2018 APCC Statistical Downscaling Training Program
User-oriented Statistical Downscaling of Climate Change Scenario for Agriculture and Water Resources

Weather Generator and its Application to Downscaling of Seasonal Prediction

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About Instructor

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Overview

1. Introduction
2. Statistical Model of Weather Generator
3. Statistical Downscaling using Weather Generator.
4. Conclusion

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Introduction

- In agriculture and water resources, climate information is necessary.

- Climate information
  - Climate Change (~50/100 years)
  - Seasonal Prediction (~3/6 months)
  - Sub-seasonal Prediction (within 1 month)

Introduction

- APCC Seasonal Prediction
  - It is produced by using MME technique,
  - A coarse resolution in space and time.
  - It is provided in terms of climatological variables such as Z500, SLP, SST representing a large-scale circulation.

Introduction

- Agriculture and Water resources
  - A specific site or a narrow basin, which is so roughly covered with usual GCM grid systems.
  - Weather variables: TMIN, TMAX, relative humidity, dew point, solar radiation, and so on.

- There is a big cap: this is why downscaling process is a necessary step in agriculture and water resources.

Introduction

- Observation data have limitation due to their finiteness.

- Weather Generator
  - It was originally developed for overcoming the limitation of observation data.
  - Weather generators are systems of statistical models for weather in a basin.

Introduction

- Weather Generator
  - They can rapidly produce lots of weather data that share statistical property with observation data.
  - It has been studied as a tool for downscaling seasonal prediction.
  - This talk describes deeply how to use weather generator for downscaling seasonal prediction.

Overview

1. Introduction
2. Statistical Model of Weather Generator
3. Statistical Downscaling using Weather Generator.
4. Conclusion

Statistical Model

- Weather Generators are systems of Statistical Models.

- The Statistical Models describe daily precipitation and temperature in a basin.

Statistical Model

- WGEN
  - Markov model for wet/dry-spell generation,
  - Gamma distribution for rainfall amount,
  - Fourier series fitting for annual cyclic trend of temperature,
  - Vector autoregressive model for temperature anomalies.
  - Parametric modeling are mainly employed.

Statistical Model

- LARS-WG
  - Wet/dry-spell alternation scheme for spells generation (instead of Markov model),
  - Semi-empirical distribution for rainfall amount (instead of Gamma distribution),
  - Temperature model is the same as WGEN.

Statistical Model

- Markov model
  - Adopted by WGEN,
  - For wet/dry-spell generation,
  - 2-state Markov model
    - State: Wet / Dry,
    - Wet: rainfall amount > 0,
    - Dry : rainfall amount = 0.

Statistical Model

- Markov model
  - Transition
    - Wet → Dry / Dry → Wet,
    - Dry → Dry / Wet → Wet.
  - Transition Probability

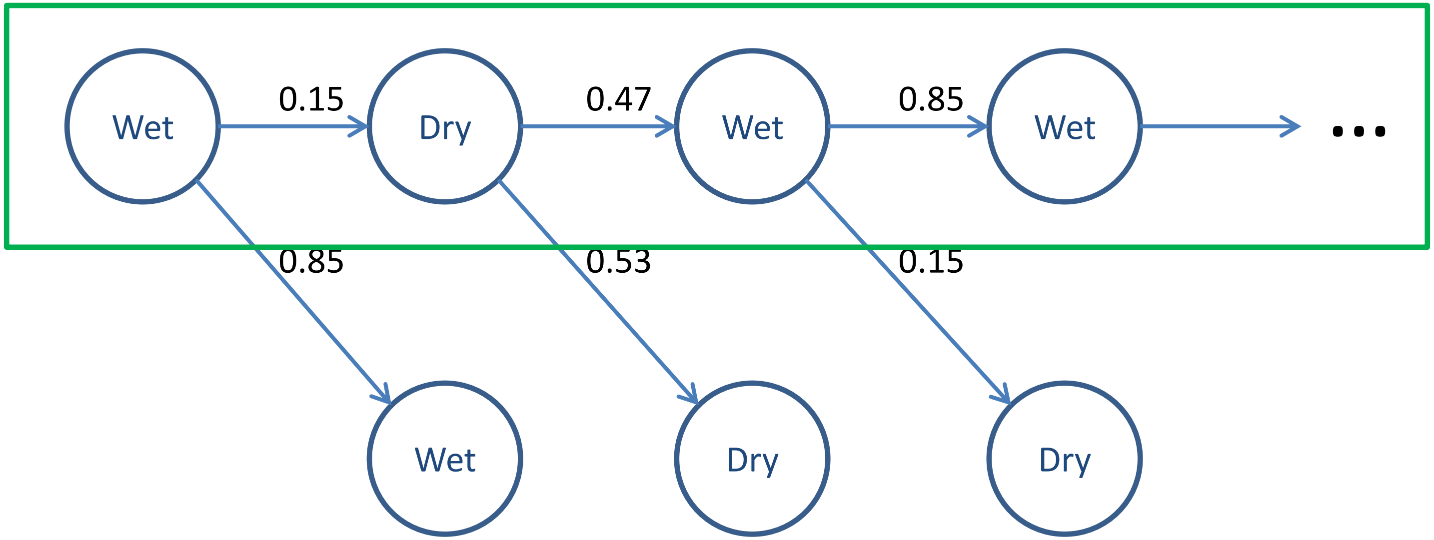
Today/Tomorrow	Wet	Dry
Wet	p_{11}	p_{12}
Dry	p_{21}	p_{22}

Statistical Model

- Markov model
  - Simulation

	Wet	Dry
Wet	0.85	0.15
Dry	0.47	0.53

Matrix of transition probabilities estimated by using observation data



Statistical Model

- Markov model
  - Simulation

	Wet	Dry
Wet	0.85	0.15
Dry	0.47	0.53

Matrix of transition probabilities estimated by using observation data

Time (day)

Repetition	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	W	W	W	D	D	D	W	W	D	D	D	D	D	W	W	W	W	W	D	W	W	W	W	D	W	W	W	W	W	D	W
2	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	D	D	W	W	W	W	D	W
3	W	W	W	W	W	W	W	W	W	W	W	W	D	W	W	W	D	W	W	W	W	W	W	W	D	D	W	W	W	W	W
4	W	D	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
5	W	W	W	W	W	W	W	W	W	W	W	W	W	W	D	D	D	D	D	D	W	W	W	W	W	W	D	D	D	D	D
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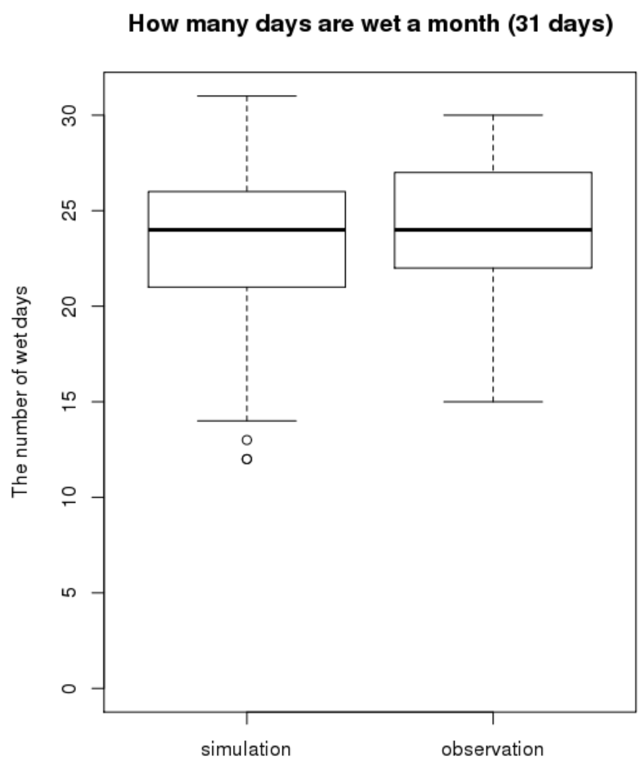
Statistical Model

- Markov model
  - Simulation vs. Observation



Spell length Statistics (day)		Simulation	Observation
Wet-spell Length	Mean	7.02	7.02
	SD	6.50	7.11
Dry-spell Length	Mean	2.14	2.14
	SD	1.57	1.94

Statistical Model

- Markov model
  - Statistical characteristics are fairly similar,
  - But, SD of simulation spell lengths are a little bit smaller than observation.

Statistical Model

- Remarks on Markov model
  - Markov model simulates real wet/dry-spells well.
  - However, it is not perfect. We are not sure that it always performs well.
  - In this viewpoint, LARS-WG adopts wet/dry-spell alternation scheme instead of Markov model.
    - The scheme is a resampling method. It requires that observation data are long enough.

Statistical Model

- Rainfall amount model
  - Gamma distribution,
  - Exponential Mixture model,
  - Empirical distribution,
  - Generalized Pareto distribution.

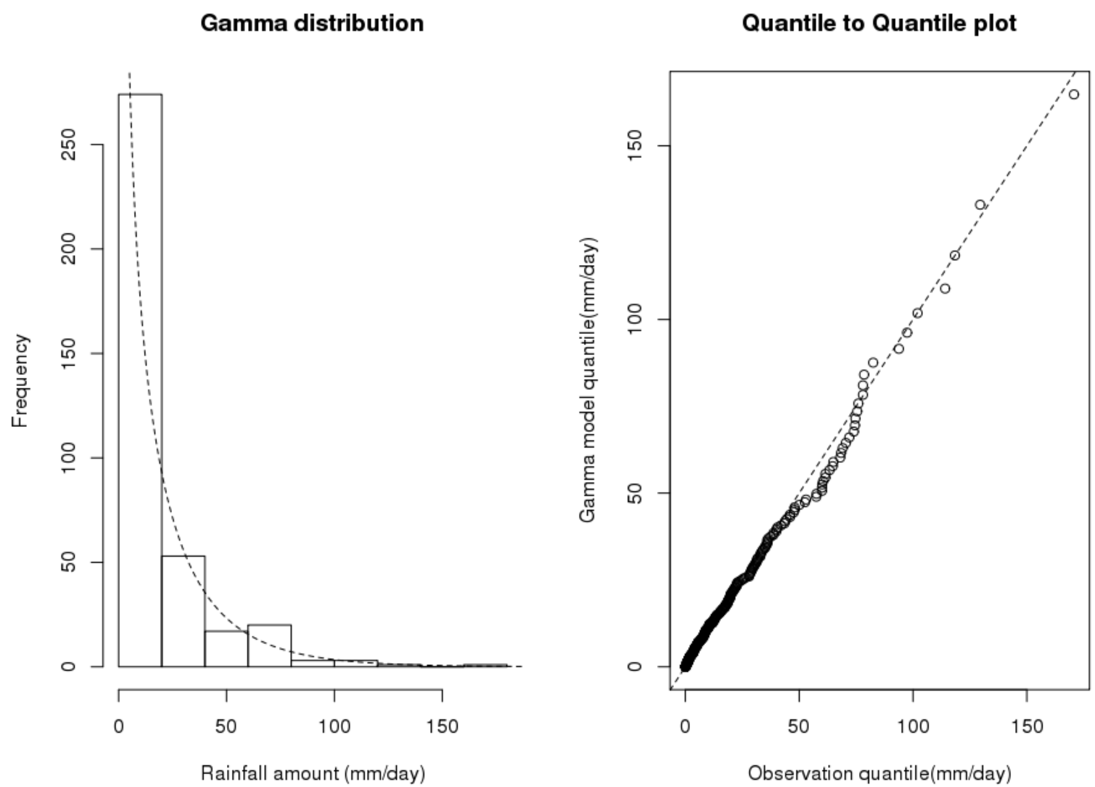
Statistical Model

- Gamma distribution
  - μ : mean of rainfall amount (mm/day)
  - α : shape parameter. $0 < \alpha < 1$ for rainfall amount

$$f(x) = \frac{\alpha^{\alpha}}{\Gamma(\alpha)\mu^{\alpha}} x^{\alpha-1} \exp\left(-\frac{\alpha x}{\mu}\right), \quad x > 0$$

Statistical Model

- Gamma distribution
  - $\hat{\mu} = 16.56$ (mm/day), $\hat{\alpha} = 0.53$.



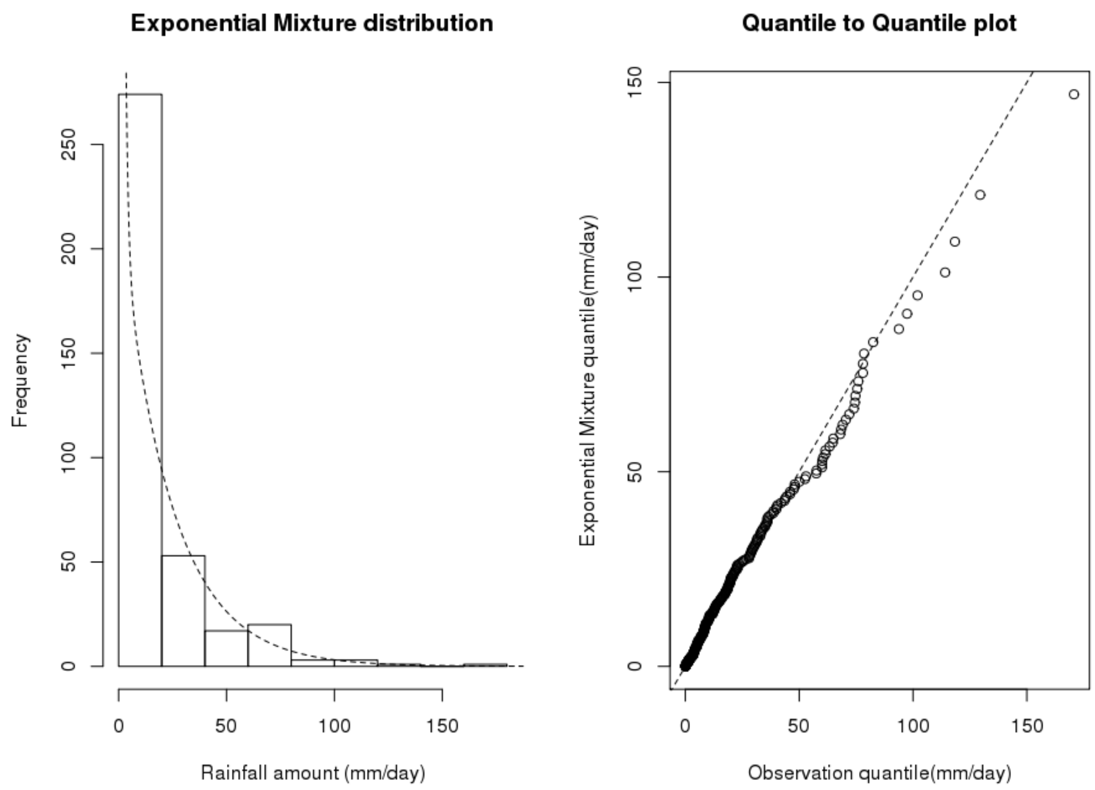
Statistical Model

- Exponential Mixture Model
  - μ_1 , μ_2: mean of the components
  - $0 < \lambda < 1$: mixture parameter
  - $\lambda\mu_1 + (1 - \lambda)\mu_2$: average of rainfall amount

$$f(x) = \lambda \exp\left(-\frac{x}{\mu_1}\right) + (1-\lambda)\exp\left(-\frac{x}{\mu_2}\right), \quad x > 0$$

Statistical Model

- Exponential Mixture Model
  - $\hat{\lambda} = 0.7, \hat{\mu}_1 = 23.5$(mm/day), $\hat{\mu}_2 = 1.16$(mm/day)



Statistical Model

- Exponential Mixture Model says
  - The first component corresponds to heavy rainfall, the second does to light one.
  - Heavy rainfall with probability 0.7 and its mean 23.5 mm/day
  - Light rainfall with probability 0.3 and its mean 1.16 mm/day

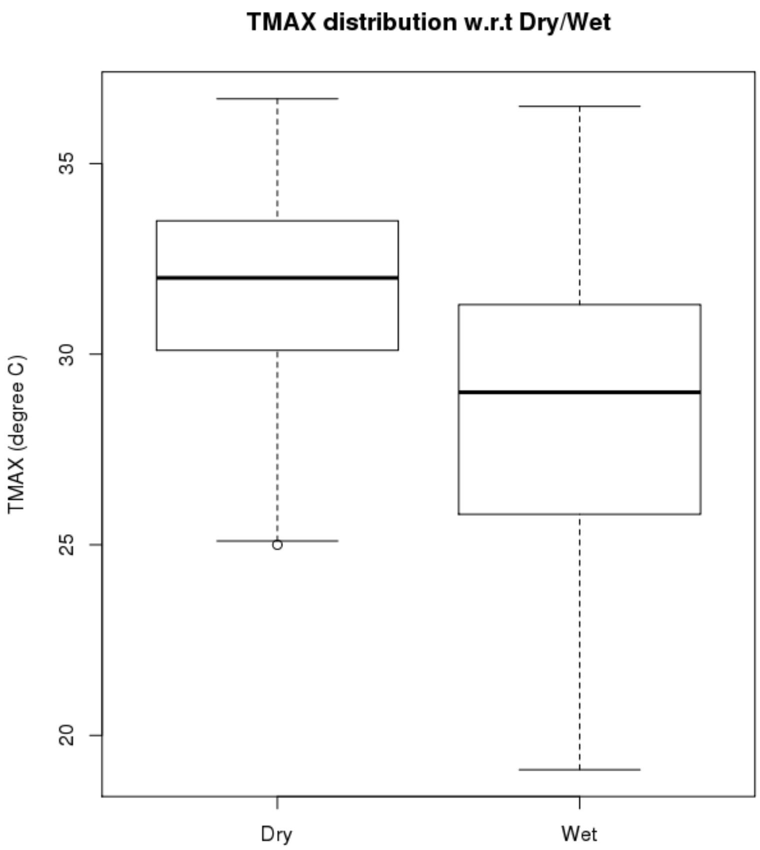
Statistical Model

- Both models are suitable to the rainfall amount data. However, not always.
- Both models may be inappropriate for *extreme rainfall with long return period*. Generalized Pareto model is a suitable model.

Statistical Model

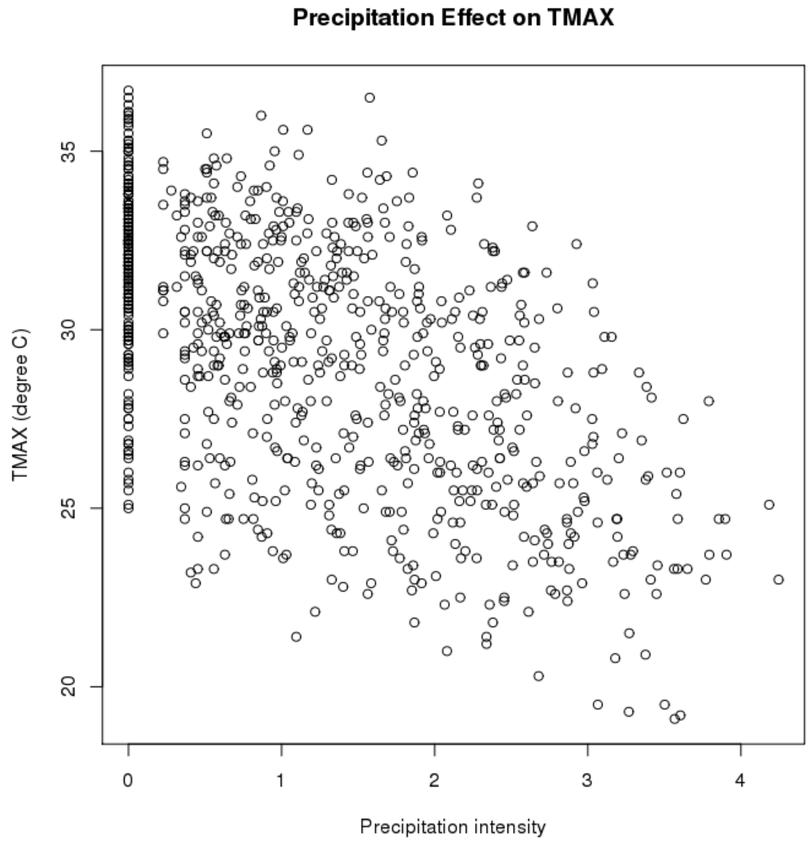
- Regression model
  - Temperature is affected by precipitation.
  - In WGEN and LARS-WG

$$\text{TMAX} = \begin{cases} \mu_{\text{Dry}} + \sigma_{\text{Dry}} \cdot (\text{anomaly}), \\ \mu_{\text{Wet}} + \sigma_{\text{Wet}} \cdot (\text{anomaly}). \end{cases}$$



Statistical Model

- Regression model
  - However, the effect is Linear!
  - Stronger Precipitation intensity, lower TMAX.



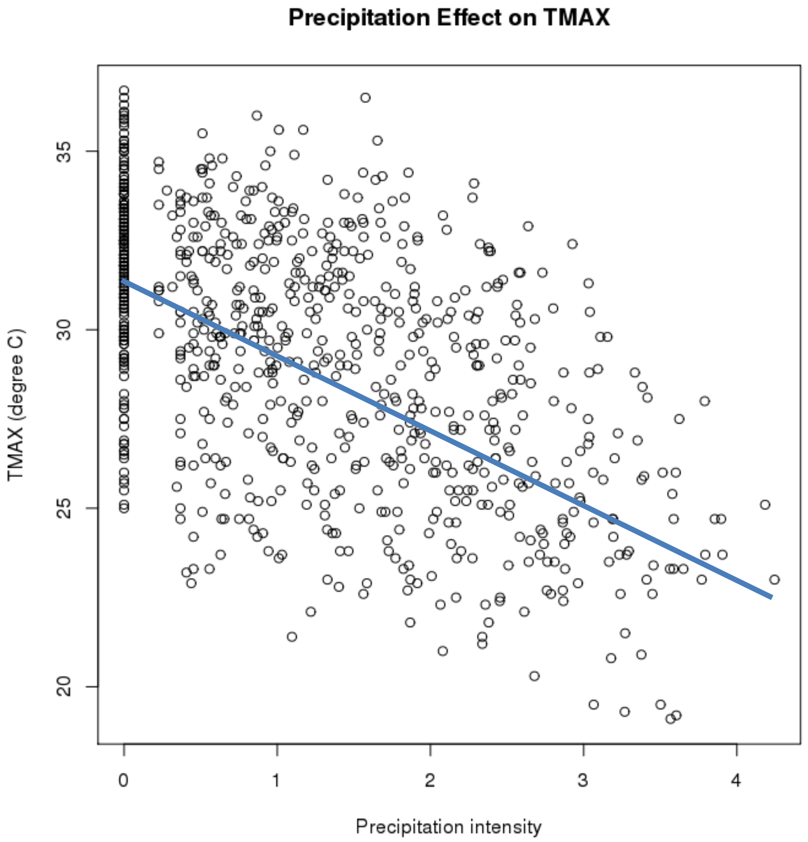
Statistical Model

- Regression model
  - The relation is formulated by regression model.

$$Y = \beta_0 + \beta_1 X + (\text{error})$$

Y: TMAX(degree C),
X: Precipitation intensity.

$$\hat{\beta}_0 = 31.66, \hat{\beta}_1 = -1.9$$



Statistical Model

- Other issues on temperature model are dealt with in the next section.
  - Temperature variation decomposition,
  - Correlation structure.

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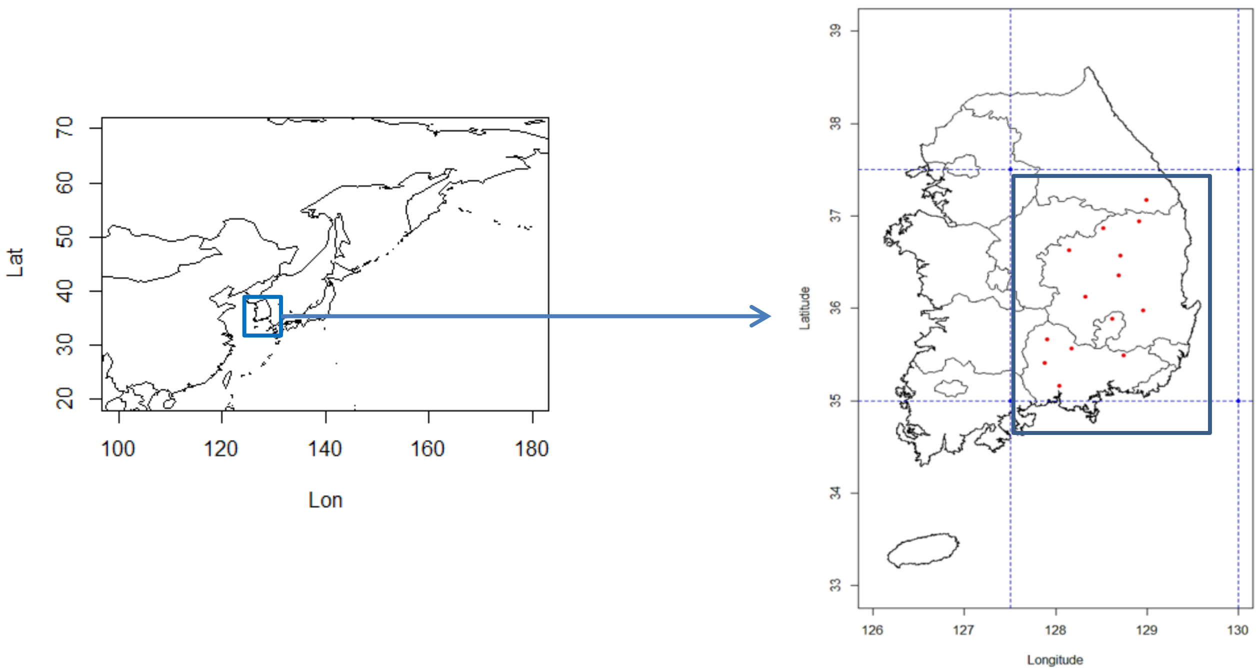
Statistical Downscaling

- Weather Generator is used for Statistical Downscaling.
  - Large-scale atmospheric circulation → local basin daily weather.
  - Large-scale atmospheric circulations are usually predicted in seasonal time scale.
    - In terms of 3-month average.
  - Weather generator plays the role of temporal disaggregation.

Statistical Downscaling

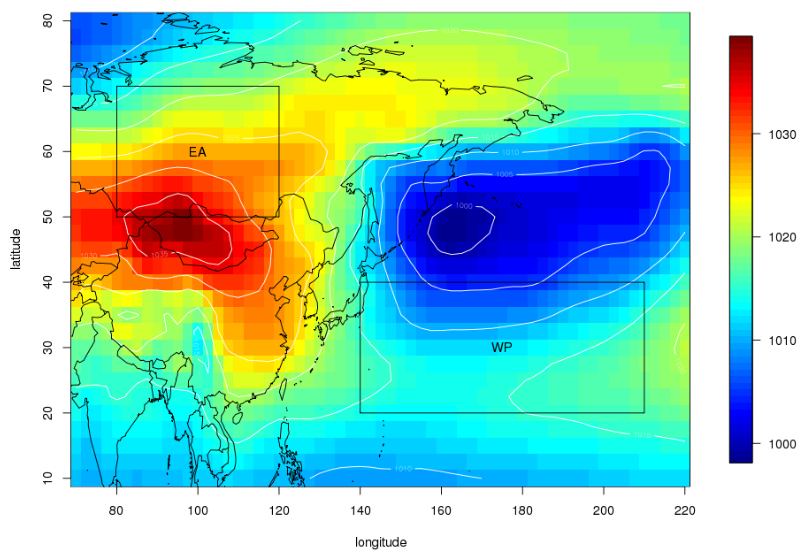
- Case Study
  - Season: Boreal Winter, DJF.
  - Nakdong River: 14 stations.



Basin location

Statistical Downscaling

- The basin is affected by EAWM (East Asia Winter Monsoon)
  - Kim et al (2017) index measuring SLP gradient.

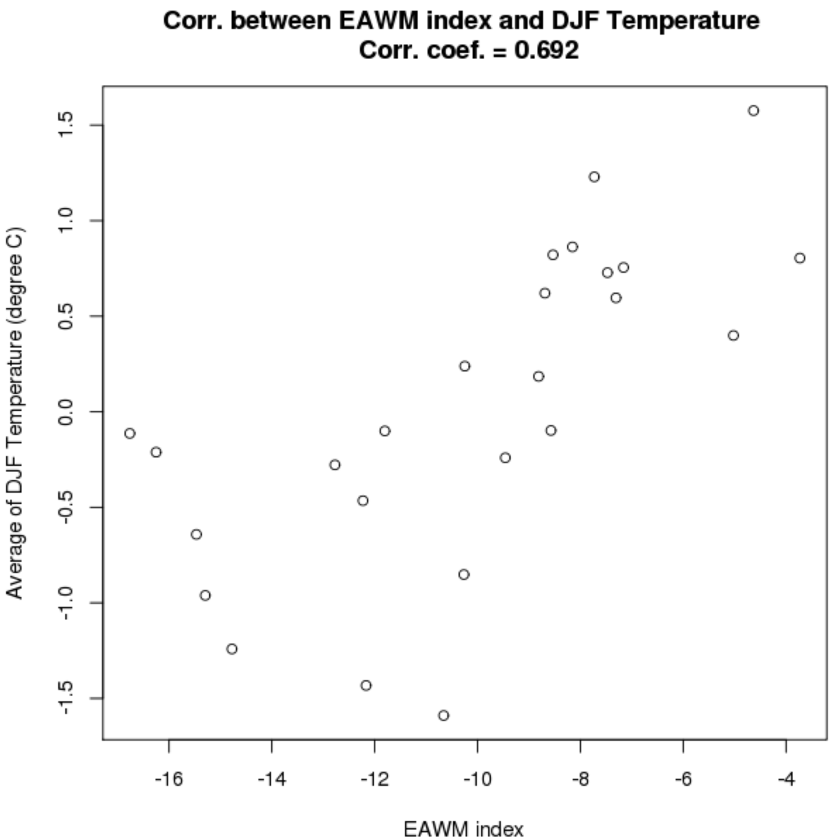


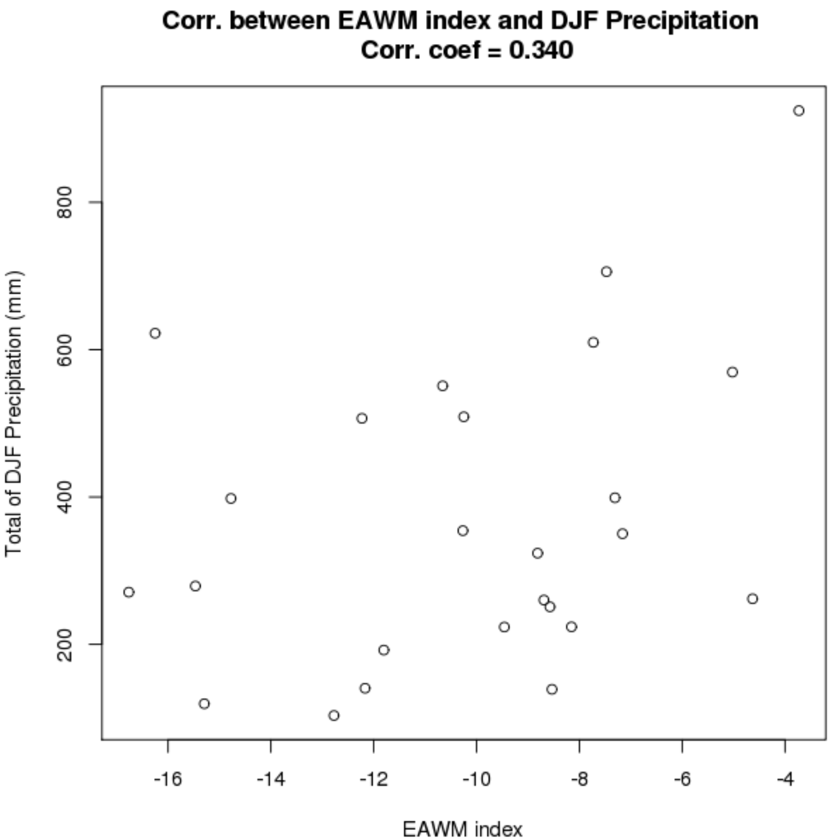
The domains of the EAWM index. The index is defined as the difference between DJF averages of SLP on WP/EA regions

Kim, S. T., Sohn, S., and Kug, J. (2017) Winter Temperatures over the Korean Peninsula and East Asia: development of a new index and its application to seasonal forecast *Clim. Dyn. Online published.*

Statistical Downscaling

- Relation with the basin DJF climate





Statistical Downscaling

- We focus on Temperature.
  - EAWM is related to temperature.
  - Boreal winter is a dry season.

- How to downscale EAWM using weather generator?
  - We will give a simple example where TMIN and precipitation are dealt with.

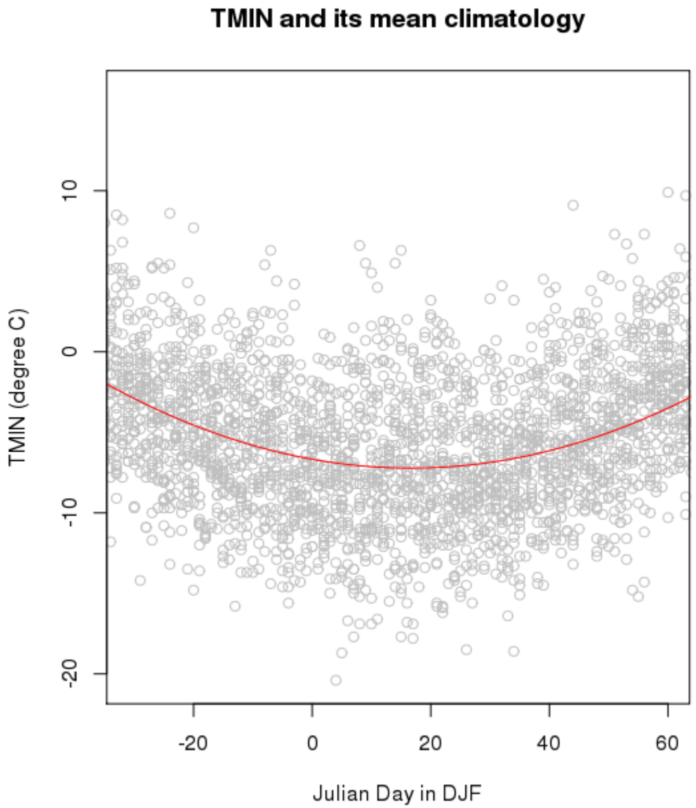
Statistical Downscaling

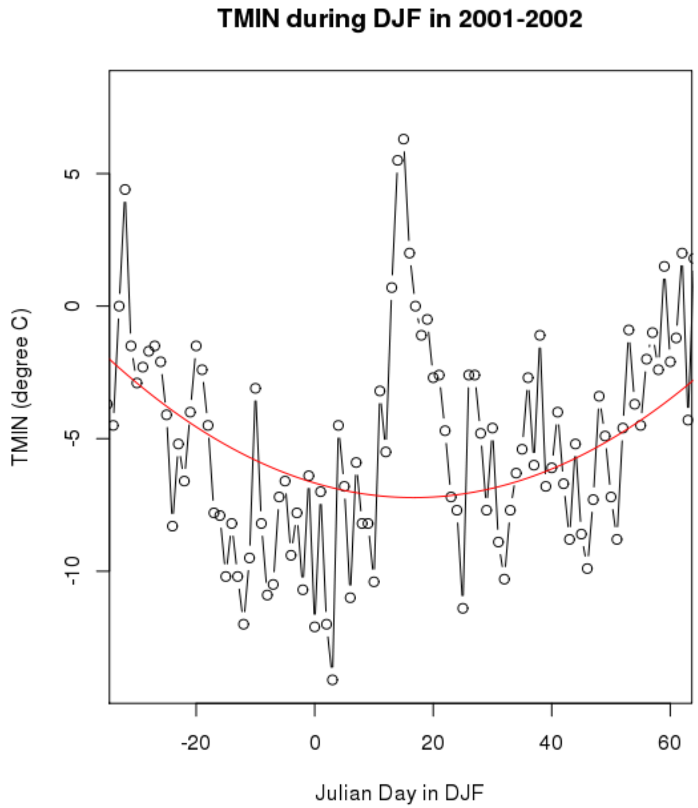
- *Slow oscillation term* is introduced to the temperature model of Weather Generator.
  - $\mu(t)$: mean climatology,
  - $T(t) - \mu(t)$: deviation (w.r.t. mean climatology),
  - $\eta(t)$: *slow oscillation*,
  - $\Delta(t)$: precipitation effect.

$$T(t) - \mu(t) = \eta(t) + \Delta(t) + (\text{anomaly})$$

Statistical Downscaling

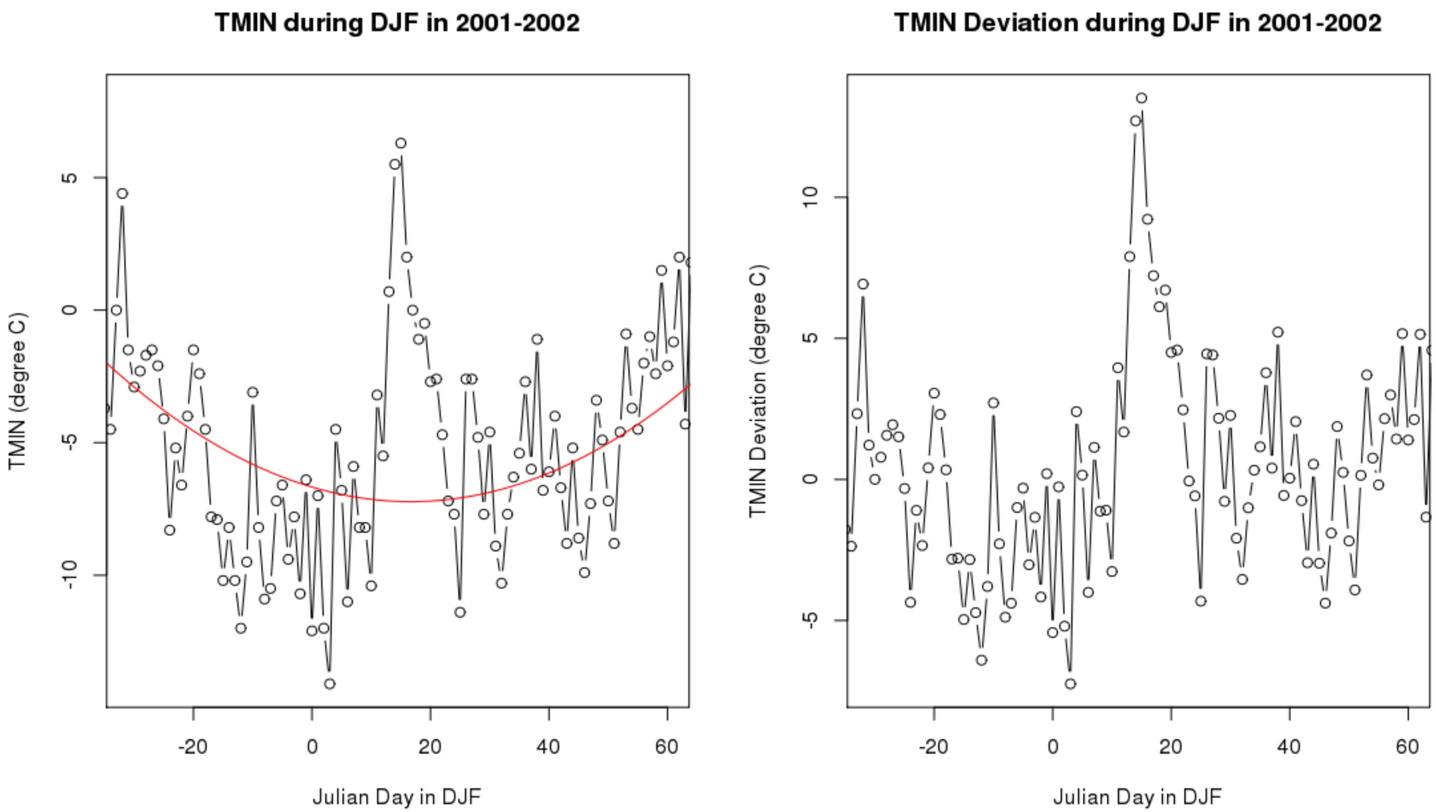
- Mean climatology and slow oscillation





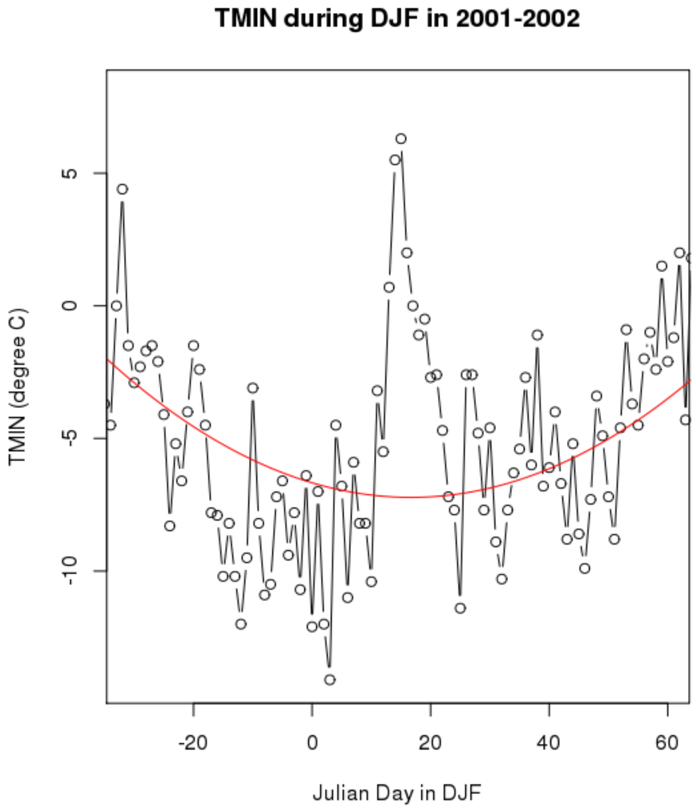
Statistical Downscaling

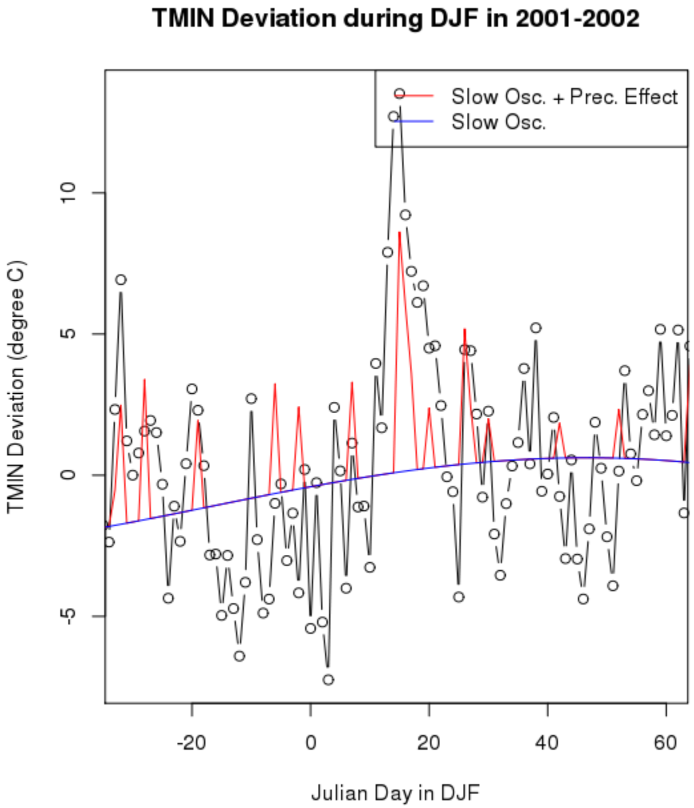
- Mean climatology and slow oscillation



Statistical Downscaling

- Mean climatology and slow oscillation





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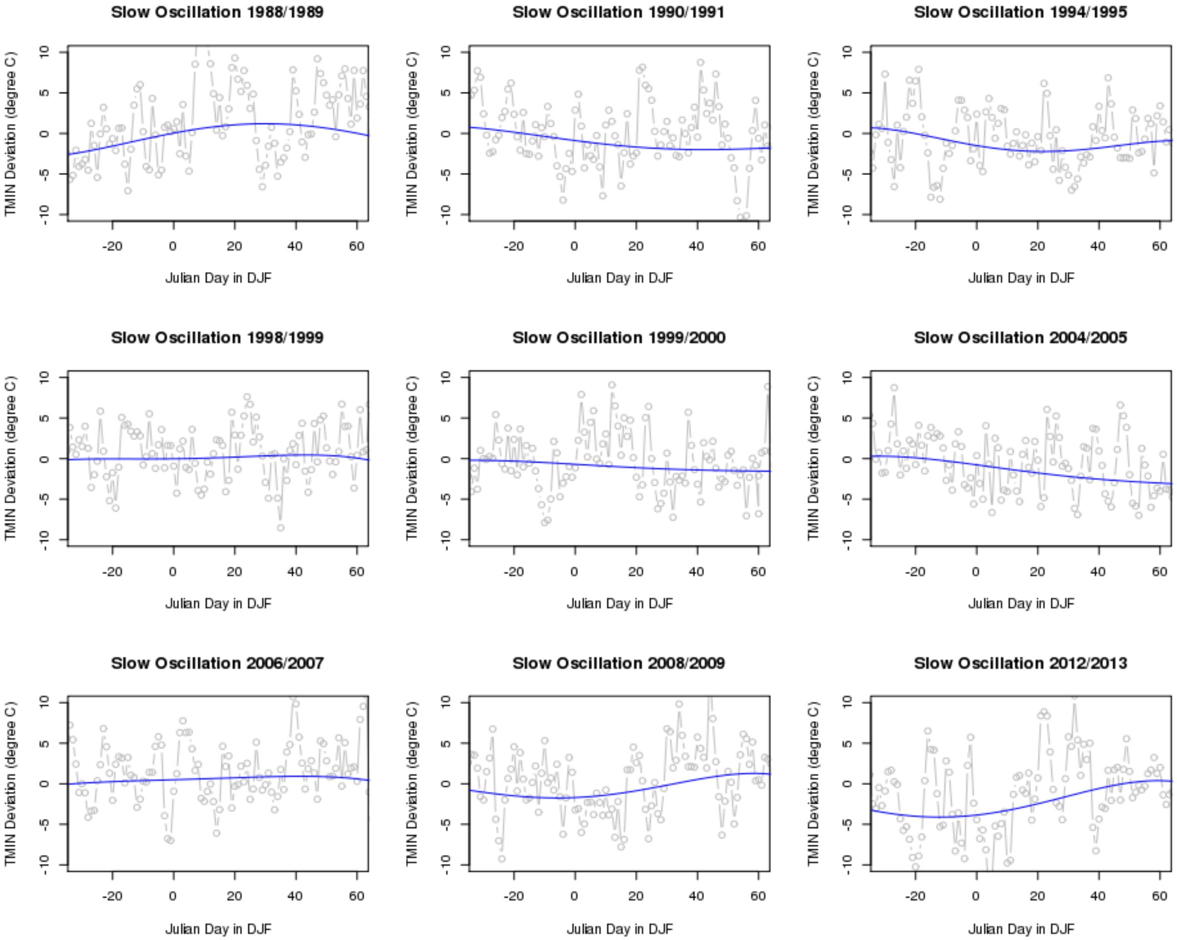
Statistical Downscaling

- Inter-annual variability of Slow oscillation



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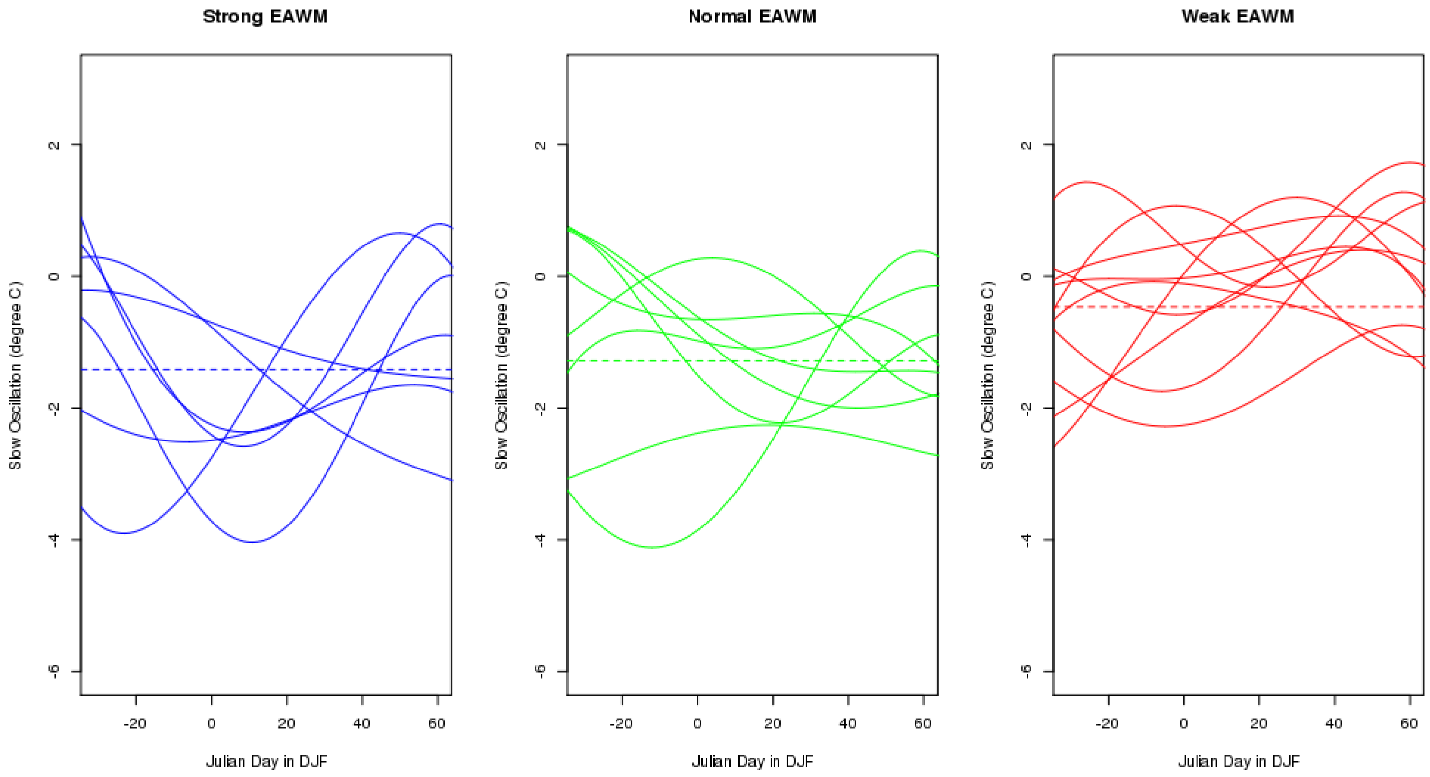
Statistical Downscaling

- The slow oscillation responds to EAWM



Statistical Downscaling

- EAWM downscaling scheme
  1. The strength of EAWM is predicted.
     - Strong/Normal/Weak.
  2. According to the prediction, we generate slow oscillation.
  3. Precipitation simulation
     - Markov model + Gamma distribution

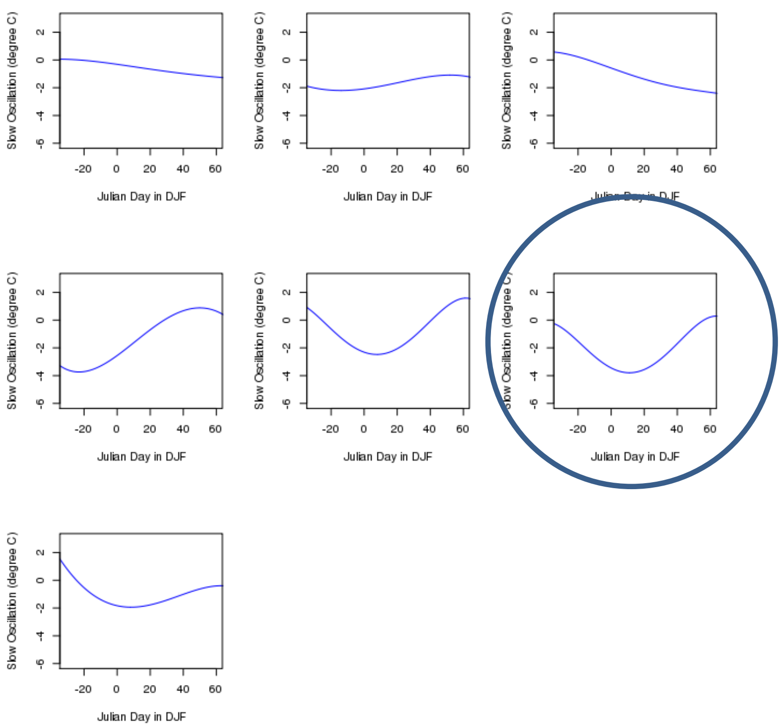
Statistical Downscaling

- EAWM downscaling scheme

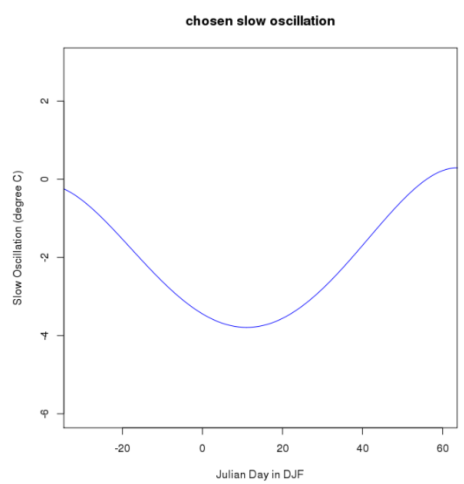
4. Slow oscillation + precipitation effect.
5. Anomaly simulation
    - ARIMA model is used.
6. Temperature construction.

Statistical Downscaling

- Assume that EAWM is predicted to be strong.
- Randomly choose one of 7 slow oscillations.



We have 7 historical slow oscillations under strong EAWM.
We choose one of them randomly.



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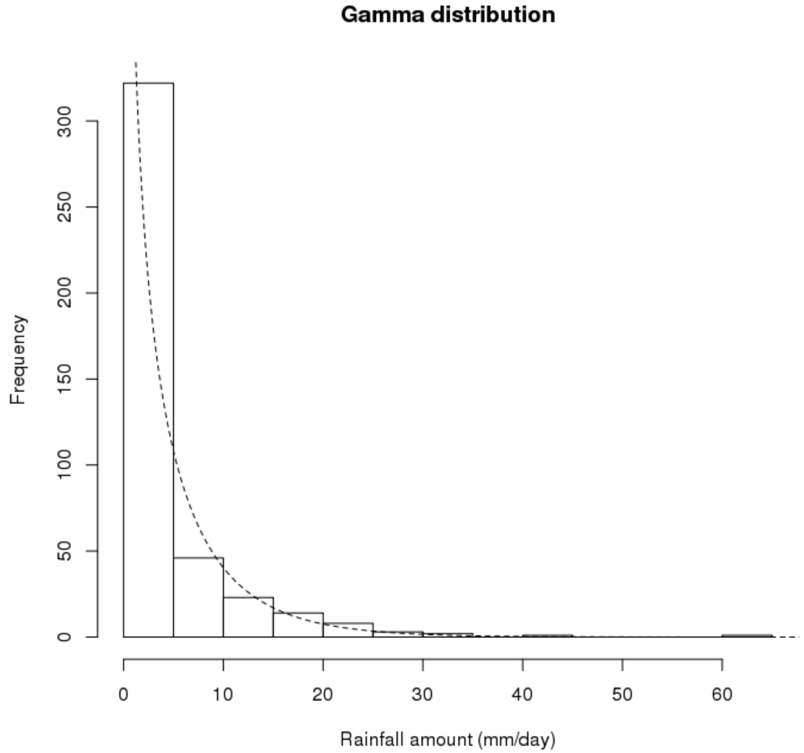
Statistical Downscaling

- Carry out Precipitation simulation



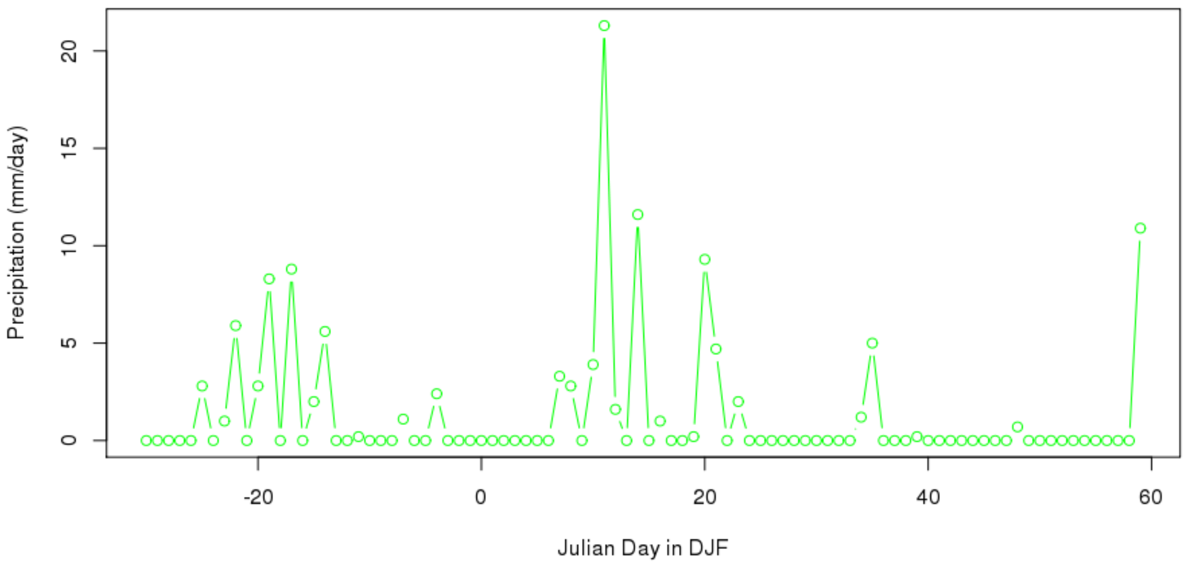
Gamma distribution with $\hat{\mu} = 4.11$ (mm/day), $\hat{\alpha} = 0.56$.

Today/Tomorrow	Wet	Dry
Wet	0.50	0.50
Dry	0.22	0.72

Transition probability matrix in during DJF

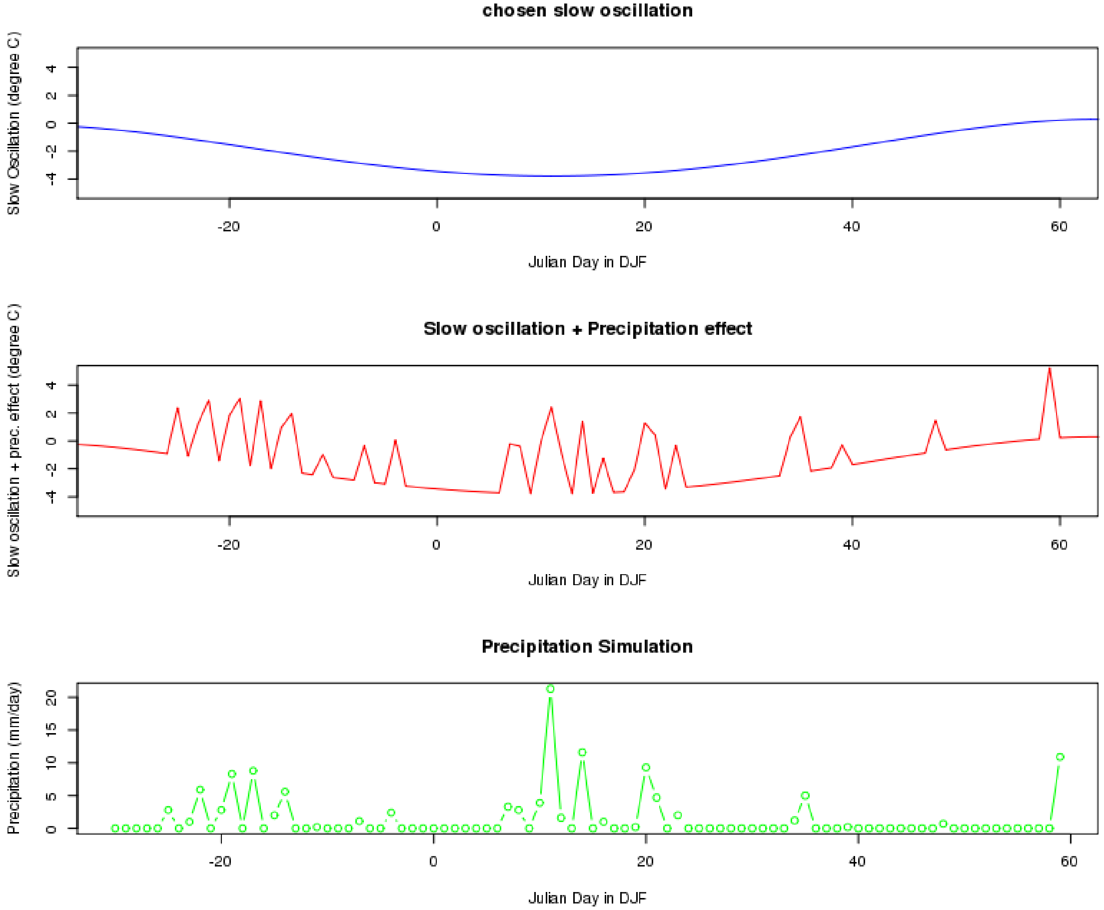
Statistical Downscaling

- Carry out Precipitation simulation



Statistical Downscaling

- Slow Oscillation + Precipitation effect



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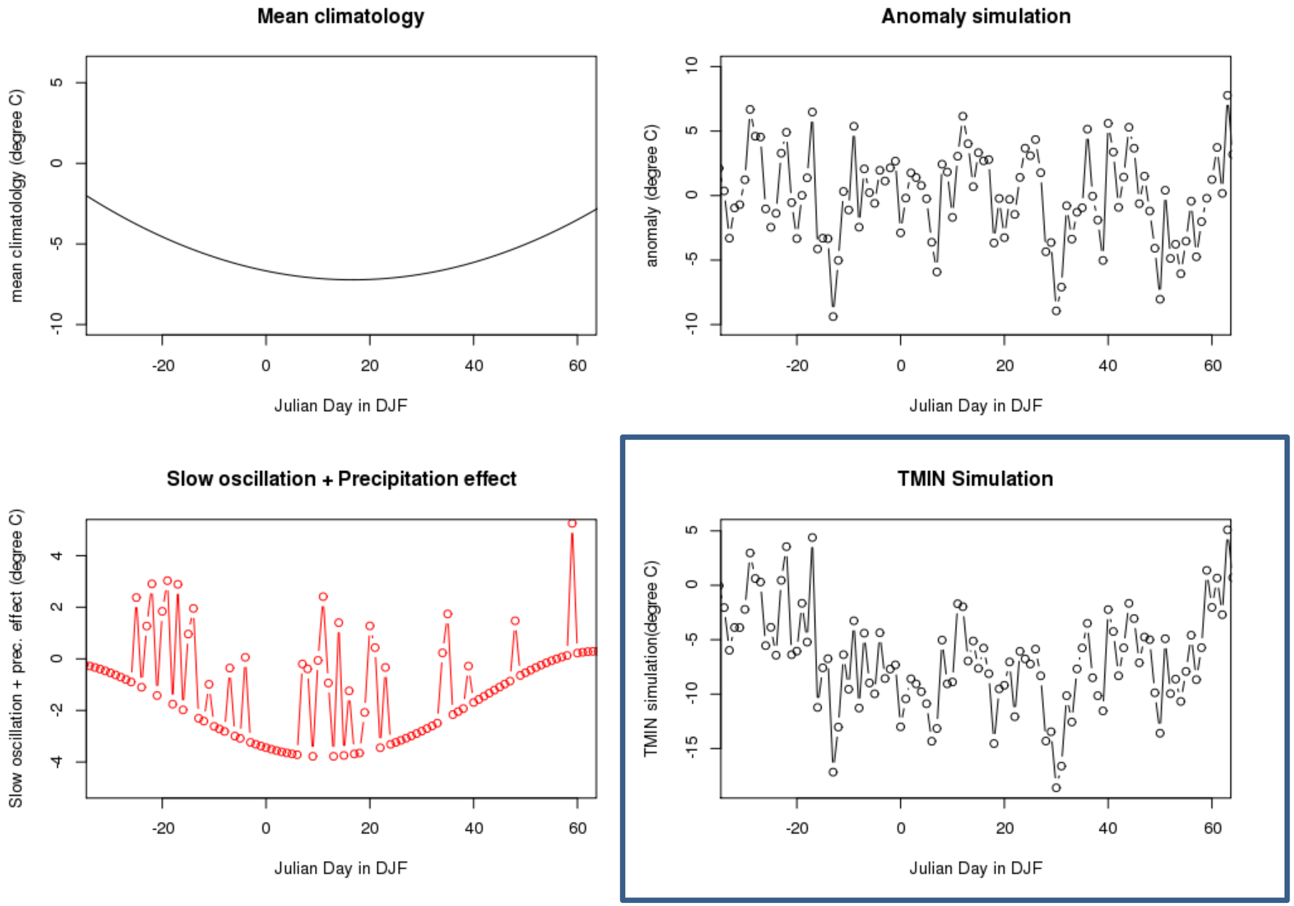
Statistical Downscaling

- Anomaly generation and final construction



Final output

Statistical Downscaling

- A lot of weather scenarios can be produced by repeating downscaling scheme.
  - Usually, 100/1,000/10,000 scenarios are produced.
  - The scenario set represents climate variability under seasonal prediction.
    - cf. Ensembles of GCM prediction.
  - They are used as input data in agricultural and hydrological studies.

Statistical Downscaling

- Slow oscillation plays a prominent role in connecting EAWM and basin temperature.
  - EAWM is related to basin temperature.

- What if a large-scale circulation is related to precipitation?
  - transition probability and the mean of rainfall amount are adjusted for the large-scale circulation.

Statistical Downscaling

- What if you apply the scheme to your basin in a season?
  - We need to know which large-scale circulation is the dominant factor on the basin climate,
  - And, which weather variables are related to the large-scale circulation.

Statistical Downscaling

- This is a simple example for illustration of downscaling process.
  - Single site case, TMIN and precipitation are dealt with.

- Actual downscaling is required to cover several variables simultaneously.
  - Solar Radiation, Humidity, etc.,
  - The variables are correlated.

Statistical Downscaling

- And, it is required to cover several sites simultaneously.
  - In water resource studies, target area is a basin rather than a single site.

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Conclusion

- Weather Generators are systems of statistical models describing weather in a basin.

- Statistical models
  - Markov model: wet/dry-spell sequence,
  - Gamma distribution, Exponential mixture: rainfall amount,
  - Regression model: precipitation effect on temperature.

Conclusion

- Weather Generator is applied to Statistical Downscaling of Seasonal Prediction of Large-scale Atmospheric Circulation.
  - Seasonal prediction is usually 3-month average. Weather Generator plays a role of temporal disaggregation.
  - For applying, we need a prior knowledge which circulation is the dominant factor of the basin climate.

Announcement

- acidWG (APCC Climate Information Downscaling Weather Generator)
  - R-package for downscaling APCC Seasonal Forecast.
  - Multisite, TMAX, TMIN, PRCP.

Announcement

- AIMS (APCC Integrated Modeling Solution)
  - An integrated platform for Climate Service including Seasonal Forecast Downscaling,
  - acidWG will be a component for downscaling.

THANK YOU!

Welcome any Comments and Questions.

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