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Defining Three Rainy Seasons and the Hydrological Summer Monsoon in Korea using Available Water Resources Index

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Abstract

A new scheme that can define three rainy seasons, and the hydrological summer monsoon in Korea, has been proposed, examined, and verified to be effective. In the scheme, the Available Water Resources Index (AWRI) that is the accumulated precipitation value in which daily reduction of water, and the duration of accumulation are taken into account quantitatively.

With this scheme, the onset and ending dates of three rainy seasons are defined by such singularities as the smallest, the biggest, the minimum, and the maximum of the AWRI in a year. The intensities of these rainy seasons are defined by the value of the maximum AWRI, flood index, and drought index.

The first rainy season (Bom-Changma) starts in early April, when the minimum value of the AWRI in a year appears, and when the mean southerly wind at 925 hPa level become stronger than that at the 500 hPa level, and ends at May 15. The second rainy season (Changma) starts in late June and ends at 16–20 July. The third rainy season (Kaul-Changma) starts at mid August, and ends at 3–5 September that has the maximum value of the AWRI in a year, and that is the last date of mean southerly wind at the 925 hPa level.

Finally, the hydrological summer monsoon is proposed to be defined as the period of increasing water resources that is from the minimum to the maximum of the AWRI, from the onset of Bom-Changma till the end of Kaul-Changma. From a turning point of meridional wind system to the end of mean southerly wind in the low level atmosphere, and that is concurrent with the summer monsoon.

1. Introduction

In India, as Huschke (1970) mentioned, the rainy season itself is sometimes termed 'the monsoon'. In Asia, neither the general public nor some scientists differentiate strictly the summer monsoon from the summer rainy sea-

son. The names of summer rainy seasons, like Changma (in Korea), Baiu (in Japan), and Meiyu (in China) are often confused with the summer monsoon (Kurashima 1968). Because no clear-cut definitions on the onsets of monsoon or rainy seasons exist, each academic study uses different onset date in the same year (Ryu 2001).

These confusions seem to arise from the fact that the summer rainy season is the most important period in the summer monsoon, not due to the wind system but due to its abundant

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Table 1. Factors used in defining the monsoon onset date.

Author	Factor
Holland (1986)	Filtered westerly zonal wind at 850 hPa.
Chang and Tan (1988)	Positive zonal wind anomaly at 850 and 700 hPa.
Orgill (1967) & Bao (1987)	Northward movement into southern China of lower tropospheric equatorial westerlies
Drosowsky (1996)	Abrupt increase of westerlies
Kung and Sharif (1980)	Consecutive daily precipitation
Nicholls (1984) & Nicholls et al. (1982)	Cumulative rainfall exceeds a specified threshold
Matsumoto (1995)	Accumulated pentad precipitation exceeds a specified threshold.
Samel et al. (1999)	Cumulative frequency distributions of daily precipitation.
Troup (1961)	Distinct change in upper level winds and rainfall near Darwin.
Hendon and Liebmann (1990)	Holland (1986) + rainfall greater than 7.5 mm/day. (averaged over all stations north of 15 S).
Tanaka (1992)	Percent of high-level cloud.
Xie et al. (1997)	OLR and westerlies

precipitation. On the contrary the summer monsoon was named—originally in India—not after the precipitation, but after the intra-annual reversal of the wind system. In this situation, for the clear differentiation of summer rainy season from summer monsoon, all seasons should be redefined again by both of the hydrological and the aerodynamic senses. This study proposes and examines a new scheme that defines the onset dates, the ending dates, and the intensities of the three rainy seasons and the summer monsoon in hydrological sense.

Several current methods defining the onset date of summer monsoon are compared as shown in Table 1. They can be divided into five kinds. The first kind of the studies defines the date by using wind data only. Holland (1986), Chang and Tan. (1988), Lau (1988, 1992), and Drosowsky (1996) thought the abrupt increase of the westerlies that is concurrent with the start of the summer rainy period, was the major symptom of the monsoon onset. Lau (1988) and Lee (1974, 1975, 1976) also mentioned that the abrupt increase of westerlies is the start of Meiyu or Baiu. Orgill (1967) and Bao (1987) defined the onset by northward movement of the lower tropospheric equatorial westerlies.

The second kind defines the date by using precipitation data only. Kung and Sharif (1980) used consecutive daily precipitation. If 5 out of 7 stations had precipitation of more than 1 mm for more than 2 consecutive days, they

defined that the monsoon had started. Nicholls et al. (1982), Nicholls (1984), and Samel et al. (1999) thought the rainy season (or summer monsoon) started when the accumulated precipitation exceeded some threshold value.

The third kind uses the combined data of precipitation and wind. Additionally on the westerlies' anomaly data, Troup (1961) took another condition for the defining of the Australian monsoon onset. He rated the day when N nearby stations had $N + 1$ inches of precipitation for more than N consecutive days. Hendon and Liebmann (1990) also took an additional condition into consideration. It is that the rainfall amount should be greater than 7.5 mm/day.

The fourth kind uses the combined data of the westerlies and outgoing long wave radiation (Xie et al. 1997). It defined summer monsoon in Southern Asia to begin when the outgoing long wave radiation was less than 235 W/m², and the westerlies started at the 850 hPa level. The fifth kind uses the high-level cloud cover (Tanaka 1992). The monsoon is considered to start when the amount of high-level cloud cover exceeded more than 25% of sky. These kinds of studies define summer monsoon by the phenomena associated with increased precipitation, and that makes some confusions with the summer rainy season.

Compared to the abundance of the studies on the onset date, only a few studies on the end-

ing dates of the summer monsoon are found. Matsumoto (1995, 1997) considered the end of summer-wet season in Korea as late September. Kawamura (1977) considers that the summer monsoon ends at the end of Kaul-Changma. Also, Bao (1987) thinks it ends in October when upper level easterlies retreat to the South China Sea. It is not easy to find some studies that differentiate clearly the summer rainy season from the summer monsoon (or summer wet season).

Besides, Tanaka (1992) and Murakami and Matsumoto (1994) made a map of the ending date of the summer rainy season using cloud data detected by satellite. Kurashima (1959) also made a map of the withdrawal date on the summer rainy season. Tanaka (1992) defined the East Asian summer monsoon from mid June till mid July, that is the same duration with the summer rainy season. KMA (1995) defined it similarly but for from late June till mid July.

There are some studies that defined not the summer monsoon but the rainy season. Nicholls (1984), and Hendon and Liebmann (1990) were interested in the relationship between the summer monsoon and the wet period. Drosowsky (1996) showed interest, not on the active/break of the monsoon. Lee (1974, 1975, 1976) defined Kaul-Changma using synoptic data without mentioning the relation to the summer monsoon. Kimura (1966) and Maejima (1967) also used the synoptic data to define the Shurin. However, no studies are found that made the relationship clear between all rainy seasons and the summer monsoon. Only a few studies are found that clearly differentiate the summer monsoon from the summer rainy season. Kurashima (1959), for example, listed some papers written as Chinese, Japanese, or Russian.

On the intensity measuring of the summer monsoon, Parthasarathy et al. (1992, 1995), Webster and Yang (1992), and Goswami (1998) are examples. Wang and Fan (1999) summarized these studies very well. Li and Yanai (1996) also show similar findings. Once in a while the monsoon intensity indexes have received exceptional attention, and have developed notable controversy (KMS 1998; MSJ 1992). But it is hard to find some studies on the intensity of the rainy season.

After the inspection of the studies explained above, it is found that there remain some gaps for further research. The first gap is that there are no exact definitions on summer monsoon, and on rainy seasons. A few studies think that the summer monsoon is the same with the summer rainy season. But others do not think so, as Kurashima (1968) pointed out. The second gap is that the boundary values, like 1 mm, 2, 5, and 7 days, 4 stations, $n + 1$ inches, and 7.5 mm/day etc., that are used for the definition, are not globally acceptable values, but acceptable only in some restricted areas.

The third is that some of them use averaged data through a certain region, but boundaries of the regions are not always chosen by objective methods. Spatial displacement of the climate region, from the nearby regime can be comprehended only partly by their schemes. The fourth, and the most important one, is that they use intensive measures that are simply accumulated precipitation data like monthly and yearly precipitation, in which the duration of the accumulation are not chosen by an objective method. Intensive measures have been already verified to be inappropriate in showing time-related conditions, in other words, on-going water-related condition changes. However, it is not easy to find other extensive measures on precipitation data. In the current study, an extensive measure that is called AWRI, first developed by Byun and Wilhite (1999), is examined to define three rainy seasons in Korea using precipitation data only. Subsequently, this study redefines the hydrological summer monsoon with the help of the AWRI, and the daily mean meridional wind.

2. Data and defining

2.1 Data

Daily precipitation data of 64 Korean stations by KMA (1999) were used for the calculation. One Korean station data is available from 1777, 10 are from early 1900, and most other stations are from 1974. NCEP/NCAR reanalysis data (daily data from 1970 till 2000) are used for the calculation of mean meridional wind.

2.2 What is the AWRI?

The AWRI is calculated from the value of accumulated precipitation in which daily reduction (by runoff, evapo-transpiration, infiltration

etc.) of water, and the duration of accumulation, are taken into account quantitatively. At first, the accumulated precipitation can be calculated by using Equation (1).

$$E = \sum_{N=1}^D \left(\sum_{m=1}^N P_m / N \right), \quad (1)$$

where P_m is the daily precipitation of m -days before, N is a dummy variable and E is the representative value of water resources accumulated during D days. Equation (1) is derived from the concept that the precipitation of m -days before is added to the total of current water resources as a form of average precipitation of m -days.

Secondly, the accumulated precipitation calculated by Equation (1) is converted to the AWRI by

$$W = E / \left(\sum_{N=1}^D (1/N) \right), \quad (2)$$

where W is the AWRI, a kind of extensive measure to indicate the amount of current water resources. The big value of W indicates plenty of water resources available and the small value its deficiency. Because W takes into account the daily reduction of water resources after precipitation, it can show daily changes of water related conditions more effectively than other values or indexes made by simple accumulated precipitation.

But in Equation (1), there are three big questions. The first one is how the daily loss of water resources is calculated. Byun and Wilhite (1999) used three equations to find the best one to represent the real nature, and concluded that Equation (1) is best at the mountainous region. Also Byun and Jung (1998) have found that the result of the rainfall-runoff model shows a similar effect as Equation (1). Figure 1 shows the daily variation of weight on precipitation to the AWRI after Byun and Wilhite (1999). 30, 365, and 1000 days of D were chosen at random for experiment. Three curves show the same shape except the interception of the ordinate axis. If this scheme is used in the plain region, rather than the mountainous region, equations other than Equation (1) should be found. But that is the next step of this study because most of Asia is mountainous.

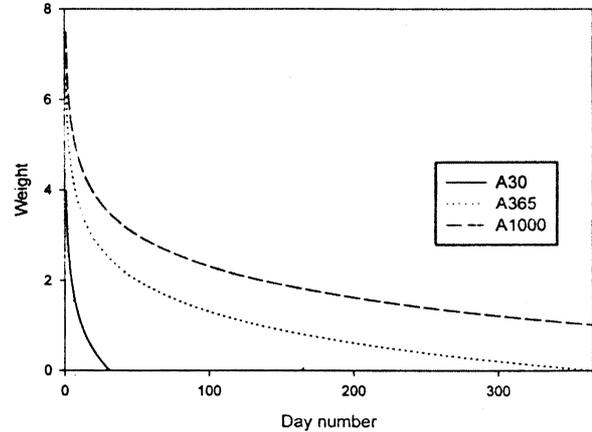


Fig. 1. Variation of the weight of precipitation to the AWRI along the day pass, which is considered in Equation (1). Ordinate axis shows a multiplied number to the rainfall amount along the day pass to calculate the AWRI. For example, in A30 curve, precipitation 1 day before being added to the AWRI after having been multiplied by 4.0, but one 30 days before is added after multiplication by $1/365$. Here 4.0 is the sum of $1/n$, in which n varies from 1 to 30. In A365 curve, 6.5 is the largest weight and in A1000 7.5.

The second question is how long the precipitation has to be accumulated. In other words, what is the best value of D ? Byun and Wilhite (1999) uses D as a variable that varies along the period of drought. In this study, two experiments to find the best value of D were carried out.

The first experiment uses the case of 6 years, with 6 consecutive annual rectangular rain curves. Figure 2a shows the variation of the AWRI during the last one-year out of 6 years. Numbers of days, counted from January 1st are on the abscissa axis. An increasing AWRI means that the water added by precipitation is more than the daily water reduction. A30 that denotes the AWRI curve accumulated during 30 days, shows no change of the AWRI from 30 days after the rain-start, till the end of rain-end in spite of 100 days of successive precipitation. This fact denotes that A30 fails to reflect the long time accumulation of precipitation. It is because of the fact that rainfall cycle may be

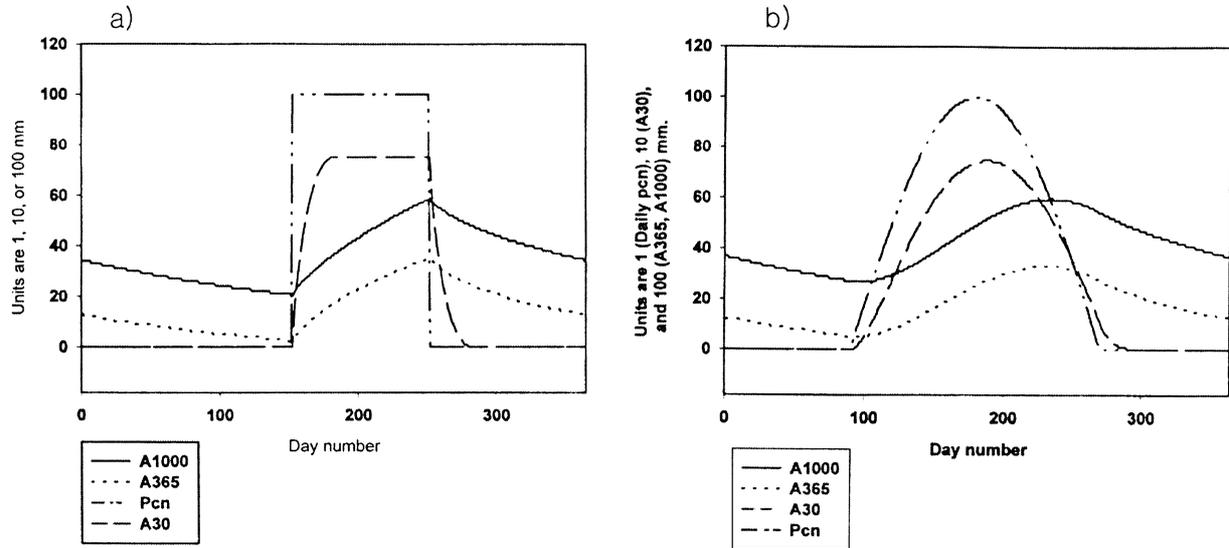


Fig. 2. Examples of the AWRI with 30 (A30), 365 (A365), 1000 (A1000) days accumulation of precipitation with equation (1) (a) on the rectangular rain curve and (b) on the sinusoidal rain curve. Pcn denotes daily precipitation.

over 30 days. However, A365 (denotes 365 days accumulation) and A1000 (1000 days accumulation) are efficient because they count enough period on the rainfall cycle that is 365 days in most of the world. It is easy to find that the minimum of AWRI is shown at the onset of rainy period and the maximum is at the end. It is also found that at the end of the rainy season the danger of flood is the highest. That means the intensity is the peak at the end of rainy season.

The second experiment uses the case of 6 years with 6 consecutive annual sinusoidal rain curves. Figure 2b shows the variation of the AWRI during the last one out of 6 years. 3 AWRI curves show the minimum value at the start of rain as Fig. 2a did. But the dates of the maximum values are different. The maximum of the original daily precipitation is at 180th day. In A30 the maximum is at 189th. And in A365 it is at 230th, and in A1000 it is at 234th. A30 is not good to reflect the peak as explained in Fig. 2a. Between A365 and A1000, peak dates show only 4 days difference. Therefore, the dates of the maximum AWRI are not perfect, but admissible to be used for the ending date of the rainy season, if D is equal to or more than 365, and if the precipitation cycle is 365 days.

The third question is whether Equation (1) reflects real nature or not. Although Equation (1) was made to reflect the real nature as best it can, it is not the last solution but one choice of useable ways to find the perfect one. Perfect simulation of the rainfall-runoff process is impossible, as Singh (1988) noticed.

2.3 Defining the ending date of rainy season

In Fig. 2a, the onset and the ending date of rainy season, and its biggest intensity are clear. In Fig. 2b, detecting the onset date of rainy season is also easy, because it is the date of the minimum AWRI. But detecting the ending date of the rainy season is not simple. If the ending date of the rainy season is considered as the peak date of the AWRI as in Fig. 2b, some days cannot be included into the rainy season, in spite of some rain. To be included or not is dependent on the weighting function of Equation (1). Although it needs further research for the best weighting function, it is allowable because all of the rainy days need not be included in the rainy season, if it has only a little.

This definition is adaptable also in the hydrological summer monsoon. Conceptually, the summer monsoon is the period of wind with thermally induced circulation, in other words,

the period of warm moist airflow from ocean to continent. But rain is not always by the warm moist airflow. And the last part of the rainy season in Fig. 2b might be caused by cold airflow. During the period of warm moist airflow, the daily precipitation may or may not increase but the AWRI generally increases due to successive supply of moisture. On the contrary, during the period of cold airflow, even if there is successive rain, rainfall amount may decrease and it can be reflected as the decrease of the AWRI. This study defines that the date of the biggest AWRI denotes the end of the rainy season. Although the date of the maximum AWRI varies along the accumulating duration (D in equation (1)), this solution is allowable because the difference along D is so small as seen at Fig. 2b. Although the date can be changed by one significant rain shower, and it can make some problems in a specific station of specific year, it is allowable with a little subjective consideration, because a rain shower is a part of climate as shown in Figs. 3 and 4.

2.4 Defining the intensity

Besides the absolute value of AWRI, the Flood Index (hereafter FI) is proposed to measure the local characteristics of the hydrological summer monsoon (or rainy season) intensity. It is the standardized value of W compared with the averaged year maximum of it.

$$V = W - A \max(W), \quad (3)$$

$$FI = V / \text{St}(V), \quad (4)$$

where $A \max(W)$ denotes averaged value of the year maximum of W . And $\text{St}(V)$ denotes standard deviation of V . D in (1) and (2) is 365 in this study. The AWRI shows simple concentration of water resources, but FI takes into account the climatic characteristics of the water concentration in local station. This differs from Drought Index (hereafter DI) by Byun and Wilhite (1999). That is

$$DI = (W' - \text{Mean}(W')) / \text{St}(W' - \text{Mean}(W')), \quad (5)$$

where w' is same as w except that D is decided on a case-by-case basis. $\text{Mean}(W')$ is the value of W' averaged through the same date of each year with the various accumulation duration. Also $\text{St}(W' - \text{Mean}(W'))$ is also calculated with various D each date.

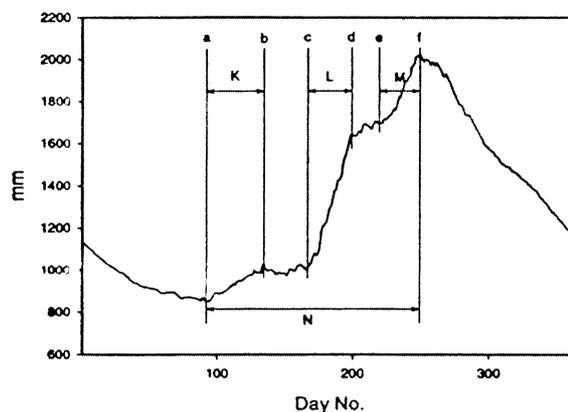


Fig. 3. The AWRI curve averaged for 24 years (1974–1997) of 64 stations in Korea. Day number means the serial day counted from January 1. K is Bom-Changma, L is Changma, M is Kaul-Changma, and N is the hydrological summer monsoon. Points a , b , c , d , e , and f denote the starts and ends of each rainy season.

3. Examples of the defining

3.1 Climatological defining the dates on whole Korea

Fig. 3 is the AWRI curve averaged per date through 25 years (1974–1997), and 64 main stations over Korea. The period K , that is from the minimum AWRI (point a) to the one of the largest (point b), is the Bom-Changma. This season has not been well known yet, but a few studies have been accumulated already. Byun and Han (1994), and Byun et al. (1992c), suggested the existence of this season, and analyzed the atmospheric circulation of this season. Though rainy season was not mentioned, Matsumoto (1992) recognized some abrupt changes in atmospheric circulations in this season. In China, Hsu and Kao (1962) mentioned that the rainfall increase over Central China in early March. Bao (1987) also mentioned its occurrence in March and April between the middle and lower reaches of the Yangtze River, and the Nanling mountains. And recently, Tian and Yasunari (1998) defined that the season of the spring persistent rain (SPR) over central China is from 25 Feb to 10 May. The period between point b and c is “the dry period before the Changma” named by

Byun et al. (1992a, b), but this is not found in other publications.

Period L is the period of rapid increase of the AWRI that is commonly called as Changma. Point c is just the start of the period L. Point d is the last of it. The period M is the Kaul-Changma, meaning autumnal rainy season, as mentioned by Lee (1975, 1976), Kwon et al. (1998). It is similar to Shurin in Japan mentioned by Murakami et al. (1962), Murakami and Sumi (1982), and Yoshino and Kai (1977). Point e is the start of period M (another rapid increase of AWRI), and point f is the maximum. The dates of each point are very similar, but not always same with the climatic seasons categorized by Lee (1975, 1976), Moon and Um (1980), Tanaka (1992), and Byun et al. (1992a, b).

This is the time when the definition of summer monsoon should be considered again. Tanaka (1992), Kurashima (1959), KMA (1995), and many others think that the summer monsoon is the same as the summer rainy season (period L) that ends at mid July. Besides, many other meteorologists consider that 'monsoon' is strictly defined by the method of synoptic meteorological situation, such as polar front etc. that causes the summer rainy period.

But Matsumoto (1995), Bao (1987), Kawamura (1977), and Kurashima (1968) differentiate summer monsoon (or summer wet season) clearly from the summer rainy period as mentioned in the introduction. These big conceptual differences are due to the differences of main concepts on summer monsoon as shown in Table 1.

This study does not want to decide which is correct, but we want to propose another concept of the summer monsoon that is along the AWRI value, and mean meridional wind. At first, differentiation of the summer monsoon from the summer rainy season is needed. Though monsoon means wind, the other names of monsoon in East Asia were made neither with any knowledge on wind reversal, nor the increased convection. They are named only with the empirical sense on the increased precipitation long ago, when the wind reversal in a year was not known to the general public. Then they should be considered not as the name of the monsoon, but as the name of the summer rainy season.

Therefore, for another definition of summer

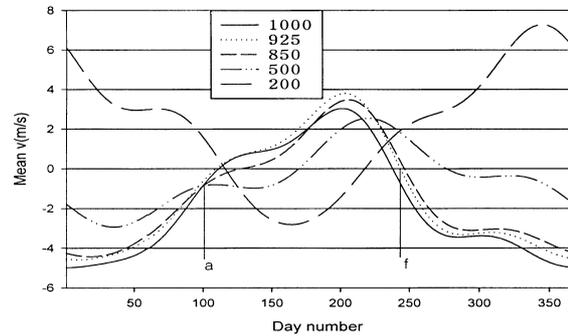


Fig. 4. Daily mean meridional wind (1970–2000) over Korea (32.5–40°N, 125–130°E). a and f are the same points in Fig. 3.

monsoon, long time averaged meridional winds over Korea (32.5–40.0°N, 125–130°E, with 2.5 grid) per level were shown in Fig. 4. From the onset date of Bom-Changma, low level (850, 1000 hPa) southerly (northerly) winds become stronger (weaker) than middle level (500, hPa) southerly (northerly), which denotes hydrostatic unstable layer in regular south-north temperature gradient. Near the end of Kaul-Changma, low level winds changes to northerly. These two changes of wind coincide well with the changes of the hydrological seasons discussed above. Therefore, this study proposes to define the period N as the hydrological summer monsoon, which is different from the Changma L. This new definition is easy to understand as figured by N in Fig. 3, and nearly in similar concept with Bao (1987), Kuwamura (1968), Kurashima (1977), and Matsumoto (1995). Also it is useful because the general public, and all ecosystems, are more sensitive to water than to wind or others. Therefore, climatological defining the onset and ending dates of the periods K, L, M, and N are successful. The notation of points a, b, c... and periods K, L... are used through the remaining part of this study with notes.

3.2 Climatological defining the dates per station in Korea

Figure 5 is the daily averaged AWRI and precipitation averaged per date through 45 years (1955–1999) of Seoul station in Korea. It is shown that big fluctuations of daily precipitation make it impossible to define the seasons.

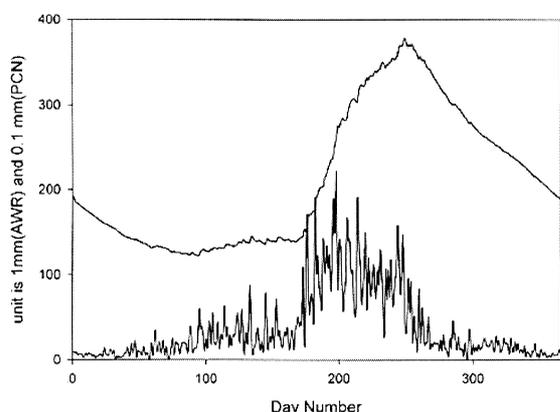


Fig. 5. Mean precipitation (unit is 0.1 mm) and mean AWRI (smooth curve, unit is 1 mm) per date (calendar day) through 45 years in Seoul station.

But when it is changed into relatively simple curve of AWRI, it is easy to detect the minimum (122 mm at 94 day, that is April 4), the smallest (138 mm at 167 day, that is June 16), and the maximum value (371 mm at 255 day, that is September 13) of the AWRI in spite of the big daily fluctuation of rainfall. And summertime concentration of precipitation that denotes the Changma results as the rapid increasing of the AWRI from some day after the smallest AWRI day (June 16).

Figure 6 shows the distribution of these rainy season dates. All of these dates are extracted from each station's averaged AWRI curves like Fig. 5. Bom-Changma (Fig. 6a) starts April 2–6 in most stations, except eastern coast where Bom-Changma does not appear. This is about one month later than Chinese SPR (Tian and Yasunari 1998). No other studies in Korea to be compared with this climatic date are found because they are rarely focused on this season, and have defined neither. All of the ending dates of Bom-Changma (not shown) are May 15, or one day before or after, that is coincided well with the start of the dry period before Changma nominated by Byun et al. (1992a, b). Bom-Changma is between the end of winter drought (18 March), and the start of the spring drought (23 May) that were defined by Byun and Han (1994).

Figure 6b shows that Changma starts from the south. These dates are almost similar to

those by KMA (1995) that are defined by subjective consideration and recorded without any reliable discussions, but more precise because dates per station can be pinpointed. Matsumoto (1995) and Tanaka (1992) have considered the onset of summer rainy season as the onset of summer monsoon. And they show similar but rough results, on the onset date of summer monsoon, because they use not daily-unit but pentad-unit data. Tanaka (1992) shows the biggest (more than 20 days) meridional difference of the onset date between southern coast and central Korea. Matsumoto (1995) shows 15 days difference, but Fig. 6b shows about 10 days difference, and KMA (1995) shows roughly 5 days difference. Only Fig. 6b is from daily station data, and others are from pentad or other data.

The end of Changma (Fig. 6c) and the onset of Kaul-Changma (Fig. 6d) are not apparent at the northern part of Korea (not dotted stations), as Lee (1975, 1976) mentioned. But in southern Korea, Changma ends from the south. KMA (1995) have defined that the ending date of Changma is two or three days earlier than Fig. 6c. Kaul-Changma ends from the north. Kawamura (1977) defined that the Kaul-Changma is from 46 till 50 pentad (Aug. 13–Sep. 7) that is very similar to Figs. 6d and 6e. Moon and Um (1980), and Lee (1975, 1976), mentioned the Kaul-Changma but not defined by the dates. Kaul-Changma, and summer monsoon, end together as in Fig. 6e.

3.3 Defining the dates and intensities per year and per station

Climatic seasonal definition over an area or on a station is explained above. Definitions of the dates of the specific year, and specific station are also examined. Figure 7a shows daily precipitation of 1997 at Seoul station. The maximum daily precipitation occurred on the 182nd day (Jul. 1), with 128.0 mm. It is more difficult to detect the onset, the end, and the peak of the summer monsoon than in Fig. 5, due to its big daily fluctuations. But with the help of Figs. 3 and 7b, the trends of hydrological situation change can be detected. Generally, detecting the starting and the ending date of rapid increase of the AWRI is easier at Fig. 7b than at Figs. 3 or 5, but deciding the minimum and maximum dates of the AWRI from Fig. 7b

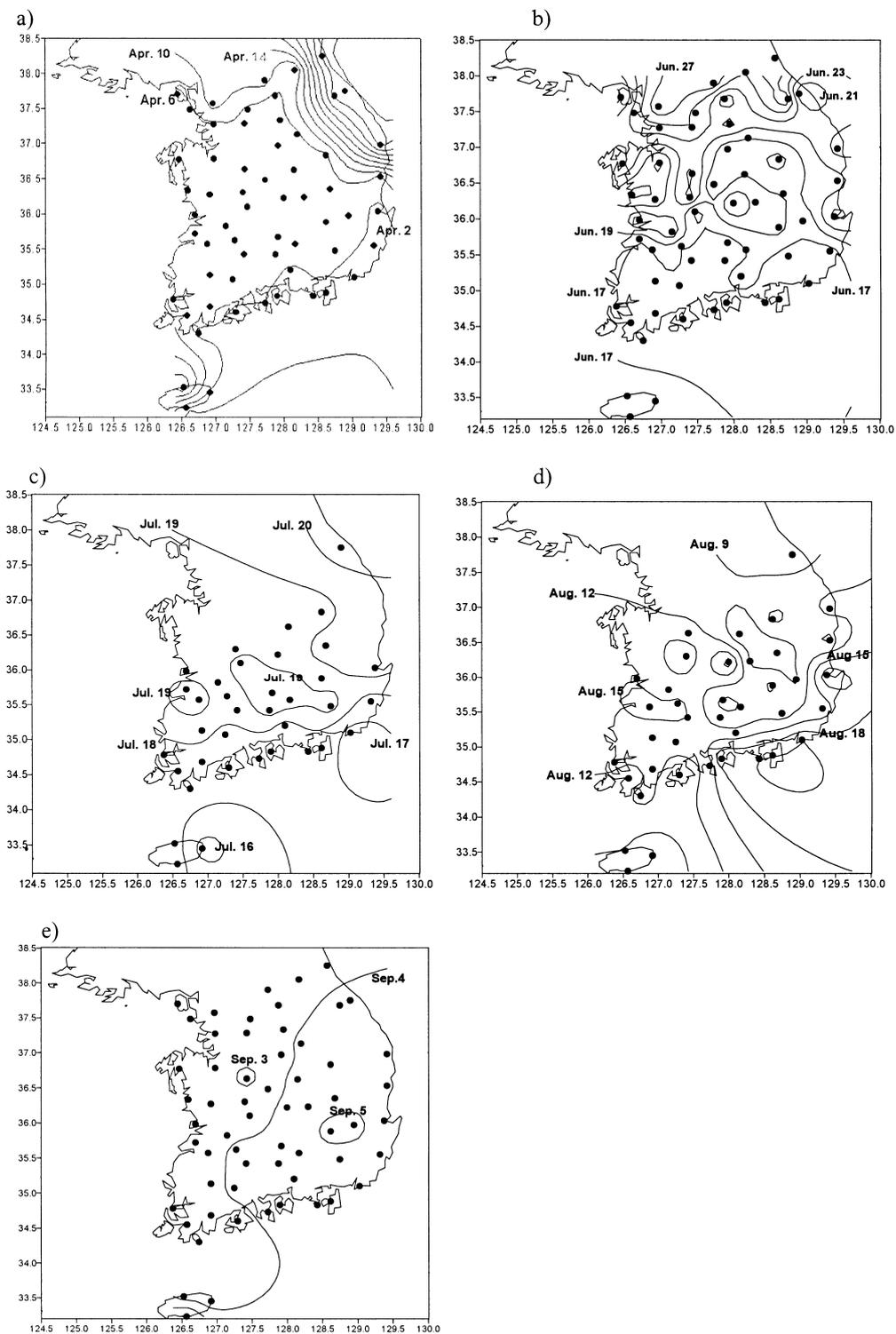


Fig. 6. Distribution of the (a) onset dates of Bom-Changma, (b) Onset dates of Changma, (c) ending dates of Changma, and (d) Onset dates of Kaul-Changma, and (e) ending dates of Kaul-Changma. Every dot means the locations of stations included in the figure. Ending dates of Bom-Changma is all May 15.

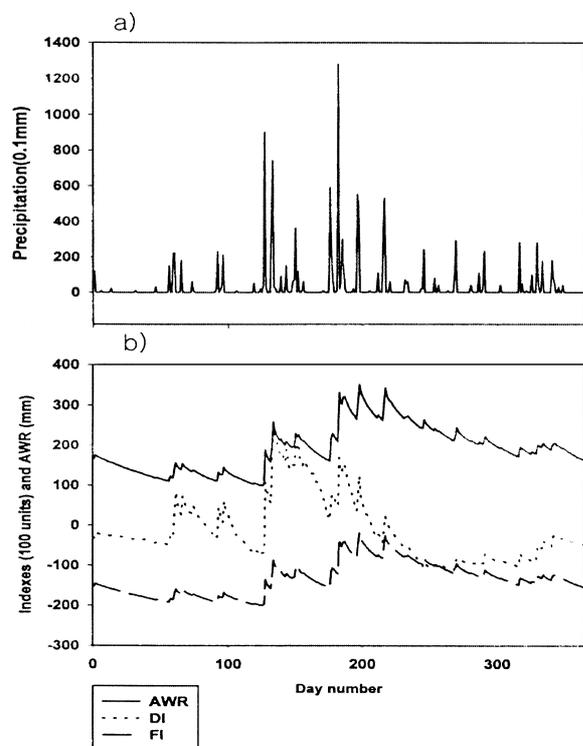


Fig. 7. Daily variation of (a) precipitation, (b) AWRI, Flood Index (*FI*), and Drought Index (*DI*) at 1997 in Seoul.

needs some subjective consideration with the help of Figs. 3 and 5.

As an example, the minimum of the AWRI is on the 126th day (May 4) with 99 mm of the AWRI. The other smallest value of the AWRI is on the 56th day (Feb. 25, 111 mm), or on the 91st day (Apr. 1, 110 mm). April 1 coincides with the climatological trends that appear by Figs. 3 and 6 as the onset of the hydrological summer monsoon. The maximum of the AWRI (351 mm) in Fig. 7b is on 198th day (Jul. 16). Another biggest one is on the 217th day (Aug. 5, 324 mm). The comparison with Figs. 3 and 5, the end of summer monsoon this year, is determined as August 5.

And the intensity of it can be defined by three indexes. The maximum AWRI is needed when compared to other year's intensity. Flood index that is the maximum of -0.19 at 198 day (Jul. 16) means that monsoon activity was very weak, and there were no dangers of flood this year (Because it is a standardized value). The large value of *DI* (2.22) at the same day denotes

abnormal affluence of water conditions this season and that the onset of the summer monsoon this year was earlier than normal. As a result, Fig. 7b offers a much easier detection of the dates than Fig. 7a, although it needs some subjective consideration.

4. Summary and conclusion

A new hydrological scheme that can define the rainy seasons, and summer monsoon using the AWRI was proposed and examined. In the scheme, the Available Water Resources Index (AWRI), that is the accumulated precipitation value in which daily reduction (by runoff, evapotranspiration, infiltration etc.) of water, and the duration of accumulation, are taken into account quantitatively was used.

Using this scheme, the existence of three rainy seasons in Korea were found and the onset and ending dates, and intensities of them, were defined for each year and each station, and also climatologically.

Climatologically, Bom-Changma (spring rainy season) starts at early April and ends near May 15. Changma (summer rainy period) starts in late June and ends the middle of July. Kaul-Changma starts in mid August and ends near September 4. A new concept of the hydrological summer monsoon was proposed and defined as the period from the minimum to the maximum of the AWRI that contains all of three rainy seasons. These new definitions can be the basics for further progress on climate researches because it can present clearer and more precise boundary values with digitized data on rain related climates.

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