기상정보 활용 양상별 유량 및 가뭄 예측
- 국내 기술 진단 및 향후 연구 방향 -

서울대학교 건설환경공학부
기후변화 적응 수자원연구실
교수 김영오
잠시 77개월 전으로 시간 여행을 ...
Use of Seasonal Climate Forecasts for Water Resources Management in Korea: Limitation and Future

September 12th, 2012

Young-Oh Kim
Department of Civil & Environmental Eng.
Seoul National University
Korea
Problem Statements
Climate Forecasts in US

- Categorical (below normal, normal, above normal)
- with probabilities

Examples

<table>
<thead>
<tr>
<th>25%</th>
<th>50%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{33.3}$</td>
<td>*</td>
<td>$r_{66.7}$</td>
</tr>
</tbody>
</table>

VALID Apr 2002
0.5 MO LL MONTHLY
PCPN OTLK

LEGEND
A - EXCESS LIKELIHOOD (>33.3 %) OF ABOVE
B - EXCESS LIKELIHOOD (>33.3 %) OF BELOW
N - EXCESS LIKELIHOOD (>33.3 %) OF NORMAL
CL - USE CLIMATOLOGY, INSUFFICIENT SKILL A, B, N
EQUALLY (33.3 %) LIKELY

NOAA 1-month probabilistic precipitation outlook for April 2002

International Conference on Climate, Water and Policy 2012
Climate Forecasts in Korea

- Also categorical (below, near, above normal)
- with **verbal** expression (“Temperature this month would be near normal”)

**Examples**

**MIMI**
(Monthly Industrial Meteorology Information)

**GDAPS**
(Global Data Assimilation and Prediction System)
What We Need Are …

- **Meteorology**
  - To assess and improve the forecasting accuracy

- **Hydrology**
  - To come up with our own methodologies that can handle characteristics of the Korean climate forecasts
  - To assess the value of the climate forecasts for water resources management
Diagnosis of Climate Forecasts Accuracy
Study 1: Accuracy of Climate Forecast

- Citation

- Objectives
  - Investigate climate forecast information available for the Korean Peninsula
  - Measure the accuracy of climate forecasts

Abstract

Since the accuracy of climate forecast information has improved from better understanding of the climatic system, particularly, from the better understanding of ENSO and the improvement in meteorological models, the forecasted climate information is becoming the important clue for streamflow prediction. This study investigated the available climate forecast information to improve the extended streamflow prediction in Korea, such as MIMI (Monthly Industrial Meteorological Information) and GDAPS (Global Data Assimilation and Prediction) and measured their accuracies. Both MIMI and the 10-day forecast of GDAPS were superior to a naive forecasts and performed better for the flood season than for the dry season, then it was proved that such climate forecasts would be useful for improving the streamflow prediction in Korea.
MIMI (Monthly Industrial Meteorology Information)

- Provider: Korea Meteorological Agency (KMA)
- Variable: temperature and precipitation
- Lead time: monthly and 10-day
- Format: categorical forecast with verbal expression
  - **Below-normal**: below 0.7 times 30-year average
  - **Near-normal**: 0.7~1.2 times 30-year average
  - **Above-normal**: above 1.2 times 30-year average
- Spatial resolution: 6 major cities in Korea
Accuracy: MIMI

- Test period: Jan, 1991 ~ Dec, 2002
- Measures: hit number and hit ratio by season

<table>
<thead>
<tr>
<th></th>
<th>Lead-time</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>1-month</td>
<td>0.273</td>
<td>0.306</td>
<td>0.250</td>
<td>0.287</td>
<td>0.279</td>
</tr>
<tr>
<td></td>
<td>10-day</td>
<td>0.319</td>
<td>0.347</td>
<td>0.292</td>
<td>0.236</td>
<td>0.299</td>
</tr>
<tr>
<td>Temperature</td>
<td>1-month</td>
<td>0.389</td>
<td>0.419</td>
<td>0.338</td>
<td>0.328</td>
<td>0.369</td>
</tr>
<tr>
<td></td>
<td>10-day</td>
<td>0.378</td>
<td>0.379</td>
<td>0.455</td>
<td>0.500</td>
<td>0.428</td>
</tr>
</tbody>
</table>

- Monthly and 10-day precipitation forecasts: inferior to the naïve forecast
- Monthly and 10-day temperature forecasts: superior to the naïve forecast
**Conclusion**

**MIMI** is the climate forecast information that can be currently utilized for the hydrological forecasting in Korea.

- Temperature forecast is superior to the naïve forecast.
- Precipitation forecast is inferior to the naïve forecast, **BUT** superior to the naïve forecast in the flood season.
Development of Hydrological Forecasting Methodologies Using Climate Forecasts
ESP: Basic Concept

- ESP: Ensemble Streamflow Prediction

  - Historical Rainfall Scenarios
  - Rainfall-Runoff Model
  - Forecasted Streamflow Scenarios
  - Initial State (Soil Moisture)
  - Statistical Analysis

- Deterministic + Probabilistic approach
- Conditional Monte Carlo simulation approach
The first ESP Application in Korea

- **Korea Water Supply Outlook (KWSO)**
  - Using only three rainfall scenarios
  - Patterns of the three rainfall scenarios are same

- **Ensemble Streamflow Prediction**
  - The KWSO and ESP are similar in their modeling structure
  - ESP employs more scenarios and patterns than the KWSO
Study 2: EPS using MIMI

- **Citation**
  

- **Objective**
  
  Propose a methodology that can incorporate Korean climate forecast information into ESP
ESP using MIMI

✓ Basic Application

1966~2002 Historical Rainfall & Temperature Scenarios

Rainfall-Runoff Model (SSARR)

Streamflow Scenarios For this month

✓ All
✓ Union
✓ Intersection

Development of Hydrological Forecasting
Selection of Scenarios

✓ All: All the historical scenarios

✓ Intersection: Rainfall scenarios matching MIMI

✓ Union: Temperature scenarios matching MIIMI
Conclusion

When these methods were applied to Chungju Dam,

✓ The accuracies with all three methods are better than the naïve forecast,

✓ The Intersection and Union scenarios are superior to the All scenarios for the flood season,

✓ The Intersection and Union scenarios are superior to the All scenarios if the forecast accuracy is improved
Study 3: Scenario Weighting with Pdf-ratio

- **Citation**

- **Objective**
  - Update probabilities associated with meteorological and hydrologic series using forecast information

---

*Journal of Hydrology* 391 (2010) 9-23

Probabilities for ensemble forecasts reflecting climate information

Jery R. Stedinger a, Young-Oh Kim b,∗

a School of Civil and Environmental Engineering, Cornell University, Ithaca, NY, USA
b Department of Civil and Environmental Engineering, Seoul National University, Seoul, Republic of Korea

ARTICLE INFO

<table>
<thead>
<tr>
<th>Article History</th>
<th>SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received 12 August 2009</td>
<td>A simple but general probability adjustment procedure is proposed for creating climate-series/probability sets that reflect historical frequencies adjusted for climate forecast information. Often forecast information is given as the conditional probability of below-normal, normal, and above-normal temperature or rainfall depths, though forecast information also can be described by the conditional mean and standard deviation of key variables such as seasonal runoff. Probability adjustment methods developed by Croley and by Willems assign the same probability to all climate series in selected categories. This results in a discontinuity at the interval boundaries, and can seriously misrepresent the mean and variance of the conditional distribution of key variables. The proposed adjustment is based on a frequency model of the seasonal climate conditions.</td>
</tr>
<tr>
<td>Received in revised form 16 June 2010</td>
<td>Accepted 27 June 2010</td>
</tr>
</tbody>
</table>

This manuscript was handled by
A. Bardossy, Editor-in-Chief, with the assistance of Ali Andre Ghassemi, Managing Editor.
## Scenario Weighting Methods

<table>
<thead>
<tr>
<th>${v_i}$</th>
<th>$x_i = g(v_i)$</th>
<th>Equal Probability</th>
<th>Updated Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_1$</td>
<td>$x_1$</td>
<td>$1/N$</td>
<td>$q_1 = ?$</td>
</tr>
<tr>
<td>$v_2$</td>
<td>$x_2$</td>
<td>$1/N$</td>
<td>$q_2 = ?$</td>
</tr>
<tr>
<td>$\vdots$</td>
<td>$\vdots$</td>
<td>$\vdots$</td>
<td>$\vdots$</td>
</tr>
<tr>
<td>$v_N$</td>
<td>$x_N$</td>
<td>$1/N$</td>
<td>$q_N = ?$</td>
</tr>
<tr>
<td>ex.</td>
<td>historical daily flow</td>
<td>monthly average flow</td>
<td>$D[g(v_i)\mid H]$</td>
</tr>
</tbody>
</table>

International Conference on Climate, Water and Policy 2012
Scenario Weighting Methods

- $x_b$ and $x_a$: the below-normal and above-normal terciles, respectively,
- $p_b$, $p_n$, and $p_a$: the probabilities of the below-normal, normal, and above-normal ranges, respectively

$q_i = \frac{1}{N}$

$q_i = \ ?$
Croley-Wilks Method: Theory


- The two approaches are identical for the univariate problem

Let $S_b, S_n, S_a = \text{set of indices for which } x_i < x_b, \ x_b < x_i < x_a, \ x_a < x_i$

$N_b, N_n, N_a = \text{number of elements in } S_b, S_n, S_a$

where $N = N_b + N_n + N_a$

Then for points $x_i$ in $S_b, S_n, S_a$, the probability for $x_i$ is changed to

$$q_i = \frac{p_b}{N_b}, \ \frac{p_n}{N_n}, \ \frac{p_a}{N_a}$$
Croley-Wilks Method: Limitation

- The block adjustment:
  - The same constant adjustment to all the points \( x_i < x_b \)
  - A completely different adjustment to all points for which \( x_b < x_i < x_a \), and \( x_b < x_i \)

- No physical importance associated with the values of \( x_b \) and \( x_a \)

- A discontinuity in the probabilities assigned to points on either side of \( x_b \) and of \( x_a \)
The expectation of $G(X)$:

$$E\{G(X)\} = \int G(X)f_0(X)dX$$

The new interest:

where $f_1(X)$ is the pdf for $X$ corresponding to $f(x|H)$

The needed revisions of the original probabilities $\{1/N\}$:

The revised probabilities for each $x_i$ corresponding to $v_i$:

- **Computational Concern:** Pdf-Ratio
Estimated vs. True CDF

- Case: \( \{\mu_0 = 3, \sigma_0 = 1\} \rightarrow \{\mu_1 = 3, \sigma_1 = 0.5\} \)
Advantages of the Pdf-Ratio Method

- very **simple** and **flexible**
- makes use of the **entire** $D_g(v|H)$ distribution
- generally provides an **adequate description** of the target conditional distribution if the initial sample is large enough
- can be used with **different families of distributions** describing the initial and target distributions for climate variables
- can deal with the **multivariate forecast case** without any difficulty
Study 4: ESP using Pre- & Post-processor

- **Citation**

- **Objectives**
  - Test the applicability of the KMA forecasts to reduce the ESP uncertainty
  - Compare various pre- & post- processors for the Korean ESP

---

Comparison of pre- and post-processors for ensemble streamflow prediction

Tae-Ho Kang1, Young-Oh Kim2, and Il-Pyo Hong1

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2Department of Civil and Environmental Engineering, Seoul National University, 599 Gwanak-Ro, Gwanak-Gu, Seoul 151-742, Republic of Korea

*Correspondence to: Young-Oh Kim, Department of Civil and Environmental Engineering, Seoul National University

**Abstract**

This study conducted a broad review of the pre- and post-processor methods for ensemble streamflow prediction using a Korean case study. Categorical forecasts offered by the Korea...
ESP with Various Pre- & Post- Processors

Pre-processors

Step 1
- Categorical forecast: CPC
- Deterministic forecast: DPC

Transforming the non-probabilistic climate forecast into a probabilistic forecast

Step 2
- Meteorological input ensembles
  - Probabilistic weather forecasts
    - Schaalke Shuffle
    - Quantile Mapping
    - Pdf-Ratio

Meteorological forecasts Conversion

Post-processors

Streamflow ensembles

- Event Bias Correction
- Optimal Linear Correction
- Quantile Mapping

Diminishing hydrological bias

Employing the probabilistic forecast to adjust the meteorological ensembles

\[ y_1, y_2, \ldots, y_{n-1}, y_n \]

\[ y^{*}_1, y^{*}_2, \ldots, y^{*}_{n-1}, y^{*}_n \]

\[ \frac{1}{N}, \frac{1}{N}, \ldots, \frac{1}{N} \]

\[ q_1, q_2, \ldots, q_{n-1}, q_n \]
The Chungju Dam (C-Dam) and the Soyanggang Dam (S-Dam) basin in Korea, which have no other dams in their upper stream region, were applied.

S-Dam, having the largest storage capability in Korea, is currently supplying 1.2 billion m³/year of water to Seoul.

C-Dam has the second largest storage capability.

- **Features of S-Dam**
  - Basin area: 2,703 km²
  - Average rainfall: 1,100 mm
  - Average runoff: 55.5 m³/sec

- **Features of C-Dam**
  - Basin area: 6,648 km²
  - Average rainfall: 1,197 mm
  - Average runoff: 154 m³/sec
Results: RPS

- The post processor is more effective in the dry season than in the wet season because TANK is more biased in dry season.

- When the hydrologic bias is diminished effectively, uncertainty of the probabilistic climate forecast mainly contributes to ESP uncertainty.

<table>
<thead>
<tr>
<th>Season</th>
<th>Basin</th>
<th>Soyanggang Dam</th>
<th>Chungju Dam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No post</td>
<td>EBC</td>
</tr>
<tr>
<td>Wet season</td>
<td>No pre</td>
<td>0.431</td>
<td>0.435</td>
</tr>
<tr>
<td></td>
<td>QM</td>
<td>0.446</td>
<td>0.464</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>0.437</td>
<td>0.458</td>
</tr>
<tr>
<td></td>
<td>PR</td>
<td>0.491</td>
<td>0.485</td>
</tr>
<tr>
<td>Dry Season</td>
<td>No pre</td>
<td>0.847</td>
<td>0.414</td>
</tr>
<tr>
<td></td>
<td>QM</td>
<td>0.813</td>
<td>0.418</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>0.828</td>
<td>0.456</td>
</tr>
<tr>
<td></td>
<td>PR</td>
<td>0.822</td>
<td>0.413</td>
</tr>
</tbody>
</table>
Conclusion

- QM generally performs well except the wet season of S-Dam

- Without post-processors, pre-processors alone can not show significant improvement

- A good pre-processor should be used together with a good post-processor that could effectively remove or at least reduces the hydrological model uncertainty
Study 5: Drought Outlook with ESP

- **Citation**

- **Objective**
  - Propose a drought outlook methodology appropriate to the Korean drought index (Modified SWSI)

---

A drought outlook study in Korea

Young-Oh Kim¹, Jae-Kyoung Lee¹ and Richard N. Palmer²

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Received 28 December 2010; accepted 16 December 2011; open for discussion until 1 February 2013

Editor Z.W. Kundzewicz; Associate editor D. Hughes


Abstract Techniques are proposed for developing a monthly and weekly drought outlook and the drought outlook components are evaluated. A drought index, the surface water supply index (SWSI) was modified and used for the drought outlook. A water balance model (abcd) was successfully calibrated using a regional regression, including
Drought Index: M-SWSI

Drought index:
\[
\frac{a \times PN_{gw} + b \times PN_{pcp} + c \times PN_{sf} + d \times PN_{rs}}{12} - 50
\]

\( a, b, c, d \) are parameters.

Climate information (precipitation, temperature)

Dam inflow
\( (PN_{rs}) \)

Streamflow
\( (PN_{sf}) \)

Groundwater
\( (PN_{gw}) \)

Climate information

abcd

model

Development of Hydrological Forecasting

International Conference on Climate, Water and Policy 2012
Monthly Drought Index Outlook

historical precipitation & temperature ensemble

streamflow & groundwater level ensemble

abcd model

MSWSI equation

\[
\frac{a \times PN_{pcp} + b \times PN_{gw} + c \times PN_{sf} + d \times PN_{rs}}{12} - 50
\]
Results: Monthly MSWSI Outlook

Drought outlook

January 2001

July 2001

November 2001

Observation

International Conference on Climate, Water and Policy 2012
Conclusion

- The monthly drought outlook with ESP is superior to the naïve forecast during the dry season.

- Therefore, the ensemble approach is appropriate for the monthly drought outlook in the Korean Peninsula.

- However, MIMI does not improve the proposed drought outlook with ESP because the current MIMI does not have skill.
Study 6: Qualitative Meteorological Information for Drought Outlook

- Citation

- Objectives
  - Investigate domestic meteorological information applicable to drought outlook
  - Propose a technique to utilize the given meteorological information for drought outlook in practice

Abstract

Despite many strides made in the development of global circulation models as well as the expansive understanding of meteorological phenomena, still many countries lack sufficient meteorological information that can be conveniently
Transforming to Quantitative Forecasts

< Qualitative >
Below normal
Near normal
Above normal

*  

< Quantitative >
(100-α)/2
(100-α)/2

α

r_{33.3} r_{66.7}

Precipitation

Determination of “alpha”

- For each basin, change the value of “alpha” from 33% to 100% and
- Find the optimal value of “alpha” that maximizes a given accuracy measure (ex. RPSS) of the transformed probabilistic forecasts
Conclusion

- Propose a methodology that can convert the verbal expression of the current climate forecast to the quantitative probabilistic forecast

- Determine “alpha” for each basin with which the probabilistic forecasts can be made
  - Sub-basin 2001: $\alpha = 38.3\%$
  - Sub-basin 2016: $\alpha = 43.3\%$
The Value of Using Forecasts for Water Resources Management
Study 7: Reservoir Operation with ESP

Citation


Objectives

- Propose a methodology that can update the monthly ESP scenario and also the SSDP-derived operating rule
- Examine the value of updating the ESP scenarios in reservoir operation

Abstract

This study proposes a new monthly ensemble streamflow prediction (ESP) forecasting system that can update the ESP in the middle of a month to reflect the meteorological and hydrological variations during that month. The reservoir operating policies derived from a sampling stochastic dynamic programming model using ESP scenarios updated three times a month were applied to the Geum River basin to measure...
Outline of the Study

- The monthly operating rules were developed using SSDP (Sampling Stochastic Dynamic Programming) optimization algorithm
  - To minimize primarily the water shortage in the Geum River Basin

- The monthly inflow forecasts were made with ESP and updated twice a month

- The value of the monthly inflow forecasts and also of updating those forecasts were assessed
Conclusion

- Updating the ESP scenario improves the forecast accuracy by up to 26%

- Updating the operating policies every month is valuable: it reduces the water shortage by $0.6 \times 10^6 \text{ m}^3/\text{year}$ compared to the policy without updating. It is more valuable when the initial storage combinations are low.

- Updating within a month is also valuable: on average each update of ESP has the value equivalent to a decrease of $0.2 \times 10^6 \text{ m}^3/\text{year}$ in the water shortage.

- The water shortage in the well-forecasted years is reduced by 20% as compared to that in the poorly-forecasted year.
Closing
Summary

- The current KMA climate forecasts should be improved in the future but some products are already skillful for the hydrological forecasting and also for the water resources management.

- The direct use of the current KMA climate forecasts seem impossible for the hydrologic forecasting but it must be possible to utilize them for the operation hydrological forecasting with some modification ideas.

- Therefore, development of our (Korean) own methodologies in hydrology is important.
다시 2019년 2월 27일에 서서 ...
PAST ESP PROJECTS WITH SNU

- SSDP with ESP by K-water (2004.07. ~ 2006.03.)

INTERNATIONAL ESP ACTIVITIES

Most Recent HEPEX Workshops
The 2018 HEPEX workshop took place in Melbourne, Australia in February 2018.

SPECIAL ISSUES

The following is a list of special journal issues related to HEPEX:

- Sub-seasonal to seasonal hydrological forecasting, 2016-2017, Hydrology and Earth System Sciences
- Ensemble prediction and data assimilation for operational hydrology, 2014, Journal of Hydrology
- Hydrological Ensemble Prediction Systems (HEPS), 2013, Hydrological Processes
- Precipitation uncertainty and variability, 2012, Hydrology and Earth System Sciences
- Latest advances and developments in data assimilation, 2011-2012, Hydrology and Earth System Sciences
- Towards practical applications in ensemble hydro-meteorological forecasting, 2011, Advances in Geosciences
- Downscaling NWP products and propagation of uncertainty, 2010, Atmospheric Science Letters
- HEPEX Workshop in Stresa, 2008, Atmospheric Science Letters
- Hydrological prediction uncertainty, 2006, Hydrology and Earth System Sciences

https://hepex.irstea.fr/
A NEW PROJECT BY K-WATER: BAYESIAN ESP

Objectives

- Develop a hydrologic forecasting model based on Bayes’ theorem
- Utilize climate forecast information for updating prior distribution

Hydrology Research

Article Contents

- Abstract
- INTRODUCTION
- METHODS
- CASE STUDY
- RESULTS
- DISCUSSION

RESEARCH ARTICLE | JANUARY 23 2019

Improvement in long-range streamflow forecasting accuracy using the Bayes' theorem

Seung Beom Seo; Young-Oh Kim; Shin-Uk Kang; Gun Il Chun
Hydrology Research nh2019098
https://doi.org/10.2166/nh.2019.098  Article history
\[ f(q) = N(\mu, \sigma^2) \]

**Likelihood function:** the probability of the ESP given the observed streamflow estimated from historical performance of the ESP based on hindcasts.

\[ f(y | q) f(q) \]

**Prior distribution:** estimated from historical streamflow series

\[ f(y) = f(y | q) f(q) \]

**Posterior distribution**
\[ \sigma_o = \frac{q_a - q_b}{\Phi^{-1}(1 - p_a) - \Phi^{-1}(p_b)} \]

**Utilization of probabilistic precipitation forecast** (issued by Korea Meteorological Administration)
# A NEW PROJECT BY K-WATER: BAYESIAN ESP

## Results

[ 1 month ahead forecast for 35 dam basins (2014.6 ~ 2017.12) ]

<table>
<thead>
<tr>
<th></th>
<th>ESP</th>
<th>Bayesian ESP (without probabilistic precipitation forecast)</th>
<th>Bayesian ESP (WITH probabilistic precipitation forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-RMSE (^1)</td>
<td>1.06</td>
<td>1.07</td>
<td>0.98</td>
</tr>
<tr>
<td>POD (^2)</td>
<td>37.6 %</td>
<td>37.4 %</td>
<td>41.2 %</td>
</tr>
<tr>
<td>POD (below normal only)</td>
<td>18.2 %</td>
<td>15.4 %</td>
<td>23.2 %</td>
</tr>
</tbody>
</table>

\(^1\) N-RMSE: Normalized - Root Mean Squared Error
\(^2\) POD: Probability of Detection (categorical forecast accuracy in terms of terciles-below normal, normal, above normal)

- Utilizing probabilistic climate forecast can lead to additional improvement in forecast accuracy
FUTURE ESP IN KOREA:
FROM ESP TO EDP (ENSEMBLE DROUGHT PREDICTION)

Seasonal Drought Prediction: Advances, Challenges, and Future Prospects

Zengchao Hao, Vijay P. Singh, and Youlong Xia

1 Green Development Institute, College of Water Sciences, Beijing Normal University, Beijing, China; 2 Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering, Texas A&M University, College Station, TX, USA; 3 IM. System Group at Environmental Modeling Center, National Centers for Environmental Prediction, College Park, MD, USA

Abstract  Drought prediction is of critical importance to early warning for drought managements. This review provides a synthesis of drought prediction based on statistical, dynamical, and hybrid methods. Statistical drought prediction is achieved by modeling the relationship between drought indices of interest and a suite of potential predictors, including large-scale climate indices, local climate variables, and land initial conditions. Dynamical meteorological drought prediction relies on seasonal climate forecast from general circulation models (GCMs), which can be employed to drive hydrological models for agricultural and hydrological drought prediction with the predictability determined by both climate forcings and initial conditions. Challenges still exist in drought prediction at long lead time and under a changing environment resulting from natural and anthropogenic factors. Future research prospects to improve drought prediction include, but are not limited to, high-quality data assimilation, improved model development with key processes related to drought occurrence, optimal ensemble forecast to select or weight ensembles, and hybrid drought prediction to merge statistical and dynamical forecasts.
FUTURE ESP IN KOREA:
FROM ESP TO EDP (ENSEMBLE DROUGHT PREDICTION)

Seasonal streamflow forecasting by conditioning climatology with precipitation indices

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1IRSTE, Catchment Hydrology Research Group, UR HBAN, Antony, France
2ECMWF, European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, UK
3now at: Hydrology Research Unit, Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden

Correspondence to: Louise Crochemore (louise.crochemore@smhi.se)

Received: 4 June 2016 – Discussion started: 15 June 2016
Revised: 7 February 2017 – Accepted: 20 February 2017 – Published: 14 March 2017

Abstract. Many fields, such as drought-risk assessment or reservoir management, can benefit from long-range streamflow forecasts. Climatology has long been used in long-range streamflow forecasting. Conditioning methods have been proposed to select or weight relevant historical time series from climatology. They are often based on general circulation model (GCM) outputs that are specific to the forecast date due to the initialisation of GCMs on current conditions. This study investigates the impact of conditioning methods on the performance of seasonal streamflow forecasts. Four conditioning statistics based on seasonal forecasts of cumulative precipitation and the standardised precipitation index were used to select relevant traces within historical streamflows and precipitation respectively. This resulted in weekly deficit volumes and durations over a wider range of lead times.

1 Introduction
1.1 Approaches to seasonal streamflow forecasting

Numerical prediction is valuable to proactively manage risks in areas such as hydropower, drinking water production and drought preparedness (Willhite et al., 2000). Regardless of the application, probabilistic forecasts are preferred over deterministic ones to convey uncertainties (Krzysztofowicz, 2001).
FUTURE ESP IN KOREA:
FROM ESP TO EDP (ENSEMBLE DROUGHT PREDICTION)

Ensemble Drought Prediction in Korea

Ensemble Weather Scenarios → Rainfall–Runoff model → Ensemble Streamflow Prediction → Ensemble Drought Prediction

Probabilistic weather forecasts from KMA (Korea Meteorological Association)

Precipitation: 40% Below Normal, 40% Near Normal, 20% Above Normal

APCC DMME

pdf $f_D$ from EDP at time $t$
FUTURE ESP IN KOREA: FROM HYDROLOGY TO PLANNING

- Overview
  - Maximum Storage = 10
  - Minimum Storage = 0
  - Average Inflow = 7
  - Release = 5 (Constant)
  - Time Period $t = 3$
  - Initial Storage $S_0 = 10$

```
I → S → R=5
```

Max=1

Min=0
FUTURE ESP IN KOREA: FROM HYDROLOGY TO PLANNING

- **Inflow Scenarios**
  - **Case 1**

<table>
<thead>
<tr>
<th>Inflow</th>
<th>Probability(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
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<td>9</td>
<td>15</td>
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<tr>
<td>11</td>
<td>13</td>
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<tr>
<td>13</td>
<td>7</td>
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</tbody>
</table>

- **Case 2**

<table>
<thead>
<tr>
<th>Inflow</th>
<th>Probability(%)</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
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<tr>
<td>7</td>
<td>40</td>
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<td>8</td>
<td>15</td>
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<td>9</td>
<td>10</td>
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<tr>
<td>10</td>
<td>5</td>
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</tbody>
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FUTURE ESP IN KOREA: FROM HYDROLOGY TO PLANNING

- Damage Function

![Damage Function Diagram]
FUTURE ESP IN KOREA: FROM HYDROLOGY TO PLANNING

- Reservoir Operation Example
  - Inflow Scenario Case I
    ① $I(t) = 1,1,1$ (Worst Case Scenario of Case I)
      \[ Pr(\Sigma I) = 0.07^3 = 0.000343 \]
      \[ S_3 = 10 + (3 - 15) = -2 \rightarrow 0 \]
      \[ S_1 = 6, S_3 = 2, S_3 = 0 \]
      \[ Damage = 0 + 100 + 10000 = 10100 \]

    ② $I(t) = 3,1,1$ or $1,3,1$ or $1,1,3$
      \[ Pr(\Sigma I) = 0.07^2 \times 0.13 \times 3 = 0.001911 \]
      \[ S_3 = 10 + (5 - 15) = 0 \]
      \[ S_1 = 8, S_2 = 4, S_3 = 0 / S_1 = 6, S_2 = 4, S_3 = 0 / S_1 = 6, S_2 = 2, S_3 = 0 \]
      \[ Damage = 10000 or 10000 or 10100 \]
Reservoir Operation Example

- Inflow Scenario Case II
  1. \( I(t) = 4,4,4 \) (Worst Case Scenario of Case II)
  
  \[
  Pr(\sum I) = 0.05^3 = 0.000125
  \]
  
  \[
  S_3 = 10 + (12 - 15) = 7 \text{ (Final Storage)}
  \]
  
  \[
  S_1 = 9, S_3 = 8, S_3 = 7
  \]
  
  Damage = 0, No Damage in all cases
Thank you for your Attentions!

Questions?