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Sensitivity of the NCAM High-Resolution Numerical Model Simulation to Two Different Initial and Boundary Datasets

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I. Introduction

As global warming continues for the past 100 years, its effects have manifested in Korea's agriculture, forestry and fisheries. For example, apple plantations in Daegu and Hallabong plantations in Jeju have expanded to the northern regions, Gyeonggi-do and Jeollabuk-do Province respectively, and occurrence of subtropical pests has increased. In the 2010s, annual catches of pollock (species living in cold water) in the East Sea decreased from about 15 tons in the 1980s to 1 ton, while those of squid (species living in warm water) increased from about 4 tons to 12 tons (Woo, 2012). Moreover, this global warming is accompanied by frequent extreme weather events, and thus more accurate prediction of these events is required.

Weather forecasts for agriculture and forestry sectors should be able to provide the medium-range and long-range weather information in high resolution. They should be coupled to other application modules, such as the drought, pest, and plant growth models, to produce the various decision-support information needed for the sustainability of municipalities and farmers farming and management. To this end, the National Center for AgroMeteorology (NCAM) constructed Land-Atmosphere Modeling Package (LAMP), a high-resolution numerical modeling system based on the Weather Research and Forecasting (WRF) and NOAH-multiparameterization (MP), a one-dimensional land surface model (LSM). The name "NOAH" for the LSM emerged at the National Centers for Environmental Prediction (NCEP) in the United States during the 1990s (N: NCEP, O: Oregon State University, A: Air Force, and H: Hydrologic Research Laboratory). The construction of LAMP has been in progress throughout a series of prior studies (e.g., Lee *et al.*, 2014; Song *et al.*, 2015; Lee *et al.*, 2016). These studies used multiple nests and high-resolution topographic and land cover data to conduct local atmospheric and surface simulations and to analyze temporal and spatial variations in air temperature, radiation, wind, precipitation and surface fluxes in agricultural and forestlands. As part of a follow-up study, this study explores the sensitivity of the LAMP simulation on the two kinds of external forcing data sets that are used for initial and boundary input data

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of the LAMP.

II. Data and Methodology

KMA synoptic weather observation equipment (Automated Synoptic Observing System, ASOS) was used to verify the 2-m temperature (T2), 10-m wind speed (WS), 2-m humidity (H2) and precipitation (P) simulation results. In this case, the observation point data present within each model domain were compared to the nearest model grid point, and the number of stations present in domains 1, 2, 3, and 4 were 94, 90, 22, and 1, respectively. Fig. 1 shows the spatial distribution of the observation point (* in black) in each domain and the grid point closest to the observation point (* in red).

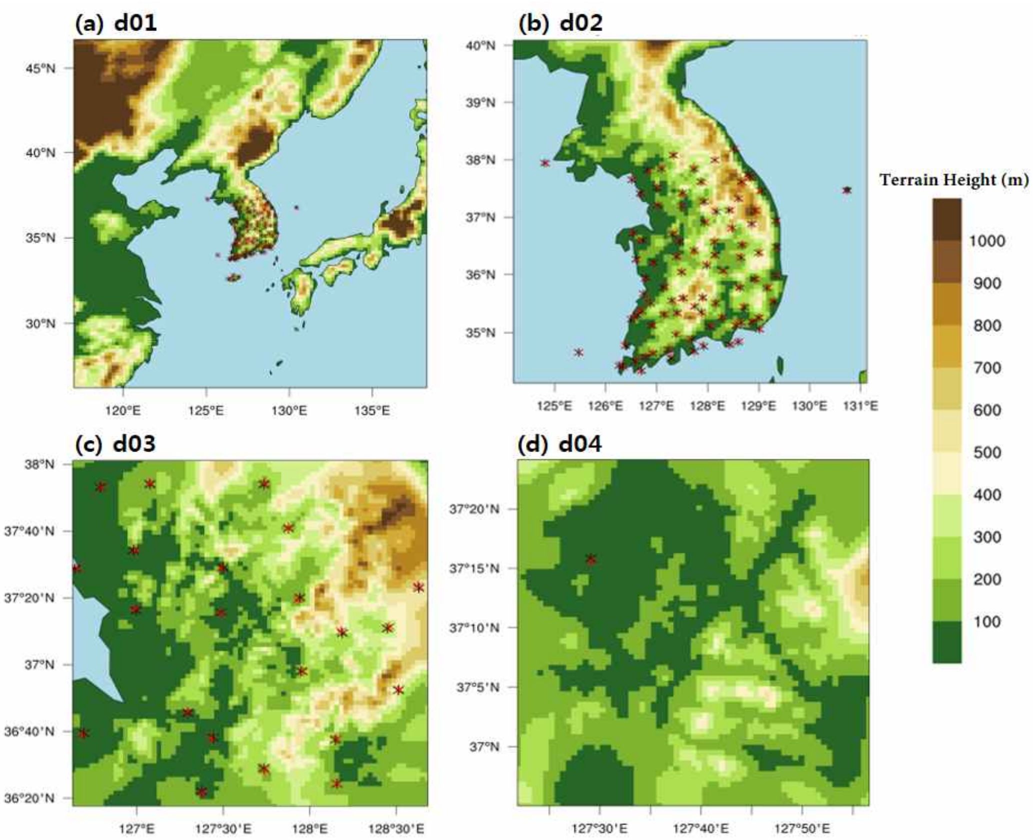

Fig. 1. Model domains and topography. Each domain's horizontal resolution is 21,870m (d01), 7,290m (d02), 2,430m (d03), and 810m (d04).

Net radiation (RNET), sensible heat (SH), latent heat (LH) flux variables, net ecosystem exchange of CO_2 (NEE), and gross primary productivity (GPP) simulations were compared at the nearest grid point to the NCAM flux towers. The four observation points are Cheorwon rice paddy (CRK; 38º 12' 5" N, 127º 15' 2" E), Gwangneung deciduous forest (GDK; 37º 45' 56" N, 127º 8' 57" E), Haenam farmland (HFK; 34º 33' 14" N, 127º 34' 12" E), and

Taehwa mixed forest (TMK; 37º 18' 15"N, 127º 18' 50" E) in Korea (Fig. 2). More information about the towers is available at http://www.asiaflux.net and http://ncam.kr/page/koflux/database/index.php.

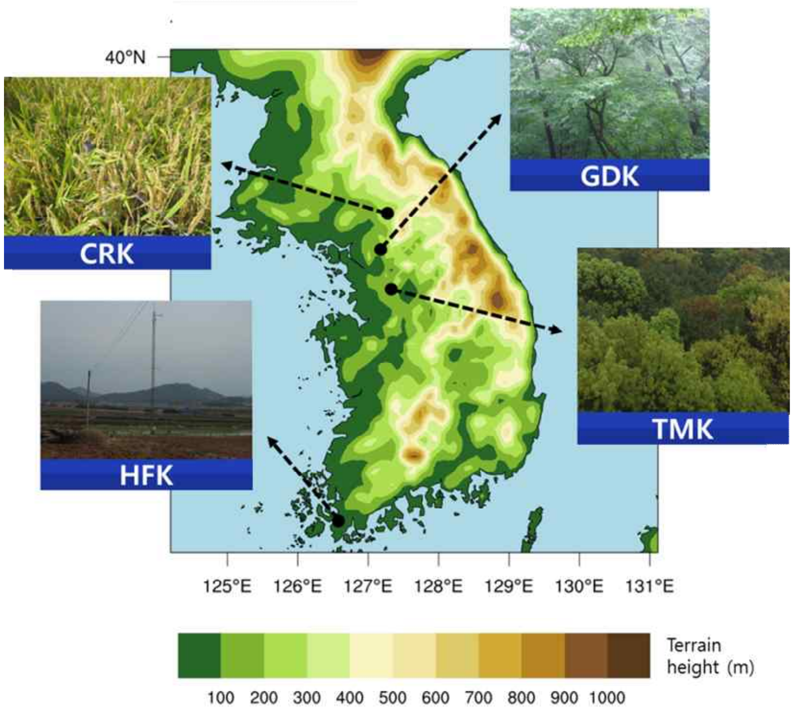

Fig. 2. The four tower sites used for the WRF/Noah-MP model validation.

Two kinds of numerical experiments were carried out: FNL-LAMP and UM-LAMP. FNL-LAMP uses NCEP Final (FNL) analysis data, while UM-LAMP uses the Unified Model (UM) as initial and boundary data. Many 7-day simulations were subsequently connected to prepare numerical simulation data for about six months from 2 May 2015 to 31 October 2015. Model domain and the atmospheric physical process follow Song *et al.* (2015). The NOAH-MP land surface model (Niu *et al.*, 2011) used the original physical parameterization settings with dynamic vegetation turned on.

III. Preliminary Results

3.1. 2-m air temperature, 10-m wind, and 2-m relative humidity

Table 1 shows that the simulated 2-m temperature had much better correlations than the wind speed and humidity with the observed data points in all domains ($r \geq 0.9$). The correlation increased and RMSE values decreased as the resolution of the model improved, leading to domain 4 having the best simulated 2-m air temperature. Domains 1, 2 and 3 showed a cold bias, while domain 4 showed a warm bias.

Among the variables in all four domains, 10-m wind showed the lowest correlation (r ≤ 0.62), but it did not show a clear tendency in accordance with the domain. It tended to excessively simulate wind speed by more than 1.2 m s^{-1} in all domains, with domain 4 exhibiting the largest deviation. Domain 4 showed improved simulations in 2-m humidity, but all domains showed a wet bias. Domains 1, 2 and 3 showed a variation of more than 6%, while domain 4 showed a wet deviation of around 1%.

Table 1. Correlation (r), bias, and RMSE of the model simulation by variable, domain, and initial/boundary condition. The underlined and/or shaded values refer to the experiment with smaller error and the domain of the smallest error

		Exp.	Domain			
			d01	d02	d03	d04
			21,870m	7,290m	2,430m	810m
T2	r	FNL-LAMP	**0.91**	**0.92**	**0.93**	**0.95**
		UM-LAMP	0.90	0.91	0.92	0.94
	Bias	FNL-LAMP	**-1.12**	**-0.92**	**-0.93**	1.06
		UM-LAMP	-1.20	-1.00	-0.95	**1.02**
	RMSE	FNL-LAMP	**2.57**	**2.43**	**2.42**	**2.16**
		UM-LAMP	2.72	2.60	2.58	2.31
WS	r	FNL-LAMP	**0.61**	**0.59**	**0.58**	**0.62**
		UM-LAMP	0.56	0.54	0.54	0.55
	Bias	FNL-LAMP	1.28	1.35	1.35	1.67
		UM-LAMP	**1.26**	**1.33**	**1.32**	**1.62**
	RMSE	FNL-LAMP	**2.13**	**2.16**	**2.07**	**2.31**
		UM-LAMP	2.19	2.21	2.09	2.33
H2	r	FNL-LAMP	**0.77**	**0.77**	**0.77**	**0.84**
		UM-LAMP	0.74	0.74	0.75	0.81
	Bias	FNL-LAMP	**8.63**	**8.06**	**6.41**	**0.68**
		UM-LAMP	9.42	8.89	6.94	1.58
	RMSE	FNL-LAMP	**16.02**	**15.99**	**15.93**	**12.09**
		UM-LAMP	17.09	17.03	16.83	13.45
Unit : T2 (℃), WS ($m\,s^{-1}$), H2 (%)						

Table 2. (a) Correlation (r), bias, and RMSE of the model simulation in domain 2 by variable, domain, initial/boundary condition. (b) Same as (a) but for NEE and GPP

(a)

Domain d02		Exp.	Site			
			Agricultural		Forest	
			CRK	HFK	GDK	TMK
RNET	r	FNL-LAMP	0.89	**0.91**	0.89	**0.91**
		UM-LAMP	0.89	0.89	0.89	0.90
	Bias	FNL-LAMP	**38.6**	**45.2**	**50.6**	**50.3**
		UM-LAMP	40.3	47.5	51.9	52.1
	RMSE	FNL-LAMP	**121.7**	**119.1**	**133.2**	**128.8**
		UM-LAMP	126.0	128.9	135.0	134.0
SH	r	FNL-LAMP	**0.65**	**0.77**	0.79	**0.81**
		UM-LAMP	0.63	0.73	**0.80**	0.80
	Bias	FNL-LAMP	**12.8**	**15.9**	**40.1**	**52.1**
		UM-LAMP	14.7	18.5	41.6	55.6
	RMSE	FNL-LAMP	**43.7**	**46.2**	**80.6**	**89.3**
		UM-LAMP	46.6	51.7	81.6	94.6
LH	r	FNL-LAMP	**0.83**	**0.85**	0.80	**0.84**
		UM-LAMP	0.82	0.84	0.80	0.83
	Bias	FNL-LAMP	42.9	60.6	53.6	36.8
		UM-LAMP	**42.8**	**60.4**	**53.2**	**35.9**
	RMSE	FNL-LAMP	100.9	**109.6**	95.2	75.4
		UM-LAMP	**100.3**	111.3	**93.8**	75.4

Unit : RNET ($W\ m^{-2}$), SH ($W\ m^{-2}$), LH ($W\ m^{-2}$)

(b)

Domain d02		Exp.	Site			
			Agricultural		Forest	
			CRK	HFK	GDK	TMK
NEE	r	FNL-LAMP	0.80	**0.82**	0.83	**0.89**
		UM-LAMP	0.80	0.81	0.83	0.88
	Bias	FNL-LAMP	-0.27	-0.30	**-0.15**	-0.02
		UM-LAMP	-0.27	-0.30	-0.16	-0.02
	RMSE	FNL-LAMP	0.40	**0.42**	0.23	**0.20**
		UM-LAMP	**0.39**	0.43	0.23	0.21
GPP	r	FNL-LAMP	0.80	**0.82**	0.85	0.89
		UM-LAMP	0.80	0.80	0.85	0.89
	Bias	FNL-LAMP	-0.11	-0.09	-0.16	-0.24
		UM-LAMP	-0.11	-0.09	-0.16	-0.24
	RMSE	FNL-LAMP	0.30	**0.23**	0.28	**0.40**
		UM-LAMP	0.30	0.24	0.28	0.41

Unit : NEE ($mg\ CO_2\ m^{-2}\ s^{-1}$), GPP ($mg\ CO_2\ m^{-2}\ s^{-1}$)

For the 2-m air temperature and humidity, the FNL-LAMP experiments generally showed better performance than the UM-LAMP experiments. For 10-m wind speed, FNL-LAMP experiments showed larger correlation and smaller RMSE, while UM-LAMP experiments showed a smaller bias.

3.2. Surface energy fluxes, NEE, and GPP

Table 2 is similar to Table 1, but the statistics were calculated in domain 2. Net radiation showed a correlation of 0.89 or higher with the observed data points, and tended to be excessively simulated at all sites. RMSE in net radiation was about 120W m^{-2}, which is within the range of values reported in Wharton *et al.* (2013). HFK and CRK, which are located in flat areas with short vegetation heights, showed slightly smaller biases and RMSEs in net radiation.

Sensible heat flux showed a somewhat higher correlation at GDK and TMK, which are located in the mountains, while it showed relatively small bias and RMSE at CRK and HFK. In particular, among the four observation points, CRK showed the least bias and RMSE in sensible heat flux. Latent heat flux showed a somewhat higher correlation at HFK, while it showed the smallest bias and RMSE at TMK.

Overall, net ecosystem exchange (NEE) and gross primary productivity (GPP) (unit: mg CO_2 m^{-2} s^{-1}) showed a slightly higher correlation at GDK and TMK than at the other two sites, and had a smaller bias and RMSE as well. TMK, especially, had the highest correlation and the smallest bias and RMSE among the four sites. Gross primary productivity showed the smallest bias and RMSE at HFK.

In the case of net radiation, sensible and latent heat, the FNL-LAMP experiments performed better than the UM-LAMP experiments in terms of correlation, bias and RMSE, except for bias of latent heat. In the case of NEE and GPP, there was little difference between the results of the two kinds of simulation experiments.

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