Development of new ensemble methods based on the performance skills of regional climate models over South Korea

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1. Introduction

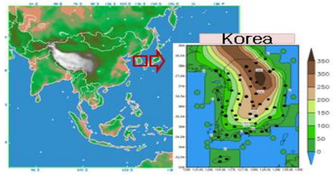
- It is well known that multi-model ensembles can reduce the uncertainties of model results and increase the reliability of model results.
- Multi-model ensembles have been widely applied to the weather forecast, global models, but they are rarely used for regional climate models because of a lack of long-term simulation with multi-RCMs.
- CORDEX (CO-ordinated Regional climate Downscaling EXperiment) for Asia provides a good opportunity to carry out ensemble research related to RCMs.
- Based on the evaluation framework of CORDEX, the Korean research group produced 20 years (1989-2008) regional climate data using the four RCMs (RegCM4, SNURCM and WRF, RSM) driven by two lateral boundary condition (LBC), ERA-Interim (ERA) and NCEP/DOE2 (R-2).
- In this study, we developed new ensemble methods based on the evaluation data, bias, RMSE and Cor. Coef.. The performance skills of new ensemble methods over South Korea are compared with equal weighted average (EWA) and regression method by using the 20 years simulation results of the four RCMs driven by the ERA and R-2 boundary condition (8 ensemble members)

2. Models & Experiment Design

1) Four RCMs used in this study

	SNURCM	WRF	RegCM4	RSM
Vertical levels	σ-24	σ-27	σ-18	σ-22
Dynamic framework	Non-hydrostatic	Non-hydrostatic	Hydrostatic	Hydrostatic
PBL scheme	YSU	YSU	Holtslag	YSU
Convective scheme	Kain-Fritch2	Kain-Fritch2	MIT-Emanuel	SAS
Land surface	CLM3	Unified Noah	CLM	NOAH LSM
Longwave radiation scheme	CCM2	RRTM	CCM3	GFDL
Shortwave radiation scheme	CCM2	Dudhia	CCM3	GSFC
Spectral nudging	Yes	Yes	Yes	Yes

2) CORDEX East Asia & Analysis region (South Korea)



3) Experiment design

Model domain	- CORDEX East Asia - 50 km - 193 (lat.) x 233 (lon.)
RCMs	RegCM4, SNURCM, WRF, RSM
Lateral boundary data	ERA-interm (ERA), NCEP/DOE2 (R2)
Simulation period	Jan. 1989 ~ Dec. 2008

1) Configurations of the four RCMs were optimized through a 1-year sensitivity experiment (1989).
2) The eight ensemble members (4 RCMs x 2 LBCs) were used for the development of new ensemble methods. For the detailed evaluation of simulated precip. and temp. over South Korea, we used the hourly precip. and temp. data at 59 stations in South Korea.
3) Fifteen and five years of data from the 20 years simulation data were used to derive the weighting coefficients (training period) and evaluate the prediction skills (prediction period).
4) The prediction skills of the new ensemble methods were compared to those of well known other ensemble methods (equal weighting averaging, multiple regression technique) by using 20 sets of 5 years prediction data.

3. Development of Ensemble Methods

1) PEA (Performance based on Ensemble Averaging) method (New ensemble method)

① Preliminary Weighting value (Pw)

$$Pw_i = \frac{1.}{[Abs(B_i)+1.0]} * \frac{1.0}{(RMSE_i+1.0)} * Abs(Corr_i) \quad (1)$$

$$Pw_i = \frac{1.0}{(RMSE_i+1.0)} * Abs(Corr_i) \quad (2)$$

$$Pw_i = \frac{1.0}{(RMSE_i+1.0)} * Corr_i \quad (3)$$

② Normalization of Pw (NPw)

$$NPw_i = \frac{Pw_i}{\sum_{i=1}^{N_M} Pw_i} \quad (4)$$

③ Calculation of Ensemble Averaging

✓ PEA_BRC [Pw = Eq. (1)] $\quad \bar{T} = \sum_{i=1}^{N_M} NPw_i T_i \quad (5)$

✓ PEA_RAC [Pw = Eq. (2)]
✓ PEA_ROC [Pw = Eq. (3)] $\quad \tilde{T} = \sum_{i=1}^{N_M} NPw_i T_i - \sum_{i=1}^{N_M} NPw_i \Delta T_i \quad (6)$

2) General ensemble method

① Equal Weighted Averaging (EWA)

$$\tilde{T} = \frac{1}{N_M} \sum_{i=1}^{N_M} M\_T_i$$

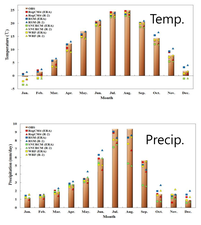
② Multi-model Regression (Mul_Reg)

$$OBS_i = a_{i0} + a_{i1} Model_{i1} + a_{i2} Model_{i2} + \cdots\cdots + a_{i8} Model_{i8}$$

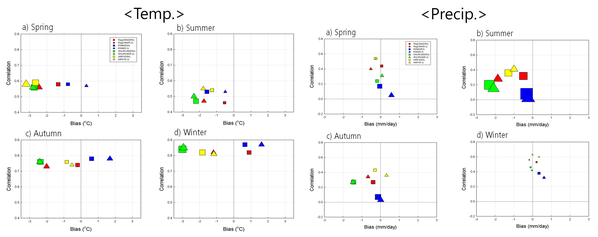
- In this study, we have developed new ensemble methods based on the model's evaluation parameters, bias, RMSE, and correlation coefficient.
- The ensemble methods are designed to take into consider the accuracy and reliability of RCMs.
- *Pw* is defined in three ways [eq. (1)~(3)] using various combination of the model's evaluation parameters.
- To avoid the mathematical problem of division by zero, we added 1 to the bias and the RMSE, and made the bias and the correlation coef. into absolute values.
- And the *Pw* is normalized into the *NPw* by eq. (4)
- The weighted ensemble is calculated by eq. (5) or (6), according to the bias inclusion or not in the *Pw*.
- The prediction skills of the new ensemble methods are compared to those of the EWA and Mul_Reg methods.

4. Simulation skills of four RCMs

1) Seasonal variation



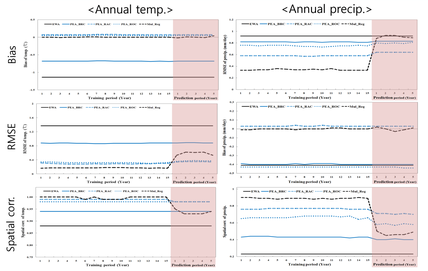
2) BRC(Bias, RMSE and Correlation) diagram



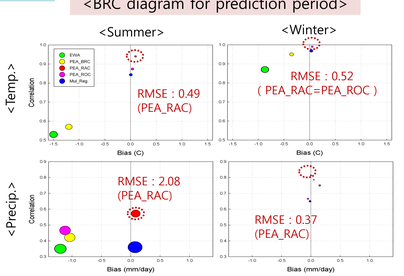
1) In general, most of the RCMs simulate the seasonal variations of temp. and precip. well. However, seasonal amplitudes of temp. and precip. are significantly underestimated, especially for the precipitation.
2) The spatial corr. of the eight ensemble members for temp. are relatively similar, with minimum and maximum in summer and winter, respectively. However, the bias and RMSE of temp. are diverse according to the models and seasons although strong negative biases are very dominant in all four seasons.
In the case of the precip., the bias, spatial corr. and RMSE are very diverse according to the models and seasons.

5. Prediction Skills of Ensemble Methods

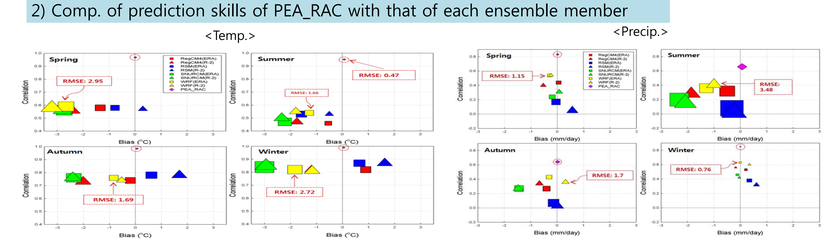
1) Skills of EMs for the training and prediction periods



<BRC diagram for prediction period>



2) Comp. of prediction skills of PEA_RAC with that of each ensemble member



6. Summary

- In this study, the prediction skills of five ensemble methods for temp. and precip., EWA, three PEA methods, and Mul_Reg, were analyzed by using the 20 years of simulation data by the four RCMs driven by two LBC data, R-2 and ERA.
- Fifteen years and five years of data from the 20 sets of 20 years simulation data were used to derive the weighting coefficients and to cross-validate the prediction skills of the five ensemble methods.
- Among the five ensemble methods, the Mul_Reg method shows the best simulation skills regardless of seasons and variables during the training period. This result is consistent with Feng *et al.* (2011)'s results. However, the simulation skills and stability of Mul_Reg are drastically reduced when the method is applied to the prediction of both temperature and precipitation.
- On the other hand, the prediction skills of PEA_RAC and PEA_ROC for temperature and precipitation, especially PEA_RAC, are only slightly reduced. As a result, the PEA_RAC shows the best simulation skill irrespective of the seasons and variables for the prediction period.
- These results confirm that the new ensemble method developed in this study, PEA_RAC, can be used for the prediction of detailed regional climate by using the simulation results of multi-models.

Reference:
Feng, J., D. K. Lee, C. Fu, J. Tang, Y. Sato, H. Kato, J. L. Mcgregor and K. Mabuchi, 2011: Comparison of four ensemble methods combining regional climate simulations over Asia. *Meteor. Atmos. Phys.*, 111, 41–53, DOI 10.1007/s00703-010-0115-7.

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