Research Paper

# STUDY OF DROUGHTS IN CA MAU PROVINCE: CHARACTERISTICS AND PREDICTION CAPABILITIES

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**ABSTRACT**

*This paper studies the characteristics of droughts in Ca Mau and its prediction capabilities. It shows that drought cycle in Ca Mau annually occurs with dry season. The most severe droughts occur in January, February and March with the frequency of 90 – 95%. Average duration of drought season is about 4 months which can be longer in few years. Longer duration drought and more severe intensity drought mostly occur in the El-Nino year. In addition, by applying the Regional Spectral Model (RSM) for drought prediction, the results show that the RSM model captures well the inter-annual variation of the SPI index at timescale of 12 months, especially during severe water scarcity periods. Underestimated errors in the predicted SPI value can be bias-corrected for more proper determination of droughts from the RSM output. An important issue of drought prediction is warning of drought intensity during either dry or rainy season. The assessment of long-term water scarcity using the SPI index can provide warning of drought intensity in future.*

**Keywords**: *Drought, Duration, Intensity, The RSM model, The SPI index.*

## 1. Introduction

Located in the West of the South Vietnam, the climate in Ca Mau province is characterized by distinct rainy and dry seasons. Droughts occur almost every year in Ca Mau, in dry season (i.e. winter and early spring) with varying intensity. Moreover, drought season in the El-Nino year usually has longer duration and more severe intensity (Nguyen et al., 1995; Nguyen and Nguyen, 2003).

In order to study characteristics of drought in Ca Mau, we proposed a number of drought indices in which monthly and annual indices are recognized as the most suitable indicators. These indices not only represent the water balance at monthly and yearly timescale but also provide the basis for determining the dry and wet season in the study area. However, the drought index is not able to represent the level of water scarcity in rainy season when precipitation, although higher than evaporation, is still lower than the climatic average value (McKee et al., 1993). Therefore, the Standardized Precipitation Index (SPI) is also used with different timescales (6 and 12 months) for assessing the level of temporary precipitation deficit as well as precipitation deficit over a long preceding period (Nguyen, 1995; Nguyen, 2014; McKee et al., 1993).

## 2. Data and method

### *2.1 Statistical method*

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Drought frequency calculation:

$$P_t(H) \quad \frac{M(H)_t}{N(H)_t} \qquad (1)$$

*Determining drought trend*

One of trend analysis methods which are usually applied in the study of climate variability is regression analysis. The regression method described in this study is the regression between the climatic variable (x) and the time (t), i.e. the variation of x in t: x = f (t).If f(t) is a linear function, then the trend will be linear. In other cases, a non-linear trend is considered (Nguyen V. Th., 2007; Hoang D. C. and Nguyen T. H., 2012; Juang and Kanamitsu, 1997].

To study the linear trend, we construct the regression equation:

$$x(t) = at + b \qquad (2)$$

where a, b is the regression coefficient determined by:

$$a \quad \frac{\sum_{t\ 1}^{n} (x_t \quad \bar{x})(t \quad \bar{t})}{\sqrt{\sum_{t\ 1}^{n} (x_t \quad \bar{x})^2 \sum_{t\ 1}^{n} (t \quad \bar{t})^2}} \qquad (3)$$

$$b \quad \bar{x} \quad a\bar{t} \qquad (4)$$

$$\bar{x} \quad \frac{1}{n} \sum_{t\ 1}^{n} x_t \qquad (5) \qquad \bar{t} \quad \frac{1}{n} \sum_{t\ 1}^{n} t \qquad (6)$$

From this equation, the linear trend of time series is recognized by the slope a. The sign of the slopea determines the increase(a> 0) or decrease (a <0) trend while the absolute value of a indicates magnitude of this trend.

For practical purpose, the total time series can be splited into different sub-series to analyze the trend. Then the trends of different periods can be determined based on different slopes (a).

*Determining drought season, drought onset and withdraw date*

Determining the date of drought onset and demise from the monthly time series applying the Conrat method:

$$\frac{K_i \quad 2}{K_i \quad K_{(i\ 1)}} xD_i \qquad (7)$$

where,

n(BDH): drought onset date

i, i+1: two adjacent months with $K_i < 2 < K_{(i+1)}$

$D_i$: number of days in month i

$$\text{n(KTH)} = 15 \text{ months i} + \frac{K_i \quad 2}{K_i \quad K_{(i\ 1)}} xD_i$$

n(KTH): date of drought demise

$K_i > 2 > K_{(i+1)}$

***2.2 Dynamical approach***

In this study, the regional spectral model (RSM) is used for drought prediction in Ca Mau by applying and analyzing the Standardized Precipitation Index (SPI). The SPI index is proposed by Mckee T. B., Doesken N. J. and Kleist J., from the Colorado State University in1993. The SPI index is calculated as the difference between the precipitation amount R(total amount for week, month, season or year) and the long-term average of precipitation then is divided by the standard deviation :

$$SPI \quad \frac{R \quad \bar{R}}{} \qquad (8)$$

In this study, the long-term average and the standard deviation are computed for the period of 1986-2005. The SPI index is based on the amount of precipitation in a specific period and is highly recommended by decision makers and researchers due to its versatility. This index can be calculated at different timescales (e.g. 3, 6, 12, 24, 48 months) thus can provide early warning of drought with level of drought intensity although applying simple calculation. Drought occurs as SPI is lower than -1.0 and drought demises as SPI returns to positive value.

The RSM applied in this study is a hydrostatic model with simulation domain from 0oN to 30°N and from 95 - 125°E (Figure 1). The horizontal resolution is 26x26km with 28 vertical levels implementing the time step of 60s. The applied parameterization schemes in the RSM model are shown in Table 1.

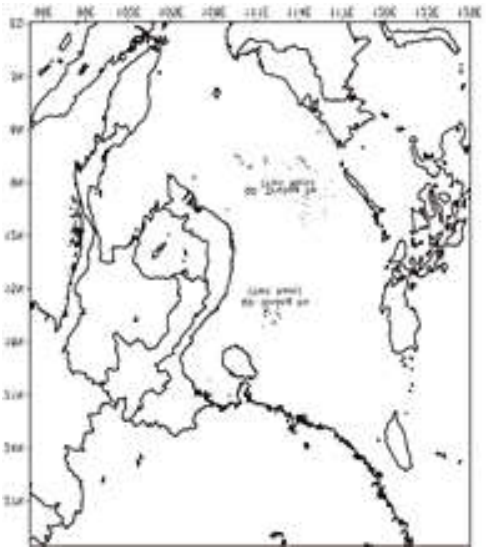


**Fig.1.** Simulation domain of the RSM model

**Table 1.** Parameterization scheme using in the RSM model (Juang et al., 1994; Saha, 2006)

| Physics options | Reference |
|---|---|
| Microphysics | Hong et al. 1998 |
| Longwave radiation (RRTM) | Mlawer et al. 1997 |
| Shortwave radiation | Chou and Suarez, 1999; Hou et al, 2002. |
| Surface layer (JMonin-Obukhov) | Skamarock et al. 2005 |
| Land surface | Pan and Mahrt, 1987 |
| Planetary Boundary Layer | Troen and Mahrt, 1986 |
| Cumulus Parameterization (SAS) | Pan and Wu 1994, Grell, 1993. |
| Vertical diffusion | Hong et al, 1996 |

## 3. Results and discussions

### *3.1. Drought characteristics in Ca Mau*

*- Drought frequency*

Table 2 presents the frequency of drought appearance in each month with three intensity levels of slight, moderate and severe. Slight droughts (or abnormally dry events) start early in November and end in May which is later than moderate and severe droughts. The appearance frequency of slight droughts is highest in December (30,8%) and April (25,6%). Slight droughts do not occur from June to October. The strong El Niño event of 1997-1998 lasted about 12 months from May/1997 to April/1998. During that time, the amount of rainfall decreased about 9 months over some Viet Nam's climatic regions by this El Nino; the most serious lack of the amount of rainfall took place in October and November/97 over the Central region, especially the coastal zone (Vu V. Th., 2016; Tran Th., 2008).

Moderate droughts start in December and end in April with highest frequency of appearance in December and January (20,5%). There is not moderate drought from May to November.

Severe droughts start in December and end in April with highest appearance frequency in February (79,5%), followed by March (64,1%) and January (61,5%).

In general, droughts occur in February with highest frequency (97,4%), then January and March (both these two months have frequency of 89,7%).

**Table 2.** Frequency of drought appearance in months (period 1979 - 2017)

| | | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Slight drought** | STH | 3 | 5 | 5 | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 12 |
| | % | 7.7 | 12.8 | 12.8 | 25.6 | 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.7 | 30.8 |
| **Moderate drought** | STH | 8 | 2 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| | % | 20.5 | 5.1 | 12.8 | 5.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.5 |
| **Severe drought** | STH | 24 | 31 | 25 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| | % | 61.5 | 79.5 | 64.1 | 25.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.6 |
| **Total** | STH | **35** | **38** | **35** | **22** | **2** | **0** | **0** | **0** | **0** | **0** | **3** | **30** |
| | % | **89.7** | **97.4** | **89.7** | **56.4** | **5.1** | **0.0** | **0.0** | **0.0** | **0.0** | **0.0** | **7.7** | **76.9** |

**Table 3.** Drought season and duration in Ca Mau during period of 1979 - 2017

| Drought onset | Drought demise | Duration (month) |
|---|---|---|
| **29/XI/1978** | 13/IV/1979 | 4.5 |
| **15/I/1980** | 18/III/1980 | 2.1 |
| **25/XI/1980** | 4/IV/1981 | 4.3 |
| **15/XII/1981** | 18/III/1982 | 3.1 |
| **26/XI/1982** | 13/V/1983 | 5.6 |
| **25/XII/1983** | 14/IV/1984 | 3.7 |
| **21/XII/1984** | 25/III/1985 | 3.1 |
| **2/I/1986** | 25/IV/1986 | 3.8 |
| **16/XII/1986** | 18/III/1987 | 3.1 |
| **16/XII/1987** | 15/IV/1988 | 4.0 |
| **9/XII/1988** | 13/III/1989 | 3.1 |
| **25/XI/1989** | 15/IV/1990 | 4.7 |
| **15/XII/1990** | 20/III/1991 | 3.2 |
| **29/XI/1991** | 15/IV/1992 | 4.6 |
| **4/XII/1992** | 4/V/1993 | 5.0 |
| **19/XII/1993** | 10/V/1994 | 4.7 |
| **26/XII/1994** | 5/V/1995 | 4.3 |
| **19/I/1996** | 13/IV/1996 | 2.8 |
| **15/XII/1996** | 4/IV/1997 | 3.7 |
| **18/XI/1997** | 15/V/1998 | 5.9 |
| **NO** | NO | |
| **21/XII/1999** | 17/III/2000 | 2.9 |
| **4/XII/2000** | 9/II/2001 | 2.2 |
| **14/XII/2001** | 16/V/2002 | 5.1 |
| **14/XII/2002** | 1/V/2003 | 4.6 |
| **26/XI/2003** | 15/IV/2004 | 4.7 |
| **24/XI/2004** | 14/V/2005 | 5.7 |
| **15/I/2006** | 15/IV/2006 | 3.0 |
| **27/XI/2006** | 1/IV/2007 | 4.2 |
| **15/XI/2007** | 15/IV/2008 | 5.0 |
| **30/XII/2008** | 14/IV/2009 | 3.5 |
| **21/XII/2009** | 15/V/2010 | 5.8 |
| **29/XI/2010** | 18/III/2011 | 3.6 |
| **17/XII/2011** | 5/III/2012 | 2.6 |
| **20/XI/2012** | 15/IV/2013 | 4.9 |
| **5/XII/2013** | 15/IV/2014 | 4.4 |
| **11/I/2014** | 14/V/2015 | 4.1 |
| **15/XII/2015** | 15/V/2016 | 5.0 |
| **15/II/2017** | 13/IV/2017 | 1.9 |

*- Drought season, duration and classification*

Table 3 presents the calculated date for drought onset and drought demise using drought index Ht during period of 1979 - 2017. During 39 years, drought occurred almost every dry season with average duration of about 4 months. Short drought season (less than 3 months) occurred in 1979 - 1980 (although the onset date of drought season is in January 1980 and demise date in March 1980, this event is still consiodered as drought season 1979 - 1980) with duration of 2,1 months; 1995 - 1996: 2,8 months,

1999 - 2000:2,9 months, 2000 - 2001: 2,2 months; 2011 - 2012: 2,6 months and 2016 - 2017: 1,9 months. However, drought season can prolong more than 5 months such as 1982 - 1983, 1992 - 1993, 1997 - 1998, 2001 - 2002, 2004 - 2005, 2007 - 2008, 2009 - 2010, 2015 - 2016. There is not drought in the dry season of 1998 - 1999.

Of the more than 5-month-drought years above, the El Nino phenomenon occurred in 1982 - 1983, 1997 - 1998, 2004 - 2005, 2009 - 2010, 2015 – 2016, whereas the ENSO of neutral state was in 1992 - 1993, 2001 - 2002 and the La Nina phase occurred in 2007 - 2008.

Short drought duration or no drought occurred in the La Nina year, excepted the drought seaon of 1979-1980 occurred in a weak phase of El Nino.

On average, there are more than 4 months of drought per year with the highest record of 6 months in 1994 and 2010. However, severe drought occurred in 2010 was stronger than that in 1994 with 5 and 3 months relatively. There are twelve years with 5 months of drought, in which 4 severe droughts occurred in 1993, 1998, 2002, 2003. There are 18 years with 4 months of drought in which severe droughts occurred in 2004, 2005, 2016. In general, severe drought occurred with highest frequency during study period (100 per total 165 drought months) and there are 25 months of moderate drought and 40 months of slight drought.

**Table 4.** Yearly number of drought month with different intensity level

| Year | Slight | Moderate | Severe | Total | Year | Slight | Moderate | Severe | Total |
|---|---|---|---|---|---|---|---|---|---|
| **1979** | 0 | 0 | 3 | 3 | **1999** | 2 | 0 | 0 | 2 |
| **1980** | 2 | 0 | 2 | 4 | **2000** | 1 | 1 | 2 | 4 |
| **1981** | 0 | 0 | 2 | 2 | **2001** | 2 | 2 | 0 | 4 |
| **1982** | 0 | 0 | 3 | 3 | **2002** | 0 | 1 | 4 | 5 |
| **1983** | 1 | 1 | 3 | 5 | **2003** | 0 | 1 | 4 | 5 |
| **1984** | 2 | 2 | 1 | 5 | **2004** | 0 | 0 | 4 | 4 |
| **1985** | 1 | 2 | 1 | 4 | **2005** | 0 | 0 | 4 | 4 |
| **1986** | 1 | 2 | 2 | 5 | **2006** | 2 | 1 | 2 | 5 |
| **1987** | 3 | 0 | 2 | 5 | **2007** | 1 | 2 | 2 | 5 |
| **1988** | 0 | 1 | 3 | 4 | **2008** | 1 | 0 | 2 | 3 |
| **1989** | 1 | 0 | 3 | 4 | **2009** | 1 | 1 | 2 | 4 |
| **1990** | 1 | 0 | 3 | 4 | **2010** | 1 | 0 | 5 | 6 |
| **1991** | 0 | 2 | 2 | 4 | **2011** | 3 | 0 | 2 | 5 |
| **1992** | 2 | 1 | 2 | 5 | **2012** | 0 | 0 | 3 | 3 |
| **1993** | 1 | 0 | 4 | 5 | **2013** | 0 | 2 | 2 | 4 |
| **1994** | 2 | 1 | 3 | 6 | **2014** | 1 | 0 | 3 | 4 |
| **1995** | 0 | 1 | 3 | 4 | **2015** | 1 | 1 | 3 | 5 |
| **1996** | 2 | 0 | 2 | 4 | **2016** | 0 | 0 | 4 | 4 |
| **1997** | 1 | 0 | 3 | 4 | **2017** | 3 | 0 | 1 | 4 |
| **1998** | 1 | 0 | 4 | 5 | **Total** | 40 | 25 | 100 | 165 |

*- Trend of drought in Ca Mau*

Based on trend analysis methods from series of drought indices, we calculated the drought trend for Ca Mau. As analyzed above, the drought index Ht is considered as the most suitable index for studying the characteristic and intensity of drought in Vietnam. Therefore, in order to be consistent with the assessment, the yearly Ht series is used to construct the linear trend equation and calculate the correlation coefficient, which determines the temporal variability.

Linear trend equation of the yearly Ht index is:

$$Y = 0.0035t + 0.3511$$

As can be seen, the higher value of the index Ht, the more severe drought occurs. During the last 40 years, there is an increase trend of drought in Ca Mau at the rate of 0.0035 unit per year.

*- Assessment of water scarcity in Ca Mau*

At timescale of 6 months, the calculated SPI index for the period of 1979 - 2017 highlights the occurrence of the water scarcity in Ca Mau during the period of 1981 - 1982, 1983 - 1987, 1990 - 1991, 2004 - 2005, 2013 - 2016 and es-

pecially in 2010 with very severe water scarcity.

During the timescale of 12 months, Ca Mau experiencesd a long period of water scarcity includes 1983 - 1992, 2004 - 2005, 2010 - 2011, 2013 - 2017.

The water scarcity condition existents in long time, leading to the occurrence of severe droughts. For example, water scarcity during 1981 - 1982 (at timescale of 6 months) causes long severe drought in 1982/1983; or water shortage during 1983 - 1987, 1990 - 1991 (timescale of 6 months) and 1983 - 1992 (timescale of 12 months) causes severe drought in 1992/1993; or water scarcity during 2004 - 2005 causes severe drought in 2004/2005; or water scarcity during 2013 - 2016 and 2013 - 2017 causes extreme severe drought in 2015/2016.

***3.2 Prediction capability using the RSM model***

Firstly, the SPI index calculated from the RSM model is compared with the SPI index calculated from the observation data using the Mean Error (ME) and Mean Absolute Error (MAE) [Saha, 2014]. The results show that the RSM model predicts higher value of the SPI index (ME is positive) in comparison with observation at all 5 leadtimes from 1 to 5 months. Longer leadtimes tend to have higher overestimated bias. MAE represents the magnitude of error for SPIprediction using the RSM model in comparison with the observation at Ca Mau station.

In general, the lowest error is achieved as using the SPI index at timescale of 12 months with MAE is approximately 1.0. In contrast, the RSM model predicts the SPI index at timescale of 3 months with highest error as MAE is from 2,2 to 3,5. In terms of leadtime differences, the leadtime of 1 month leads to highest MAE in comparison with all timescale from 1 to 6 months of the SPI index.

**Table 5.** Mean Error (ME) and Mean Absolute Error (MAE) of SPI prediction using the RSM model

| Leadtime | 1-month | | 3-months | | 6-months | | 12-months | |
|---|---|---|---|---|---|---|---|---|
| | ME | MAE | ME | MAE | ME | MAE | ME | MAE |
| **leadtime01** | 0.3 | 2.8 | 0.1 | 3.5 | 0.1 | 1.9 | 0 | 0.9 |
| **leadtime02** | 0.3 | 2.4 | 0.3 | 2.6 | 0.2 | 1.6 | 0.1 | 1.1 |
| **leadtime03** | 0.3 | 2.2 | 0.3 | 2.3 | 0.2 | 1.3 | 0 | 0.9 |
| **leadtime04** | 0.5 | 2.1 | 0.4 | 2.2 | 0.4 | 1.3 | 0.5 | 1.1 |
| **leadtime05** | 0.6 | 2.3 | 0.4 | 2.6 | 0.2 | 1.3 | 0.3 | 1.1 |

**Table 6.** Probability of correct prediction for drought using the RSM model

| Leadtime | 1-month prediction | 3-month prediction | 6-monthprediction | 12-monthprediction |
|---|---|---|---|---|
| **leadtime01** | 29 | 35 | 44.7 | 5.8 |
| **leadtime02** | 9.7 | 22.5 | 23.4 | 17.3 |
| **leadtime03** | 12.9 | 25 | 25.5 | 13.5 |
| **leadtime04** | 9.7 | 20 | 23.4 | 11.5 |
| **leadtime05** | 12.9 | 22.5 | 21.3 | 15.4 |

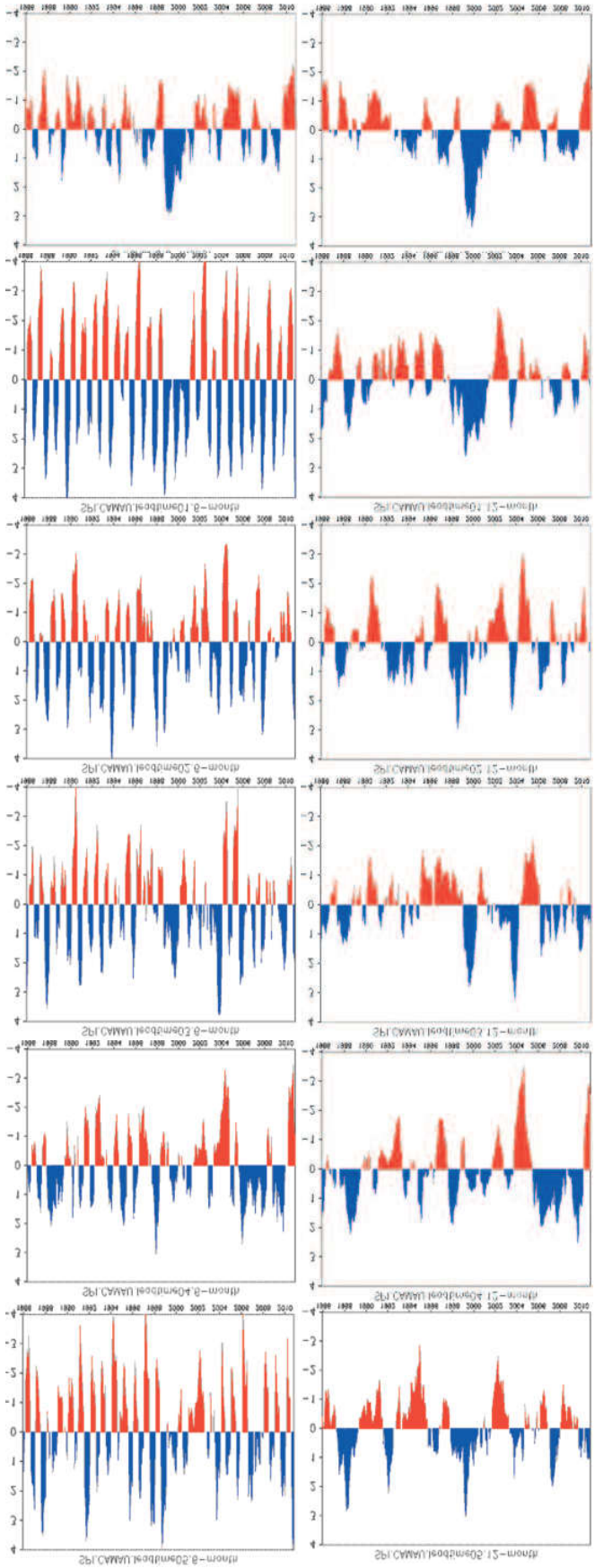


**Fig. 2.** Inter-annual variation of the SPI at timescale of 6 months (left) and 12 months (right) from observation and the RSM model

Table 6 presents the probability of correct prediction (PC) for monthly drought using the RSM model with the SPI index in which drought month determined by less than -1 of SPI value. The results show that the highest PC is attained as using the SPI index at timescale of 6 months (21-45%), especially the PC at leadtime of 1 month reaches 44,7%. Applying the SPI index at timescale of 3 months, the PC is higher than 20% in comparison with other leadtimes. The prediction results implementing the SPI index at timescale of 1 and 12 months are worse than at timescale of 3 and 6 months with PC is mostly from 10 to 17%.

For more detailed assessments of the prediction capability using the RSM model, the inter-annual variations of the SPI at timescale of 6 months and 12 months are calculated and presented in Figure 2.The results highlight that although the PC value at timescale of 6 months is higher than that of 12 months, the RSM model is unable to capture well the duration and intensity of droughts in compared with observation. The droughts at 6 months timescale predicted from the RSM model have shorter duration than observation but more severe in intensity. Meanwhile, within the timescale of 12 months, the RSM model generally captures better the drought characteristics in Ca Mau. According to the observation, noticeable water scarcity events occurred in Ca Mau in 1986, 1988, 1990-1992, 2004-2006 and 2010. In comparison with observation, the RSM model represents almost these water scarcity periods, especially with leadtime of 2 months. The duration of predicted water scarcity periods is approximate to the observation but the magnitude of error is still high. Generally, the RSM model can be implemented for prediction of water scarcity at long timescale in Ca Mau. However, bias correction is required for better prediction results.

## 4. Conclusion

Droughts in Ca Mau occur at annual cycle (i.e. every year) coinciding with dry season, however their trend becomes more and more severe. The most severe droughts occur in January, February, March with the frequency of 90 – 95%. Average duration of drought season is about 4 months which can be longer in few years. Longer duration drought and more severe intensity drought mostly occur in the El-Nino year.

In this study, the RSM model and the SPI index are applied for drought prediction in Ca Mau. The results show that the RSM model capture well the inter-annual variation of the SPI index at timescale of 12 months at the meteorological observation station Ca Mau, includes severe water scarcity condition existences in long time. There are still the underestimated errors in the prediction of the SPI value. However, these errors tend to have systematical bias which can be bias corrected or adjusted the index threshold for proper determining droughts from the model output.

Since drought occurs every year, drought prediction is not limited to the prediction of drought season and drought frequency, the more important issue is warning and prediction of drought intensity during either dry or rainy season. The calculation and assessment of long-term water scarcity using the SPI index can provide warning of drought intensity in future.

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