Statistical Review of Annual Precipitation at Seoul in 1778-2015

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Statistical Review of Annual Precipitation at Seoul in 1778-2015

C/O/N/T/E/N/T/S

1 OBJECTIVE

2 HISTORICAL RECORDS

3 DATASET

4 STATISTICAL ANALYSIS

5 DISCUSSION
1 Dataset Understanding
   - review two or three recorded Chukwookee (1778-1907) and modern (1908-2015) rain data of view point of historically and scientifically

2 Statistical Features
   - check monthly and annual data using exploratory data analysis and graphics
   - check statistical test among specific samplings for similarity and consistency

3 Variability and Trend
   - investigate long-term period of annual precipitation
   - evaluate the climate variation and apply socio-economic impacts in Seoul
Chukwookiee and Observing Network

- King Sejong invented Chukwookiee (Korean rain-gauge) which is standardized as cylinder type rain-gauge in May.

- Commanded daily measurements through organized observation networks in September of 1441.

- Rain records of Royal Secrecariat (Seungjeongwon Ilgi) in 1770-1894 and Record of Daily Reflections (Ilseongnok) in 1785-1910.

- Unfortunately, rain measurement temporally quitted up on the invasion and restarted in 1770. With this reason precipitation recording data using Korean rain-gauge remains only between 1770-1907.
# HISTORICAL RECORDS

## Documents with Daily Weather Description

<table>
<thead>
<tr>
<th>Document</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Joseon Wangjo Sillok</strong> [1392-1863]</td>
<td>Joseon Dynasty Royal documents includes 28 Kings chronological daily records, 1,893 books (Korea National Treasure 151, UNESCO in 1997)</td>
</tr>
<tr>
<td><strong>Seungjeonwon Ilgi</strong> [1623-1907]</td>
<td>The daily records written by royal secretariat of Joseon Dynasty, 3,243 books (Korea National Treasure 303, UNESCO in 2001)</td>
</tr>
<tr>
<td><strong>Ilseongnok</strong> [1752-1910]</td>
<td>The daily reflections from secretariats in Palace, 2,329 books (Korea National Treasure 153, UNESCO in 2011)</td>
</tr>
<tr>
<td><strong>Goongnaebu Ilgi</strong> [1894-1885]</td>
<td>A part of Seungjeonwon Ilgi, 5 books</td>
</tr>
</tbody>
</table>
It rained. A daily rain depth of Chukwookee was recorded to 1 Chuck, 1 Chon and 5 Poon.

$\rightarrow 200\text{mm} + 20\text{mm} + 5 \times 2\text{mm} = 230\text{mm}$

**Bamboo scale**

- 1 Chuck ($\text{尺}$) $\approx 200\text{mm}$
- 1 Chon ($\text{寸}$) $\approx 20\text{mm}$ (1 Chuck ($\text{尺}$) / 10)
- 1 Poon ($\text{分}$) $\approx 2\text{mm}$ (1 Chon ($\text{寸}$) / 10)

Website: [http://www.history.go.kr](http://www.history.go.kr)
East Palace Screen (East of main Palaces [Chang Deok Gung Palace and Chang Gyeong Gung Palace], size of the screen is 567 cm × 273 cm, composed 16 pieces folding screen. It was painted by anonymous palace artists in 1824. Korean Government declared National Treasure No. 249 in 1989)
Royal Meteorological Office in Chang Gyeong Gung Palace

**Wind flagpole** observed 24-directional wind direction and speed (invented in 1770). Korean Treasure No 846.

**Sun-Dial** observed time measurement (invented in 1434).

**Celestial globe** made from copper, observed celestial movement (invented in 1437). This one is portable type.

**Rain-gauge** is to observed rain amount in nationwide (invented in 1441).
Wada’s Version (1917)
- Constructed rain-gauge data (1770-1907) from Seungjungwon Ilgi and Ilseungnok
- Calendar system: solar (Gregorian) calendar instead of Lunar calendar
- Arakawa (1956) introduced the monthly dataset of Chukwookooe

Hahn’s Version (1996)
- Reanalyzed old Korean Official Document and Wada’s version in 1996
- Compiled Chukwookooe data in eight provinces of Joseon Dynasty in 18 Century
- Calendar system: solar (Gregorian) calendar instead of Lunar calendar

Jhun’s Version (1997)
- Recompiled Chukwookooe dataset from Seungjungwon Ilgi and Ilseungnok
- Data Base: Converting solar calendar to luni-solar calendar and set up by daily unit

KAMC (Korean Academy of Meteorology and Climate, 2010)
- Daily precipitation data edited by the local government report of (1892-1907)
- Restoring continuous Chukwookooe data for Gaksadeungnok
- Statistical data
  - $Month = \sum \text{Daily Rainfall}$
  - $Year = \sum_{i=1}^{n=12} \text{Month}$

- Dataset
  - Period-I: Chukwookee (1770-1905)
  - Period-II: Modern rain-gauge (1908-2015)

- Monthly data Missing Rate

Table 1-1. Precipitation missing data and its percentage in Period-I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing number</td>
<td>84</td>
<td>74</td>
<td>16</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>39</td>
</tr>
<tr>
<td>Available (%)</td>
<td>35.9</td>
<td>43.5</td>
<td>87.8</td>
<td>100.0</td>
<td>99.2</td>
<td>98.5</td>
<td>99.2</td>
<td>99.2</td>
<td>97.7</td>
<td>95.4</td>
<td>92.4</td>
<td>70.2</td>
</tr>
</tbody>
</table>

※ Winter: liquid water of snow is not recorded
※ First Sino-Japanese War (1894)

Table 1-2. Precipitation missing data and its percentage in Period-II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

※ Missing number: Korean War
Old Korean Chukwoonoe (rain-gauge) data

- Guideline to Qualifying Data
  - WMO-No.100 regulation: collected ratio over 80% is available

- Guideline to Detecting Outliers
  - By exploratory data analysis (e.g., plotting boxplot)

  \[
  \text{Chk- I} \quad \begin{cases} < Q_1 - 1.5(Q_3-Q_1) \\ > Q_3 + 1.5(Q_3-Q_1) \end{cases} \quad \text{Chk- III} \quad < \mu - 2\sigma \\
  \text{Chk- IV} \quad > \mu + 2\sigma 
  \]

  ※ to check extremely minimum and maximum values

Modern Rain-gauge Data

- WMO-No. 100 regulation for data management
- Quality Control: range checks, temporal checks, internal consistency check etc.
- ISO 9001 guideline for data quality management
### Descriptive Statistics and Checking Outliers

#### Table 2-1. Summary of Summer precipitation statistic data and Outlier limit at Seoul

<table>
<thead>
<tr>
<th>Month</th>
<th>Min</th>
<th>$Q_1$</th>
<th>Median</th>
<th>Mean</th>
<th>$Q_3$</th>
<th>MAX</th>
<th>SD(σ)</th>
<th>Chk- I</th>
<th>Chk- II</th>
<th>Chk- III</th>
<th>Chk- IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period-I (Chukwookee)</td>
<td>156.0</td>
<td>508.0</td>
<td>660.0</td>
<td>741.4</td>
<td>879.5</td>
<td>2018.0</td>
<td>335.48</td>
<td>-49.25</td>
<td>1436.7</td>
<td>70.4</td>
<td>1412.36</td>
</tr>
<tr>
<td>Period-II (Rain gauge)</td>
<td>246.0</td>
<td>574.5</td>
<td>774.0</td>
<td>807.2</td>
<td>972.5</td>
<td>1784.0</td>
<td>292.97</td>
<td>-22.5</td>
<td>1569.5</td>
<td>221.26</td>
<td>1393.14</td>
</tr>
<tr>
<td>Period I+II</td>
<td>156.0</td>
<td>536.0</td>
<td>724.0</td>
<td>771.0</td>
<td>947.0</td>
<td>2018.0</td>
<td>318.03</td>
<td>-80.5</td>
<td>1563.5</td>
<td>134.94</td>
<td>1407.06</td>
</tr>
</tbody>
</table>

#### Table 2-2. Summary of annual precipitation statistic data and Outlier limit at Seoul

<table>
<thead>
<tr>
<th>Year</th>
<th>Min</th>
<th>$Q_1$</th>
<th>Median</th>
<th>Mean</th>
<th>$Q_3$</th>
<th>MAX</th>
<th>SD(σ)</th>
<th>Chk- I</th>
<th>Chk- II</th>
<th>Chk- III</th>
<th>Chk- IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period-I (Chukwookee)</td>
<td>374.0</td>
<td>882.0</td>
<td>1097.0</td>
<td>1150.0</td>
<td>1359.0</td>
<td>2566.0</td>
<td>393.5</td>
<td>166.5</td>
<td>2074.5</td>
<td>363.0</td>
<td>1937.0</td>
</tr>
<tr>
<td>Period-II (Rain gauge)</td>
<td>48.3</td>
<td>1085.0</td>
<td>1254.0</td>
<td>1320.0</td>
<td>1547.0</td>
<td>2355.0</td>
<td>370.4</td>
<td>392.0</td>
<td>2240.0</td>
<td>579.2</td>
<td>2060.8</td>
</tr>
<tr>
<td>Period I+II</td>
<td>48.3</td>
<td>963.0</td>
<td>1190.0</td>
<td>1228.0</td>
<td>1452.0</td>
<td>2566.0</td>
<td>391.7</td>
<td>229.5</td>
<td>2185.5</td>
<td>444.6</td>
<td>2011.4</td>
</tr>
</tbody>
</table>

1. Chk- I $< Q_1 - 1.5(Q_3 - Q_1)$  
2. Chk- II $> Q_3 + 1.5(Q_3 - Q_1)$  
3. Chk- III $< \mu - 2\sigma$  
4. Chk- IV $> \mu + 2\sigma$
Normalization

Z-scores and analysis

\[ \mu = \frac{\sum_{i=1}^{n} X_i}{N} \]

\[ \sigma = \sqrt{\sum_{i=1}^{n} (x_i - \mu)^2} \]

\[ Z = \frac{X - \mu}{\sigma} \]

- \( Z \): Z-score
- \( \mu \): Mean
- \( \sigma \): Standard deviation
- \( X \): Data set

Dataset

- Period I (1708-1907, Chukwookee )
- Period II (1908-2015, modern rain-gauge)
- Period III (1708-2015, Chukwookee + modern rain-gauge)
- Climate Normals (1981-2010)

Analysis

- Probability density function
- Box plot distribution
Monthly precipitation is illustrated to Poisson distribution.
Distribution of monthly precipitation

January

February

March

April

May

June

July

August

September

October

November

December

Rain amount (mm/Mon)
STATISTICAL ANALYSIS

ANALYSIS (histograms, Q-Q Plot, CDF)
**Hypothesis Testing**

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0 : \mu_{Hahn} = \mu_{Jhun}$</td>
<td>$\alpha = 0.05$</td>
</tr>
<tr>
<td>$H_a : \mu_{Hahn} \neq \mu_{Jhun}$</td>
<td>if p-value &lt; $\alpha$ (0.05) then $H_0$ = reject</td>
</tr>
</tbody>
</table>

$H_0 : \mu_{\text{Period-I}} = \mu_{\text{Period-II}}$

$H_a : \mu_{\text{Period-I}} \neq \mu_{\text{Period-II}}$

- **Test statistics**

$$t^* = \frac{\bar{X}_{\text{Period-I}} - \bar{X}_{\text{Period-II}}}{\sigma(\bar{X}_{\text{Period-I}} - \bar{X}_{\text{Period-II}})} = \frac{\bar{X}_{\text{Period-I}} - \bar{X}_{\text{Period-II}}}{\sqrt{\left(\frac{S^2_{\text{Period-I}}}{n_{\text{Period-I}}} + \frac{S^2_{\text{Period-II}}}{n_{\text{Period-II}}}\right)}}$$

- $\mu$: mean
- $\sigma$: standard deviation
- $\bar{X}_{\text{Period-I}}$: mean of Chukwookee precipitation (1778 - 1907), Seoul
- $\bar{X}_{\text{Period-II}}$: mean of modern precipitation (1908 - 2015), Seoul station
### Statistical Procedure

1. **Quality Assurance**
   - Hahn’s Data set (1778-1907)
   - Jhun’s Data set (1778-1907)
   - Chukwookee Data (1778-1907)
   - Modern Data (1908-2015)

2. **Quality Assurance**
   - (> 80% in recorded)

3. **var.test using R package**
   - F-test
   - Welch Two sample t-test
   - Two sample t-test

4. **p-value > 0.05**
   - Yes
   - No

5. **H₀:**
   - Reject
   - Can not reject

6. **Chukwookee Periods**
7. **Modern Observation Periods**
8. **Power Spectrum Analysis**
### Hypothesis Testing

**Table 3-1. t-test results between Hahn and Jhun dataset at Seoul**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Winter (DJF)</th>
<th>Spring (MAM)</th>
<th>Summer (JJA)</th>
<th>Fall (SON)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-statistic</td>
<td>7.020</td>
<td>3.4015</td>
<td>1.1449</td>
<td>-0.14113</td>
</tr>
<tr>
<td>Degree of freedom</td>
<td>243.89</td>
<td>257.96</td>
<td>257.53</td>
<td>255.95</td>
</tr>
<tr>
<td>P-value</td>
<td>2.187e-11</td>
<td>0.000776</td>
<td>0.2575</td>
<td>0.8879</td>
</tr>
</tbody>
</table>

**Table 3-2. t-test results between Period-I and Period-II dataset at Seoul**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Winter (DJF)</th>
<th>Spring (MAM)</th>
<th>Summer (JJA)</th>
<th>Fall (SON)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-statistic</td>
<td>8.4702</td>
<td>2.9417</td>
<td>1.611</td>
<td>2.407</td>
</tr>
<tr>
<td>Degree of freedom</td>
<td>214.58</td>
<td>229.35</td>
<td>234.16</td>
<td>226.890</td>
</tr>
<tr>
<td>P-value</td>
<td>3.894e-15</td>
<td>0.0035</td>
<td>0.1085</td>
<td>0.016</td>
</tr>
</tbody>
</table>

※ Sampling of summer show large p-value, statistically the two samples are similar
Monthly Mean Precipitation Amount at Seoul

- Period I: 1778–1907
- Period II: 1908–2015
- Period I+II: 1778–2015

Rain Amount (mm) vs. Month
Statistical Review of Annual Precipitation at Seoul in 1778-2015

Normalization of Precipitation (August, 1778–2015)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Min</th>
<th>Q1</th>
<th>Median</th>
<th>Mean</th>
<th>Q3</th>
<th>Max</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate normal (1981-2010)</td>
<td>68.2</td>
<td>194.4</td>
<td>284.2</td>
<td>364.2</td>
<td>501.1</td>
<td>1238.0</td>
<td>257.4</td>
</tr>
<tr>
<td>Period - II (1908-2015)</td>
<td>13.4</td>
<td>159.3</td>
<td>243.3</td>
<td>283.4</td>
<td>336.7</td>
<td>1238.0</td>
<td>195.4</td>
</tr>
<tr>
<td>Period - I (1778-1907)</td>
<td>26.0</td>
<td>147.3</td>
<td>238.0</td>
<td>265.2</td>
<td>336.6</td>
<td>982.0</td>
<td>171.6</td>
</tr>
</tbody>
</table>
Annual Precipitation Amount for 1778-2015
Annual Precipitation Amount for 1778-2015

- 23 -
### Extremely Maximum and Minimum Annual Rainfall in Top 10 for 1778-2015

<table>
<thead>
<tr>
<th>Rank</th>
<th>Above Mean + 2*Sigma (&gt;= 2011.4 mm)</th>
<th>Below Mean - 2*Sigma (&lt;= 461.8 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2,566.0 (1821) : flooded houses(5,805), drowned person(251)</td>
<td>48.3 (1951, Korean War)</td>
</tr>
<tr>
<td>2nd</td>
<td>2,462.0 (1879) : flooded houses(2,351), farmland, Korea</td>
<td>374.0 (1901)</td>
</tr>
<tr>
<td>3rd</td>
<td>2355.5 (1990)</td>
<td>442.0 (1894, First Sino - Japanese War)</td>
</tr>
<tr>
<td>4th</td>
<td>2349.1 (1998)</td>
<td>446.0 (1900)</td>
</tr>
<tr>
<td>5th</td>
<td>2242.0 (1832) : flooded houses(10,837), drowned person(357)</td>
<td>594.0 (1887)</td>
</tr>
<tr>
<td>6th</td>
<td>2145.1 (1940)</td>
<td>608.0 (1904)</td>
</tr>
<tr>
<td>7th</td>
<td>2043.5 (2011)</td>
<td>623.5 (1949)</td>
</tr>
<tr>
<td>8th</td>
<td>2039.3 (2012)</td>
<td>630.0 (1780)</td>
</tr>
<tr>
<td>9th</td>
<td>2018.9 (1966)</td>
<td>638.7 (1939)</td>
</tr>
<tr>
<td>10th</td>
<td>2012.0 (2003)</td>
<td>640.0 (1906)</td>
</tr>
</tbody>
</table>

#### Classification of Extreme Rainfall Events

<table>
<thead>
<tr>
<th>Classification</th>
<th>Direct TC</th>
<th>Indirect TS, TD</th>
<th>Chang-ma front</th>
<th>Stationary front</th>
<th>Meso-cyclone</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>1</td>
<td></td>
<td>6</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>4</td>
<td></td>
<td>7</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>2</td>
<td>2</td>
<td>13</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9</strong></td>
<td><strong>4</strong></td>
<td><strong>13</strong></td>
<td><strong>2</strong></td>
<td><strong>15</strong></td>
<td></td>
</tr>
</tbody>
</table>
Surface Weather Chart (1940.07.23.00UTC-12UTC)
Power Spectrum Analysis of Annual Precipitation at Seoul for 1778-2015

5-year (red), 17-year (orange), 25-year (yellow), 41-year (green), 66-year (blue) and 87-year (purple) cycles
Power Spectrum Analysis of Summer (JJA) Precipitation of Seoul for 1778-2015

※ Using Mean and Median during Korean War (1951)

Periods are analyzed with 5-year, 17-year, 25-year, 41-year, 66-year and 87-year cycles
These set of periods are approximately similar with annual ones
Summary

- shown to annual and seasonal precipitation in near-normal distribution of, while monthly precipitation in poisson distribution.
- extracted long-term periods by annual base of rain in more than 230 years long ex) about 5-year, 17-year, 25-year, 41-year, 66-year and 87-year cycles
- analyzed extreme value cases associated with chang-ma, meso-cyclone, and tropical cyclone events
- investigated five events of top 10 cases (more than 2 sigma) and larger standard deviation value after 1980’s

Future Plan

- using proxy data (e.g., tree-ring data) for compensation of missing data treatments and previous (before 1770’s) data estimations
Rain Observing in Royal Meteorological Office in Joseon Dynasty
Statistical Review of Annual Precipitation at Seoul in 1778-2015

Thank You