HYDRO-METEOROLOGICAL VARIABILITY AND ITS INTEGRATED FLOOD RISK ASSESSMENT FOR THE KOREAN HAN RIVER BASIN DURING DIFFERENT EL NIÑO PHASES


Sun-kwon Yoon
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- Different Phases of ENSO and its Local Impacts
- Changes in Typhoon Activities over the KP
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Introduction
Research Goal

Coupled Human-Environmental Hydroclimatic System

- ENSO Climate Index
- Hydro-climate Drives
- CMIP 5 GCMs
- Extremes Typhoon

- Downscaling
- Uncertainty
- Climate Scenarios
- Climate Forecasts
- Teleconnections

- Long-range Flooding
- Hydrologic Flooding
- Remote Sensing
- Short-term Flood

- Hydrom-environmental Issues
- Flood Risk/Vulnerability
- Socio-economic Factors
- End Users/Stakeholders
- Decision Making
- Water Use Policy

- Local Impacts
- Rainfall-Runoff Modeling
- Distribute Models
- Watershed Models
- Frequency Analysis
- GIS Analysis

Research Goal

Hydrom-environmental System

Hydrology

Water Res. Management

Socio-economy

Ecology

• Local Impacts
• Rainfall-Runoff Modeling
• Distribute Models
• Watershed Models
• Frequency Analysis
• GIS Analysis
Interdisciplinary work in APCC

By Coupling with Hydro-climate, Remote Sensing, and Advanced Hydrology for Extreme FLOOD and Heavy Rainfall analysis

A. Extreme Climate Patterns and its Long-range Flood Forecasting

B. Atmospheric Model-based Rainfall Forecast (RS, Radar, WRF)

C. Early Warning System for Flooding using R-Runoff Model Simulations
Background

- The **seasonal characteristics** of **hydrometeorological variability** are closely related to **global climate phenomena** and **climate changes** (Wang et al. 2000; Grimm, 2011).
- Investigating the significant correlation between **climatic factors** and **hydrologic data** is very important for the accurate **prediction and management of water resources** (Horel and Wallace 1981; Pizarro and Lall 2002; Kim et al. 2011).
- Moreover, **typhoons in the WNP** have a strong influence on the **hydrometeorological variables** over the Korean Peninsula (KP) during warm season. Recent climate have also indicated that the number and intensity of **TCs in the WNP are likely to increase slightly in the 21st century** (Emanuel et al., 2008; Knutson et al., 2010).
- In Korea, Nearly three-fourths of annual discharge occurs during the warm season (June–September). Warm season **hydroclimatology is a key determinant of extreme flood control** and **water resources management** in the KP.
- This research investigated the characteristic changes and physical mechanism in hydrologic variables that occur in the Korean major River Basin and their sub-watersheds in association with the **different ENSO phases** and **typhoon activities** in a changing climate.
Emerging Issues for Research

- New type of El Niño (Ashok and Yamagata, 2009)
- Projection of future typhoons (Knuston et al., 2010)
Modoki
: from the Japanese word meaning “similar, but different”

(Ashok and Yamagata, 2009)
Recent Researches

- Kao and Yu (2009), Contrasting eastern-Pacific and central-Pacific types of El Niño, *J. Climate*
- Kug et al. (2009), Two types of El Niño events: Cold tongue El Niño and warm pool El Niño, *J. Climate*
- Yeh et al. (2009), El Niño in a changing climate, *Nature*
- Feng et al. (2011), Different impacts of El Niño and El Niño Modoki on China rainfall in the decaying phases, *IJOC*
- Pradhan et al. (2011), Modoki Indian Ocean Dipole and western North Pacific typhoons: Possible implications for extreme events, *JGR*
- Ren and Jin (2011), Niño indices for two types of ENSO, *GRL*
- Kug et al. (2012), Improved simulation of two types of El Niño in CMIP5 models, *ERL*

- Sea Surface Temperatures (SST) in the tropical Pacific Ocean has been reported to have experienced a change in the cycle, intensity, and genesis of El Niño
- New type of El Niño phenomenon has caused changes in the hydrometeorological patterns throughout the world
- However, quantitative studies on features of CT/WP El Niño were found to be relatively insufficient for the Korean watersheds
Projections of future typhoons

Tropical cyclones and climate change

Thomas R. Knutson¹*, John L. McBride², Johnny Chan³, Kerry Emanuel⁴, Greg Holland⁵, Chris Landsea⁶, Isaac Held⁷, James P. Kossin⁸, A K Srivastava⁹ and Masato Satô⁠₀

(Knutson et al., 2010)
Three research objectives

- To analyze the characteristics and sensitivity of hydrometeorological data during the warm season.
- To analyze the effect of the different types of El Niño on rainfall and its characteristic regional changes.
- To provide basic information necessary for maintaining stable water supply and efficient management of water resources at the basin scale by analyzing the effect of CT/WP El Niño on TC-induced rainfall.
China’s Flooding

- In 1887 flooding, 2 Million deaths (The Yellow River)
- In 1931 flooding, 4 Million deaths (The Yangtze River)
- In 1938 flooding, a Million deaths (The Yellow River)

--> China’s Sorrow

Thailand Flooding (Jul. – Sep., 2011)

- Jul. 25- Sep., 2011, 3-month duration of Flooding
- One-third of the country, including also flooded Bangkok
- 283 lives death, 2Milion affected, $0.51 Billion Damaged
**India and Pakistan, Flooding (2010, 2014)**

Deaths: 557 lives  
Affected: 80,000 lives  
Flooding: 2,500 villages

**South Korea, Flooding (1990, 2002)**

- **Han River bank failure by Extreme Rainfall**
  - Deaths: 163 lives  
  - Affected: 187,265 lives  
  - Damage: 52.03 Million dollars

Typhoon RUSA, struck in Kangnung Province, South Korea

- Deaths: 321 lives, Affected: 63,085 lives  
- Damage: 5.15 Billion dollars
Analysis and Results

- Different Phases of ENSO and its Local Impacts
- Changes in Typhoon Activities over the KP
- Integrated Flood Risk Analysis in the Korean Han River Basin
(II-1) Different Phases of ENSO and its Local Impacts
Study Area

**Figure 1.** The 5 major river basin locations of Korean Peninsula (KP). Especially, the Han River Basin and its 24 sub-watersheds located in the center of the KP.

(a) Fractional Precipitation (Han River)

(b) Fractional Flow (Han River)

* Data From WAMIS (http://www.wamis.go.kr)
Two types of El Niño, SST Composite

* CT/WP El Niño

\[ N_{CT} = N_3 - \alpha N_4 \]
\[ N_{WP} = N_4 - \alpha N_3 \]
\[ \alpha = \begin{cases} 
  2/5, & N_3 N_4 > 0 \\
  0, & \text{otherwise.} 
\end{cases} \]

Figure 1. (a) Normalized Time series of \( N_3 \) (black) and \( N_{CT} \) (blue) indices, and (b) those of \( N_4 \) (black) and \( N_{WP} \) (pink) indices. Dotted grey lines indicate one standard deviation of \( N_{CT} \) and \( N_{WP} \) indices.

Figure 2. Scatter plots (a) for \( N_3 \) and \( N_4 \) indices, and (b) for \( N_{CT} \) and \( N_{WP} \) indices. CORs denote correlations between two indices in each panel.

* Data From NOAA (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)
Two types of El Niño Classification

Figure 3. Composite sea surface temperature anomalies (SSTA) in the developing phases of two types of El Niño during December-January.

Table 4. Classification of the Strong CT El Niño years and Strong WP El Niño years.

<table>
<thead>
<tr>
<th>El Niño Type</th>
<th>The Strong years during 1950-2011</th>
</tr>
</thead>
</table>

- Source: ENSO data ➔ [URL:http://www.cpc.ncep.noaa.gov/data/indices]
Global Precipitation Patterns over Asia

**Figure 5.** Composite anomalies of GPCP seasonal precipitation (MAM: March to May, JJA: June to August) during the CT El Niño and WP El Niño years over the Asia domain.

* Data From NOAA GPCP (global precipitation climatology project, http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)
Figure 6. Composite anomalies of GPCC precipitation and V6 combined seasonal (MAM: March to May, JJA: June to August) precipitation data during the CT El Niño and WP El Niño years.

* Data From NOAA, (http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)
### Seasonality

**Figure 7.** Annual total precipitation and seasonal mean precipitation over the Mid-watershed in the Han River basin.

**Figure 8.** Percentage changes of seasonal fractional flows and the coefficient of variations during (a and c) spring season (March to May) and (b and d) summer season (June to August) over the Han River basin, Korea.
Figure 9. Empirical probability density function for the seasonal precipitation and the seasonal streamflow by percentage of seasonal composite anomalies during CT El Niño and WP El Niño over the spring and summer season over the Han River basin, Korea.
Hydrological Variability (MAM Precipitation)

Figure 10. Percentage changes of MAM precipitation and coefficient of variations in composite anomalies (departures from the 1971-2000 normals) during (a and c) CT El Niño years and (b and d) WP El Niño years over the Han River basin, Korea. The effects of both phases of ENSO are shown with different color schemes (increases in blues and decreases in reds). The hatched polygon shows statistically significant in seasonal precipitation (March to May) based on a 90 % confidence level.
Hydrological Variability (JJA Precipitation)

Figure 11. Percentage changes of JJA precipitation and coefficient of variations in composite anomalies (departures from the 1971-2000 normals) during (a and c) CT El Niño years and (b and d) WP El Niño years over the Han River basin, Korea. The effects of both phases of ENSO are shown with different color schemes (increases in blues and decreases in reds). The hatched polygon shows statistically significant in seasonal precipitation (June to August) based on a 90 % confidence level.
Hydrological Variability (MAM Streamflow)

**Figure 12.** Percentage changes and coefficient of variations in composite anomalies for MAM streamflow (departures from the 1971-2000 normals) during (a and c) CT El Niño years and (b and d) WP El Niño years over the Han River basin, Korea. The effects of both phases of ENSO are shown with different color schemes (increases in blues and decreases in reds). The hatched polygon shows statistically significant in seasonal streamflow (March to May) based on a 90 % confidence level.
Figure 13. Percentage changes and coefficient of variations in composite anomalies of JJA streamflow (departures from the 1971-2000 normals) during (a and c) CT El Niño years and (b and d) WP El Niño years over the Han River basin, Korea. The effects of both phases of ENSO are shown with different color schemes (increases in blues and decreases in reds). The hatched polygon shows statistically significant in seasonal streamflow (June to August) based on a 90 % confidence level.
Figure 14. Percentage anomaly (departures from the 1971-2000 normals) changes between precipitation and streamflow in Spring (MAM) and Summer (JJA) season during different ENSO types over the Han River Basin and its sub-watersheds.

Table 3. Summary statistics in seasonal variability associated with different ENSO types

<table>
<thead>
<tr>
<th>ENSO</th>
<th>Statistics</th>
<th>Spring (MAM)</th>
<th>Summer (JJA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Precipitation</td>
<td>Streamflow</td>
</tr>
<tr>
<td>CT El Niño</td>
<td>Average Change (%)</td>
<td>3.47</td>
<td>5.59</td>
</tr>
<tr>
<td></td>
<td>Significant (α=0.10)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td>0.20</td>
<td>0.44</td>
</tr>
<tr>
<td>WP El Niño</td>
<td>Average Change (%)</td>
<td>17.80</td>
<td>21.75</td>
</tr>
<tr>
<td></td>
<td>Significant (α=0.10)</td>
<td>2/23</td>
<td>10/23</td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td>0.54</td>
<td>0.24</td>
</tr>
</tbody>
</table>
Hydrometeorological Variability over KP during JJAS Season

(a) WP El Nino
(b) CT El Nino
(c) La Nina

JJAS Steamflow (%)
31.24 - 41.13
23.80 - 30.29
18.48 - 20.95
5.31 - 10.47
-0.44 - 4.52
5.31 - 10.47
12.72 - 16.71
18.48 - 20.95
23.80 - 30.29
31.24 - 41.13

JJAS Rainfall (%)
-1.08 - 6.79
-6.24 - -2.14
-14.77 - -11.48
-22.51 - -19.25
-29.21 - -27.11
-35.61 - -30.69
-43.13 - -37.36
-24.80 - -20.59
-19.27 - -14.35

(a) DJF (Korean Peninsula)
(II-2) Changes in Typhoon Activities over the Korean Peninsula
Figure 1. Distribution of seasonal precipitation (June–September) in Korea during the 1966–2007 periods. (a) Five major river basins in Korea. (b) Distribution of seasonal precipitation. The annual long-term average precipitation was noted with the number for each histogram. The fraction of seasonal precipitation and TC-induced precipitation are expressed in percentage.
Figure 2. TC frequency of the CT El Niño and WP El Niño years. The solid lines mean a climatological mean of TC frequency in each region (WNP: 16.13/year, KP: 5.0/year).

Figure 3. TC intensity of the CT El Niño and WP El Niño years. (a) means central pressure, and (b) means wind speed in each CT/WP El Niño year.

\[ F_{TC} = \frac{N_{KP}}{N_{WNP}} = 0.30 \]

\[ F_{TC} = \frac{N_{KP}}{N_{WNP}} = 0.29 \]
Figure 6. Composite differences of tropical cyclones (TCs) passed through the Korean domain (shown in a solid blue line) during CT and WP El Niño years. The solid (dashed) line indicates the seasonal mean (June-September) of the WNP subtropical high (5880 gpm) during the WP (CT) El Niño years.

The movement route of typhoons frequently appeared to be widely spread and in an irregular zigzag pattern during CT El Niño years. During WP El Niño years, relatively powerful typhoons tended to move along the seas around the KP and along the Kuroshio.
Large-Scale Environments

Figure 7. SST-composed anomalies obtained from Hadley SST in (a) CT years and (b) WP years. Shading indicates values over 90% confidence based on Student’s $t$-test.

During WP El Niño years, SSTAs are comparatively high across the WNP, except for an extended area incorporating the eastern Kuroshio off Japan and the coastal seas off the KP. These higher SSTAs should provide favorable conditions for TC development as latent heat generation might reinforce or maintain the intensity of TCs that migrate northward towards the KP after forming at low latitudes.
Figure 8. Vertical wind shear anomalies obtained from NCEP-NCAR reanalysis. Shading indicates values over 90% confidence based on Student’s $t$-test.

During the CT El Niño period, negative VWS anomalies appear to be narrow around latitude 20°, whereas a positive anomaly appears over latitude 25°. Meanwhile, during the WP El Niño period, negative VWS anomalies form a wider area from latitudes 20°N to 35°N. We assume that this negative VWS zone can maintain or reinforce the intensity of TCs that go north towards the KP.
Local Impacts on TC-induced Heavy Rainfall

Figure 9. Composite anomalies of TC-induced rainfall during CT/WP El Niño years. The hatched polygons indicate statistically significant changes in TC rainfall based on the 10% significance level.

Figure 10. Composite anomalies of TC-related heavy rain days (≥50mm/day) during CT/WP El Niño years. The hatched polygons indicate statistically significant changes in TC-induced rainy days based on the 10% significance level.
(II-3) Integrated Flood Risk Analysis in the Korean Han River Basin
Integrated Flood Risk Map for Decision Making

**Conceptual Framework**
- Development of a hierarchy for flood risk index incorporating several factors
  - Categorized: Hydrological, Socio-economic, and Ecological criteria
  - ENSO, TC, and Extreme rainfall indicators

Risk = Hazard + Vulnerability,  \[(\text{Maskrey, 1989})\]

<table>
<thead>
<tr>
<th>Goal</th>
<th>Criteria</th>
<th>Components</th>
<th>Determinants</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated</td>
<td>Hazard</td>
<td>Hydrologic</td>
<td>Trigger</td>
<td>Rainfall totals ($H_{1}$)</td>
</tr>
<tr>
<td>Risk Index</td>
<td></td>
<td></td>
<td></td>
<td>Peak rainfall ($H_{2}$)</td>
</tr>
<tr>
<td>(IRI)</td>
<td></td>
<td></td>
<td></td>
<td>Frequency of extreme events ($H_{3}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Condition</td>
<td>Elevation ($H_{4}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Slope ($H_{5}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SCS CN ($H_{6}$): Land use, Soil type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Response</td>
<td>Flow volume ($H_{7}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Peak flow ($H_{8}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flood area ($H_{9}$)</td>
</tr>
<tr>
<td>Vulnerable</td>
<td>Exposure</td>
<td>Socio-economic</td>
<td>Population ($S_{1}$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Housing ($S_{2}$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Urbanization ($S_{3}$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Susceptibility</td>
<td>Farmer production ($S_{5}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Industry production ($S_{6}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Resilience</td>
<td>Refuge facility ($S_{7}$)</td>
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<tr>
<td></td>
<td></td>
<td>Ecological</td>
<td>Biodiversity</td>
<td>Forest rate ($E_{i}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pollution loads</td>
<td>BOD pollution load ($E_{2}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TN pollution load ($E_{3}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TP pollution load ($E_{4}$)</td>
</tr>
</tbody>
</table>

* Integrated flood Risk Index (IRI) = function \((H_{i}, S_{j}, E_{k})\)

* Data Source: Hydrology data \(\rightarrow\) (WAMIS; [http://wamis.go.kr/](http://wamis.go.kr/))
  ENSO data \(\rightarrow\) (URL:[http://www.cpc.ncep.noaa.gov/data/indices](http://www.cpc.ncep.noaa.gov/data/indices))
**Data Collection**

**Table 1.** Hydrologic hazard, socio-economic vulnerability, and ecological vulnerability indices over the Korean Han River basin.

<table>
<thead>
<tr>
<th>ID</th>
<th>Sub-basin Name</th>
<th>Catchment Area (km²)</th>
<th>Annual Precipitation (mm)</th>
<th>Annual Discharge (m³/s)</th>
<th>Flood Area Density (ha/km²)</th>
<th>Flood Dam (TWh/km²)</th>
<th>Land Use Urban Area (%)</th>
<th>Hydrologic hazard</th>
<th>Socio-economic vulnerability</th>
<th>Ecological vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001</td>
<td>Upstream of Naehan River</td>
<td>2447.9</td>
<td>1,240</td>
<td>20,960</td>
<td>0.0425</td>
<td>362</td>
<td>0.5</td>
<td>27.5</td>
<td>12.6</td>
<td>99</td>
</tr>
<tr>
<td>1002</td>
<td>Phyeongchang River</td>
<td>1773.4</td>
<td>1,294</td>
<td>15,538</td>
<td>0.0274</td>
<td>294</td>
<td>0.6</td>
<td>33.6</td>
<td>14.0</td>
<td>76</td>
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<td>1003</td>
<td>Chungju Dam</td>
<td>2483.8</td>
<td>1,210</td>
<td>17,504</td>
<td>0.0444</td>
<td>325</td>
<td>1.3</td>
<td>56.4</td>
<td>27.1</td>
<td>130</td>
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<tr>
<td>1004</td>
<td>Dal Stream</td>
<td>1614.4</td>
<td>1,174</td>
<td>11,410</td>
<td>0.1188</td>
<td>368</td>
<td>2.2</td>
<td>128.4</td>
<td>53.8</td>
<td>137</td>
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<td>1005</td>
<td>Downstream of Chungju Dam</td>
<td>524.4</td>
<td>1,211</td>
<td>3,796</td>
<td>0.1028</td>
<td>702</td>
<td>0.6</td>
<td>47.5</td>
<td>18.1</td>
<td>13</td>
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<td>1006</td>
<td>Seom River</td>
<td>1491.0</td>
<td>1,298</td>
<td>12,151</td>
<td>0.0441</td>
<td>299</td>
<td>3.6</td>
<td>211.0</td>
<td>71.1</td>
<td>179</td>
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<td>1007</td>
<td>Downstream of Namhan River</td>
<td>2072.7</td>
<td>1,297</td>
<td>16,669</td>
<td>0.2279</td>
<td>288</td>
<td>2.2</td>
<td>190.4</td>
<td>65.6</td>
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<tr>
<td>1008</td>
<td>Kumgangsan Dam</td>
<td>2973.8</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td>1009</td>
<td>Dam of Peace</td>
<td>351.3</td>
<td>1,094</td>
<td>8,263</td>
<td>0.0211</td>
<td>169</td>
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<td>0.1</td>
<td>1</td>
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<td>1010</td>
<td>Chuncheon Dam</td>
<td>1587.4</td>
<td>1,187</td>
<td>14,740</td>
<td>0.0069</td>
<td>184</td>
<td>1.2</td>
<td>28.8</td>
<td>10.1</td>
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<td>1011</td>
<td>Inbook Stream</td>
<td>931.3</td>
<td>1,150</td>
<td>8,336</td>
<td>0.0045</td>
<td>283</td>
<td>1.0</td>
<td>15.5</td>
<td>5.7</td>
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<td>1012</td>
<td>Soyang River</td>
<td>1852.0</td>
<td>1,252</td>
<td>18,975</td>
<td>0.0082</td>
<td>238</td>
<td>0.8</td>
<td>25.0</td>
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<td>Uiyam Dam</td>
<td>721.7</td>
<td>1,311</td>
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<td>3.7</td>
<td>340.3</td>
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<td>1014</td>
<td>Hongcheong Rive r</td>
<td>1566.0</td>
<td>1,303</td>
<td>15,893</td>
<td>0.0112</td>
<td>111</td>
<td>1.3</td>
<td>43.3</td>
<td>15.6</td>
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<td>1015</td>
<td>Cheongpyeong Dam</td>
<td>760.6</td>
<td>1,337</td>
<td>8,019</td>
<td>0.0424</td>
<td>146</td>
<td>1.9</td>
<td>129.5</td>
<td>49.0</td>
<td>61</td>
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<tr>
<td>1016</td>
<td>Kyungan Stream</td>
<td>561.1</td>
<td>1,267</td>
<td>5,116</td>
<td>0.0733</td>
<td>154</td>
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*Data: WAMIS ([www.wamis.go.kr](http://www.wamis.go.kr)), * NA represents that data is not available.
Figure 1. Trend analysis of annual precipitation and runoff during different period in the Han River basin, (Period I: 1966-1990, Period II: 1991-2007)
**Figure 2.** Flood damage and flooded area for urban and rural areas during different periods (Period I: 1971-1990, Period II: 1991-2007).
Ternary Diagrams

Figure 3. Ternary diagrams for flood risk in the Han River basin between Period I (Red: 1971-1990) and Period II (Blue: 1991-2007), and in different SST conditions. Each point corresponds to fractional indices of flood risk and vulnerability subject to the constraint $H_i + S_j + E_k = 1$. 
Radar chart of the Flood Risk Index (FRI)

Figure 4. Radar chart of flood risk index (FRI) between urban areas and rural areas during different periods. (a), (b) show estimated results for FRI on hydrological hazard in urban and rural areas, (c), (d) illustrate estimated results for FRI on socio-economic vulnerability in urban and rural areas, and (e), (f) represent estimated results for FRI on ecological vulnerability in urban and rural areas, respectively. The solid lines indicate FRI for Period I (1971-1990), and the dotted lines indicate FRI for Period II (1991-2007).
**Spatial Distribution of Flood Risk in Different SST conditions**

**Figure 5.** Hydrologic hazard, socio-economic and ecological vulnerability assessment during the different strongest SST conditions over the Han River basin, Korea.
### Integrated Flood Risk Map

#### (1) IFRI in different periods

- **(a) Flood Risk Index (Period I)**
- **(b) Flood Risk Index (Period II)**

#### (2) IFRI in extreme SST conditions

- **La Nina (2000)**
- **WP El Nino (2005)**

---

<table>
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<tr>
<th>Integrated Flood Risk Index Range</th>
<th>Classification</th>
<th>Period I Coverage (%)</th>
<th>Period II Coverage (%)</th>
<th>Difference (%)</th>
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<td>-8.74 (↓)</td>
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<th>Integrated Flood Risk Index Range</th>
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<th>La Nina Coverage (%)</th>
<th>WP El Nino Coverage (%)</th>
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<td>0.80 - 0.60</td>
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<tr>
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<td>0.40 - 0.20</td>
<td>Low</td>
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<td>0.20 - 0.00</td>
<td>Very Low</td>
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III  Conclusions
• During WP El Niño years, increased more precipitation and runoff during JJA season better than CT El Niño years over the KP. The findings confirm that water resources in the KP and its sub-basins during the MAM and JJA seasons are sensitive to CT/WP El Niño events.

• The TC-induced summer rainfall over the major Korean river basins decreased from normal years during CT El Niño years (-3.94%) and increased over normal years during WP El Niño years (33.92%).

• The integrated flood risk (IFRI) during WP El Niño year appears increasing tendency than La Niña years. It may provide in developing seasonal hydrologic estimates conditioned upon large-scale climate state for stable water supply and flood risk management in a changing climate.

The findings of relationship between climatic factors and hydrologic parameters are need to support more physical mechanisms in atmospheric sciences. Also it has statistical significance problem due to the lack of data sets. Despite it can be used to sustainable water supply and to the long-range flood forecasting system for water resources management to end-users and stakeholders.
Thank you!

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- Prof. Shaleen Jain
- Prof. Tae-Sam Lee
- Mr. Sang-Myeong Oh

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Conceptual Framework for Long-range Flood Forecasting

APCC MME Forecast

Streamflow Forecast

Long-range Flood Risk

a. Number of days over 150mm rainfall per day

b. Daily rainfall probability of 100 years storm
Empirical estimates of typhoon-induced streamflow

4-day time window: 98% of the historical typhoon events with intercepts in the Korean domain

Source: Kim et al. 2012, IJOC
Typhoon Tracks and Daily Discharge

Based on the historical record (1966–2005), 198 typhoon storm tracks have been recorded within the restricted Korean domain (120°E–138°E, 32°N–40°N)

Source: Kim et al.