int/). The domain data used for developing season onset prediction in this research was 40°E-80°W and 30°N-30°S.

Rainfall Data Preparation

The TRMM data was extracted for Malang Regency area by transforming the data formation into tabular data. The extraction was done using Grid Analysis and Display System (GrADS) software (http://cola.gmu.edu/grads/). The reliability of TRMM data was then tested by comparing it with the observed rainfall station data. The comparison was done by plotting both data at daily scale into scatter plot, and by analyzing the trendline pattern compared to 1:1 plot.

Season Onset Determination

Season onset date was determined using Liebmann's method (Liebmann et al., 2007). The method used a daily cumulative rainfall anomaly in defining the onset date (Equation 1).

$$A = \sum_{n=1}^{365}[R(n) - \bar{R}] \quad (1)$$

where A is the accumulation of rainfall anomalies, $R(n)$ daily rainfall (mm), and $\bar{R}$ annual average of daily rainfall (mm). Dry season was initiated when the accumulation of daily rainfall anomalies reached the maximum value, while onset date of rainy season was minimum value of the rainfall anomalies accumulation.

Domain Selection

To develop model prediction for season onset date, we selected domain time and domain area used as predictor in the model. For domain time, we used rainfall data at 1-, 2-, and 3-month before the average month at which onset date occurred. For domain area, the selection was done by calculating spatial cor-

[1] website: http://iridl.ldeo.columbia.edu/

relation between the calculated onset date at each domain time with the four atmospheric variables data. The selected area was the area with correlation value longer as it covered seven months (November-May). Malang more than 0.51. This combination between domain time and area resulted 12 predictors for further analysis.

Principal Component Analysis (PCA)

Before the predictors were used to predict onset date, the four climate variables in each domain time were tested its multicollinearity using principal component analysis (PCA). Multicollinearity was a condition that showed correlation among independent variables. Multicollinearity could be detected if a variance inflation factor (VIF) exceeds 10 (Marcus et al., 2012). The PCA aimed to reduce data dimensions contained significant variations in data and replace it with new variables (Wilks, 2011). This analysis was commonly used to overcome multicollinearity problems in multiple regression models. The new variable, principal component (PC), contains a linear combination of original data, which explains the data information. In general, the PCA's steps include: (i) preparing the data, (ii) subtracting each data (predictor), (iii) calculating covariance matrix, eigenvectors, and eigenvalues of the covariance matrix, (iv) choosing components and forming a feature vector, and (v) deriving the new data set.

Principal Component Regression (PCR) Analysis

The season onset prediction models used principal component regression (PCR). The PCR is a regression technique combining the main components of PCA results as its predictors. The predictors were PCs obtained from the PCA process as reduction of initial predictor data, namely MSLP, OLR, and zonal wind at height of 200 hPa and 925 hPa. Since the PCA was done for each domain time analysis, there were three regression models resulted in this analysis for each season (dry and rainy season).

Model Validation

Models for predicting season onset in Malang were validated against the observed onset date. The validation process followed Leave-One-Out Cross-Validation (LOOCV) method, which quantified the accuracy of model by dividing data into two parts, namely training and test data. In this method, we took a year from the 14 years data as a testing data, while the rest data were used as input value on model equation. For instance, season onset dates in 2000 were predicted using data from 2001 to 2013. The test was done alternately for each year during the analysis period.

The model's accuracy was then quantified using two statistical indicators goodness of fit, namely root mean square error (RMSE) and correlation coefficient (r). The RMSE value was used to measure error of the model in predicting onset date. Mathematically, RMSE value was calculated based on Equation 2.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(y_o - y_p)^2}{n}} \qquad (2)$$

where y_o is the observed season onset date, y_p the predicted onset date, n the number of observations, and i the order of the tested data. A lower value of RMSE (close to 0) indicates a good model fit for prediction.

The correlation value was used to measure the strength of the relationship between the relative movements of predicted and observed onset date. The value ranged between -1 and 1 which stands for the strongest negative and positive correlation. A correlation value closes to 0 shows a weak correlation between predicted and observed onset date. The correlation value was calculated using Equation 3.

$$r = \frac{n\sum_i^n y_o y_p - (\sum_i^n y_o)(\sum_i^n y_p)}{\left[n\sum_i^n {y_o}^2 - (\sum_i^n y_o)^2\right]^{\frac{1}{2}} \left[n\sum_i^n {y_p}^2 - (\sum_i^n y_p)^2\right]^{\frac{1}{2}}} \qquad (3)$$

We carried out an independent t-test to see the results difference of onset date from model and observation. The t-test was a parametric statistical test method used to compare the mean (μ) of two unpaired samples (Wilks, 2011). The null hypothesis (H0) in this study was that there was no difference between the average onset date from model (μ1) and the observed season onset date (μ0), while H1 showed that there was difference between both data. The test results were considered as statistically significant based on p-value less than 0.05, which indicates strong evidence against the null hypothesis.

RESULTS AND DISCUSSION

Climate condition of Malang Regency

The climate condition was analyzed based on spatial rainfall data from the Tropical Rainfall Measuring Mission (TRMM). In general, the TRMM's daily rainfall has a similar pattern with observed data of Karangkates station as shown by the trendline at scatter plot during the analysis period (Figure 1a). This result implied that the TRMM data represented local rainfall conditions and could be used for further analysis on determining the onset date of seasons in Malang Regency.

Based on the monthly data, the rainfall pattern of Malang Regency was categorized to monsoonal type (Figure 1b). Dry season occurred from June to October in which the area received rainfall less than

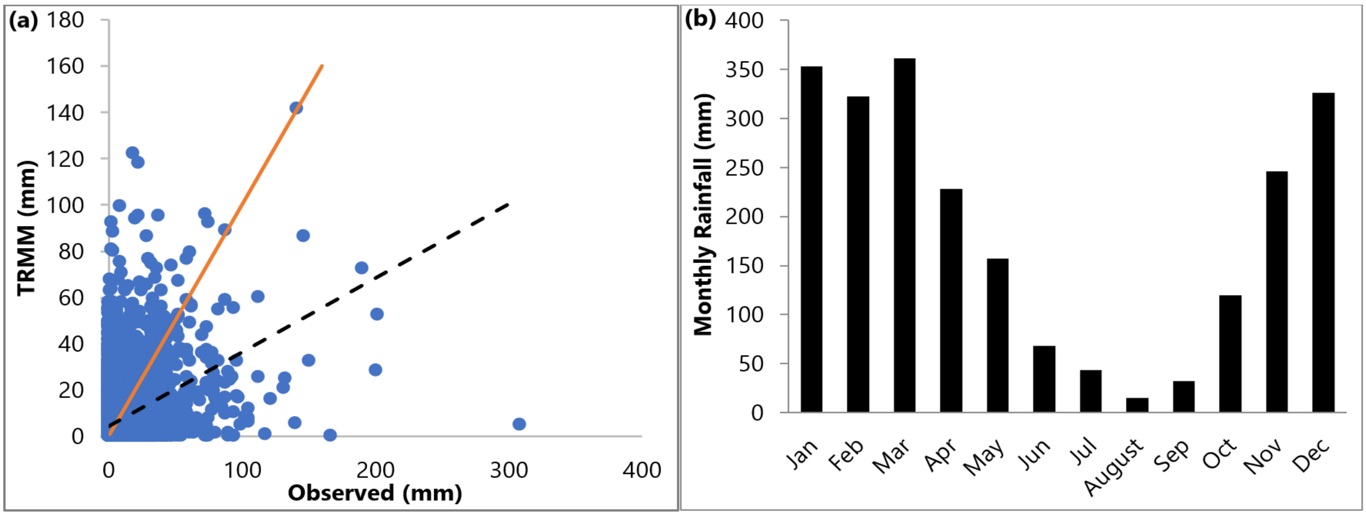

Figure 1. Rainfall in Malang Regency for the period of 2000-2013: (a) daily rainfall comparison between the Tropical Rainfall Measuring Mission data (TRMM) and the Karangkates station data (observed), and (b) monthly rainfall from the TRMM data. The orange line represents 1:1 plot, while the black dash line is trendline of daily data.

150 mm. August became the driest month as its rainfall was only 15 mm. Meanwhile, rainy season lasted experienced wettest months during December until March as shown by high monthly rainfalls (more than 300 mm/month). These results were coincided with several previous studies about rainfall condition in Malang (Khaerudin et al., 2020; Susanawati and Suharto, 2017). Monsoonal type of rainfall is affected by the presence of two monsoons, namely the Asian monsoon from November to March (NDJFM) and the Australian monsoon from May to September (MJJAS) (Aldrian and Susanto, 2003).

Season Onset Date

The onset date of dry season was defined as a date when the cumulative rainfall anomaly reached its maximum, while the rainy season initiated at its minimum. For example, in 2000, Malang experienced the onset date for its dry and rainy seasons were on 30 April and 13 October, respectively (Figure 2). The rainfall anomalies were accumulated up to 600 mm as its maximum at Julian day of 121. Even though the accumulated rainfall was fluctuated until 151st day, it gradually decreased until -200 mm (minimum value) at 287th day (rainy season onset date).

Based on the onset date analysis for each year during the period 2000-2013, dry season started in April-June, while the rainy season's onset ranged from October to December (Figure 3). The average onset date for dry season was on May 1 (Julian day 122), while the rainy season was on November 3 (Julian day 308). For dry season, Malang experienced two years with onset date 38 days later compared to its average date (in 2009 and 2013) and one time that started more than 40 days before 1st of May. Meanwhile, for the rainy season, there were two times when the onset date occurred more than a month later (in 2006) and earlier (in 2008) prior to its average date. There was only one onset date, which coincided with the average date, for each season. Those happened in 2000 for dry season, and in 2011 for rainy season.

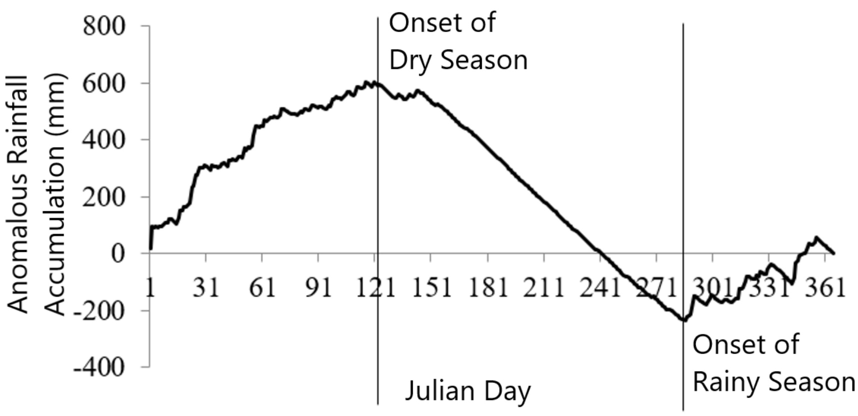

Figure 2. Visualization of daily rainfall anomalies accumulation (mm) in Malang Regency in 2000.

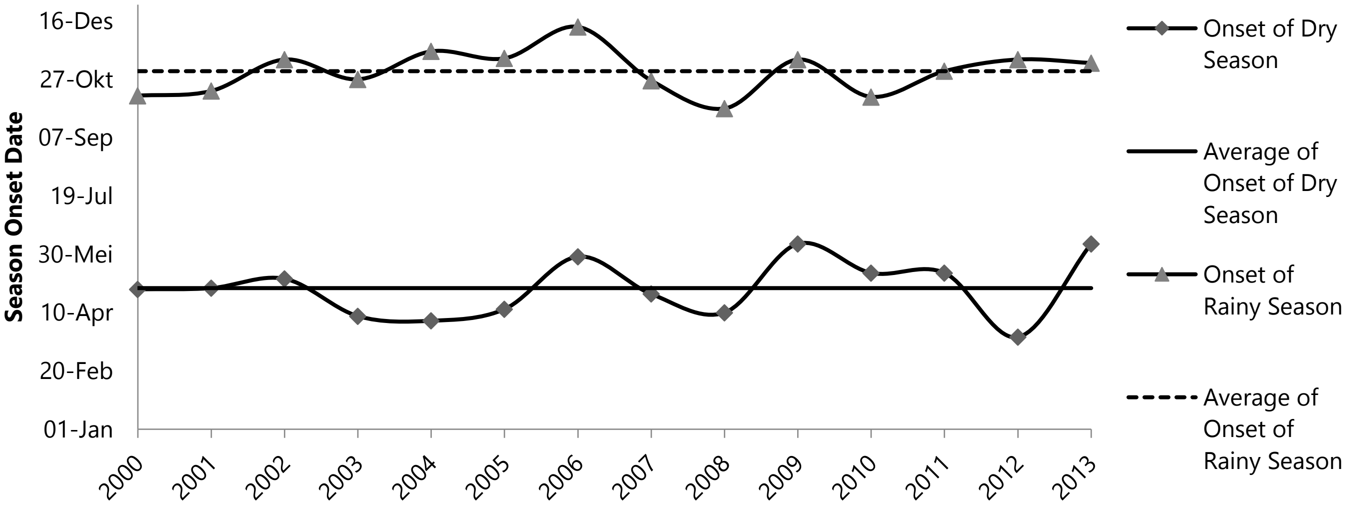

Figure 3. The onset date of dry season (♦), rainy season (▲), and its average dates for Malang Regency in the period of 2000-2013.

In general, variability of onset date for dry and rainy season had similar pattern, which meant that dry season length was remained steady. There were two years that had longer dry seasons (in 2004 and 2012). The shift of onset date and its effect on season length were due to climate variability. There are several climate phenomena such as El Nino Southern Oscillation, Indian Ocean Dipole, and Madden-Julian Oscillation, which influenced rainfall variability over Java, including Malang Regency (e.g. Amirudin et al., 2020; Hidayat et al., 2018; Qian, 2020).

Predictors for Season Onset Model

Models for predicting season onset in Malang were developed by predictors retrieved from selected domain. For domain time, we selected February-April as model1 until model3 to predict dry season onset date. Meanwhile, for rainy season, we chose August-October as model1 to model3. For domain area, we had selected box area that had strongest correlation with onset date for each atmospheric variable (Table 1). These domain areas could represent a convective region due to the different pattern of thermal condition and circulation, which occurred along the Asia-Pacific region, associated with monsoon (Pai and Nair, 2009).

Correlation values, which had identified from the domain area, varied among the atmospheric variables for each model. For dry season, model3 was the only one model which consistently had negative correlation with all variables. The model1 and model2 had the same pattern of correlation, which were negatives for its relation to outgoing longwave radiation (OLR) and zonal wind at 925 hPa (U925), and positives for mean sea level pressure (MSLP) and zonal wind at 200 hPa (U200). Meanwhile, for the rainy season, model2 had constantly positive correlation with the variables. The correlation values were dominated by more than 0.8, which indicated as strong correlation. The highest correlation for model1 was combined with OLR (0.85), model2 with U200 (0.83), and model3 with U925 (-0.89). This result showed that the selected domain was best used to predict the onset date of rainy season.

Season Onset Date Models

The models used for predicting season onset were conducted principal components resulted from principal component analysis (PCA) of the atmospheric variables for each model. The PCs in all models for dry season explained more than 80% of predictor data variations. Specifically, two main PCs in model1 had explained 84%, then that of model2 and model3 had explained 82% and 88%, respectively. For the rainy season, cumulative eigen value of two PCs was 10 point higher than that of for dry season. The PCs explained at least 90% of predictor data variations for each model, which were 90%, 95% and 95% for model1, model2 and model3.

The PCs were then used as predictor in regression model to predict onset date. The equation for each model was summarized in Table 2. The model1 had the highest coefficient of determination (R^2) for onset prediction of dry season, which was about 80%. Meanwhile, the highest R^2 value for rainy season model was also the model1, which was slightly over 90%. The number of PCs used in the models had met the PC criteria representing an 80% proportion of variance indicated by the cumulative eigenvalue in principal component regression (PCR) (Marcus et al., 2012).

Table 1. Summary of selected predictors used for modeling season onset date prediction in Malang Regency. The abbreviation in atmospheric variables: mean sea level pressure (MSLP), outgoing longwave radiation (OLR), zonal wind at 925 hPa (U925), and zonal wind at 200 hPa (U200). The DSO and RSO denotes for dry and rainy season onset; PC is the principal components.

Model	Domain Time	Atmospheric Variables	Domain Area	Correlation	Model's Equation
			Dry season		
Model1	February	MSLP	155-170°W, 25-30°N	0.63	DSO = 122 - 13.8 PC1 + 4.69 PC2
		OLR	165-175°W, 10-20°N	-0.75	
		U925	105-115°E, 21-27°S	-0.71	
		U200	155-180°E, 8-14°N	0.69	
Model2	March	MSLP	80-100°E, 22-30°S	0.65	DSO = 122 + 14.4 PC1 - 7.27 PC2
		OLR	120-135°W, 20-30°N	-0.67	
		U925	80-100°W, 20-25°S	-0.63	
		U200	65-85°E, 15-20°N	0.57	
Model3	April	MSLP	123-135°E, 14-18°S	-0.70	DSO = 122 - 12.1 PC1 - 5.72 PC2
		OLR	100-108°E, 7-14°S	-0.76	
		U925	125-145°W, 20-25°S	-0.67	
		U200	90-105°E, 6°N-6°S	-0.63	
			Rainy season		
Model1	August	MSLP	110-145°E, 3-15°S	0.70	RSO = 308 + 10.6 PC1 - 1.97 PC2
		OLR	80-90°E, 7-13°N	0.85	
		U925	100-115°E, 26-30°S	0.80	
		U200	130-140°E, 12-16°S	-0.82	
Model2	September	MSLP	75-85°E, 4-12°S	0.68	RSO = 308 + 8.63 PC1 + 4.73 PC2
		OLR	105-110°E, 2°N-4°S	0.82	
		U925	130-155°E, 0-8°N	0.75	
		U200	105-115°W, 5-10°N	0.83	
Model3	October	MSLP	85-100°E, 5-13°N	0.80	RSO = 308 - 9.04 PC1 - 6.86 PC2
		OLR	105-115°E, 0-10°S	0.83	
		U925	40-52°E, 6-12°S	-0.89	
		U200	145-155°W, 5-10°S	-0.80	

The Validation of Season Onset Prediction Model

The prediction models of season onset were validated by comparing its onset date to the observed onset date. The comparison in each season was done by looking at the anomalies of onset date from observation and those three models based on the average onset date of observed data. We also analyzed the pattern of annual onset date changes based on its time series plot. Furthermore, the performance of each model was quantified using root mean square error (RMSE) and correlation (r) as shown in Table 2.

For dry season, the onset date anomalies showed that most onset date from all models (more than 50%) had similar condition to the observed data (Figure 4a). During the years with inconsistent onset date anomalies, the model2 was more frequent in having different anomalies with the observed data compared to other models. The differences could be seen in 2002, 2007, 2010, and 2011. The model3 had

Table 2. Statistical goodness of fit for season onset prediction models at Malang. R^2 denotes for the coefficient of determination; RMSE is root mean square error, and r is correlation.

Model	R^2	RMSE	r
	Dry Season		
Model1	80.1%	10.71	0.89
Model2	79.8%	10.71	0.89
Model3	70.3%	13.09	0.84
	Rainy Season		
Model1	90.8%	5.53	0.95
Model2	73.7%	9.31	0.86
Model3	85.0%	7.05	0.92

the least occurrence of opposed condition to observed anomalies, yet the deviations were higher than onset date anomalies from model2 (in 2000 and 2007).

The time series plot showed that, in general, all models followed the annual pattern of observed onset date (Figure 4b). The plot also confirmed that model2 had a slight difference at several times, such as in 2000 and 2008. Based on the statistical indicators, all models for predicting dry season onset had satisfactory results with high correlation (r > 0.8) and low error (see Table 2). Model1 and model2 had identical results for the performance's test. The model's error on predicting onset date was less than two weeks. It ranged from 10 to 13 days.

For rainy season, the anomalies onset date from all models were in line with the observed onset date, yet the anomaly's intensity varied among the models during the analysis period (Figure 5a). The model1 became the only model which always had same pattern of anomalies with the observed. The anomalies onset date of model1 were mostly (up to 70%) less than four days apart from the observed anomalies. Meanwhile, model2 and model3 experienced at least one time at which the anomalies opposed the observed data, which were in 2013 and 2011, respectively.

The similarity between the dynamics of onset date from models and observation were also proven by its pattern in time-series plot (Figure 5b). The plot showed that model1 was coincided with the observation, yet only in 2001, it had far different onset date (16 days). Statistically, all models for predicting onset date of rainy season had better performance compared to the models for dry season as they had lower error and higher average correlation. The models error varied from 5 to 9 days, and the correlation values were more than 0.85. Overall, the model1 for rainy season had the highest performance (R^2=90%, RMSE=5.5, r=0.95) to predict onset date in Malang Regency.

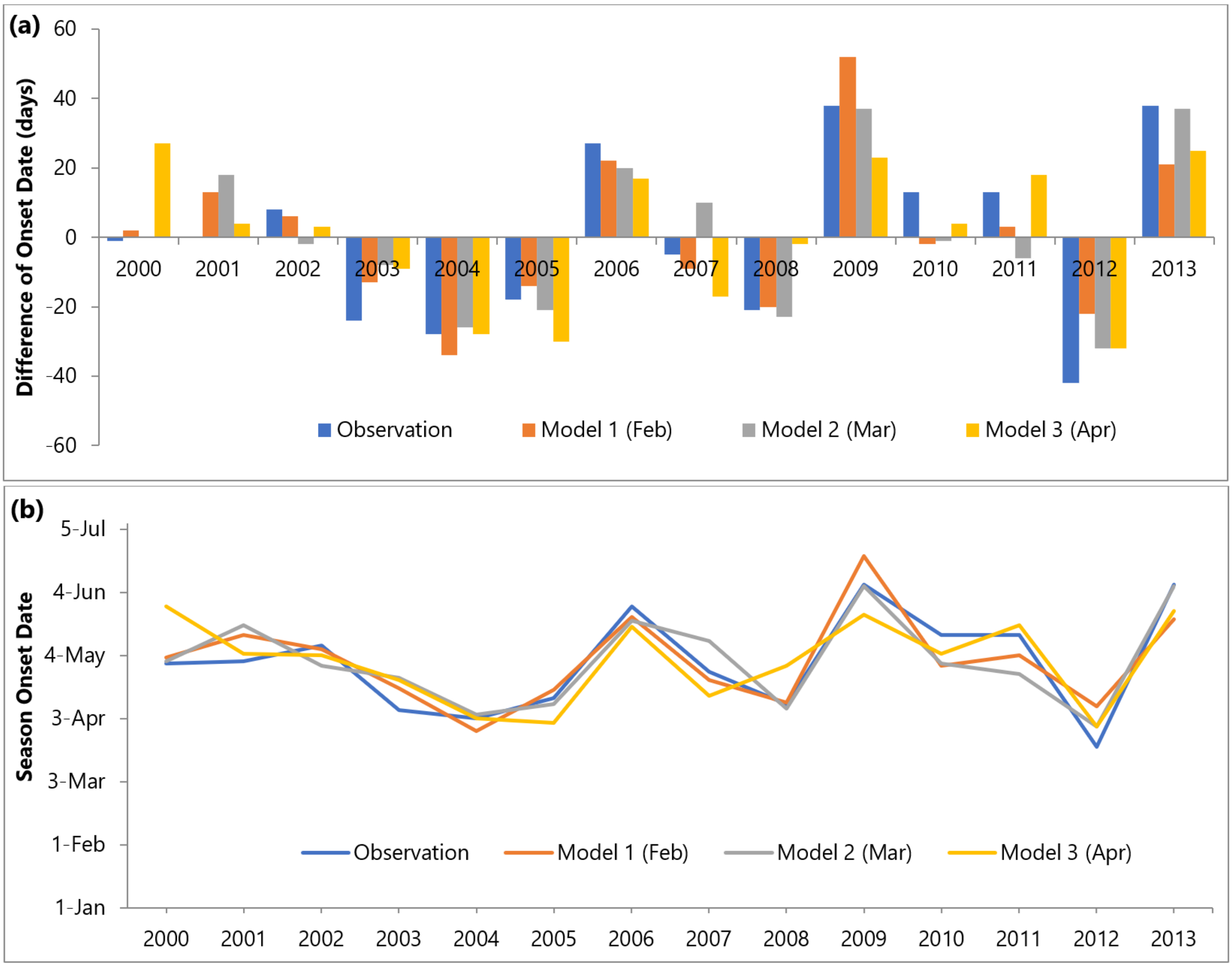

Figure 4. The comparison of onset dates from dry season models and observation in Malang Regency for the period of 2000-2013: (a) difference from the average onset date, and (b) time-series plot of the onset dates.

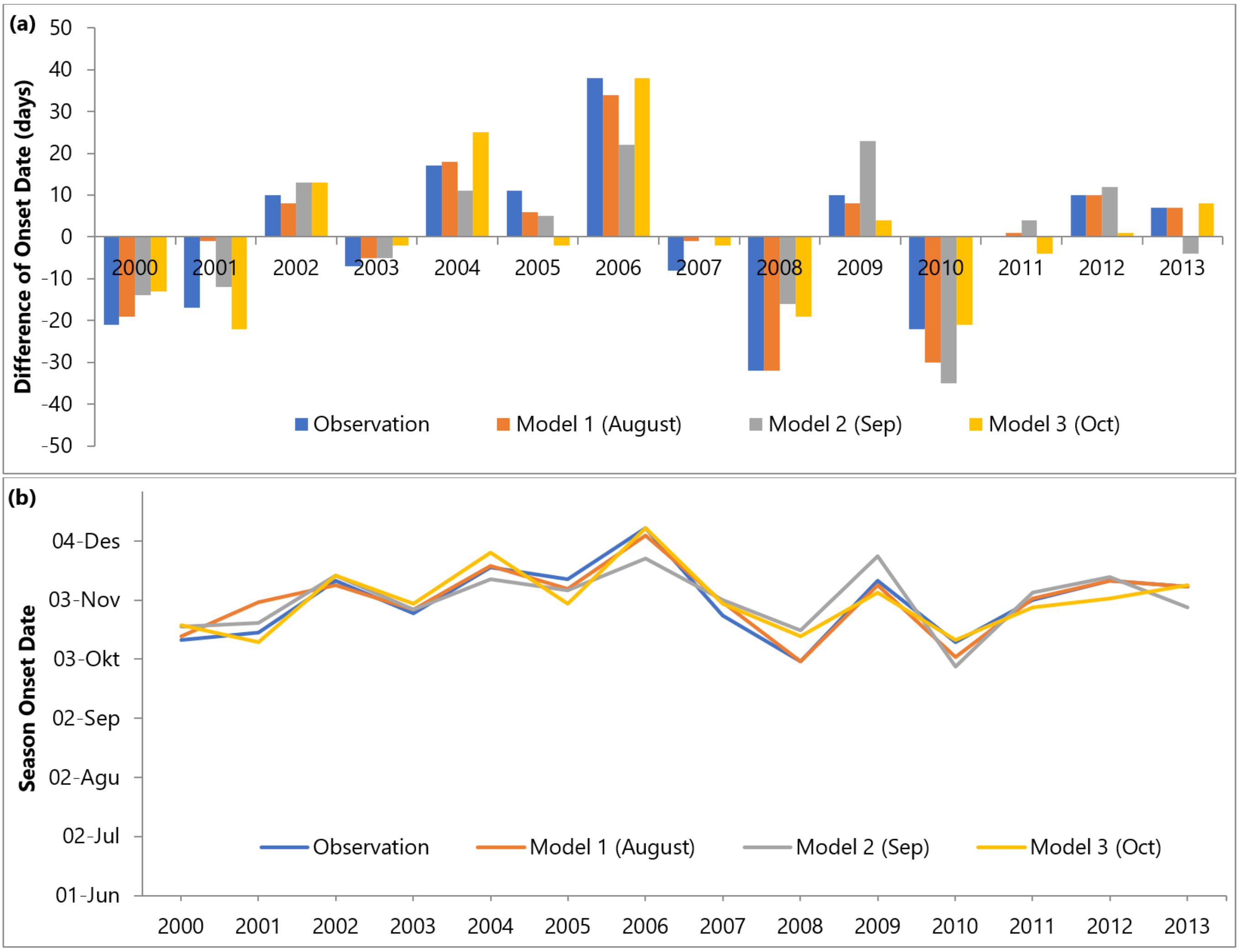

Figure 5. The comparison of onset dates from rainy season models and observation in Malang Regency for the period of 2000-2013: (a) difference from the average onset date, and (b) time-series plot of the onset dates.

The use of pricipal component regression (PCR) analysis in predicting season onset date had already proven resulting a good predictive model. The PCR's model showed good skill in predicting monsoon onset over Kerala during 1997-2007 (Pai and Nair, 2009). Another study has used PCR method to determine onset date of rainy season in West Africa (Laux et al., 2008). Based on the average onset date, the model resulted one day earlier than the observed average onset date either in dry or rainy season. Furthermore, the results of independent t-test showed that there was no significant differences between onset dates from model and observation (p-value > 0.05). This finding implied that the model could estimate the onset date of season, which likely close to the observed onset date.

CONCLUSIONS

This research was conducted daily spatial rainfall data to determine onset date of dry and rainy season in Malang. Based on cumulative anomalies rainfall, the onset dates for dry season occurred in the early May, while for rainy season was in early November. Statistical model for predicting season onset was developed using domain time and principal component analysis (PCA) of several atmospheric variables, namely sea level pressure, outgoing longwave radiation, and zonal wind. The results showed that regression models of the principal components resulted good skill to predict onset date for both seasons shown by low error and high correlation. Visually, the dynamic of onset dates from model was mostly identical to the observation. The predictive model for rainy season had higher performance compared to the model for dry season. This result was also confirmed by insignificant difference resulted from the independent t-test between model and observed onset dates. The best model for dry season was conducted by domain time of February, whereas for rainy season was domain time of August.

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