Recent Drought and Drought Prediction System Development in Korea

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Background and Objective

- **Current drought occurrence in Korea (1980 – 2015)**
  - Minor or serious drought occurrence per 2-3 year cycle, but almost every year since 2008

  - Imbalance of water budget mainly due to rainfall deficiency and temperature increase
  - Lack of rainfalls from June to August during summer flooding season
  - Low impact of Jangma and Typhoon during rainy season
  - Impact of El Niño, La Niña phenomena in the worldwide

- **Objectives**
  - To introduce our 2014-2015 drought experience in Korea
  - To address our current efforts for drought monitoring and outlook system development
2014-2015 Drought in Korea

- Drought conditions

- SPI drought maps during April-November, 2015
Precipitation condition (Meteorological drought)

- Annual precipitation in 2015 is recorded only 72% (3rd lowest year) of normal year (1307.7mm)
  - Precipitation in May-September is 34-62% of normal year (982.4mm)
  - Almost all regions has lower precipitation except for southern coast region, especially less than 60% in central regions

### Monthly Precipitation

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Precipitation (mm)</td>
<td>25.1</td>
<td>25.5</td>
<td>40.5</td>
<td>126.0</td>
<td>56.5</td>
<td>95.5</td>
<td>180.3</td>
<td>111.2</td>
<td>55.1</td>
<td>64.3</td>
<td>127.8</td>
<td>40.2</td>
<td>948.2</td>
</tr>
<tr>
<td>Normal Average Ratio(%)</td>
<td>89</td>
<td>73</td>
<td>69</td>
<td>153</td>
<td>51</td>
<td>62</td>
<td>62</td>
<td>42</td>
<td>34</td>
<td>134</td>
<td>267</td>
<td>169</td>
<td>72</td>
</tr>
</tbody>
</table>

### Regional Precipitation

<table>
<thead>
<tr>
<th></th>
<th>Gyeonggi</th>
<th>Gangwon</th>
<th>Chungbuk</th>
<th>Chungnam</th>
<th>Jeonbuk</th>
<th>Jeonam</th>
<th>Gyeongbuk</th>
<th>Gyeongnam</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm) ('15.1~12.31)</td>
<td>709.8</td>
<td>887.4</td>
<td>801.3</td>
<td>809.3</td>
<td>908.5</td>
<td>1238.5</td>
<td>801.0</td>
<td>1235.5</td>
<td>948.2</td>
</tr>
<tr>
<td>Normal average ratio(%)</td>
<td>53</td>
<td>65</td>
<td>63</td>
<td>63</td>
<td>70</td>
<td>88</td>
<td>72</td>
<td>85</td>
<td>72</td>
</tr>
<tr>
<td>Normal average precipitation (mm)</td>
<td>1336.0</td>
<td>1362.3</td>
<td>1277.9</td>
<td>1280.5</td>
<td>1293.6</td>
<td>1401.5</td>
<td>1123.3</td>
<td>1460.6</td>
<td>1307.7</td>
</tr>
</tbody>
</table>

Source: 2015 abnormal climate report (Government Coordination Office, KMA)
**Agricultural reservoir condition (Agricultural drought)**

- Average reservoir storage ratio is 61.6% compared to 77.9% in normal year (‘15.12.31)

- Especially, Jeonbuk and Jeonam are recorded 50.3%, 57.5% respectively

Source: Agricultural Infrastructure Management(http://rims.ekr.or.kr/awminfo/report.aspx)
### Hydrological condition of multipurpose dam (Hydrological drought)

- 9 out of 18 multipurpose dams are caution, alert and serious condition ('15.12.31)

- Especially, reservoir storage ratio of Daechung and Boryeong dam are 79% and 48% to the dam capacity

<table>
<thead>
<tr>
<th></th>
<th>Han River(3)</th>
<th>Nakdong River(2)</th>
<th>Geum River(3)</th>
<th>Seomjin River(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage rate(%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(normal year ratio)</td>
<td>48.6 (90)</td>
<td>50.9 (99)</td>
<td>36.3 (72)</td>
<td>31.1 (56)</td>
</tr>
<tr>
<td></td>
<td>31.1 (56)</td>
<td>32.1 (80)</td>
<td>26.8 (47)</td>
<td>36.3 (72)</td>
</tr>
<tr>
<td></td>
<td>26.8 (47)</td>
<td>29.3 (48)</td>
<td>41.4 (79)</td>
<td>32.1 (80)</td>
</tr>
<tr>
<td></td>
<td>29.3 (48)</td>
<td>35.7 (71)</td>
<td>26.8 (47)</td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>caution</td>
<td>caution</td>
<td>caution</td>
<td>alert</td>
</tr>
<tr>
<td></td>
<td>caution</td>
<td>caution</td>
<td>caution</td>
<td>serious</td>
</tr>
<tr>
<td></td>
<td>caution</td>
<td>caution</td>
<td>caution</td>
<td>caution</td>
</tr>
</tbody>
</table>

#### Graphs

- **[Soyanggang Dam]**
  - Water Level
  - Daily Precipitation
  - Low-water Level
  - Water Level: 172.7m
  - Precipitation: 844.4mm

- **[Boryeong Dam]**
  - Water Level
  - Daily Precipitation
  - Low-water Level
  - Water Level: 59.9m
  - Precipitation: 1020.5mm
Drought causes & 2016 Drought Forecast

2015 Drought Causes
- Precipitation during flood season (May-September) is only 34-62% of normal year
- Water ratios of multipurpose and agricultural reservoir are decreased due to less precipitation

Failure to secure water storage in water facilities due to 2-year continuous less precipitation (2014, 2015)
- Precipitation in May-July of 2014 is one-third of normal year level, 4th lowest record since 1973

<table>
<thead>
<tr>
<th>River</th>
<th>Han</th>
<th>Nakdong</th>
<th>Geum</th>
<th>Seomjin</th>
<th>AVE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm)</td>
<td>78.3</td>
<td>111.5</td>
<td>69.6</td>
<td>108.2</td>
<td>90.8</td>
</tr>
<tr>
<td>Normal Average Ratio(%)</td>
<td>34.5</td>
<td>47.2</td>
<td>29.2</td>
<td>38.0</td>
<td>38.0</td>
</tr>
</tbody>
</table>

Drought prospect in Spring season, 2016
- Domestic, industrial and agricultural water use in 2016
  → Agricultural and Hydrological droughts are expected due to less reservoir water storage
Drought Management Status and Problems

Drought management Agencies

KMA (Korea Meteorological Administration)
- Provide various meteorological drought indices through KMA web site
- Information: Precipitation, Temperature, SPI, PDSI, PN

K-Water (Korea Water Resources Corporation)
- Estimate and provide various hydrological drought indices
- Information: Dam inflow, GW level, WADI, MSWSI

KRE (Korea Rural Community Corporation)
- Provide agriculture drought information on web
- Information: Reservoir storage ratio index, No-rainy day index, Normal ratio

MPSS (Ministry of Public Safety and Security)
- Establish the social security framework through the enhancement of institutional drought protection capacity
- Information: Socioeconomic Drought Index

Problems
- Insufficient understanding of drought task and different drought information between agencies
- Lack of drought prediction/outlook system compare to drought monitoring system
Core techniques in this system

- Drought Monitoring & Outlook
  - Coupled system of Atmosphere-Hydrology
  - Technology of land surface model in East-Asia
  - Assessment for hydrometeorological forecast information in East-Asia
  - Establishment of drought forecast/outlook information in East-Asia

- Field Operation
  - Establish hydro-meteorological and geographical information DB
  - Develop modules providing disaster information
  - Develop Web-based system providing real-time drought information

- Drought analysis techniques
  - Create long-term weather forecast information in high quality
  - Establish Mesoscale LSM
  - Coupled system development and accuracy enhancement

- Field Operation
  - Produce drought information in Korea & East Asia
  - Real-time Drought Early Warning System
  - Water balance analysis of LSM
  - Long-term Weather Forecast
Glosea5 (GS5) for generating monthly/seasonal weather prediction

Glosea5 hindcast Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>432 (Interval: 0.83°, 92.5km)</td>
</tr>
<tr>
<td>Latitude</td>
<td>325 (Interval: 0.55°, approx. 49.3km)</td>
</tr>
<tr>
<td>Lead time</td>
<td>240 days (1, 4, 7, 10 month), 220 days (others)</td>
</tr>
<tr>
<td>Data form</td>
<td>Daily</td>
</tr>
<tr>
<td>Variables</td>
<td>Temperature, Maximum temperature, Minimum temperature, Precipitation, U10m-wind, V10m-wind</td>
</tr>
<tr>
<td>Ensemble</td>
<td>Integrate 4 times/month (1, 9, 17, 25 day) (3 ensembles on each starting date)</td>
</tr>
</tbody>
</table>

Glosea5 forecast Information

<table>
<thead>
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<th>Description</th>
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<td>Longitude</td>
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<td>Latitude</td>
<td>325 (Interval: 0.55°, approx. 49.3km)</td>
</tr>
<tr>
<td>Lead time</td>
<td>230 days (1, 4, 7, 10 month), 220 days (others)</td>
</tr>
<tr>
<td>Data form</td>
<td>Daily</td>
</tr>
<tr>
<td>Variables</td>
<td>Temperature, Maximum temperature, Minimum temperature, Precipitation, U10m-wind, V10m-wind</td>
</tr>
<tr>
<td>Ensemble</td>
<td>Start model run everyday (2 ensembles on each day)</td>
</tr>
</tbody>
</table>
LSM Setup over Korea & East Asia Domain

- Land Surface Model (LSM)
  - Use hydrologic distributed model for simulating energy and water balance based on atmosphere-vegetation-soil interaction
  - Composed of water balance, channel Routing, energy balance modules
  - Widely used for analyzing atmosphere-surface interactions on various grid scale (12.5km)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Input Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin</td>
<td>DEM</td>
</tr>
<tr>
<td>Forcing</td>
<td>Precipitation, Maximum Temperature, Minimum Temperature, Wind Speed</td>
</tr>
<tr>
<td>Soil</td>
<td>Soil Properties</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Landuse</td>
</tr>
</tbody>
</table>
Local (Korea) & global data are used for LSM input data

- Meteorological data: Precipitation, Temperature, Wind speed
- Topographical data: DEM, Land coverage, Soil map
- Convert local (100) & global (1, 5km) resolution to LSM grid resolution (12.5km, 25km)
**LSM model calibration/verification in East Asia regions**

- 18 out of 34 basins are used for model verification under the assumption of ungauged basins
- Simulate flows at the selected basins after transferring the model parameters based on regionalization method
- Statistical results: CC(0.62-0.97), ME (0.30-0.95), VE(<35%)

<table>
<thead>
<tr>
<th>Basins</th>
<th>CC</th>
<th>ME</th>
<th>RMSE (mm/mon)</th>
<th>VE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea 0 Average (8 basins)</td>
<td>0.84</td>
<td>0.74</td>
<td>22.01</td>
<td>-1.97</td>
</tr>
<tr>
<td>Russia 1 Bolshaya Bira</td>
<td>0.84</td>
<td>0.60</td>
<td>22.50</td>
<td>24.40</td>
</tr>
<tr>
<td>China 4 Hongshui He</td>
<td>0.62</td>
<td>0.30</td>
<td>33.59</td>
<td>12.43</td>
</tr>
<tr>
<td>China 5 Laoguan He</td>
<td>0.97</td>
<td>0.95</td>
<td>9.09</td>
<td>1.37</td>
</tr>
<tr>
<td>China 7 Wu Jiang</td>
<td>0.92</td>
<td>0.79</td>
<td>30.24</td>
<td>-14.37</td>
</tr>
<tr>
<td>China 8 Gan Jiang</td>
<td>0.65</td>
<td>0.40</td>
<td>19.69</td>
<td>-14.27</td>
</tr>
<tr>
<td>China 10 Liao He</td>
<td>0.83</td>
<td>0.68</td>
<td>11.19</td>
<td>-19.31</td>
</tr>
<tr>
<td>North Korea 12 Sangwan</td>
<td>0.66</td>
<td>0.45</td>
<td>44.55</td>
<td>-23.04</td>
</tr>
<tr>
<td>Japan 16 Chikugo</td>
<td>0.94</td>
<td>0.7</td>
<td>66.96</td>
<td>-35.57</td>
</tr>
<tr>
<td>Japan 17 Oyodo</td>
<td>0.91</td>
<td>0.79</td>
<td>77.03</td>
<td>-19.35</td>
</tr>
<tr>
<td>Japan 18 Gono</td>
<td>0.91</td>
<td>0.75</td>
<td>40.7</td>
<td>-20.8</td>
</tr>
<tr>
<td>Japan 19 Yoshino</td>
<td>0.83</td>
<td>0.65</td>
<td>51.78</td>
<td>15.96</td>
</tr>
<tr>
<td>Japan 21 Yodo</td>
<td>0.86</td>
<td>0.68</td>
<td>26.11</td>
<td>6.42</td>
</tr>
<tr>
<td>Japan 22 Tenryu</td>
<td>0.89</td>
<td>0.64</td>
<td>40.92</td>
<td>-26.39</td>
</tr>
<tr>
<td>Japan 26 Tokachi</td>
<td>0.82</td>
<td>0.62</td>
<td>26.83</td>
<td>-15.62</td>
</tr>
<tr>
<td>Average</td>
<td>0.83</td>
<td>0.64</td>
<td>35.80</td>
<td>-9.15</td>
</tr>
</tbody>
</table>
Development of drought outlook information system

- Design drought monitoring and outlook system
  - Drought Monitoring
  - Drought Outlook

- Current Time

- Observation weather and Topographical data
  - DEM
  - Soil

- Calculation of Hydrologic analysis information
  - Land Surface Model
  - Runoff, Evapotranspiration, Soil moisture

- Production of Drought Monitoring
  - SPI, PDSI, SRI, SSI, DDI...

- Evaluation of Drought information

- Weather and hydrological outlook
  - KMA Long-term Weather model
  - Precipitation, Temperature, Average wind velocity
  - Runoff, Evapotranspiration, Soil moisture

- Production of Drought Outlook
  - SPI, PDSI, SRI, SSI, DDI...
## Applicability of drought indices in 2008 and 2009 (Regional analysis)

<table>
<thead>
<tr>
<th>Drought period</th>
<th>Drought region</th>
<th>Contents of evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008.09 ~ 2009.04</td>
<td>Gangwon-Do, Jeolla-Do, Gyeongsang-Do</td>
<td>SPI performance is insufficient denoting drought demise on Gangwon regions in March</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PDSI is missing the demise of the event in May 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SRI, SSI perform drought situation properly for both starting and ending of the drought event</td>
</tr>
</tbody>
</table>

### SPI(3), PDSI

### SRI(3), SSI(3)

### Drought regions

![Image of drought regions in South Korea with SPI(3), PDSI, SRI(3), SSI(3) maps]

- Gwangwon
- Chungnam
- Chungbuk
- Gyeongbuk
- Jeonnam
- Gyeongnam
- Jeonbuk
- ROC analysis for drought indices (SPI, SRI, SSI)

  - The indices are accurate in the order of SRI > SSI > SPI

<table>
<thead>
<tr>
<th>Verifying analysis</th>
<th>Drought Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought Event</td>
<td>Drought</td>
</tr>
<tr>
<td></td>
<td>Hit(H)</td>
</tr>
<tr>
<td></td>
<td>Missing(M)</td>
</tr>
<tr>
<td></td>
<td>False(F)</td>
</tr>
<tr>
<td></td>
<td>Negative hit(N)</td>
</tr>
</tbody>
</table>

Hit Rate = \( \frac{H}{H + F} \), \hspace{1cm} False Alarm Rate = \( \frac{M}{M + N} \)

- Evaluate the performance of SRI index over the East Asia domain
Bayesian method for enhancement of drought prediction accuracy

Real-time Generation System of Drought Forecast Information using Bayesian Method
Prior Distribution: $P(\theta_t)$

Assumed normal distribution: Gaussian distribution is estimated from the mean and variation of monthly precipitation

$\theta_t \sim N(\mu_{ot}, \sigma_{ot}^2)$

$\theta_t$: observed precipitation for test period

$\mu_{ot}$: mean precipitation for reference period

$\sigma_{ot}^2$: variance of precipitation for reference period

Likelihood Function: $P(x_t | \theta_t)$

Use linear regression to extract relationship between observed and predicted values

$\mu_{li} = \alpha + \beta \theta_i$

$V_i = \frac{1}{n-2} \sum_{t=1}^{n-1} (x_i - \alpha - \beta \theta_i)^2$

$\beta = \frac{n^{-1} \sum_{t=1}^{n-1} \theta_t x_i - \left( \sum_{t=1}^{n-1} \theta_t \right) \left( \sum_{t=1}^{n-1} x_i \right)}{n^{-1} \sum_{t=1}^{n-1} \theta_t^2 - \left( \sum_{t=1}^{n-1} \theta_t \right)^2}$

$\alpha = x - \beta \theta_i$

$x_t$: Simulated precipitation for test period

$\mu_{li}$: Regression estimated precipitation

$V_i$: Variance of regression estimated precipitation

$\alpha$: Intercept coefficient

$\beta$: Gradient coefficient

$n$: Data period

<Example of Likelihood function using linear regression>
Posterior Distribution: \( P(\theta_t \mid x_t) \)

Posterior Distribution is proportional to prior distribution \( x \) likelihood function with normal distribution

\[
P(\theta_t \mid x_t) \propto P(x_t \mid \theta_t)P(\theta_t)
\]

\[
P(\theta_t) = N(\mu_{ot}, \sigma_{ot}^2) = \frac{1}{(2\pi)^{1/2} \sigma_{ot}^2} \exp\left(-\frac{(\theta_t - \mu_{ot})^2}{2\sigma_{ot}^2}\right)
\]

\[
P(x_t \mid \theta_t) = N(\alpha + \beta \theta_t, V_t) = \frac{1}{(2\pi)^{1/2} V_t} \exp\left(-\frac{(x_t - \alpha - \beta \theta_t)^2}{2V_t}\right)
\]

Mean \((\mu_t)\) and variance\((\sigma_t)\) of posterior distribution

\[
\sigma_t^2 = \frac{\sigma_{ot}^2 \cdot \sigma_{lt}^2}{\sigma_{ot}^2 + \sigma_{lt}^2}, \quad \mu_t = \frac{\mu_{ot} \sigma_{lt}^2 + y_t \sigma_{ot}^2}{\sigma_{ot}^2 + \sigma_{lt}^2}
\]

\[
y_t = (x_t - \alpha) / \beta
\]

\[
\sigma_{lt}^2 = V_t / \beta^2
\]
Compare the drought outlook accuracy with/without Bayesian method
Display real-time drought monitoring & outlook information to KMA

Drought information on East Asia & Korea

Drought Monitoring

Drought Outlook
Conclusion and Remarks

- Introduce the 2014-2015 drought event and issued the problems for drought management in Korea
- Develop coupled atmosphere-land surface model for drought monitoring and outlook system over Korea and East Asia
- Suggest institutional cooperation techniques for better understanding and management of future drought disasters in Korea
Thank you