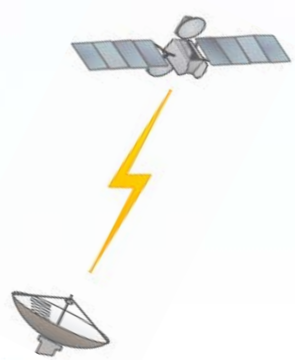
# Extreme Monitoring and Forecasting Assessment using the Hydrometeorological Information



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The University of Seoul

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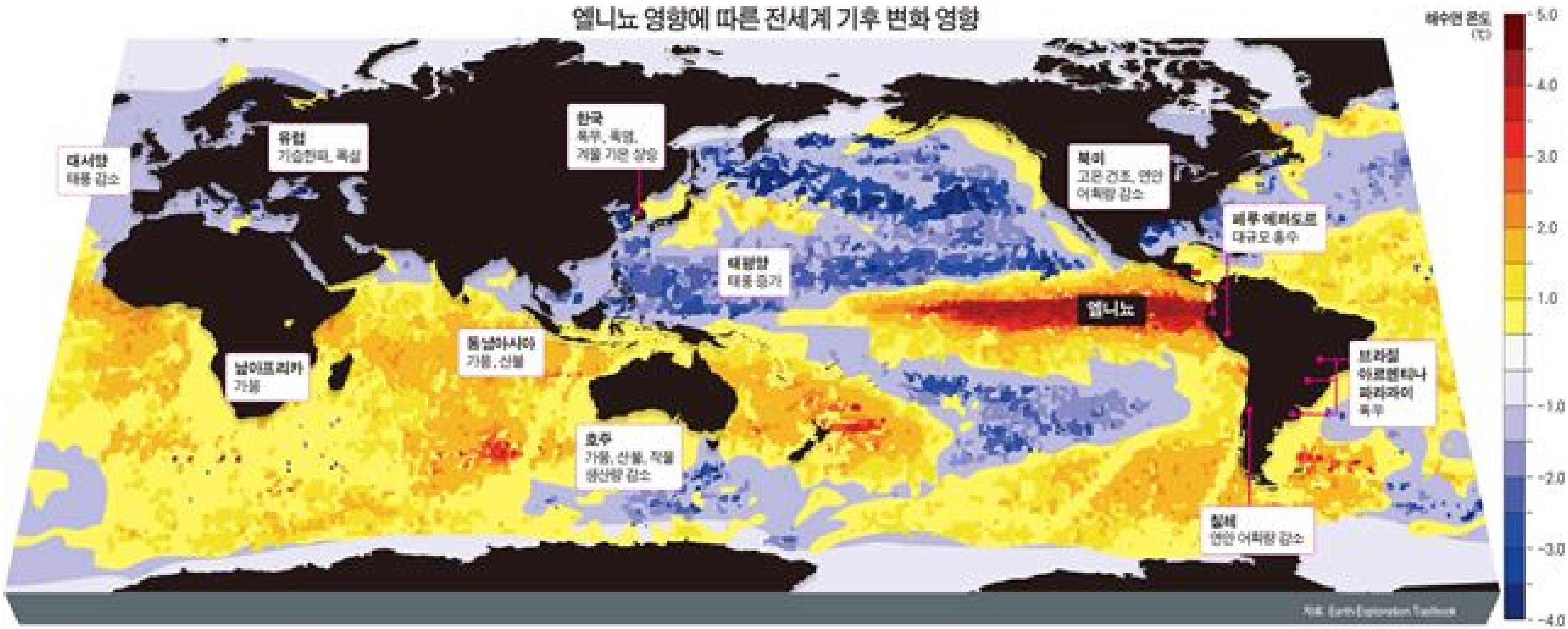
**Extreme Monitoring and Forecasting Assessment**

# I. Emerging Issues

YTN News (2016.05.16)

# I. Emerging Issues




http://www.hankookilbo.com

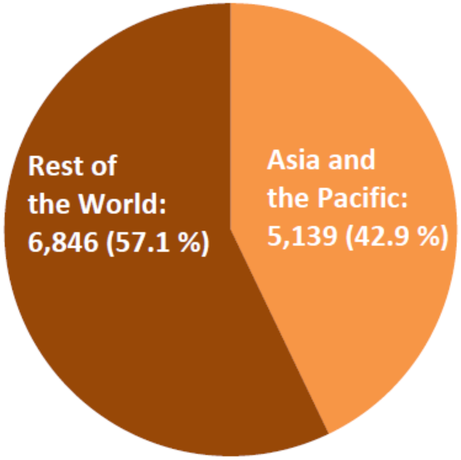
## Why such a different type of El Nino occurs more frequently during recent decades ?

- A different type of El Niño may be due to global warming (Yeh et al. 2009; Kim and Yu, 2012).
- As anthropogenic global warming intensifies, we may see more of these events compared to the traditional El Niño.
- The future climate states will be favorable for more frequent and intense WP El Nino events under global warming(Yet et al. 2009; Lee and Mcphaden, 2010; Na et al. 2011)
- New type of El Niño phenomenon may have caused changes in atmospheric circulation patterns in the Pacific Rim countries, but the mechanisms of El Niño have not yet been clearly discovered.

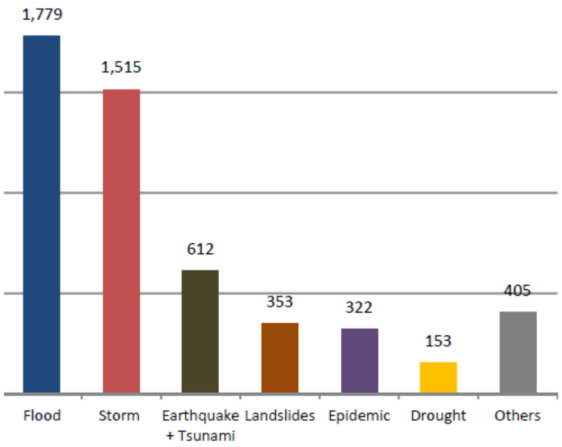
# I. Emerging Issues

➢ **Natural Disaster Events in Asia and the Pacific (1970-2014)**

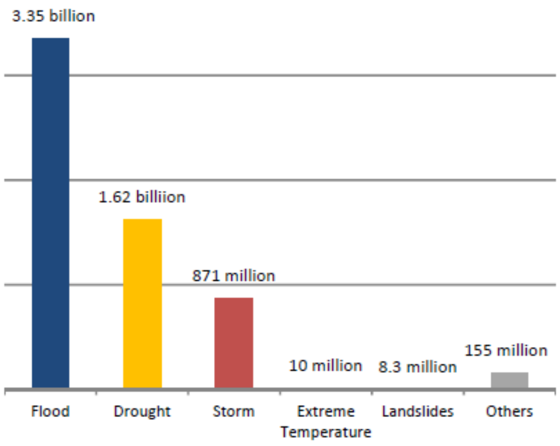
Source: http://www.unescap.org




<Total Occurrences of Natural Disaster Event>




<Occurrences of Natural Disaster Events by Type>




<Total affected from Natural Disasters>

- From 1970 to 2014, the world reported a total of 11,985 natural disaster events, of which 5,139 (or 42.9 per cent) took place in Asia and the Pacific.
- Floods and storms were the most frequent in the region, accounting for 64 per cent of the total number of such events reported between 1970 and 2014.

# Collapse of Classic Maya Civilization Related to Modest Reduction in Precipitation

Martín Medina-Elizalde and Eelco J. Rohling*

The disintegration of the Classic Maya civilization in the Yucatán Peninsula and Central America was a complex process that occurred over an approximately 200-year interval and involved a catastrophic depopulation of the region. Although it is well established that the civilization collapse coincided with widespread episodes of drought, their nature and severity remain enigmatic. We present a quantitative analysis that offers a coherent interpretation of four of the most detailed paleoclimate records of the event. We conclude that the droughts occurring during the disintegration of the Maya civilization represented up to a 40% reduction in annual precipitation, probably due to a reduction in summer season tropical storm frequency and intensity.

Ever since the discovery of the ancient Maya civilization, climate change has been invoked as a causal factor to explain its collapse centuries before the first arrival of Europeans on the American continent (*1*, *2*). It has since become well established that the disintegration of the Classic Maya Civilization was a complex process occurring from around 800 to 1000 A.D. [known as the Terminal Classic Period (TCP)] (*1*–*7*). Despite evidence suggesting that climate change does not fully explain the complex geographic and sociopolitical events of the TCP (*2*, *8*), paleoclimate records and archaeological evidence suggest that the TCP was punctuated by a series of drought events (*9*–*15*) that probably triggered significant societal disruptions at this time (*16*, *17*). Unfortunately, paleoclimate records have been interpreted largely in qualitative terms, and no coherent interpretative framework of these records exists. The TCP drought signals suggested by paleoclimate records are not far outside the amplitude of those preceding this time interval, when the Maya civilization flourished. Perhaps the magnitude of these droughts was rather modest despite the large associated environmental and societal disruptions.

Here we develop the first coherent, quantitative view of the four best-dated and best-resolved paleoclimate records from the Yucatán Peninsula (YP) (Figs. 1 and 2). We evaluate YP lake responses to perturbations to the seasonal precipitation cycle using a straightforward isotope mass balance model, for comparison with environmental patterns suggested by these records. This approach provides a single consistent interpretative framework for all records considered and thus for a quantitative cross-validation of the environmental signals.

The key YP paleoclimate records that we consider (Fig. 2) show similar environmental patterns over the TCP, which are near to synchronous within chronological uncertainties. The high-resolution U-Th–dated stalagmite (named Chaac after the Maya god of rain) $\delta^{18}O$ record represents variability in the annual mean $\delta^{18}O$ of precipitation and reveals a succession of extended drought periods interrupted by brief recoveries (*14*) (Fig. 2A). The Lake Chichancanab gastropod and Punta Laguna ostracod $\delta^{18}O$ records show

National Oceanography Centre, University of Southampton, Southampton, UK.

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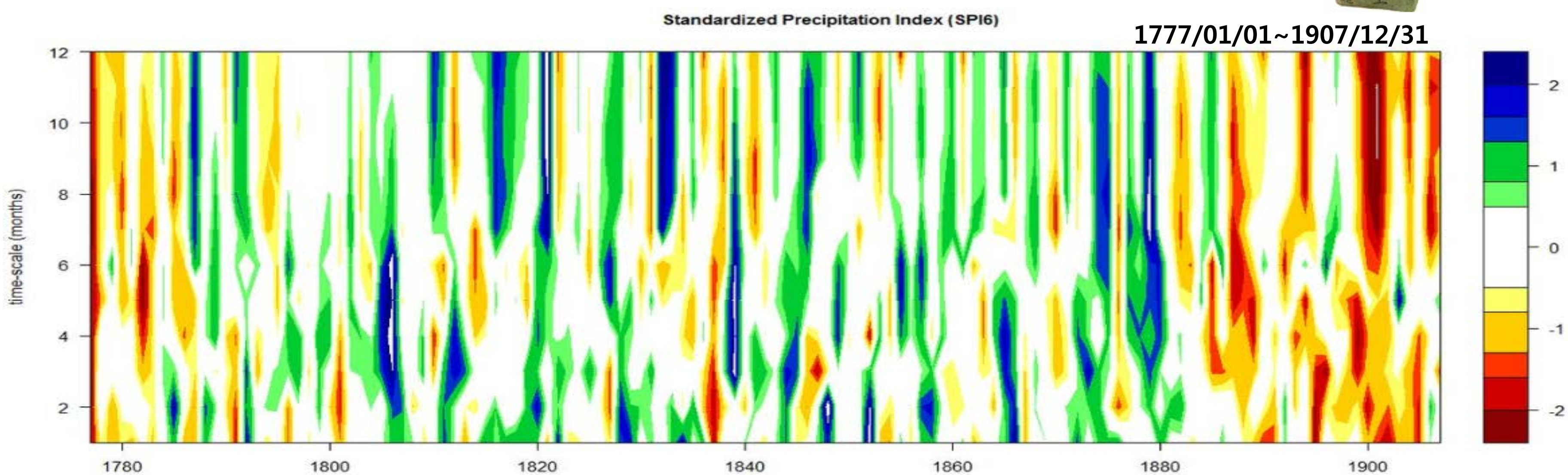
24 FEBRUARY 2012 VOL 335 SCIENCE www.sciencemag.org


세종대왕
Sundial
Chukwookee
Armillary sphere

# Restorations and Analyses of Rainfall Amount Observed by Chukwookee


1777/01/01~1907/12/31




## The King of Chosun Dynasty

| Jungzo | Sunzo | Hyunjong | Chuljong | Gojong |
|---|---|---|---|---|
| (1776-1800) | (1800-1834) | (1834-1849) | (1849-1863) | (1863-1907) |

在位时间

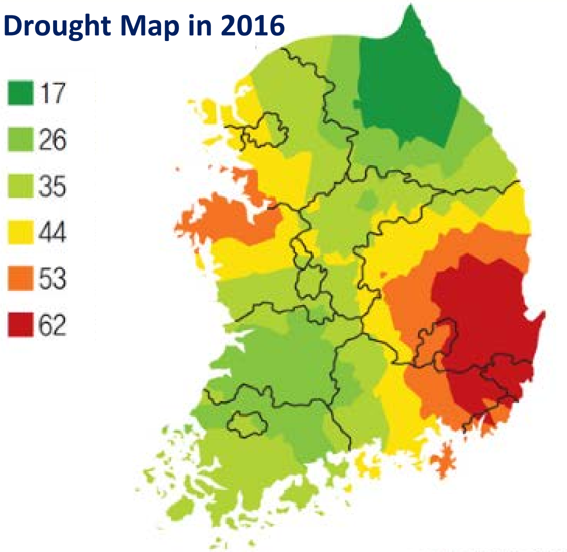
| 乾隆 | 嘉庆 | 道光 | 咸丰 | 同治 | 光绪 |
|---|---|---|---|---|---|
| (1735-1795) | (1796-1820) | (1820-1850) | (1850-1861) | (1861-1875) | (1875-1908) |

# I. Emerging Issues

## 2. Drought

**Annual Drought Frequency (days)**


**Drought Map in 2016**




**by Rural Development Administration (RDA)**

- **'Drought Risk Calendar' by RDA**
- **YongNam in 2016, Kyungbuk in 2018,19**
- **After 2020, Drought lasts for more than 50 days/year… almost every year in the 2030s**
- **In 2020, Drought will be lasted for more than 24 days in April and May (farming season)**

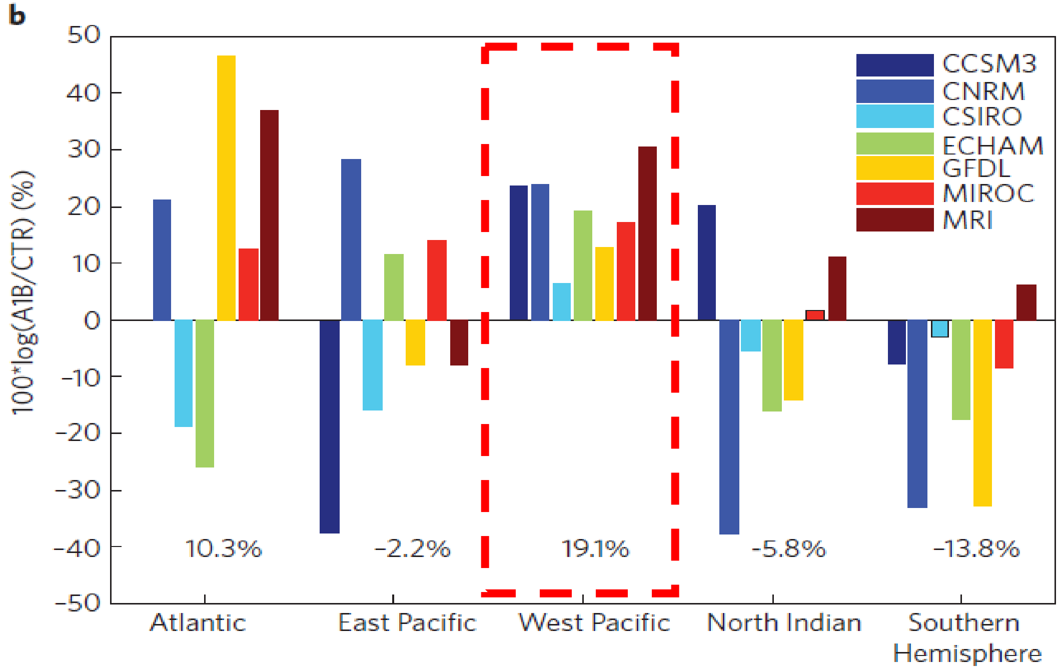
## Projections of future typhoons

**Future projections** based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with **intensity increases of 2-11% by 2100.**

nature geoscience
REVIEW ARTICLE
PUBLISHED ONLINE: 21 FEBRUARY 2010 | DOI: 10.1038/NGEO779

Tropical cyclones and climate change

Thomas R. Knutson[1]*, John L. McBride[2], Johnny Chan[3], Kerry Emanuel[4], Greg Holland[5], Chris Landsea[6], Isaac Held[1], James P. Kossin[7], A. K. Srivastava[8] and Masato Sugi[9]




Knutson et al.(N. geoscience, 2010)

# Projections of future typhoons

Emanuel (PNAS, 2013)

## Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century

Kerry A. Emanuel[1]

Program in Atmospheres, Oceans, and Climate, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139

Edited by Benjamin D. Santer, E. O. Lawrence Livermore National Laboratory, Livermore, CA, and approved June 10, 2013 (received for review January 20, 2013)

A recently developed technique for simulating large [O($10^4$)] numbers of tropical cyclones in climate states described by global gridded data is applied to simulations of historical and future climate states simulated by six Coupled Model Intercomparison Project 5 (CMIP5) global climate models. Tropical cyclones downscaled from the climate of the period 1950–2005 are compared with those of the 21st century in simulations that stipulate that the radiative forcing from greenhouse gases increases by 8.5 W·m$^{-2}$ over pre-industrial values. In contrast to storms that appear explicitly in most global models, the frequency of downscaled tropical cyclones increases during the 21st century in most locations. The intensity of such storms, as measured by their maximum wind speeds, also increases, in agreement with previous results. Increases in tropical cyclone activity are most prominent in the western North Pacific, but are evident in other regions except for the southwestern Pacific. The increased frequency of events is consistent with increases in a genesis potential index based on monthly mean global model output. These results are compared and contrasted with other inferences concerning the effect of global warming on tropical cyclones.

climate change | natural hazards

humidity of the free troposphere. The response of one or more of these additional factors to global climate change generally results in a reduction of the global frequency of tropical cyclones as the climate warms, seen in many explicit and downscaled simulations using global climate models (7). The most likely explanation for this decrease is the increase in the saturation deficit of the free troposphere as represented by the nondimensional parameter $\chi$ defined by Emanuel (8):

$$\chi \equiv \frac{h^* - h_m}{h_0^* - h^*}, \qquad [1]$$

where $h^*$ is the saturation moist static energy of the free troposphere (nearly constant with altitude in a moist adiabatic atmosphere), $h_m$ is a representative value of the actual moist static energy of the middle troposphere, and $h_0^*$ is the saturation moist static energy of the sea surface. ($h_m$ is probably better represented by a pressure-weighted mean over the moist convective layer. In that case, Eq. 1 can be interpreted as the ratio of the time scale for surface fluxes to saturate the troposphere to the time scale for surface fluxes to bring the whole troposphere into thermodynamic equilibrium with the ocean.)

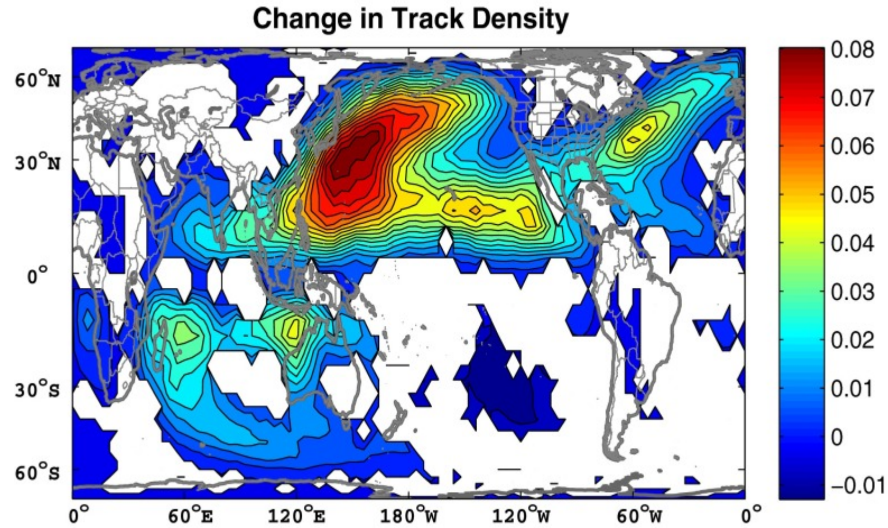



**Figure**. Change in track density, measured in number of events per 4° × 4° grid box per year, averaged over the six models. The change is the average over the period 2006–2100 minus the average over 1950–2005.

# II. Overview of Work Experience

Postdoctoral Research Fellow

## City University of Hong Kong, Hong Kong

August 2011 ~ July 2012

- Regional Flood/Drought Analysis Associated with ENSO and Large-scale Atmospheric Circulations
- Tropical Cyclone Activity Associated with ENSO and Atmospheric Teleconnections
- Framework to Understand Climate-Hydrology-Ecology Linkages in Support of Sustainable Water Resources Management over the Korean Peninsula

Postdoctoral Research Associate

## University of Maine, USA

July 2008 ~ March 2011

- Statistical hydroclimatology & Characterization of Hydroclimatic Extremes
- Diagnostic and Modeling Studies to Understand Climate-induced Variability in Regional Streamflow
  Analyses to Quantify the Climate-Hydrology-Water Quality Linkages in Sebago Lake, Maine
- Investigation of Hydrologic Variability in Asia within the Context of Atmospheric Circulation Patterns

Graduate Student Researcher

## University of Seoul, Korea

March 2002 ~ June 2008

- Development of Evaluation Technique on the Abnormal Flood: Regional Frequency Analysis and Risk Analysis
- 21st Century Frontier R&D: Sustainable Dam Technique Development: Nonparametric Dam Risk Analysis for Dam Rehabilitation
- University-linked Emergency River Management during the Rainy Season

# II. Overview of Work Experience

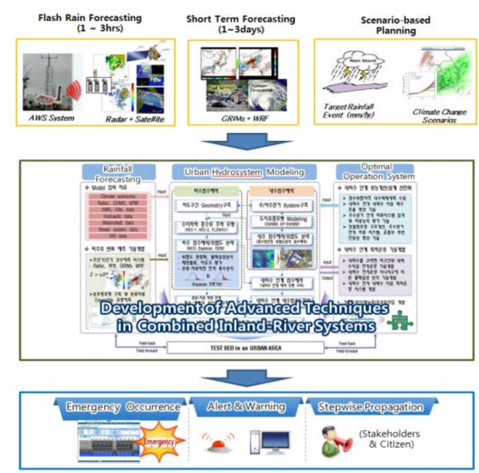
## *Urban Flood Research Institute , Univ. of Seoul*

September 2012 ~ Present

Research Professor, Dept. of Civil Eng.,
Senior Manager of Urban Flood Research Institute

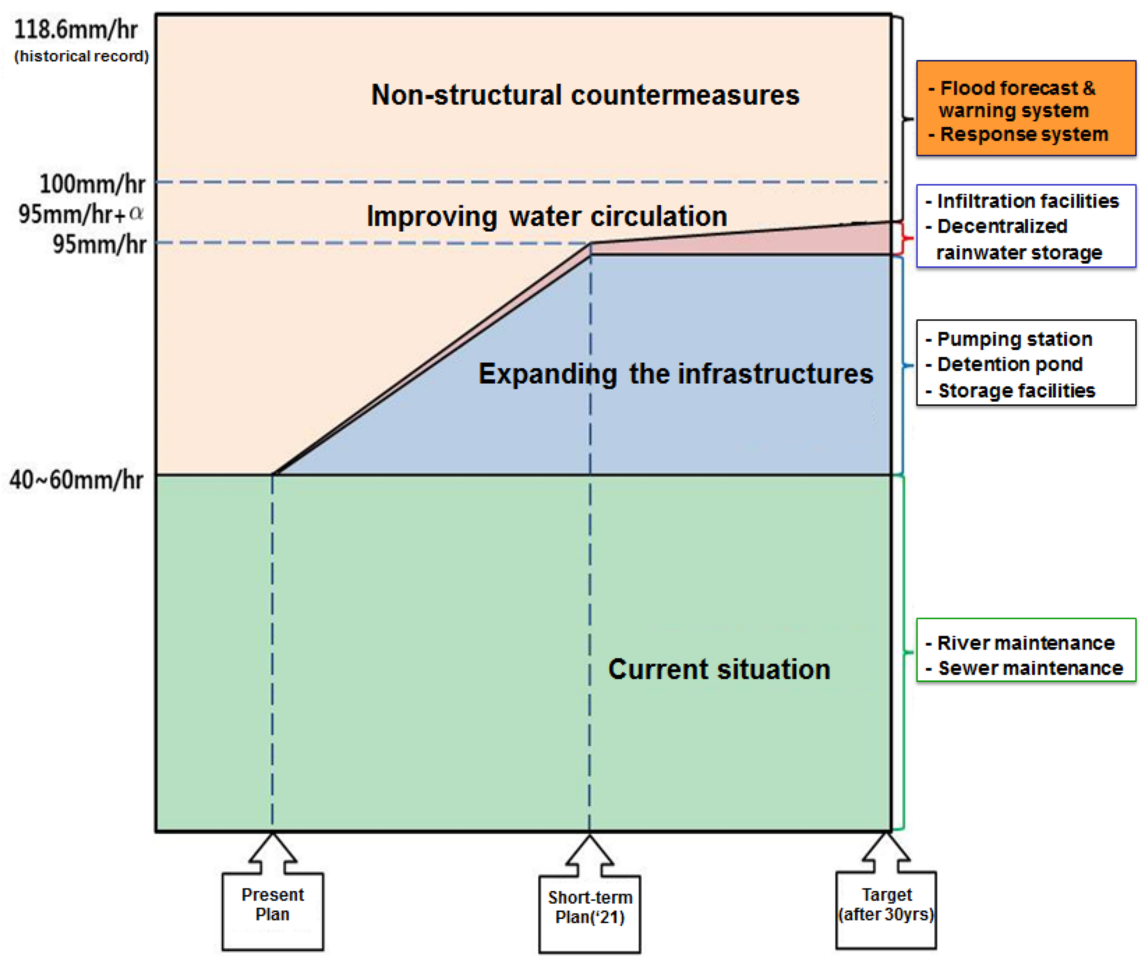
- Climate Change Adaptation for Water Resources: Dam Risk and Rehabilitation Assessment
- Development of Advanced Techniques in Combined Inland–River Systems for Reducing Urban Inundation
- Development of Short and Mid–term Hydrologic Forecasting and Generation Techniques under Climate Change
- Development of Drought Outlook · Response Techniques on Korea and East Asia
- Development of Real–time Drought Forecasting Method based on Statistical–Dynamic Integrated Model


**Urban Flood Research Institute(UFRI) Opening (Feb. 28, 2013)**




**Development of advanced techniques in combined-inland river system**

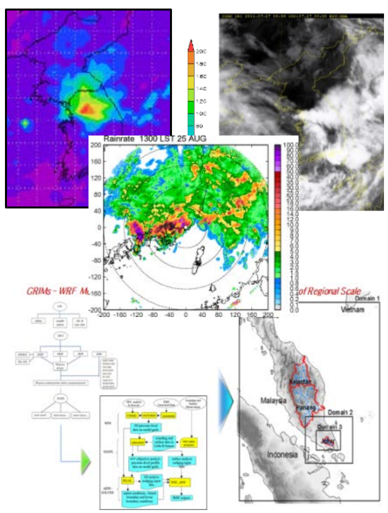
# Response Strategy to Prevent Flood Damage in Seoul



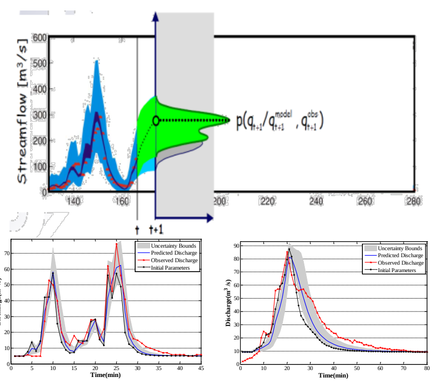
# Development of Advanced Techniques in Combined Inland-River System

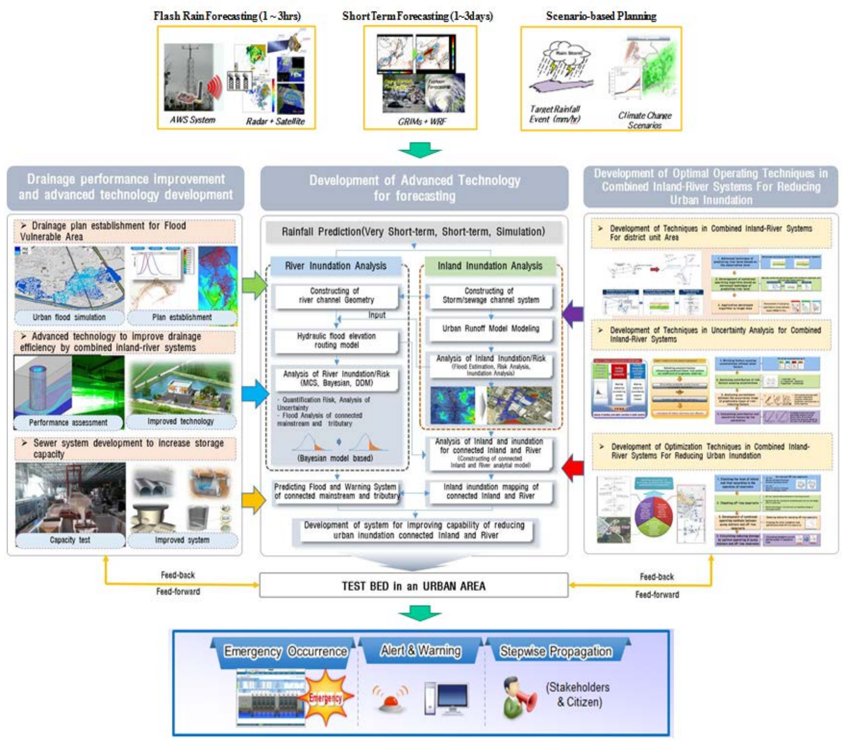
## Multi-Sensor based Precip. Monitoring & Forecasting Algorithm

TRMM COMS

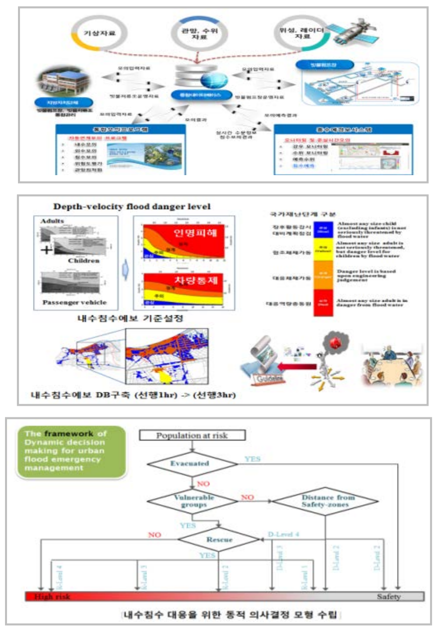


## Bayesian & Urban Hydrosystem Modeling



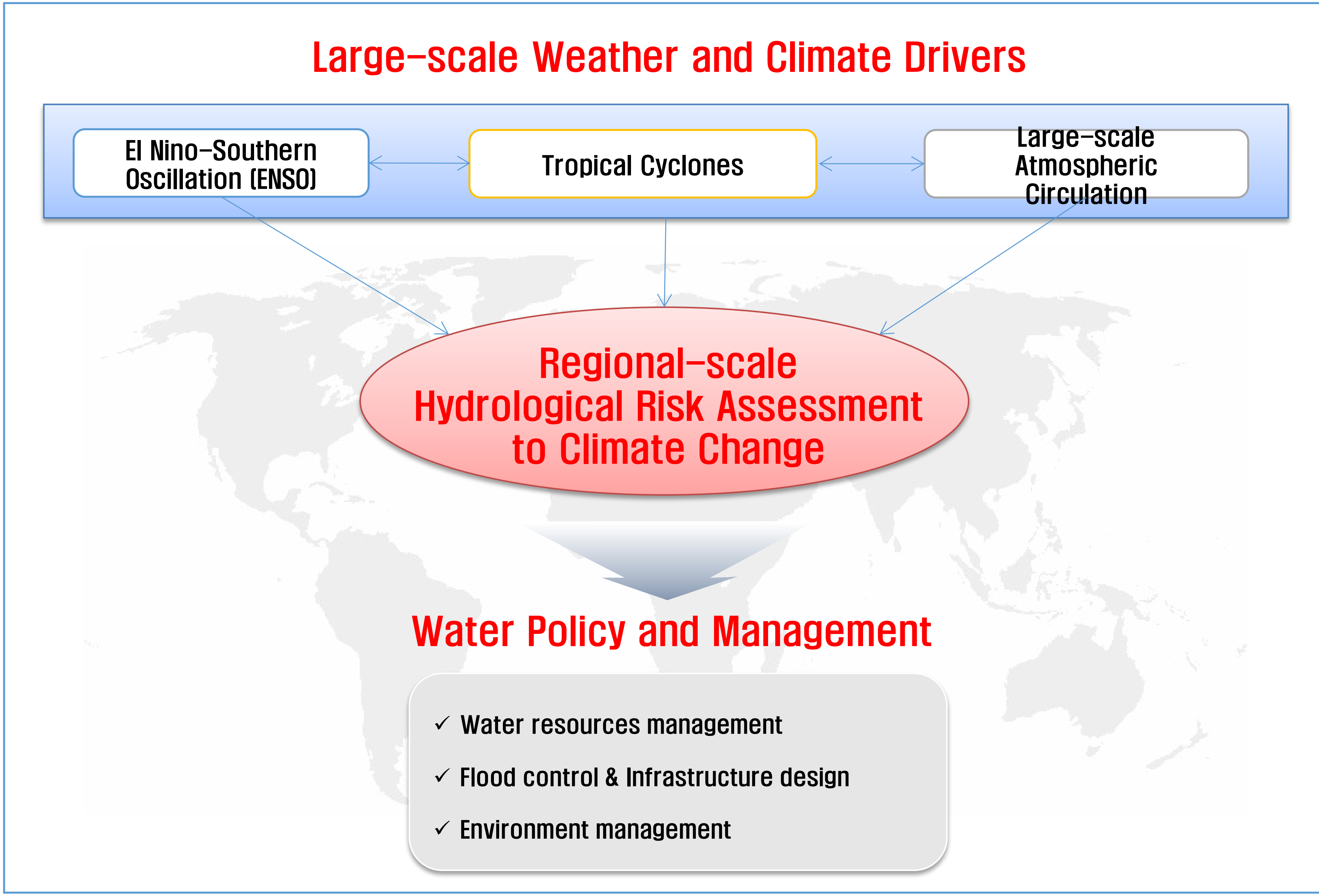




## Guideline & Counterstrategy for Urban Flood Management

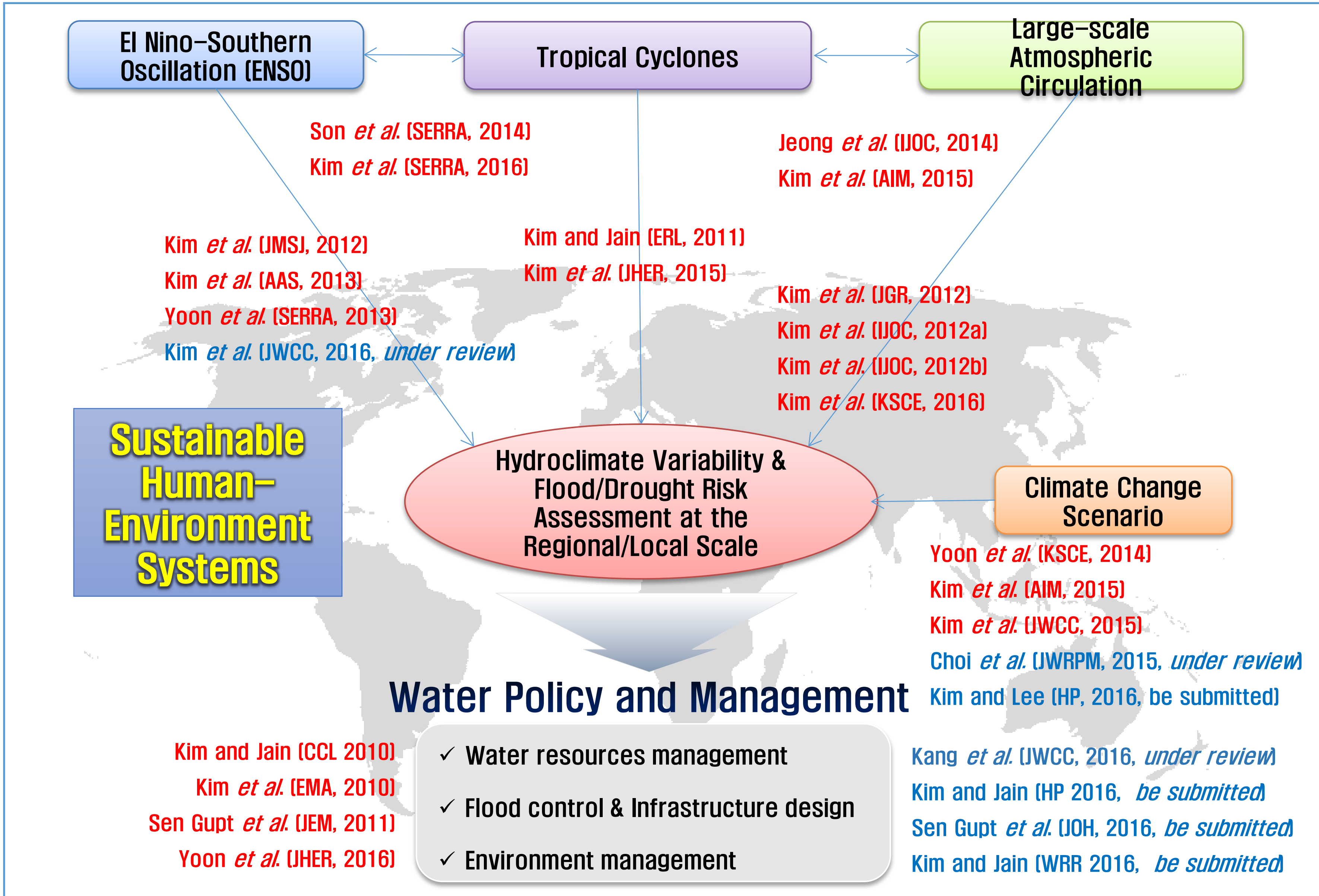



- **Real-time river monitoring** for reducing the flood damage in urban stream
- **Development of flood forecasting and warning system** based on real-time and the predicted rainfall
- This will help prevent natural disasters and to provide useful data for stakeholders and decision makers faced with addressing the challenges of a changing climate.

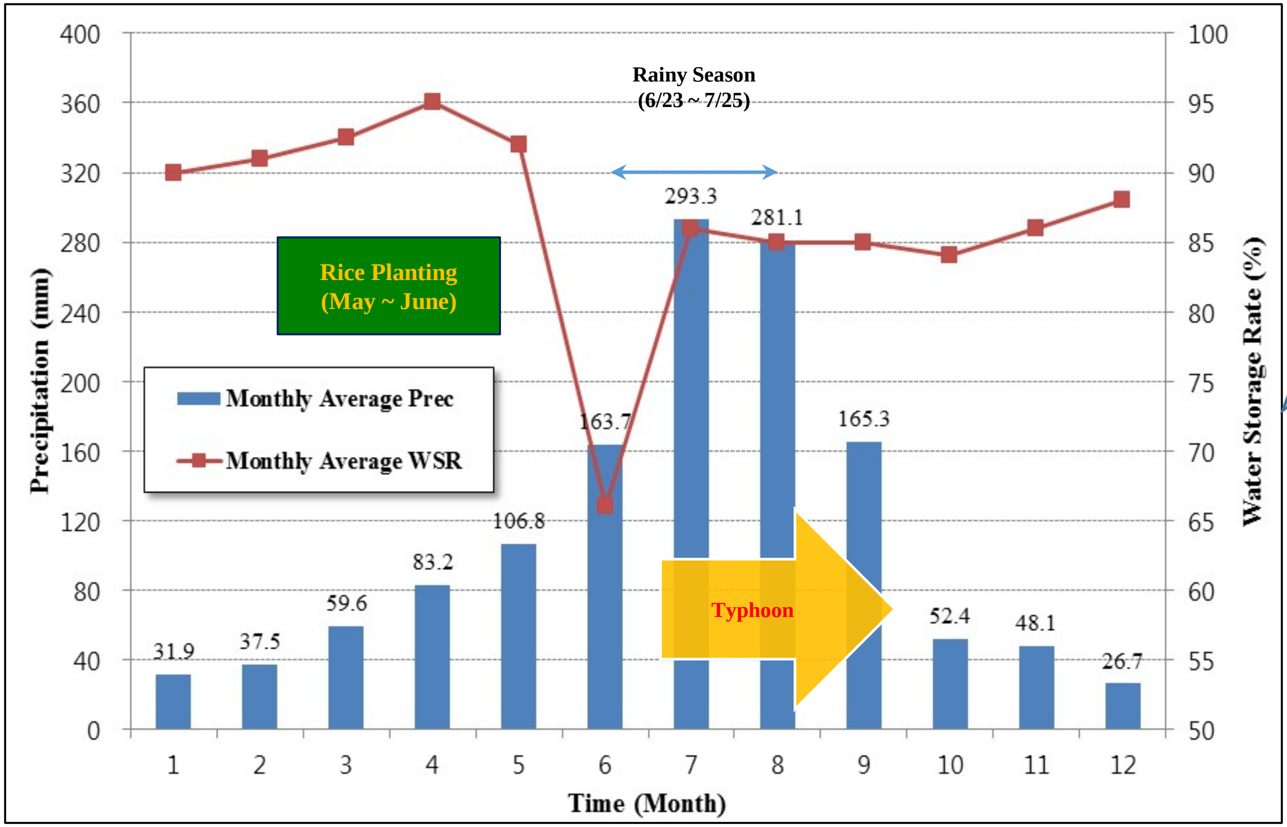
# Enhancing resilience of Human-Environment Systems



# Enhancing resilience of Human-Environment Systems



# Climatological Characteristics of South Korea




The average annual precipitation in Korea is about 1200-1300 mm and 60-70 % of rainfall is concentrated in the summer season (June – September).

In the period of rice-planting season (May-June), a huge amount of agricultural water is required.

Kim *et al.* (2015)

- To overcome the temporal variation of rainfall, we need to keep the water resources preserved from Jun to August in multipurpose dams and utilize them for a living, agriculture, and industry until next summer.
- If we don't have sufficient rain water during summer, we suffer from water shortage in spring and all the year around.

# III. Case Studies

1. TC rainfall and Climate-related Risk
2. Influence of the Two Types of El Nino
3. Influence of Central Pacific Warming
4. Statistical Drought Forecasting using Satellite Information
5. Integrated Regional Risk Assessment
6. Hydroclimatic Change on the Regional Scale

## Case 1: TC Rainfall and Climate-related Risk

IOP Publishing — Environmental Research Letters
Environ. Res. Lett. 6 (2011) 034033 (8pp) — doi:10.1088/1748-9326/6/3/034033

### Precipitation trends over the Korean peninsula: typhoon-induced changes and a typology for characterizing climate-related risk

**Jong-Suk Kim**[1] **and Shaleen Jain**[2,3,4]

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**Abstract**
Typhoons originating in the west Pacific are major contributors to climate-related risk over the Korean peninsula. The current perspective regarding improved characterization of climatic risk and the projected increases in the intensity, frequency, duration, and power dissipation of typhoons during the 21st century in the western North Pacific region motivated a reappraisal of historical trends in precipitation. In this study, trends in the magnitude and frequency of seasonal precipitation in the five major river basins in Korea are analyzed on the basis of a separation analysis, with recognition of moisture sources (typhoon and non-typhoon). Over the 1966–2007 period, typhoons accounted for 21–26% of seasonal precipitation, with the largest values in the Nakdong River Basin. Typhoon-related precipitation events have increased significantly over portions of Han, Nakdong, and Geum River Basins. Alongside broad patterns toward increases in the magnitude and frequency of precipitation, distinct patterns of trends in the upper and lower quartiles (corresponding to changes in extreme events) are evident. A trend typology—spatially resolved characterization of the combination of shifts in the upper and lower tails of the precipitation distribution—shows that a number of sub-basins have undergone significant changes in one or both of the tails of the precipitation distribution. This broader characterization of trends illuminates the relative role of causal climatic factors and an identification of 'hot spots' likely to experience high exposure to typhoon-related climatic extremes in the future.

**Keywords:** summer precipitation, Korean peninsula, trend typology, quantile regression, climate risk

S Online supplementary data available from stacks.iop.org/ERL/6/034033/mmedia

**1. Introduction**

Recent studies have reported trends toward increases in the frequency of heavy precipitation over the Korean peninsula during the summer season, as well as significant increases in the seasonal precipitation totals (Jung *et al* 2002, Chang and Kwon 2007, Bae *et al* 2008, Jung *et al* 2011). Extreme precipitation events are critically important not only for their episodic impacts, such as floods, but also for their significant contribution to seasonal freshwater supplies that maintain the integrity of human and natural systems. In Korea's five major

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1748-9326/11/034033+08$33.00 1 

Kim & Jain (ERL, 2011)

- Typhoons originating in the west Pacific are major contributors to climate-related risk over the Korean peninsula.
- A majority of heavy precipitation events are concentrated in the summer season, in part due to the coincident typhoon season in the western North Pacific.
- The need for improved characterization of climatic risk and the projected increases in the typhoon events motivates a reappraisal of historical trends in precipitation over the Korean peninsula.

# Research Questions ?

- ✓ What is the relative contribution of typhoon and non-typhoon moisture sources to the observed trends in the magnitude and frequency of warm season precipitation?
- ✓ What are the spatial characteristics of trends parsed by principal moisture sources?
- ✓ What are the temporal shifts in the empirical probability distribution of seasonal precipitation, and the nature of trend typology in seasonal precipitation extremes?

# Spatial variations of seasonal precipitation

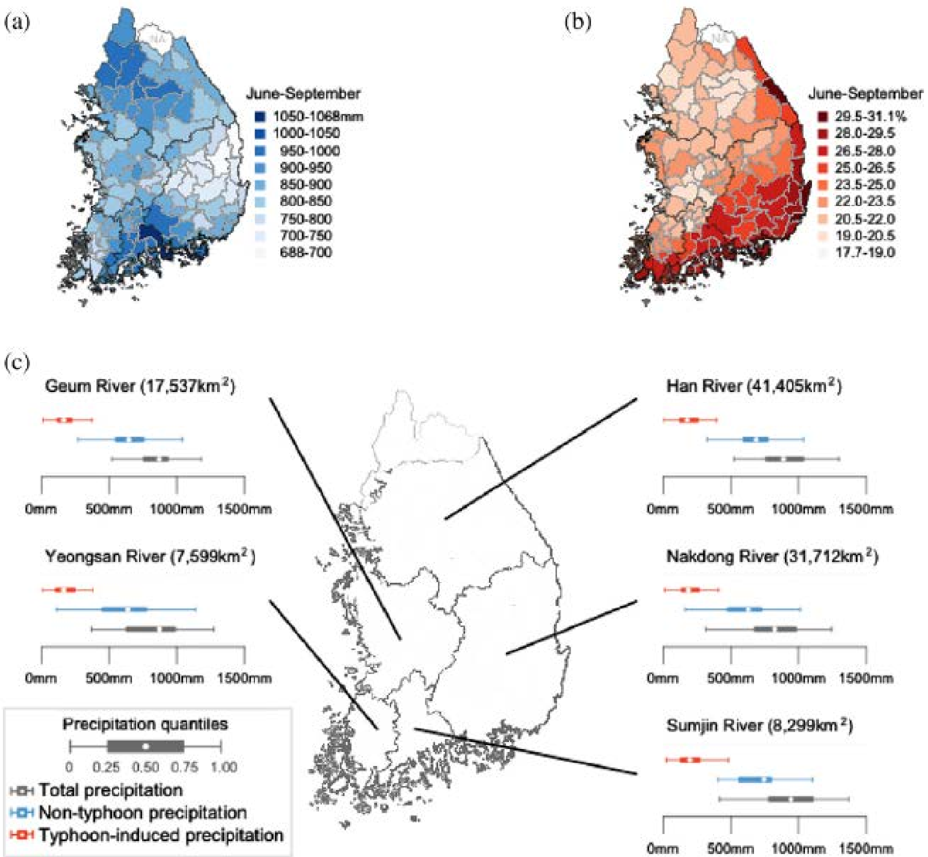



**Fig. 1.** Spatial variations of seasonal precipitation (June–September) in the Korean peninsula during the 1966–2007 periods.

High interannual variability indicates that an important first step in understanding precipitation variability and trends is a characterization of the empirical probability distribution wherein:

(a) upper and lower tail probabilities (signifying extreme events) can be quantified

(b) a separation of precipitation by moisture sources (typhoon, non-typhoon) facilitates an assessment of the individual and joint contributions from typhoon and non-typhoon precipitation to extreme precipitation trends.

## Precipitation trend & its typological characteristics

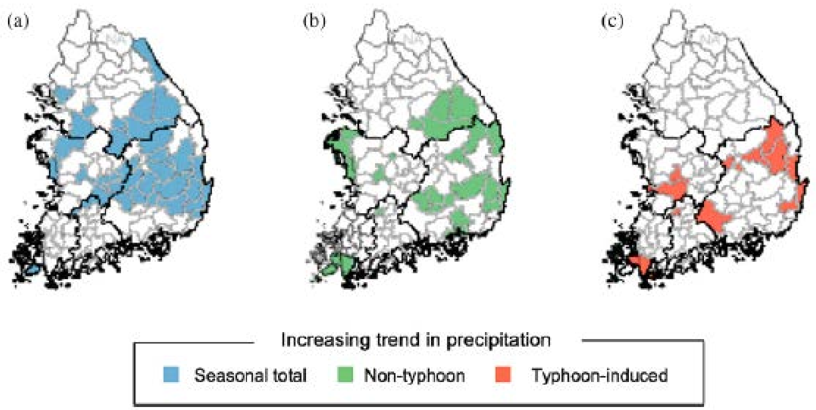



**Fig. 2**. Trends based on a median quantile regression of seasonal precipitation (June-September).

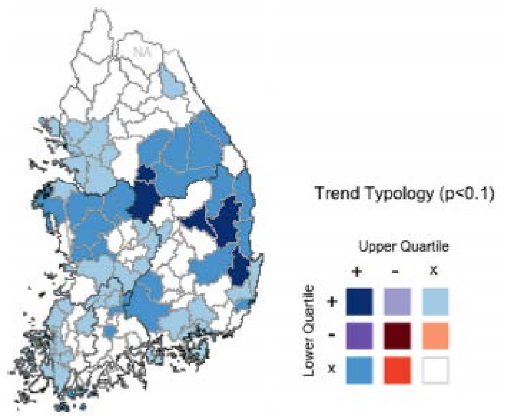
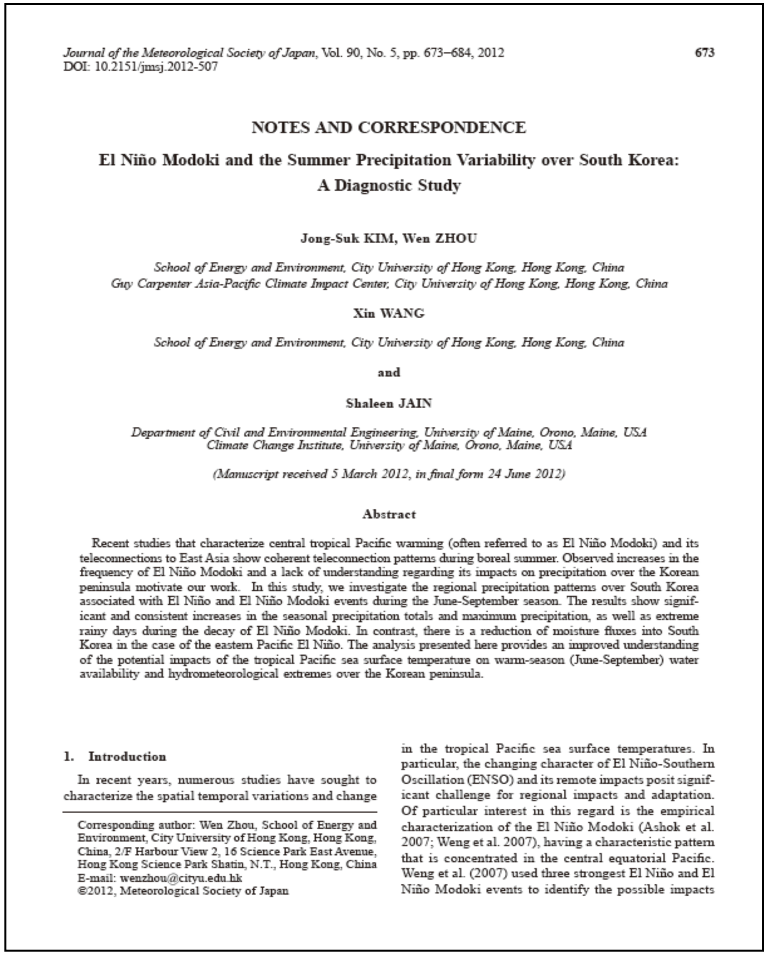



**Fig. 3.** Typology on trends in seasonal precipitation.

- A careful characterization of precipitation variability and trends is an important starting point for adaptation and decision making involving environmental and human contexts, such as: water resources, hazard response, engineering design, agriculture, and ecosystem services.
- In this study, we used an empirical approach to identify the relative contribution of typhoon and non-typhoon precipitation to changes in magnitude and frequency of seasonal precipitation in the five major river basins.
- The broader characterization of trends illuminates the relative role of causal climatic factors and an identification of 'hot spots' likely to experience high exposure to typhoon-related climatic extremes in the future.

# Case 2: Influence of the Two Types of El Nino


*Journal of the Meteorological Society of Japan*, Vol. 90, No. 5, pp. 673–684, 2012 673
DOI: 10.2151/jmsj.2012-507

NOTES AND CORRESPONDENCE

El Niño Modoki and the Summer Precipitation Variability over South Korea: A Diagnostic Study

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*Department of Civil and Environmental Engineering, University of Maine, Orono, Maine, USA*
*Climate Change Institute, University of Maine, Orono, Maine, USA*

*(Manuscript received 5 March 2012, in final form 24 June 2012)*

Abstract

Recent studies that characterize central tropical Pacific warming (often referred to as El Niño Modoki) and its teleconnections to East Asia show coherent teleconnection patterns during boreal summer. Observed increases in the frequency of El Niño Modoki and a lack of understanding regarding its impacts on precipitation over the Korean peninsula motivate our work. In this study, we investigate the regional precipitation patterns over South Korea associated with El Niño and El Niño Modoki events during the June-September season. The results show significant and consistent increases in the seasonal precipitation totals and maximum precipitation, as well as extreme rainy days during the decay of El Niño Modoki. In contrast, there is a reduction of moisture fluxes into South Korea in the case of the eastern Pacific El Niño. The analysis presented here provides an improved understanding of the potential impacts of the tropical Pacific sea surface temperature on warm-season (June-September) water availability and hydrometeorological extremes over the Korean peninsula.

1. Introduction

In recent years, numerous studies have sought to characterize the spatial temporal variations and change in the tropical Pacific sea surface temperatures. In particular, the changing character of El Niño-Southern Oscillation (ENSO) and its remote impacts posit significant challenge for regional impacts and adaptation. Of particular interest in this regard is the empirical characterization of the El Niño Modoki (Ashok et al. 2007; Weng et al. 2007), having a characteristic pattern that is concentrated in the central equatorial Pacific. Weng et al. (2007) used three strongest El Niño and El Niño Modoki events to identify the possible impacts

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Kim *et al.* (JMSJ, 2012)

- From the standpoint of understanding the regional impacts related to precipitation, what is particularly salient is that this nuanced view of Pacific sea surface temperature variability is likely to provide twofold knowledge: (1) regional patterns of precipitation sensitivity to El Niño Modoki and (2) a clearer perspective regarding the potential future impacts, contingent upon changing statistics of El Niño Modoki.
- The purpose of this study is to explore the relative impacts of the two types of El Niño: Canonical El Niño and El Niño Modoki on precipitation over the Korean peninsula.

Case 2

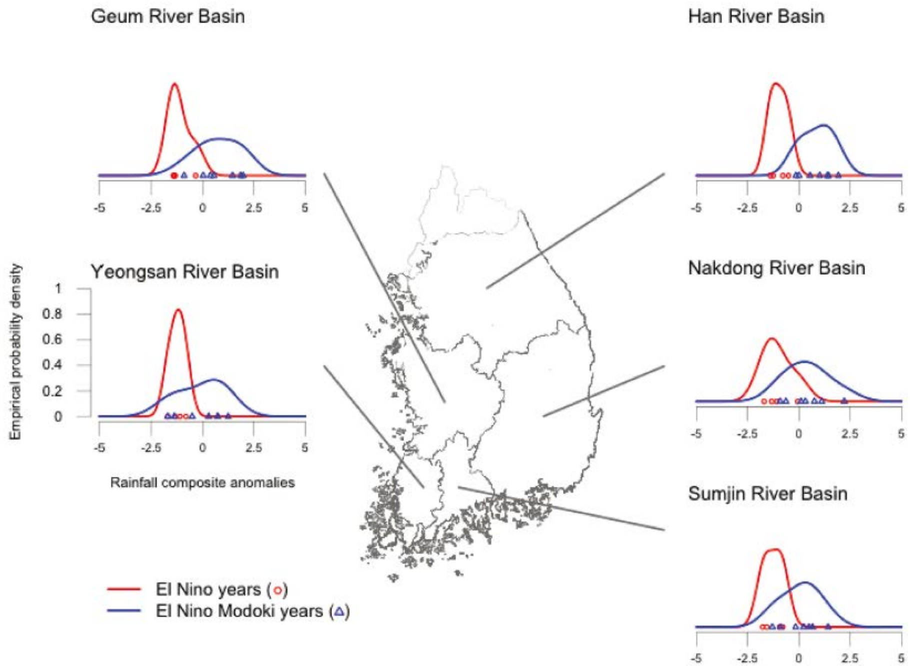



**Fig. 1.** Empirical probability density function for the seasonal rainfall composite anomalies (June-September) for the five major river basins in South Korea.

- The patterns of precipitation anomalies indicate significant difference between El Niño and El Niño Modoki.
- For the El Niño years, the probability density functions (PDF) display sharp distributions and positive skew for all basins, indicating that negative anomalies are generally found.
- In contrast, for the El Niño Modoki years, the conditional distributions clearly show positive anomalies in seasonal precipitation.
- Distinct positive anomalies appear in the Han and Geum river basins.

# III. Case Studies

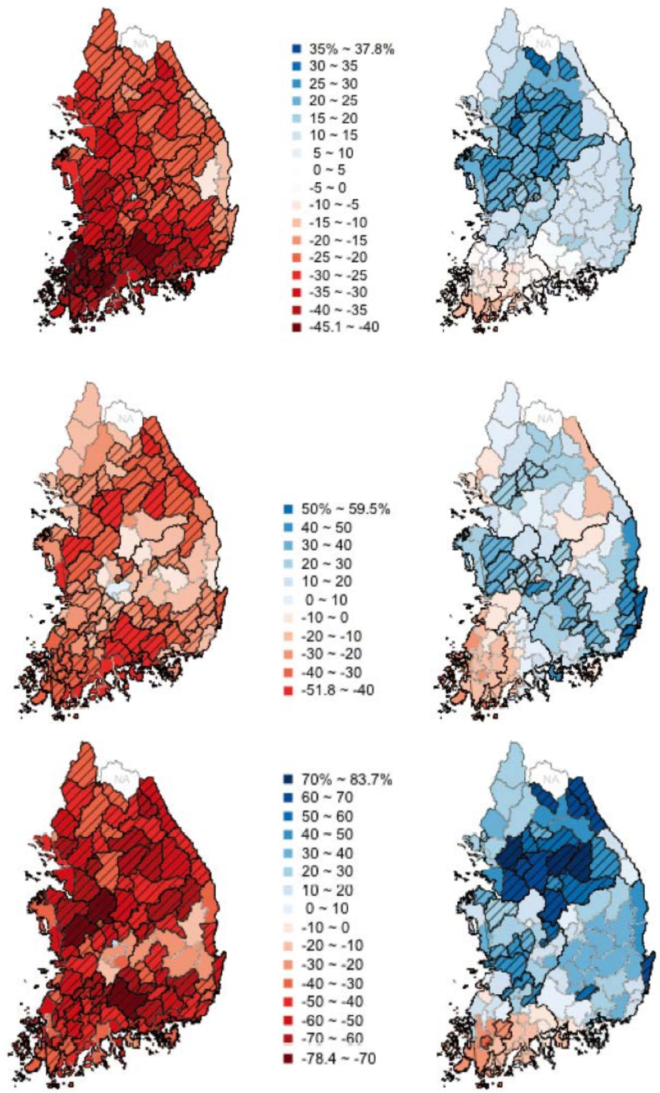
## Case 2

**El Nino years** | **El Nino Modoki years**

Summer Rainfall (June–September)

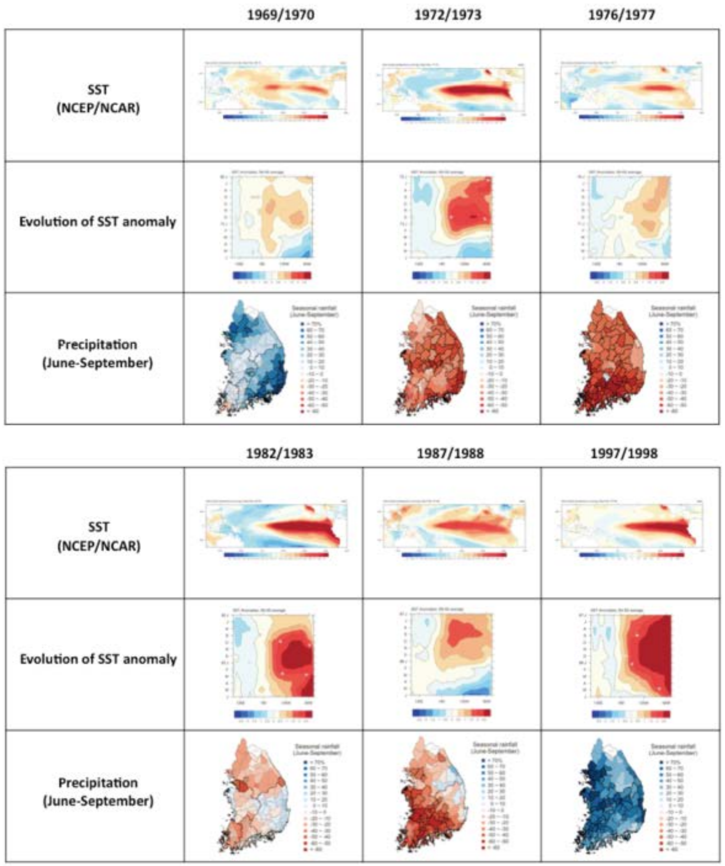
Seasonal Maximum Rainfall

Heavy Rainy Days (>50mm/day)

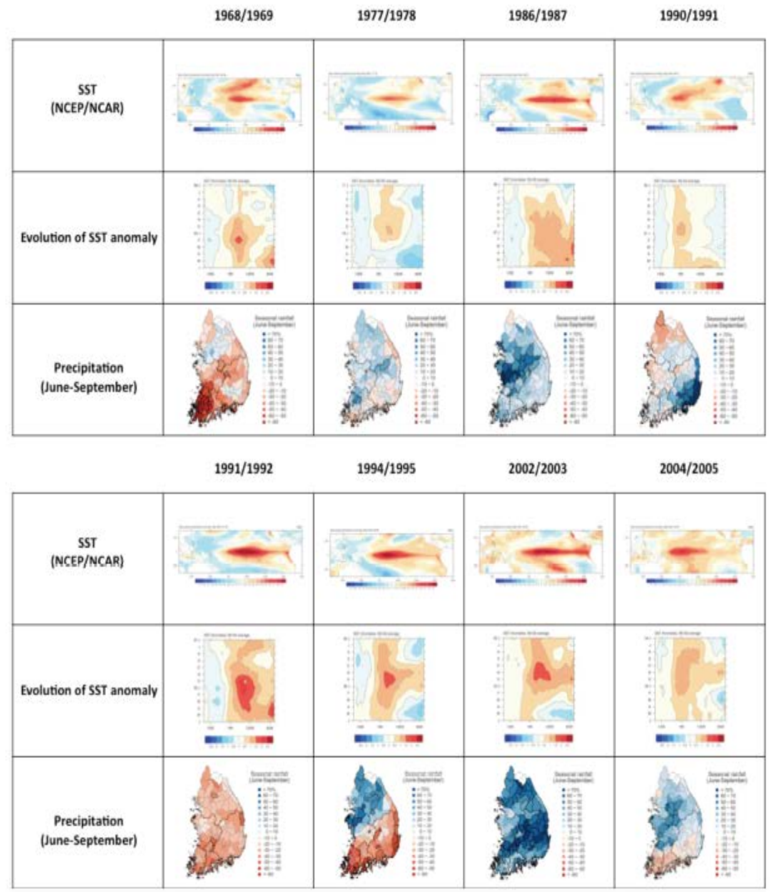



- During the El Niño years, significant drier conditions are observed throughout South Korea.
- In contrast, in the El Niño Modoki years, wetter conditions prevail over the interior and western river basins

## El Nino years




## El Nino Modoki years




**Appendix. 1.** SST anomalies for the El Niño and El Niño Modoki events. SST anomaly patterns during each El Niño and El Niño Modoki in developing, peak phases, and precipitation over South Korea corresponding to the decaying phase of El Niño and El Niño Modoki.

# Three Evolution Patterns of Central–Pacific El Nino

GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L08706, doi:10.1029/2010GL042810, 2010

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## Three evolution patterns of Central-Pacific El Niño

Jin-Yi Yu[1] and Seon Tae Kim[1]

Received 4 February 2010; revised 12 March 2010; accepted 26 March 2010; published 29 April 2010.

[1] Three evolution patterns are identified for the Central-Pacific (CP) type of El Niño based on events that occurred during 1958–2007: (1) a symmetric-decaying pattern whose sea surface temperature anomalies grow and decay symmetrically with respect to a peak phase; (2) a prolonged-decaying pattern that decays slowly and is followed by a warm event in the eastern Pacific (EP); and (3) an abrupt-decaying pattern that terminates rapidly after the peak and is followed by a cold event in the EP. The depth of the equatorial thermocline is found to determine which evolution pattern occurs. If the CP El Niño occurs in a recharged thermocline state (i.e., deeper-than-normal depth), an EP warming may appear in the decaying phase of the CP event to slow down the decay, giving rise to the prolonged-decaying pattern. If the thermocline is in a discharged state (i.e., shallower-than-normal depth), an EP cooling may occur to abruptly terminate the CP El Niño. If the thermocline is in a neutral state (i.e., normal depth), the CP event may have a symmetric pattern of growth and decay. Although a few exceptions exist, these results indicate that the equatorial thermocline state at the peak phase of a CP El Niño event can be a potential predictor of the way the event may decay. **Citation:** Yu, J.-Y., and S. Tae Kim (2010), Three evolution patterns of Central-Pacific El Niño, *Geophys. Res. Lett.*, 37, L08706, doi:10.1029/2010GL042810.

### 1. Introduction

[2] Recent studies have suggested that there are two different types of interannual sea surface temperature (SST) variability in the tropical Pacific [*Larkin and Harrison*, 2005; *Yu and Kao*, 2007; *Ashok et al.*, 2007; *Kao and Yu*, 2009; *Kug et al.*, 2009]. One of them is the conventional type that has most of its (SST) anomalies centered in the eastern Pacific, and the other is a non-conventional type that has SST anomalies confined more to the central Pacific. *Kao and Yu* [2009] refer to these two types as the Eastern-Pacific (EP) and Central-Pacific (CP) types, respectively. Studies have shown that these two types have different impacts on global weather and climate [e.g., *Larkin and Harrison*, 2005; *Kao and Yu*, 2009; *Weng et al.*, 2009; *Kim et al.*, 2009; *Yeh et al.*, 2009]. It was argued that the CP El Niño events have become more frequent during recent decades [*Ashok et al.*, 2007; *Kao and Yu*, 2009; *Yeh et al.*, 2009; *Yu et al.*, 2010]. Thus, interest in the dynamical processes responsible for the CP El Niño events has been increasing rapidly.

[3] By examining the associated subsurface ocean temperature variations, *Kao and Yu* [2009] concluded that the EP type is produced by basin-wide thermocline variations similar to those described by the recharge-discharge oscillator [*Wyrtki*, 1985; *Jin*, 1997] theory, while the CP type involves only local air-sea interactions. According to the recharge-discharge theory, the EP type of El Niño acts as a mechanism to remove excess ocean heat content from the equatorial to the off-equatorial Pacific. After an EP El Niño event, the equatorial thermocline is in a discharged state that is characterized by above-normal depths and is ready to produce an EP type of La Niña event. After an EP La Niña event, the thermocline is recharged to below-normal depths, and is ready to produce the EP type of El Niño again.

[4] As for the CP type, its specific generation mechanism is not fully understood yet. *Yu et al.* [2009] used numerical experiments to argue that the CP type can be generated by Asian and Australian monsoon forcing. *Kug et al.* [2009] argued that the zonal ocean advection plays a key role in developing the CP El Niño. *Yu et al.* [2010] further suggested that the ocean advection processes are important only after the CP type SST anomalies onset at the equator, and that the initial establishment of the equatorial SST anomalies is forced by subtropical atmospheric forcing. Despite some differences, these studies agree that equatorial thermocline variations are not crucial to producing CP El Niño/La Niña events, although *Ashok et al.* [2007] still emphasized the importance of wind-induced thermocline variations within the tropical Pacific to the SST evolution of their Modoki.

[5] By inspecting the evolution of SST anomalies in the tropical Pacific, it has come to our attention that the CP El Niño tends to evolve differently from event to event and can be followed by a warm or cold phase of the EP type. There is a need to summarize these evolution patterns and explore their possible causes. In particular, we want to know if these evolution patterns occur randomly or they are determined by certain oceanic conditions. Answers to these questions are important to further understanding the generation mechanism of the CP type of El Niño/La Niña.

### 2. Data

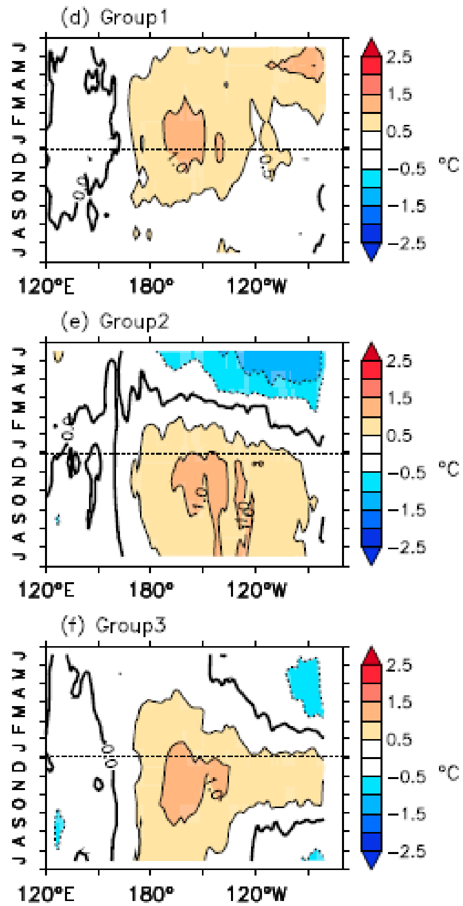
[6] For SST information, we use the National Oceanic and Atmospheric Administration Extended Reconstruction of Historical Sea Surface Temperature version 3 (ERSST V3) data [*Smith and Reynolds*, 2003] from the National Climate Data Center (NCDC) and the Met Office Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST) [*Rayner et al.*, 2003]. For subsurface ocean temperature information, we use the dataset taken from the Simple Ocean Data Assimilation Reanalysis (SODA) [*Carton et al.*, 2000]. We choose to analyze the period 1958–2007, during which both the ERSST and SODA are available. Anomalous quantities are computed by removing the monthly-mean

[1]Department of Earth System Science, University of California, Irvine, California, USA.


0094-8276/10/2010GL042810



Yu and Kim (GRL, 2010)




**Group 1 (Prolonged-decay)**
: a prolonged-decaying pattern that decays slowly and is followed by a warm event in the eastern Pacific (EP)

**Group 2 (Abrupt-decay)**
: an abrupt-decaying pattern that terminates rapidly after the peak and is followed by a cold event in the EP

**Group 3 (Symmetric-decay)**
: a symmetric-decaying pattern whose sea surface temperature anomalies grow and decay symmetrically with respect to a peak phase.

# Case 3: Influence of Central Pacific Warming

Stoch Environ Res Risk Assess (2014) 28:1147–1156
DOI 10.1007/s00477-013-0804-0

ORIGINAL PAPER

**Characteristics of tropical cyclone-induced precipitation over the Korean River basins according to three evolution patterns of the Central-Pacific El Niño**

**Chan-Young Son · Jong-Suk Kim · Young-Il Moon · Joo-Heon Lee**

Published online: 22 September 2013


**Abstract** This study carried out a comparative analysis of the changes in tropical cyclone (TC) genesis, TC track, and TC intensity focusing on TCs that affected the Korean peninsula (KP) according to three evolutionary patterns (prolonged, abrupt and symmetric-decay) of the abnormal sea surface temperature in the Central-Pacific (CP) region. As a result of the analysis, the activity pattern of TCs was found to vary depending on the evolution patterns of the CP El Niño, and such changes appeared to result in clear variations in the regional rainfall in Korea. In the prolonged-decaying and symmetric-decaying years, the KP received considerable TC rainfall. On the other hand, in abrupt-decaying years, it was subtly affected by the TC rainfall. Although rather limited conditions and relatively short observation data were used to analyze the effects of the evolution pattern of the CP El Niño on TCs, the results can be used to quantitatively identify the spatial features of TCs affecting the KP. These results are expected to be helpful in managing the disaster risks in vulnerable areas, including plans to secure stable water resources in the basin, and in establishing effective and active measures to cope with natural disasters by extreme events over the KP.

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J.-H. Lee
Department of Civil Engineering, Joongbu University, Chung-nam, Korea

**Keywords** CP El Niño · Typhoon · SST evolution · Korean River basins · South Korea

**1 Introduction**

Severe natural disasters including flooding and landslides, occur repeatedly in the Korean peninsula (KP) due to the heavy rainfall induced by tropical cyclones (TCs) and localized torrential downpours during the summer season, resulting in considerable casualties as well as severe social and economic loss (Kim and Jain 2011). Recently, TCs, such as Tenbin and Bolaven in August 2012 and Sanba in September 2012, were reported to have direct and indirect influences on the KP. Although the damage by these TCs was not as serious as the damage by RUSA in 2002 and Maemi in 2003, the TC central pressure of Tenbin was 950 hPa, and the pressures of Bolaven and Sanba were 910 and 900 hPa, respectively. Therefore, they were recorded as strong TCs (Typhoon Research Center; http://www.typhoon.or.kr).

In the twenty-first century climatic conditions with continuous climate change, the intensity and frequency of TCs in the western North Pacific (hereafter called the WNP) region are expected to increase, and the level of TC damage in the KP is also expected to become more serious (Emanuel et al. 2008; Knuston et al. 2010; Kim and Jain 2011; Kim et al. 2012a). In this regard, a quantitative effect evaluation of TCs and the preparation of measures to cope with them are urgently needed.

According to previous studies, TCs are closely related to the sea surface temperature (SST). In particular, the El Niño Southern Oscillation (ENSO) phenomenon has caused changes in the hydrometeorological patterns throughout the world, and has a statistically significant influence on the

Springer

Son *et al.* (SERRA, 2014)

- With regard to CP warming, it was found that TCs are more likely to be formed in the northwestern parts of the western Pacific region (Kim et al. 2011).
- This shift in warm SST forcing has a significant effect on large-scale ocean–atmosphere interactions, which leads to an enhancement of the TC landfall in East Asia including Korea and Japan (Chen and Tam 2010; Kim et al. 2011).
- This study tracked the path and genesis positions of TCs with particular focus on the Western North Pacific (WNP) and Korean Peninsula (KP) according to the three types of CP El Nino evolution patterns

## Seasonal rainfall variability in East Asia

Kim *et al.* (JWCC, 2016)

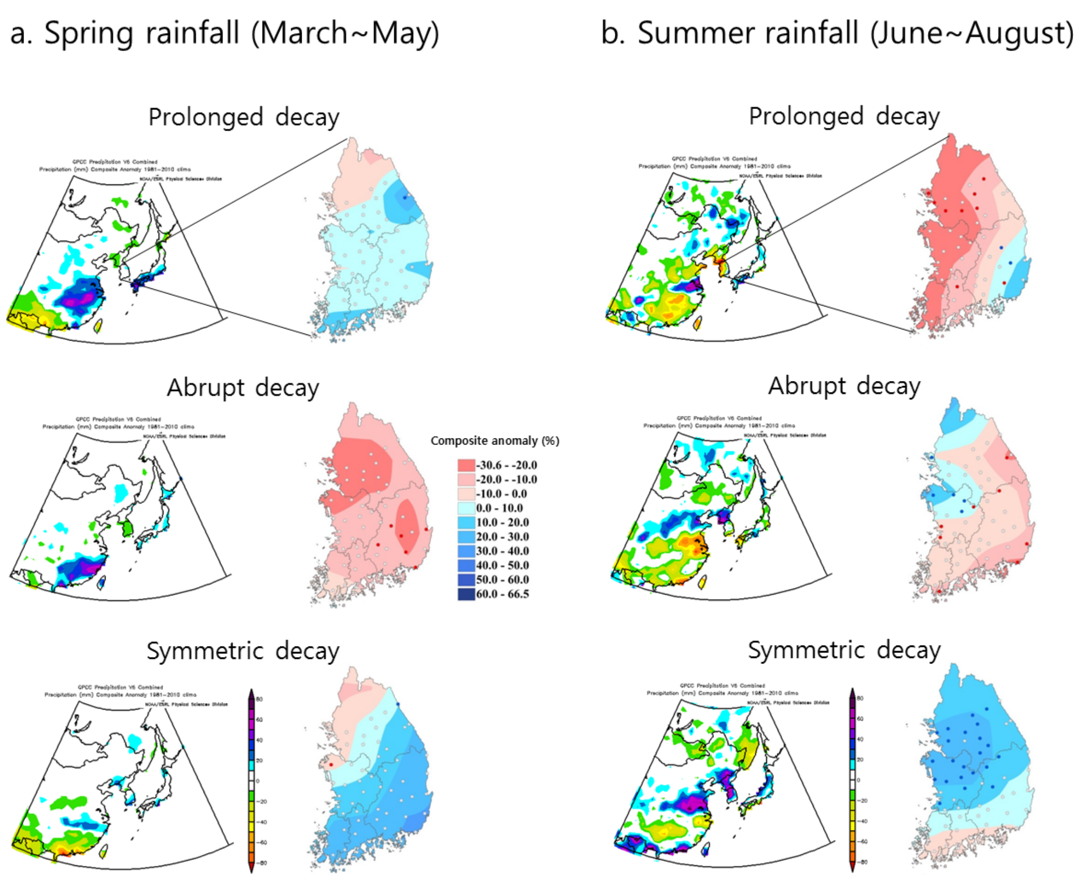
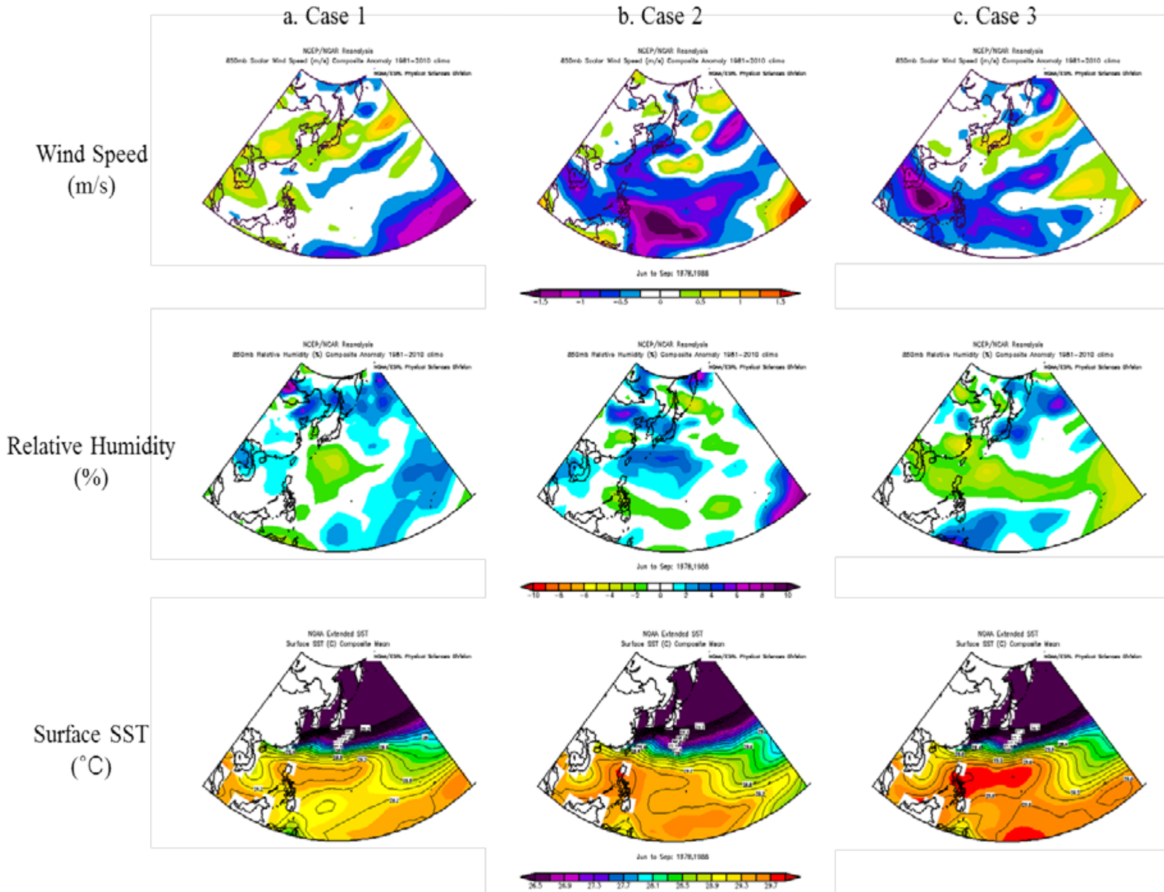



**Fig. 1.** Percentage changes in the composite anomalies of seasonal rainfall according to three evolution patterns of CP El Niño

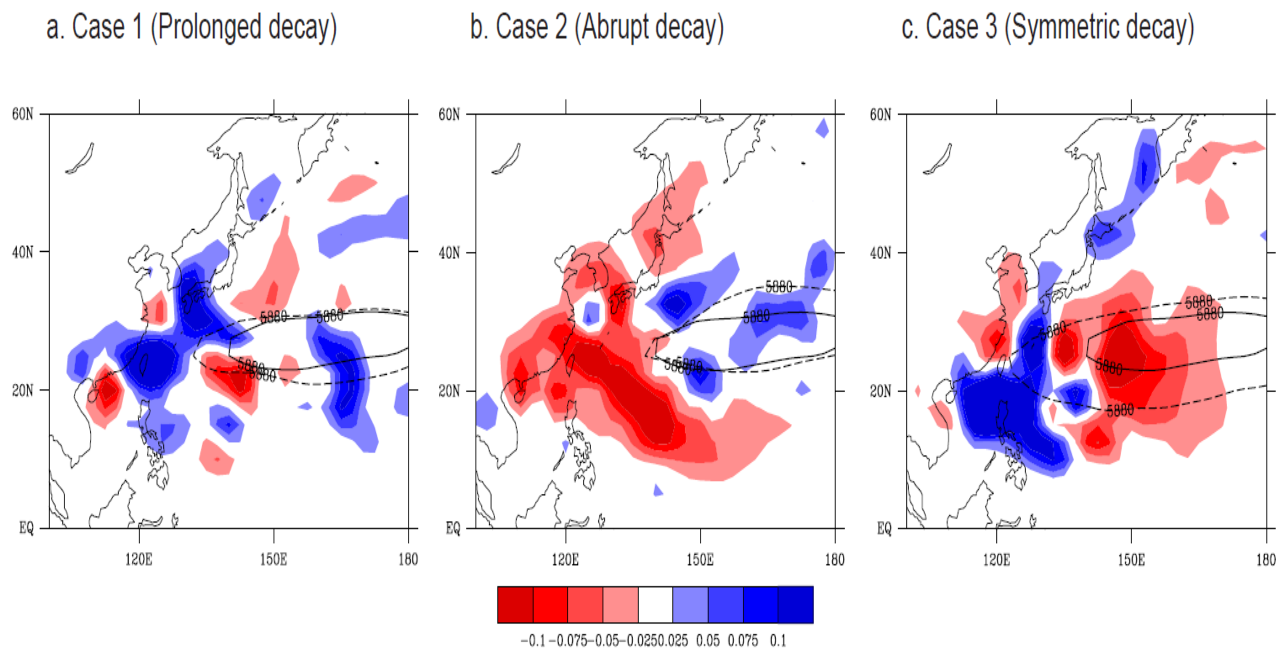



Son *et al.* (SERRA, 2014)

- TCs are generated on the vast tropical sea, where the wind is weak, humidity is high, and SST is more than 26.5 C (Wallace and Hobbs 2006; Nolan et al. 2007)
- The TCs affecting Korea develop mainly on the eastern sea of the Philippines or northwestern Pacific, and then move and approach China, Korea, or Japan as rotating clockwise in an arching pattern along the southern edges of the North Pacific high pressure.

**Fig. 2.** Large-scale environments in the WNP region during the TC season (June-September) corresponding to the CP El Niño events. Spatial patterns of composite anomalies of 850-hPa wind speed (m/s), 850-hPa relative humidity (%), and composite mean SST (° C) are shown for (a) Prolonged-decaying years, (b) Abrupt-decaying years, and (c) Symmetric-decaying years

## Tropical cyclone activities in the WNP region

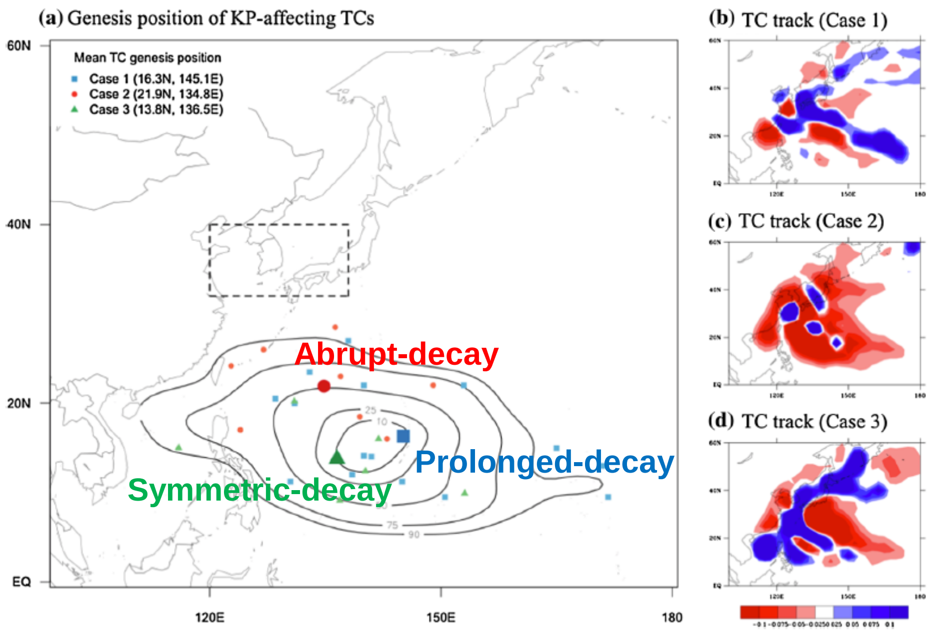



Kim *et al.* (SERRA, 2016)

**Fig. 3**. Composite anomalies (departures from the 1958-2007 norms) of the TC track density in the WNP region. a. Case 1 (Prolonged decaying years). b. Case 2 (Abrupt decaying years). c. Case 3 (Symmetric decaying years). The TC track density is estimated by counting the TC passage in each 2.5° × 2.5° grid. The dashed (solid) line indicates the June-September mean of the WNP subtropical high based on 5880gpm during each group of the CP El Niño years (50-year climatology)

# III. Case Studies

## Case 3




Son *et al.* (SERRA, 2014)

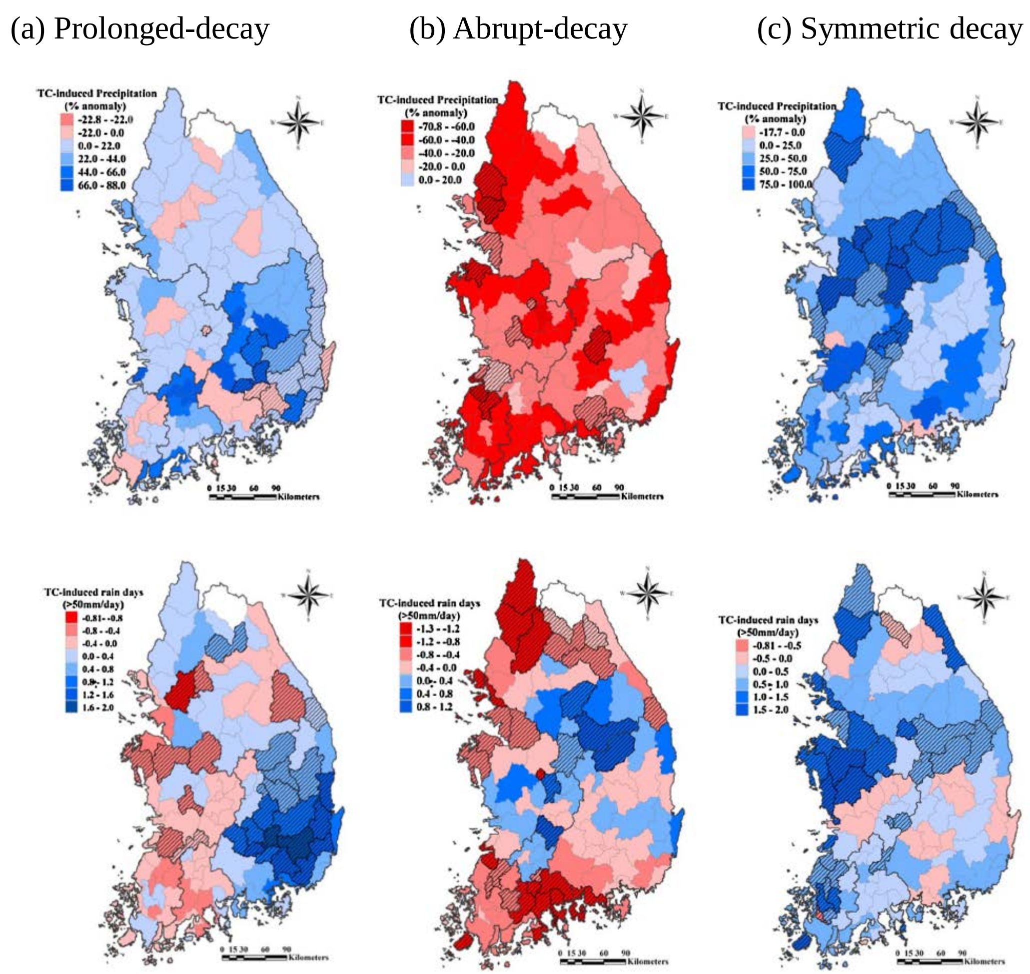
**Fig 4.** Genesis position and tracks of TCs passed through the Korean domain (shown by dashed line). a Summer genesis position of TCs, b–d TC tracks for three different CP cases. The contour lines (10th, lower quartile, median, upper quartile, 90th levels are shown) in (a) summarize the genesis position for 208 TCs affecting the KP during the period, 1966–2007. TC track anomalies shown in (b)–(d) were estimated by counting the number of TC occurrences in each 2.5 x 2.5 grid in the WNP region

- The track and genesis positions of the TCs affecting the KP and the abnormal SST pattern differed according to the evolution pattern of the CP El Nino.
- Case 1 (prolonged-decaying years) showed TC genesis positions slanted toward the east compared to the overall occurrence positions of 208 TCs (1966–2007).
- Case 2 (abrupt-decaying years) showed TC generation slanted toward the northwest direction. The TC genesis positions in the abrupt decaying years are relatively more adjacent to the KP than the points where the TCs occur in the other CP-El Nino evolution patterns
- Case 3 (symmetric-decaying years) showed TC generation toward the western direction.

## TC-induced rainfall over the KP

TC-induced rainfall (June–September)

Heavy Rainy Days (>50mm/day)




Son *et al.* (SERRA, 2014)

# Case 4: Statistical Drought Forecasting

J. Korea Water Resour. Assoc. Vol. 49, No. 4 (2016), pp. 305-314
doi: 10.3741/JKWRA.2016.49.4.305
pISSN 1226-6280
eISSN 2287-6138

## Agricultural drought monitoring using the satellite-based vegetation index

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[a]Dept. of Civil Engineering Joongbu University, Goyang 10279, Korea
[b]Urban Flood Research Institute, University of Seoul, Seoul 02504, Korea
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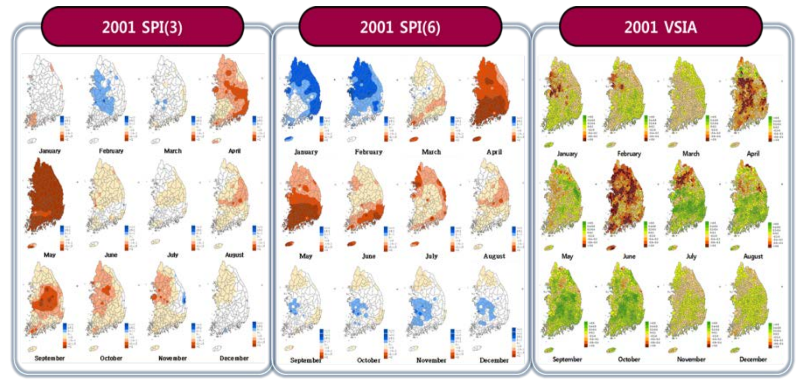
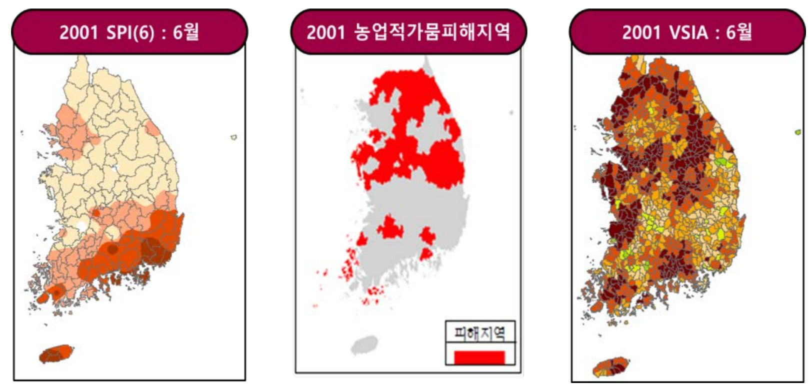
Paper number: 15-103
Received: 14 December 2015; Revised: 11 February 2016 / 22 February 2016; Accepted: 22 February 2016

### Abstract

In this study, a quantitative assessment was carried out in order to identify the agricultural drought in time and space using the Terra MODIS remote sensing data for the agricultural drought. The Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) were selected by MOD13A3 image which shows the changes in vegetation conditions. The land cover classification was made to show only vegetation excluding water and urbanized areas in order to collect the land information efficiently by Type1 of MCD12Q1 images. NDVI and EVI index calculated using land cover classification indicates the strong seasonal tendency. Therefore, standardized Vegetation Stress Index Anomaly (VSIA) of EVI were used to estimated the medium-scale regions in Korea during the extreme drought year 2001. In addition, the agricultural drought damages were investigated in the country's past, and it was calculated based on the Standardized Precipitation Index (SPI) using the data of the ground stations. The VSIA were compared with SPI based on historical drought in Korea and application for drought assessment was made by temporal and spatial correlation analysis to diagnose the properties of agricultural droughts in Korea.

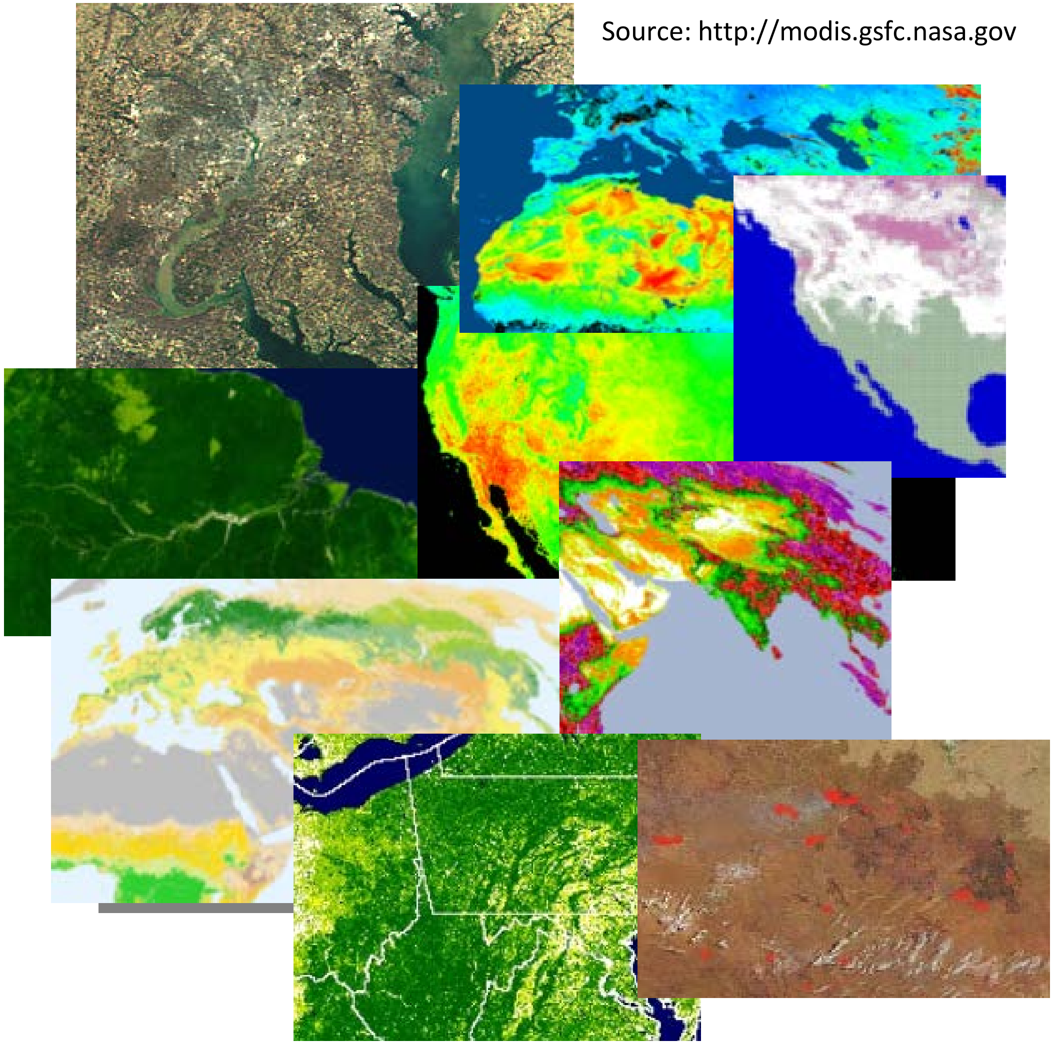
**Keywords:** DROUGHT, EVI, MODIS, NDVI, VSIA




Bae *et al.* (KWRA, 2016)

- MODIS Land Products



Source: http://modis.gsfc.nasa.gov

## Energy Balance Product Suite

- Surface Reflectance
- Land Surface Temperature, Emmis ivity
- BRDF/Albedo
- Snow/Sea-ice Cover

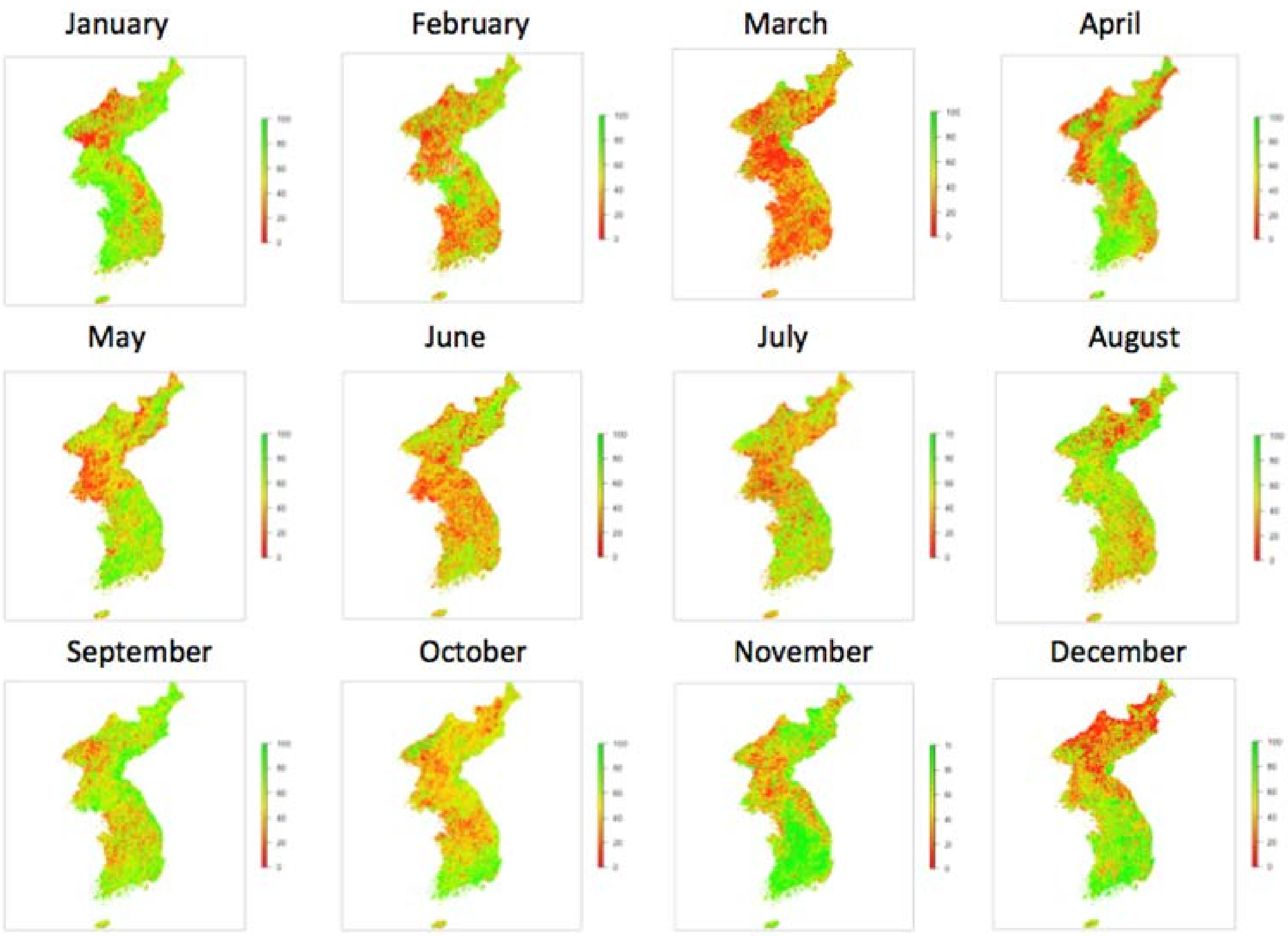
## Vegetation Parameters Suite

- Vegetation Indices
- LAI/FPAR
- GPP/NPP

## Land Cover/Land Use Suite

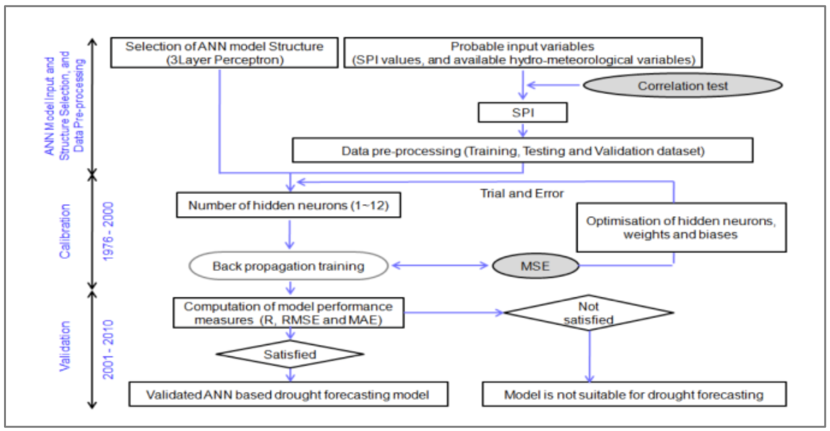
- Land Cover/Vegetation Dynamics
- Vegetation Continuous Fields
- Fire and Burned Area

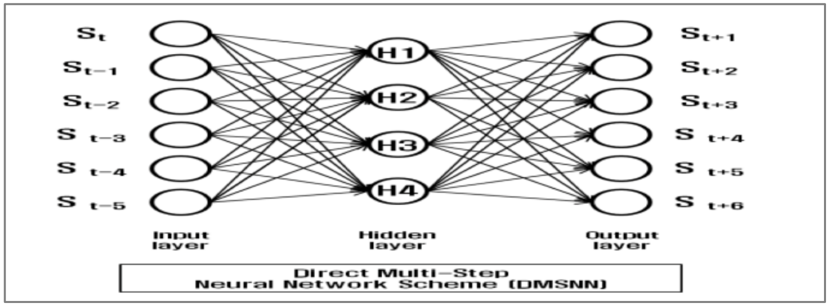
- Drought in 2015 - VCI



*Development of Drought Forecasting System based on the Multi Layer Perceptron (MLP) Artificial Neural Network Model*

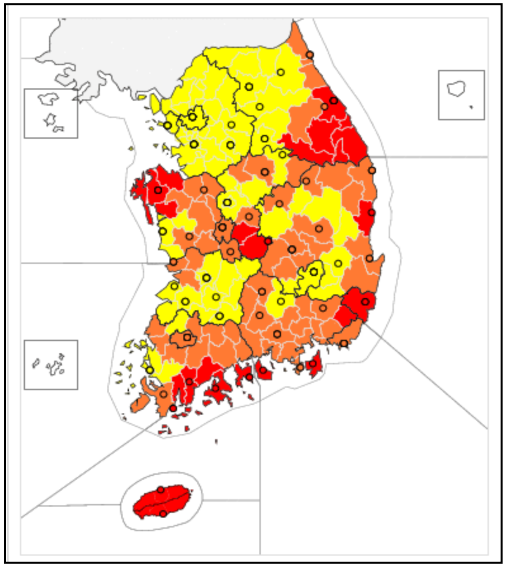
**MLP-ANN Model**




**GloSea5**


**3-month forecast**



GloSea5

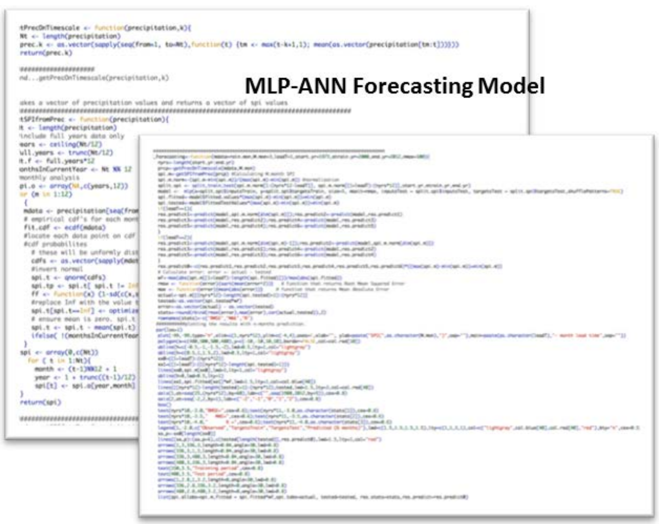
기상청

## Input data & System

Input: r_input_sample. txt (monthly data)
Station: 59 sites (stn_nm_table.txt)
Duration: Jan. 1981-present (Apr. 2015)

SPI Estimation model

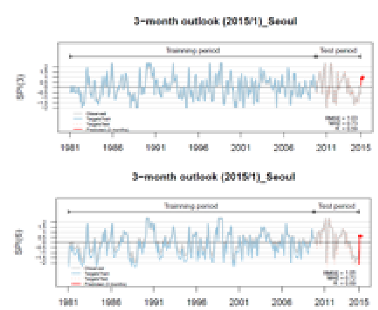
MLP-ANN Forecasting Model



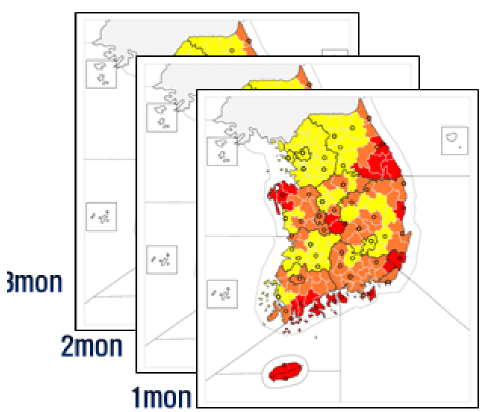
## Output

# Drought Forecasting System

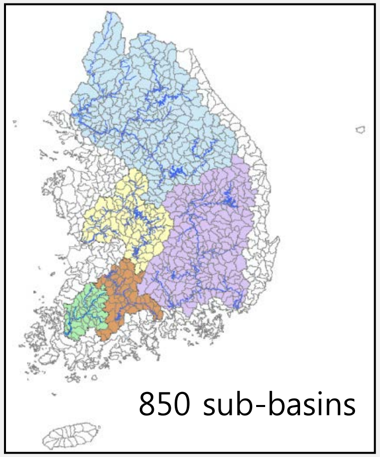
3-month Outlook



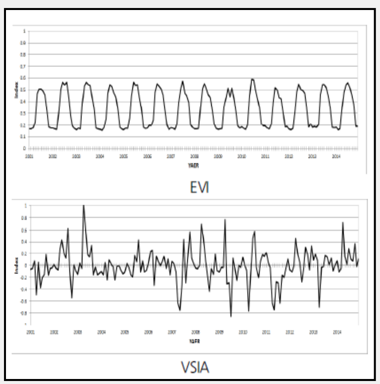

Result: Training period(85%)+Test period(15%)
Number of Training: 1000
Number of Station: 59 sites in Korea
Runtime: 60 sec
Statistics: RMSE, MAE, R

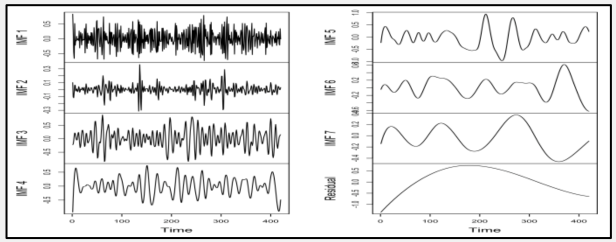


## Statistical Drought Forecasting

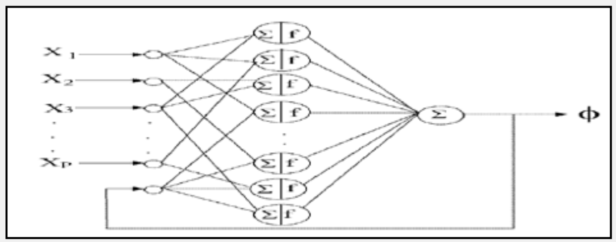



Monthly index (2001-2014)

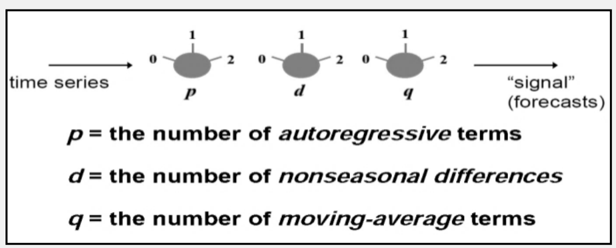


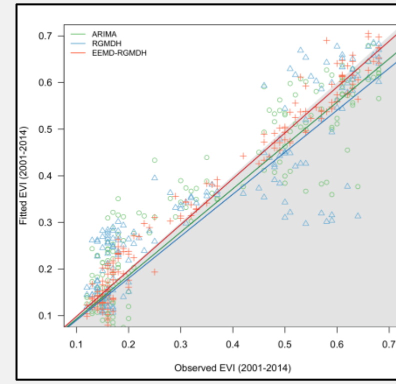

Ensemble Empirical Mode Decomposition



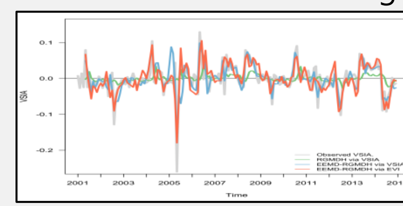

Revised GMDH-Type Neural Network Algorithm

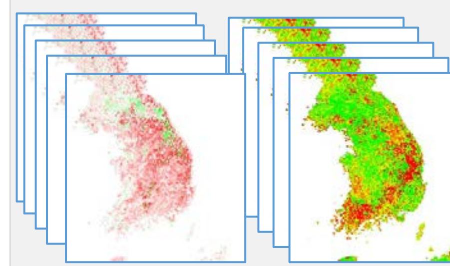



Autoregressive Integrated Moving Average (ARIMA)

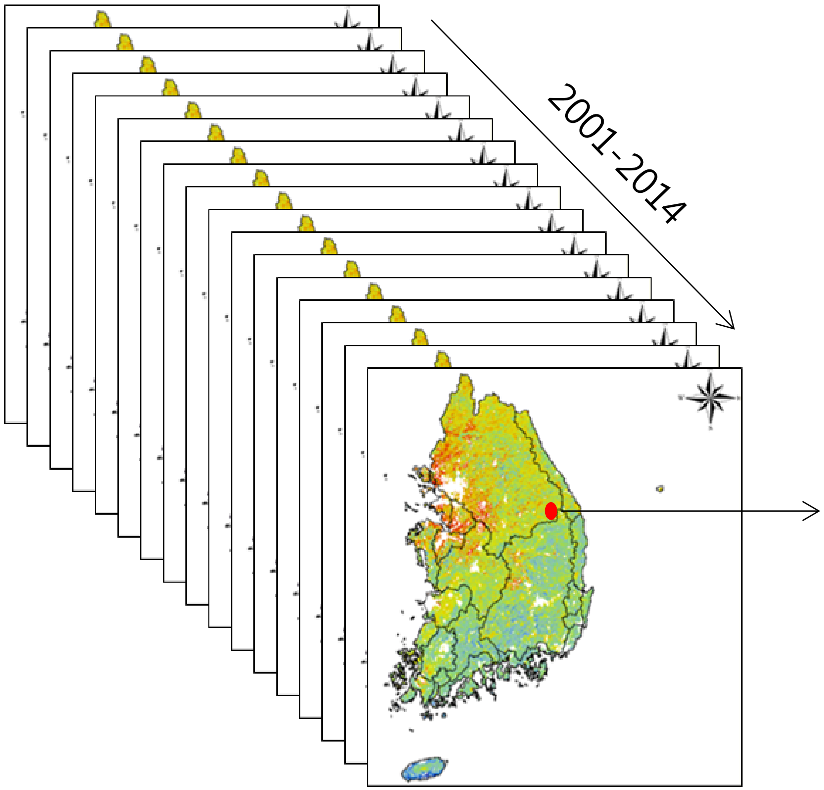



Short term forecasting



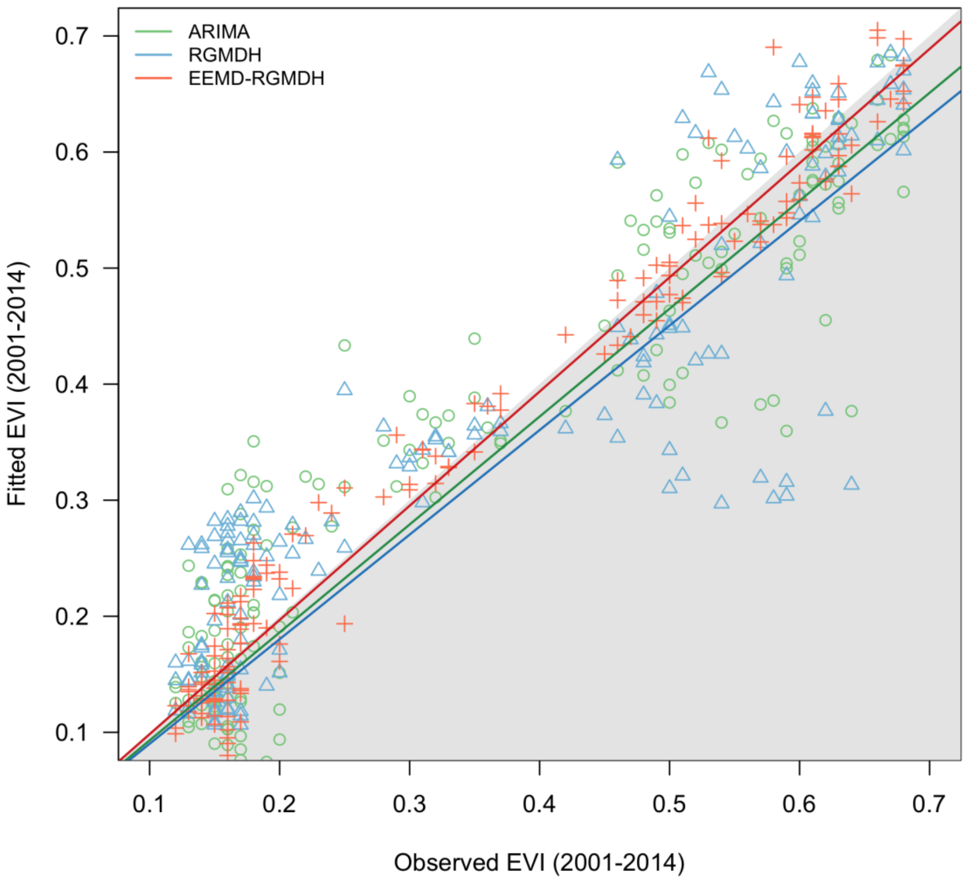



EVI VSIA

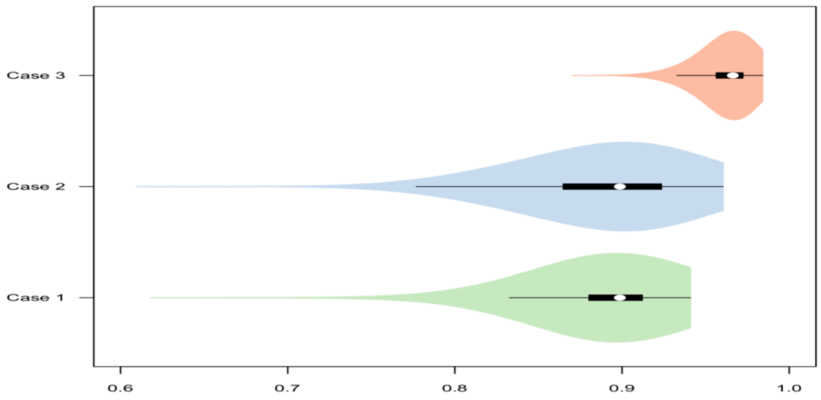


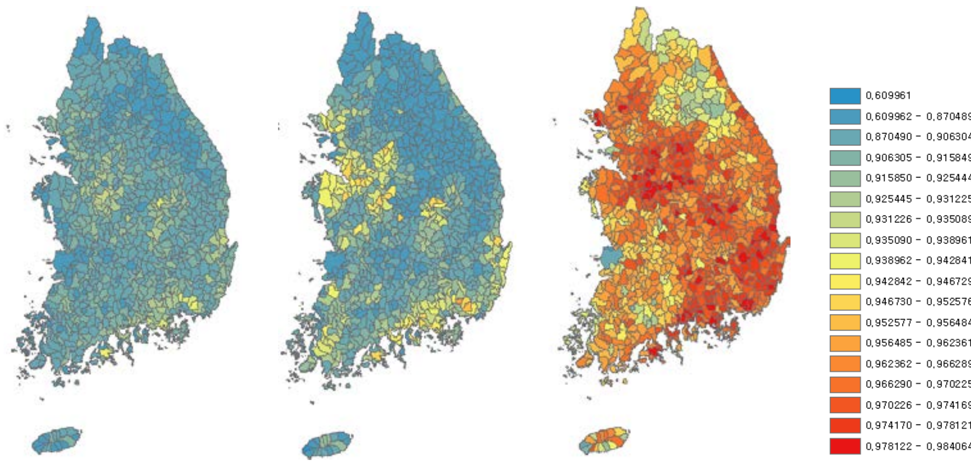

Monthly EVI (Enhanced Vegetation Index)

Kwangdong dam (100101)

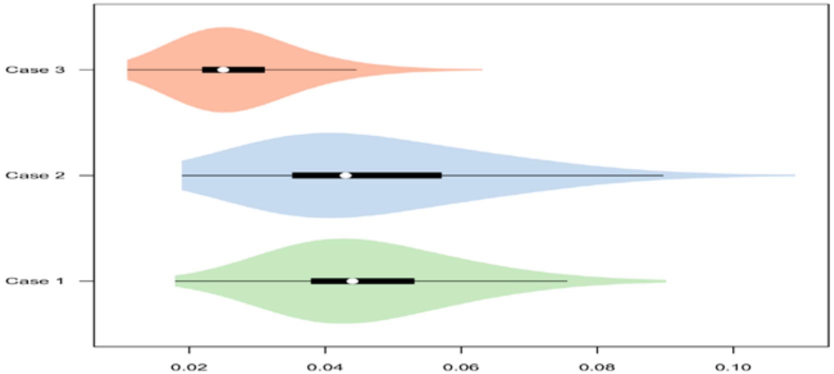


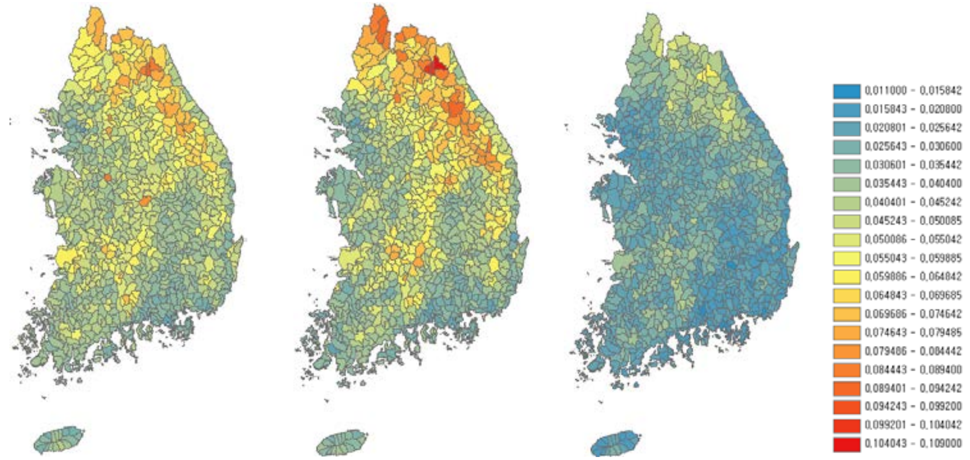
- Assessing forecast model performance ($R^2$)



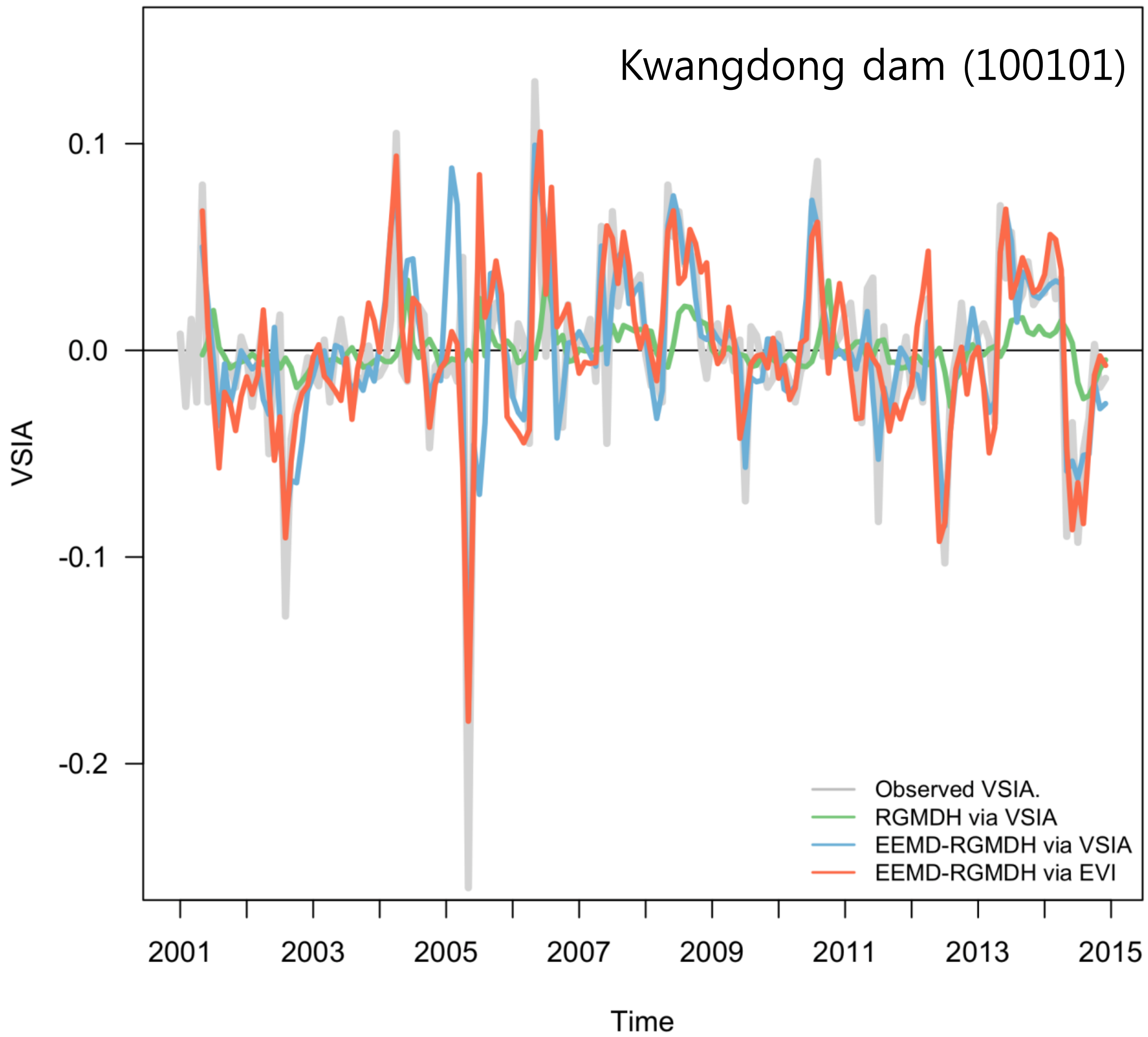




- Assessing forecast model performance (RMSE)



- Assessing forecast model performance



# Case 5: Integrated Regional Risk Assessment

***2014 BNU Study***

"A Case Study of Regional Risk Assessment of River Restoration Project: Nakdong River Basin in South Korea"

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## A case study of regional risk assessment of river restoration projects: Nakdong River Basin, South Korea

Jong-Suk Kim, Sun-Kwon Yoon, Minha Choi and Young-Il Moon

**ABSTRACT**

An integrated approach to risk assessment that can pose significant challenges to mitigation and adaptation at the local or regional levels in the context of climate change was developed. First, a conceptual framework for flood risk analysis was developed based on the hydrologic hazard and the socioeconomic vulnerability of a region. Second, weighting factors for each indicator were estimated using the modified Delphi approach based on the results of a survey of an expert group. Third, geographic information system analysis described the hydrologic risk at the regional level before and after completion of the Four Major Rivers Restoration Project at the Nakdong River Basin, South Korea. Finally, sensitivity analysis was conducted to evaluate the extent of the resilience of the Nakdong River Basin based on climate change scenarios to extend the existing research. It was found that the effect of river restoration project in the future would be insignificant in terms of risk control over regions where floods are likely to increase upon climate change. We believe that this study provides useful information for the development of scientific, effective risk management tools for consistent application in a time of changing climate.

**Key words** | climate change scenarios, four major river restoration project, hazard, hydrologic risk, vulnerability

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### INTRODUCTION

Climate change can be defined as a change in the average climatic conditions of a certain region over an extended period (IPCC 2007). Evidence of recent climate change is seen all over the world in such changes as the reduction in the volume of the Alpine glaciers and the increase in the average global temperatures (Thomas *et al.* 2006; Hegerl *et al.* 2007). Rainfall discontinuity, seasonal fluctuation, and changes to periodicity due to climate change may be significant factors contributing to recent uncertainty concerning the security and sustainability of stable water supplies (Hegerl *et al.* 2007; Bae *et al.* 2008; Kim *et al.* 2012).

A large body of published research concerns the management of risk to global water resources related to climate change and the evaluation of the extent of vulnerability of water resources to climate change (Anselmo *et al.* 1996; Kasperson *et al.* 2005; Zheng *et al.* 2009; Wang *et al.* 2011). These studies suggest a variety of impact evaluation and management measures that can be used to respond and adapt to climate change. Despite the growing body of research that predicts and evaluates the potential effects of climate change on water resources, it is, in fact, difficult to precisely predict hydrometeorological phenomena. The challenge partly arises from the high level of uncertainty involved and the ambiguity of the standard of overall evaluation.

Watson *et al.* (1996) investigated the international research trends in risk analysis vulnerability evaluation related to climate change. They proposed that climate change is a multi-dimensional phenomenon in which vulnerability, defined as the extent to which climate change may cause damage to systems, consists of sensitivity, adaptation, and exposure. Connor & Hiroki (2005) also argued that climate change vulnerability is multi-dimensional and proposed a meteorological and hydrologic index, a socioeconomic

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Kim *et al.* (JWCC, 2015)

# III. Case Studies

Case 5

Beijing Normal University
ESPRE
State Key Laboratory of Earth Surface Processes and Resource Ecology

- Selected among the 10 advanced young scientists for 2010/2014 "Summer Institute for Disaster and Risk Research" leaded by professor Roger Kasperson at Clark University, the U.S., and funded jointly by the State Administration of Foreign Experts Affairs, Ministry of Education, and the Beijing Normal University in China.

- Discussed with both renowned and emerging researchers (primarily junior faculty, young researchers, post-docs, and advanced doctoral students) in various areas including engineers, economists, and social scientists regarding climate-related issues including structural/non-structural measures for the disaster and risk.


# Four Major Rivers Restoration Project


naturalresources2011.wordpress.com

- The project was spearheaded by former South Korean president Myung-bak LEE and was declared complete on October 21, 2011.
- It was first announced as part of the "Green New Deal" policy launched in January 2009, and was later included in the government's five-year national plan in July 2009.
- The government estimated its full investment and funding totaled 22.2 trillion won (Approximately 17.3 billion USD)

**The project had five key objectives:**

- securing abundant water resources
- implementing comprehensive flood control measures
- improving water quality and restoring river ecosystems
- creating multipurpose spaces for local residents
- regional development centered on the rivers

# Risk = f (Hazard, Vulnerability)

$$IRRI(j) = \sum_{i=1}^{m} h_i \times H_i + \sum_{j=1}^{n} v_j \times V_i$$

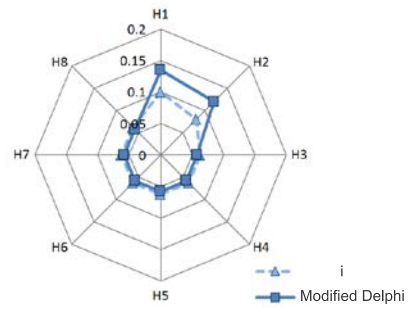
Here, IRRI is the integrated risk index, *h* and *v* are the weights of each factor, *H* is the hydrologic hazard index, and *V* is the socioeconomic vulnerability index

| | Components | Determinants | Indicators |
|---|---|---|---|
| Integrated Regional Risk Index | Hydrologic Hazard | Trigger | Number of days over 150mm rainfall per day; $h_1$ |
| | | | Daily rainfall probability of 100 years storm; $h_2$ |
| | | Condition | River length (km); $h_3$ |
| | | | Area rate of un-refurbished area (%); $h_4$ |
| | | | Slope of watershed; $h_5$ |
| | | Response | Water level changes at the connection of main stream and tributaries; $h_6$ |
| | | | Effective area of backwater from newly installed dams; $h_7$ |
| | | | Historical flood damage amount; $h_8$ |
| | Socio-economic Vulnerability | Exposure | Number of people over 61 and less tan 15 years old; $v_1$ |
| | | | Population density (number of people/km$^2$); $v_2$ |
| | | | Town area near river; $v_3$ |
| | | Susceptibility | Property density($/m$^2$); $v_4$ |
| | | Resilience | Sewer ratio (%); $v_5$ |
| | | | Prevention results of local governments; $v_6$ |
| | | | Financial independence (%); $v_7$ |
| | | | Number of government employees; $v_8$ |
| | | | Number of hospital per million people; $v_9$ |
| | | | Hazard mitigation system; $v_{10}$ |

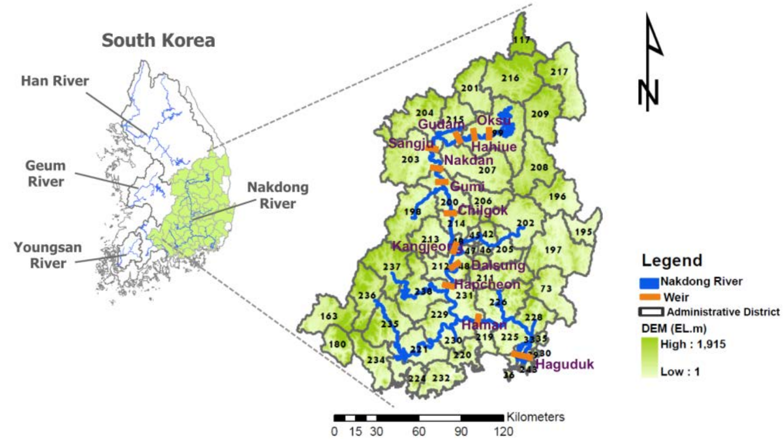
※ Indicators used here are obtained from the national achievements of Korea National Emergency Management Agency

a. Hydrological hazard

b. Socio-economic vulnerability




Delphi
Modified Delphi

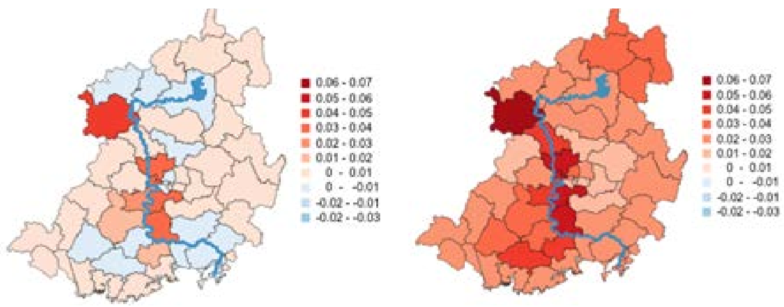



| ID | Name | ID | Name | ID | Name | ID | Name | ID | Name | ID | Name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | Jungu, Busan | 44 | Namgu, Daegu | 196 | Bukgu, Pohang | 206 | Gunwi | 217 | Uljin | 231 | Changnyeong |
| 27 | Seogu, Busan | 45 | Bukgu, Daegu | 197 | Kyungju | 207 | Uideong | 219 | Changwon | 232 | Goseong |
| 30 | BusanJingu | 46 | Suseonggu | 198 | Kimcheon | 208 | Cheongsong | 220 | Happogu, Changwon | 234 | Hadong |
| 33 | Bukgu, Busan | 47 | Dalseogu | 199 | Ahndong | 209 | YeongYang | 221 | Jinju | 235 | Sancheong |
| 35 | Keumjeonggu | 48 | Danseong | 200 | Gumi | 211 | Cheongdo | 224 | Sacheon | 236 | Hamyang |
| 36 | Kangseogu | 73 | Ulju | 201 | Yeongju | 212 | Goryeong | 225 | Kimhae | 237 | Geochang |
| 39 | Sasanggu | 117 | Taeback | 202 | Yeongju | 213 | Seongju | 226 | Miryang | 238 | Hapcheon |
| 41 | Jungu, Daegu | 163 | Namwon | 203 | Sangju | 214 | Chilgok | 228 | Yangsan | 243 | Sahagu, Busan |
| 42 | Donggu, Daegu | 180 | Gurye | 204 | Munkyung | 215 | Yecheon | 229 | Uiryeong | | |
| 43 | Seogu, Daegu | 195 | Namgu, Pohang | 205 | Kyungsan | 216 | Bonghwa | 230 | Hanan | | |

# Integrated Regional Risk Analysis

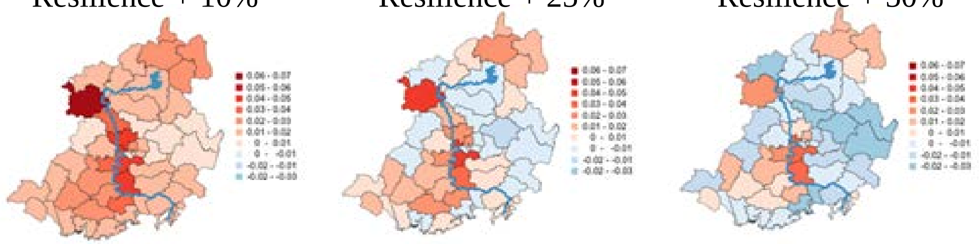
(a) Risk difference before and after the restoration project

(b) Risk difference associated with climate change

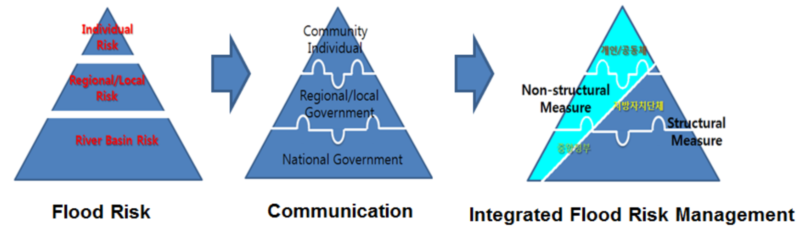


- ✓ The IRRI would increase by 1.5% after the project and 19.6% due to climate change after the project.
- ✓ It turned out that the effect of river restoration project in the future would be insignificant in terms of risk control over regions where floods are likely to increase upon climate changes.

Resilience + 10% Resilience + 25% Resilience + 50%



- ✓ The resilience of the Nakdong River Basin increased by 4.8, 10.0, and 14.0% with increases of 10, 25, and 50%, respectively.
- ✓ The results strongly suggest that: (a) future climate can be handled effectively by increasing basin resilience in each administrative district; and (b) it is feasible to use structural/nonstructural measures as basin characteristics.




- In this study, the risk due to climate change was defined as the combination of hydrologic hazard and socioeconomic vulnerability
- This study is advantageous because it evaluates hydrologic risk due to climate change using standardized and quantitative factors.
- Specifically, this study provides a measure with the potential to obtain basic information to efficiently evaluate the changes to regional hydrologic risk over a river area affected by the Four Major Rivers Restoration Project as well as a method for assessing systematic water resource management and climate change vulnerability

## Case 6: Hydroclimatic change on the regional scale

Climatic Change (2010) 102:699–707
DOI 10.1007/s10584-010-9933-3

LETTER

**High-resolution streamflow trend analysis applicable to annual decision calendars: a western United States case study**

**A letter**

**Jong-Suk Kim · Shaleen Jain**

Received: 29 December 2009 / Accepted: 10 July 2010 / Published online: 31 July 2010


**Abstract** Changes in the seasonality of streamflow in the western United States have important implications for water resources management and the wellbeing of coupled human-natural systems. An assessment of changes in the timing and magnitude of streamflow resolved at fine time scales (days to weeks and seasons) is highly relevant to adaptive management strategies that are responsive to changing hydrologic baselines. In this paper, we present a regional analysis of the changes in streamflow seasonality through a broad classification of streams and quantification of increases and decreases in flow, based on a quantile regression methodology. This analysis affords a useful research product to examine the diversity of trends across seasons for individual streams. The trend analysis methodology can identify windows of change, thus revealing vulnerabilities within decision calendars and species lifecycles, an important consideration for adaptation and mitigation efforts.

**1 Introduction**

Information needs for effective decision-support in a changing climate require data that are tailored to suit needs of a range of sensitive sectors and systems.

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Springer

Kim and Jain (CCL, 2010)

- Information needs for effective decision-support in a changing climate require data that are tailored to suit needs of a range of sensitive sectors and systems.
- Recent evidence of shifts in the magnitude and timing of streamflow in the western United States is a signal of regional hydrologic change and suggests a need for mitigation and adaptation measures.
- The efficient uptake and assimilation of information regarding changes in seasonality depend upon: (a) the availability of analyses tailored to match the time scales of decisions, and (b) metrics suited to individual decision calendars of at-risk systems.

## Seasonal cycle of streamflow in the western US

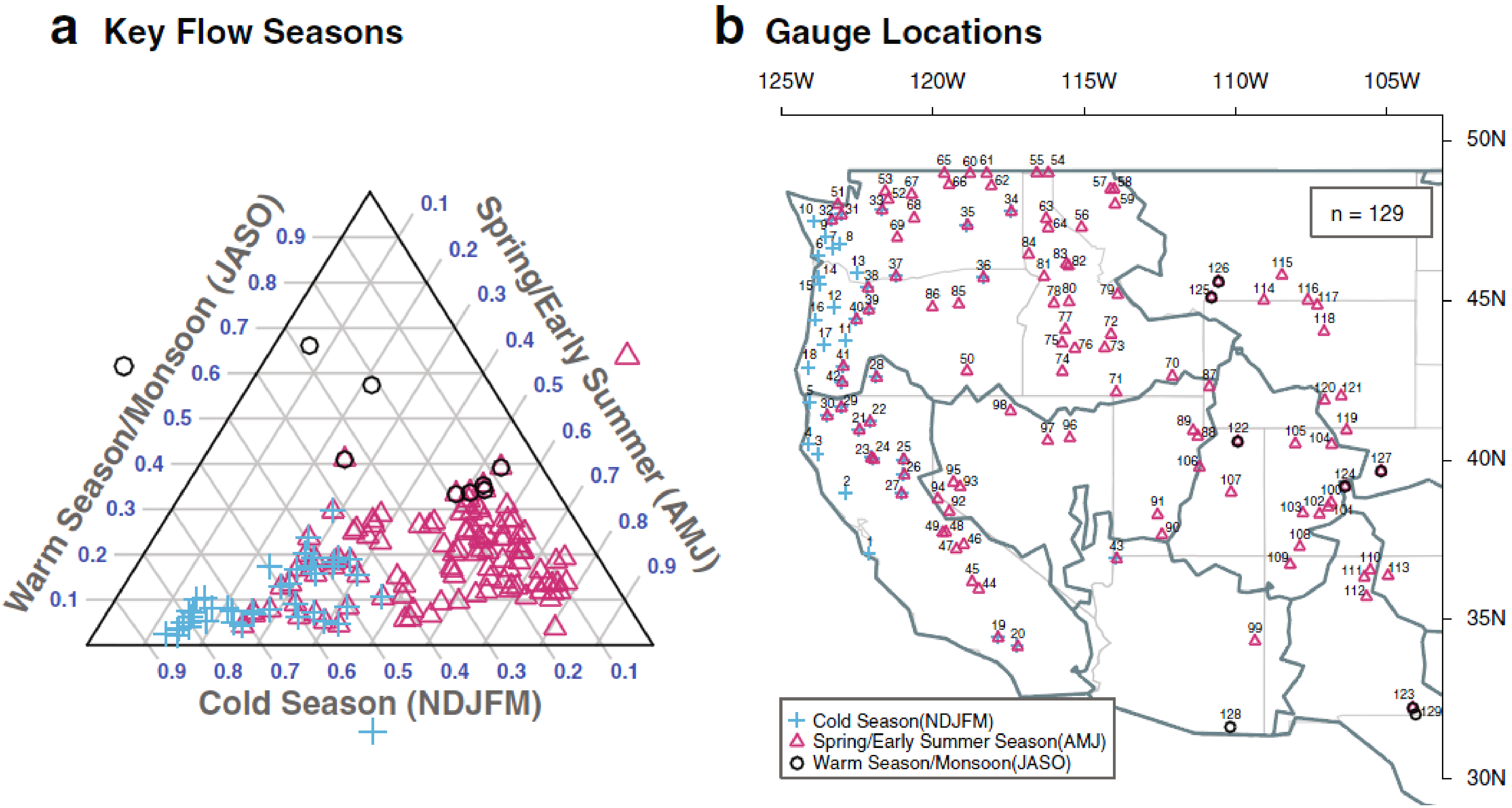



**Fig 1.** Seasonal cycle of streamflow in the western United States. **a** A ternary diagram showing the fraction of water year runoff volume for the three key seasons. **b** Map of the eleven western states showing the location of streamgauges with serially complete records for the 1948–2007 period. The key flow season(s) associated with each streamgauge are identified with distinct symbols.

## Trend analysis on daily streamflow in the western US

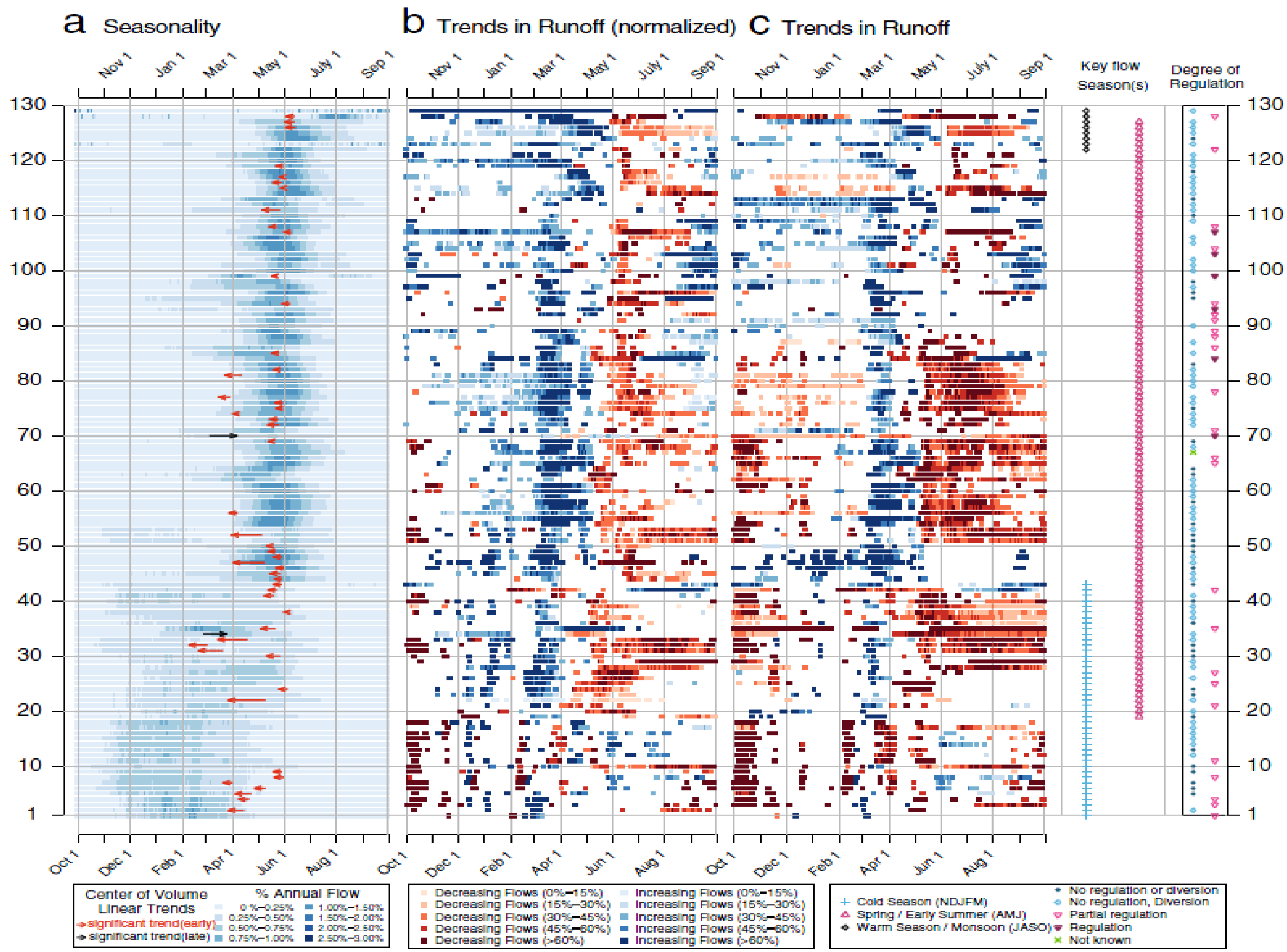
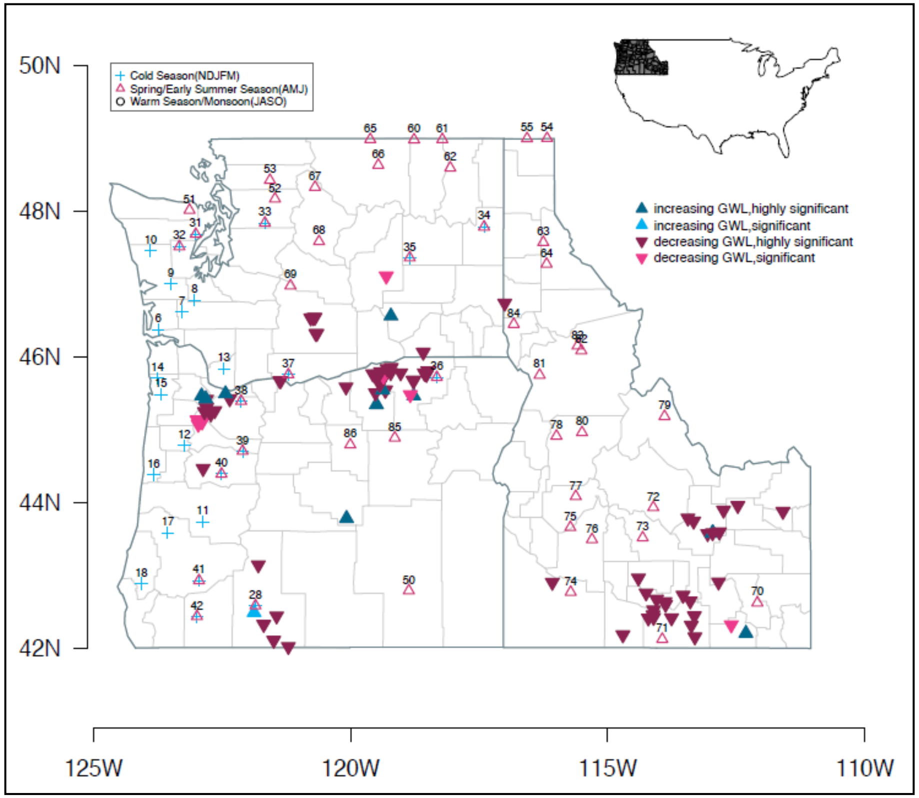
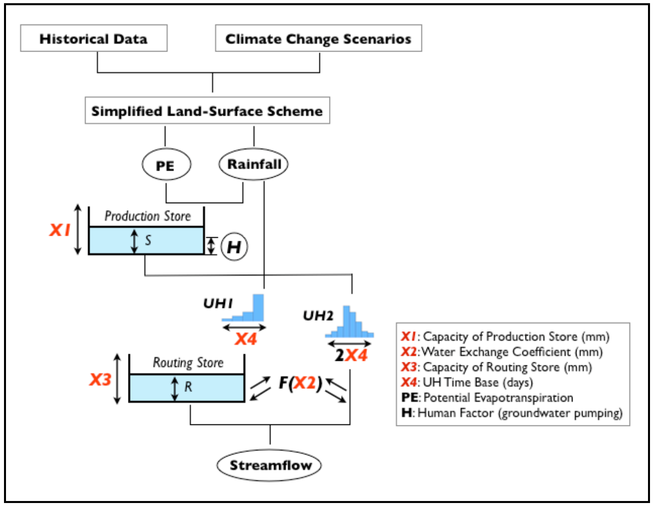



**Fig 2.** Trend analysis based on a median quantile regression of daily streamflow in the western United States (1948–2007). **a** Discharge for each day is expressed as a percent of the total water year discharge.

## Trends in Ground-Water Level

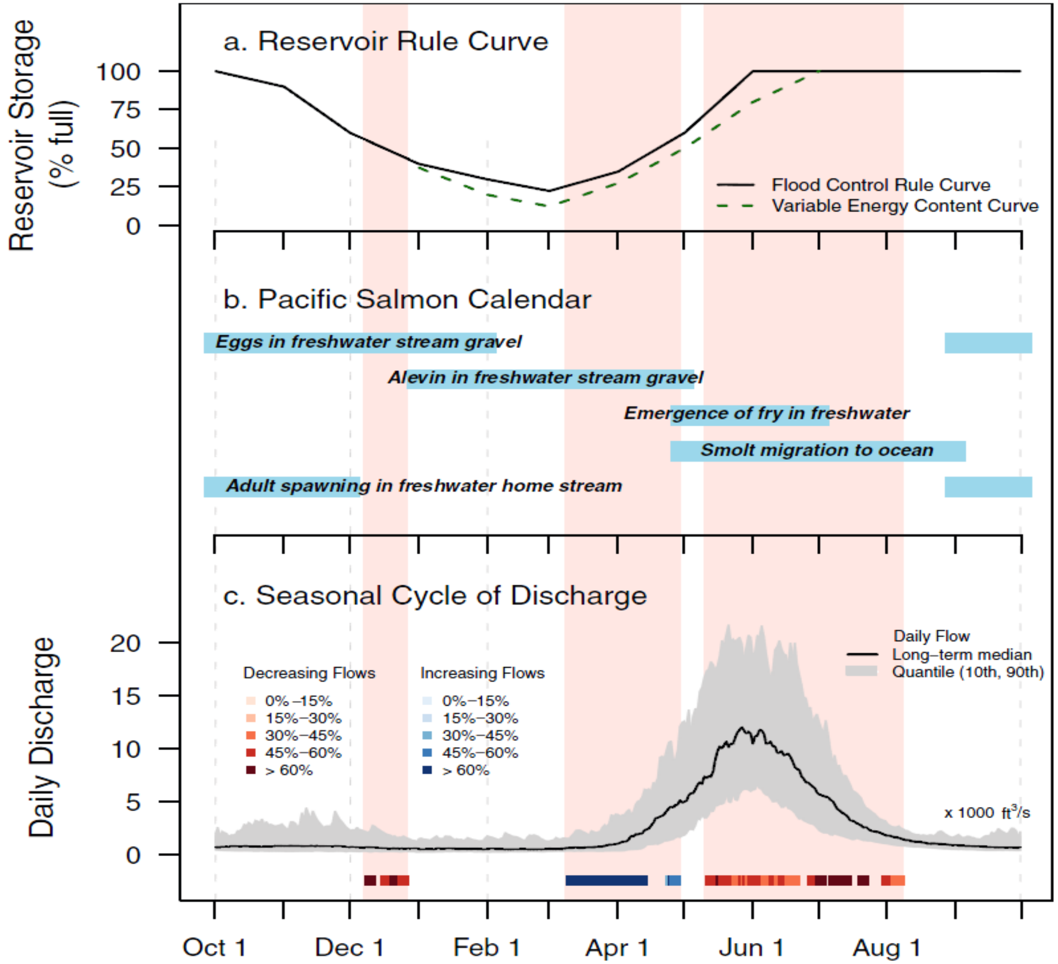



<hydrologic modeling framework>

**Fig. 3.** Long-term trends in annual groundwater level (GWL) over the 1960-2000 period based on the USGS monitoring network data. Based on a Mann-Kendall test for trends, the p-values, increases (decreases) in groundwater level are classified as highly significant ($p < 0.05$) and significant ($0.05 < p \leq 0.1$) and color coded blue (red).

## Decision calendars and information context




- The analyses presented here facilitates the task of understanding the changes in timing and magnitude of streamflow across the region at high temporal resolution
- Understanding the potential impacts of changes in the seasonality of streamflow is a critical first step in adaptation and risk mitigation efforts. Numerous water-sensitive human-environmental systems rely on annual decision calendars.

**Fig 4.** The linked nature of streamflow, decision-calendar for water management, and salmon lifecycle in the Columbia River Basin. **a** Reservoir rule curves in Columbia River basin.

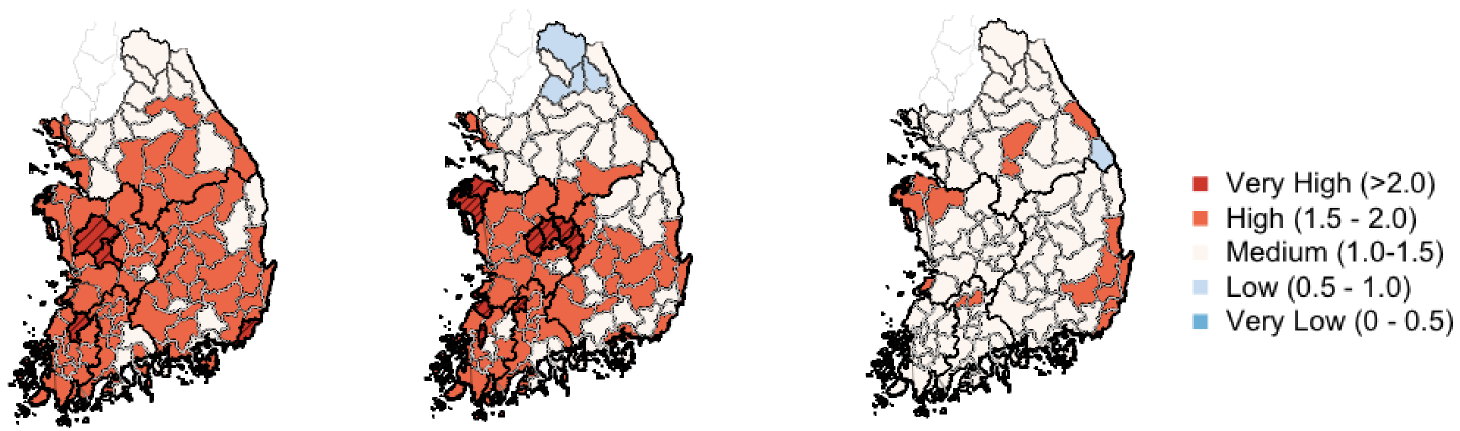
# IV. Ongoing Studies & Research Plans


1. Improve Hydroclimatic Forecasts
2. Support Regional Climate Impacts Studies

# Conditional Hydrologic Risk (SPI≤-1.0) based on RCP 4.5/8.5

$$Risk(i,j)=\frac{P[(Q_j^{S_i}\le Q_{25j}^{S_0})\,|\,SPI_j^{S_i}\le -1.0]}{P(Q_j^{S_0}\le Q_{25j}^{S_0})}$$

**SPI3≤-1.0**

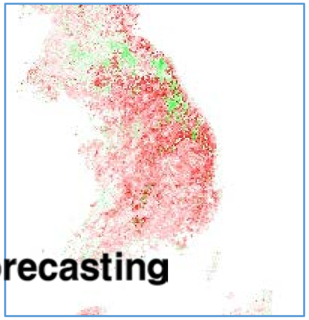



$S_1$ (2011-2040) $S_2$ (2041-2070) $S_3$ (2071-2099)

- ✓ Based on the conditional hydrologic risk assessment, specific vulnerabilities can be diagnosed.
- ✓ The drought index-based risk assessment methodology for streams across the river basins allows tailoring of information for watershed-specific water allocation and management.

# IV. Ongoing Studies & Research Plans

- **Satellite DB**
  - Amount of precipitation/Temperature
  - Soil water and Vegetation
  - Evapotranspiration...
- **Correlation analysis between different indices**
- **Development of hydrologic drought index and forecasting**



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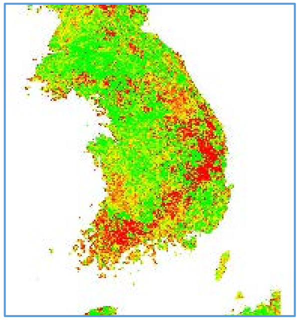
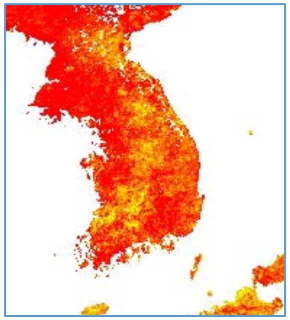
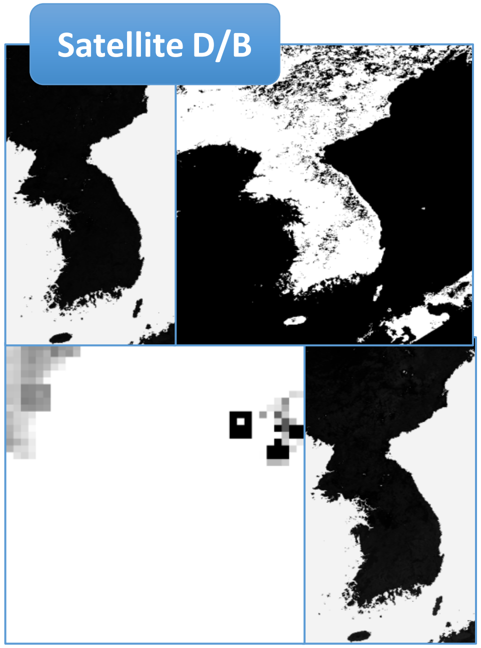
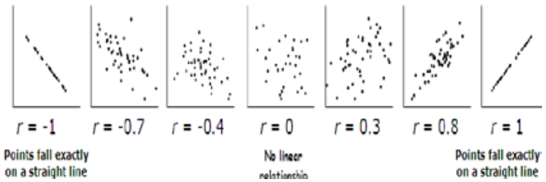


✓ VCI

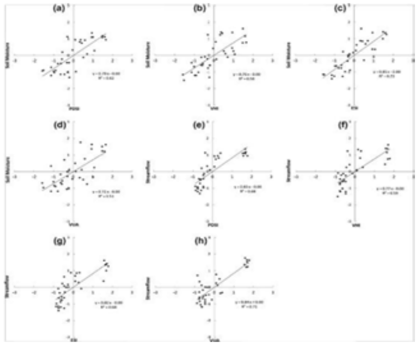


✓ TCI

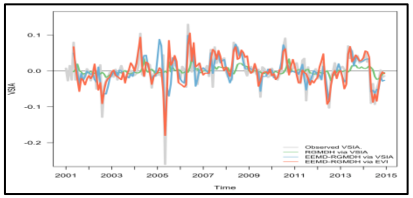



<Correlation Coefficient>



Hydrologic Drought Index



# IV. Ongoing Studies & Research Plans

## • Coping with Extreme Drought in a Changing Climate

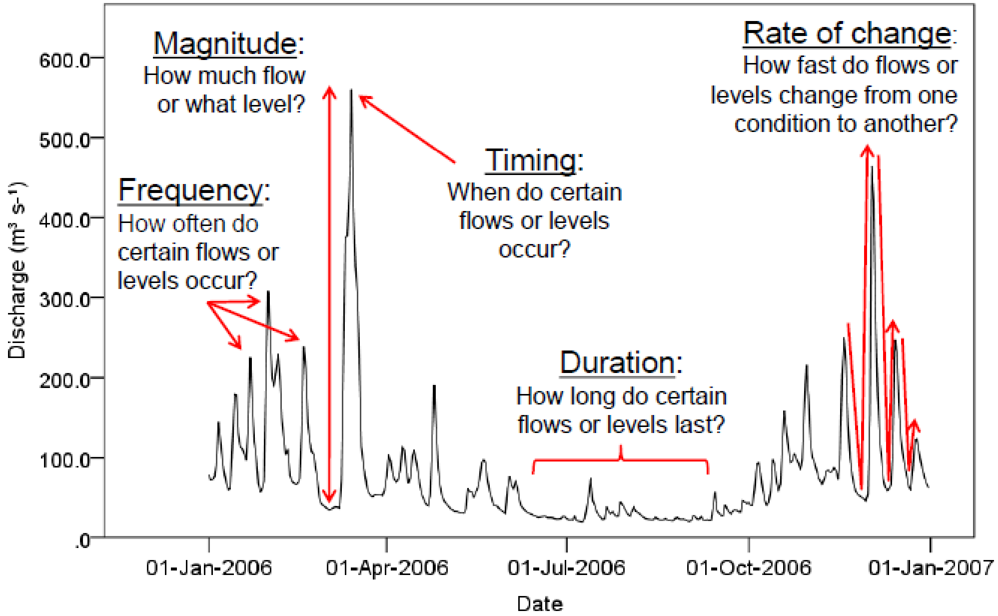
- ✓ Establishing and managing information about drought damage for different areas & cases
- ✓ Finding out problems in using drought indexes and suggesting ways to standardize drought information in different organizations (building up cooperative systems for different ministries to apply unified drought information)
- ✓ Re-evaluating existing dams and re-adjusting water supply plans (past dam development was done for unmeasured areas, post-four major river restoration project in Korea)
- ✓ Building an integrated control tower in charge of drought management (Discussing and coordinating major national policies, making national plans and laws for emergency to cope with extreme drought)

# IV. Ongoing Studies & Research Plans

*Sensitivity of ecologically relevant flow metrics to climate variations*

Environmental Flow Requirements or eflows are: **"The quantity, quality and timing of water flows required to sustain freshwater ecosystems and the human livelihoods and well-being that depend on these ecosystems."** -*The Brisbane Declaration* made at the International River*symposium* in 2007

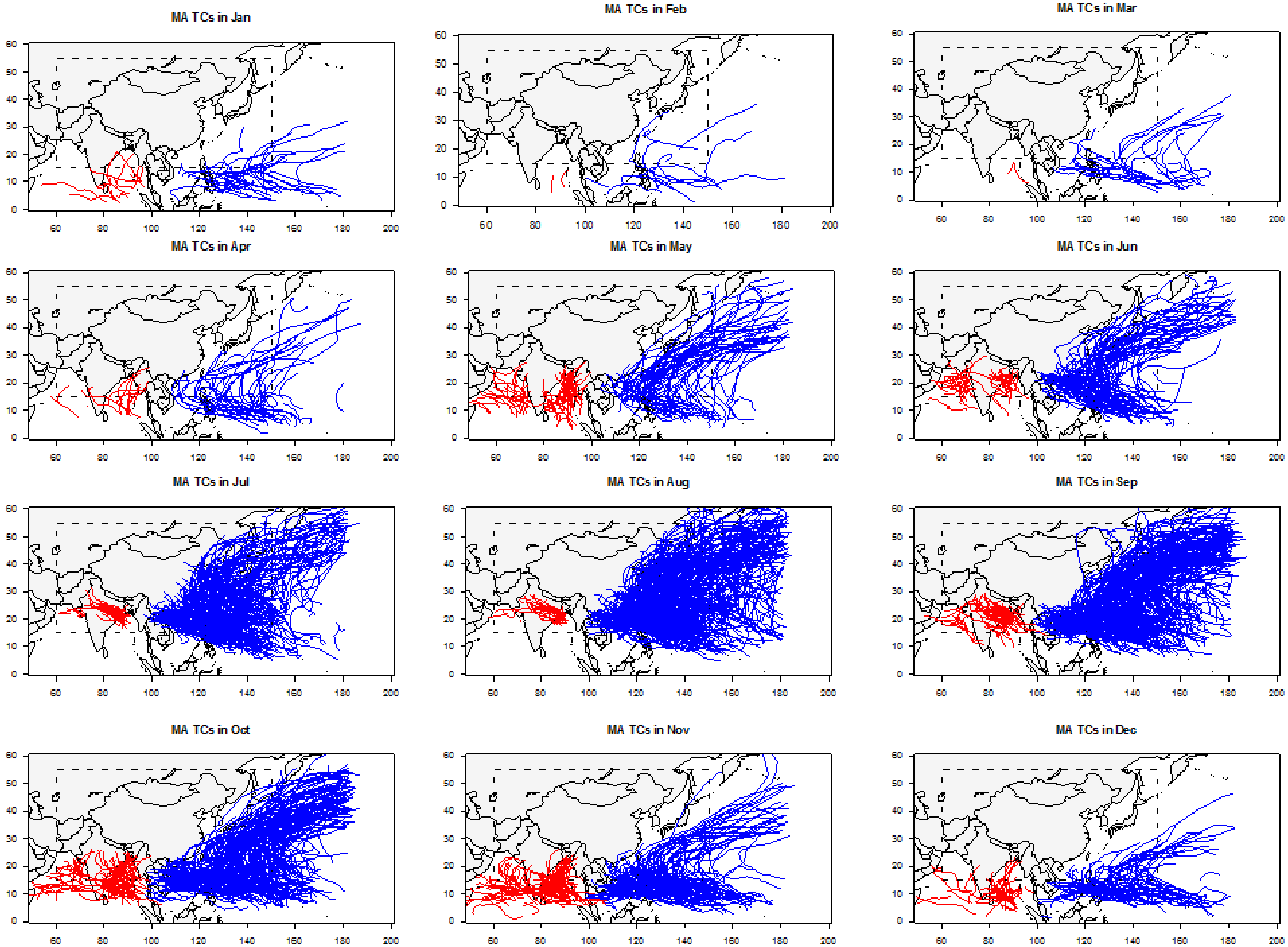
**Quantifying the ecohydrological regime**



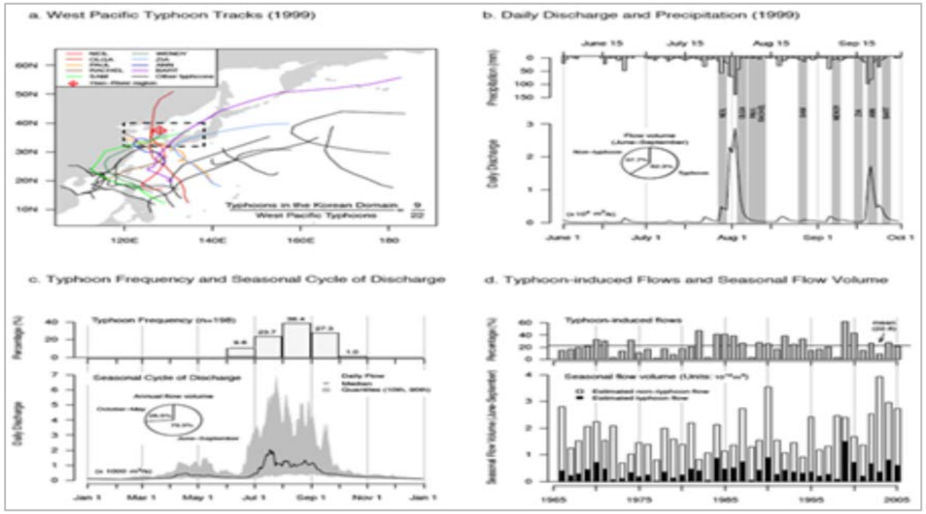

**Adapted from Wendy A. Monk(2011)**

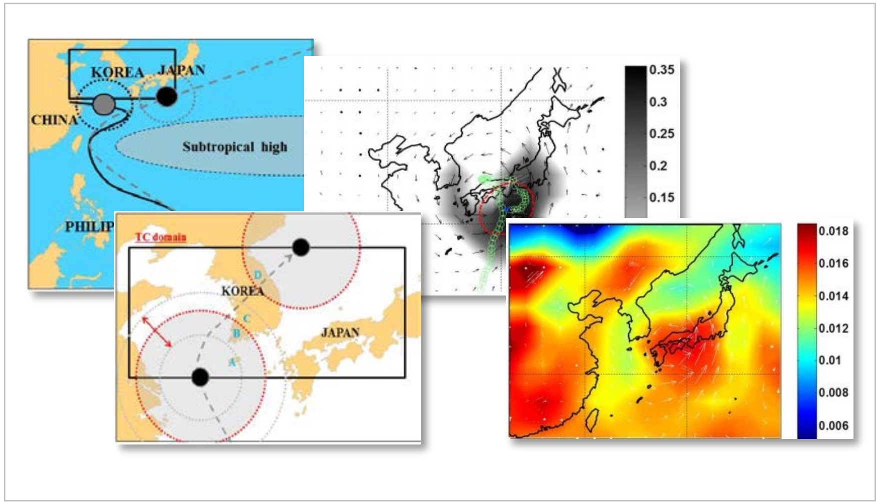
# IV. Ongoing Studies & Research Plans

TC Tracks over MA (1951-2014)

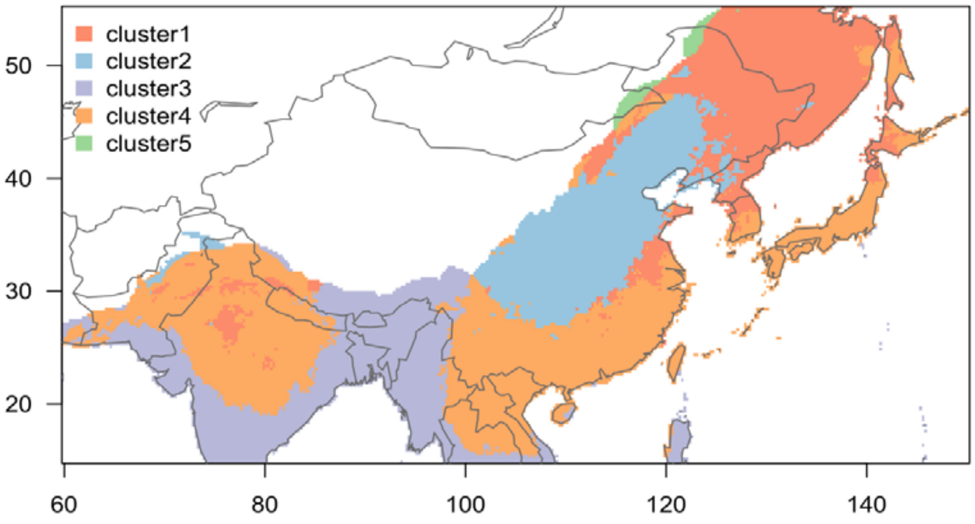


# IV. Ongoing Studies & Research Plans

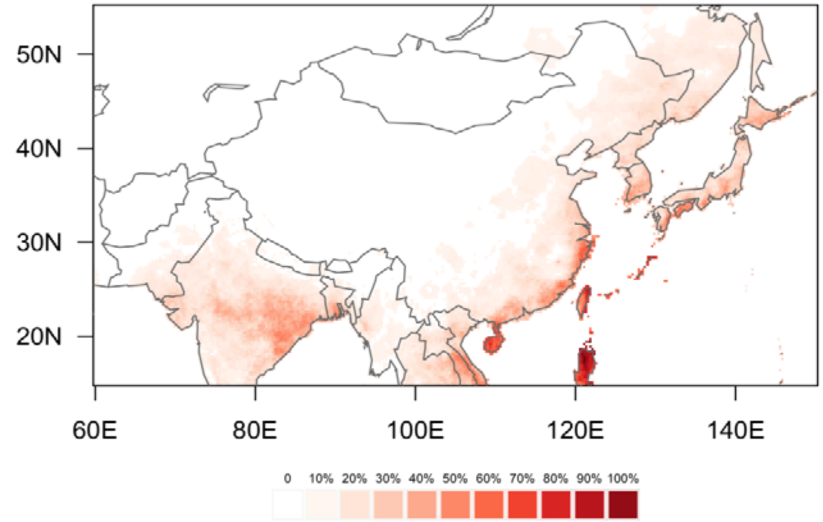



**cluster analysis on TC onset**

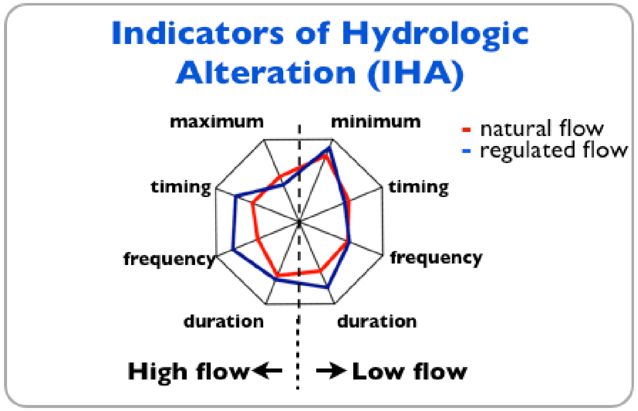



**Number of TC-induced annual peaks (%)**



## Sustainable Water Management for Biodiversity and Human Health

- ✓ The development of flow management guidelines based on scientific foundation is a great challenge for scientists, water-resource managers and stakeholders to provide sustainable water supplies for people, industry and river ecosystem health.
- ✓ The purpose of this research is to explore the impact of altered hydrologic regime on stream and riparian ecosystems that are most vulnerable to climate variability and extremes.




**Flow alteration-ecological response relationships**

↓

**Development of flow management guidelines and standards**

# My Research…

- To systematically diagnose **changes in observed hydroclimatic trends** to clarify the nature and extent of **shifts in hydrologic regime** stemming **from episodic extreme events**

- **To identify relevent hydroclimatic drivers** that "downscale" the signature and footprint of changes in the **global climate system** to **regional or river basin scales**

- **To perform an assessment** of a suite of streamflow metrics based on the **sensitivity of the key parameters** to individual **climatic precursors** and **their past and future trajectories**

**My research provides an usable framework to achieve the goal of sustainability in the Asia-Pacific region.**

# Thank you very much for your attention !



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