Impact of increasing model resolution on added values in regional climate simulation of heavy precipitation

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1. Introduction

1. **East Asia summer precipitation** is predicted to be increased by numerous studies.
2. East Asia is vulnerable to precipitation related disasters due to megacities situated along the coast, as well as the combination of complex topography and various meteorological phenomena.
3. As high-performance computing resources developed, simulating **the high-resolution global model** has been possible.
4. The **added value (AV)** gained from using a high-resolution model has been constantly emphasized.
5. However, most previous studies mainly researched on spatial distribution of the weather elements through a simple qualitative comparison without damaging the raw model data.
6. The **kinetic energy (KE)** can be used for analyzing precipitation scale.

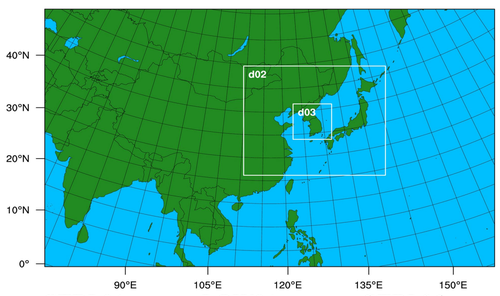
In this study, we investigated relationship between kinetic energy wavelength and meso-beta or smaller scale of precipitation.

2. Data & Methods

• Model configuration

	Advanced Research WRF (ARW) v4.1.2		
	d01	**d02**	**d03**
Horizontal Resolution	36-km (277×173)	12-km (262×220)	4-km (214×214)
Topography Resolution	5-min	5-min	30-sec
Vertical Layers	33 hybrid levels (surface to 50hPa)		
Microphysics	WSM6		
Cumulus Parameterization	MSKF		
Radiation	RRTMG		
Planetary Boundary Layer	YSU		
Land Surface	Noah LSM		
Spectral Nudging	Yes ($\lambda < 1000\ km$)		
Initial & Boundary data	ERA-Interim (0.7° and 6 h)		
Simulation Period	0000 UTC on 1st May to 0000 UTC on 1st September 2001, 2006, 2009, and 2011.		
Analysis Period	0000 UTC on 1st June to 0000 UTC on 1st September 2001, 2006, 2009, and 2011.		

• Model Domain



• **CTRL04** • **LOW04** • **CTRL36**

• Experimental Design

1) Topography
- CTRL04 & CTRL36 : obtained from GTMED2010
- LOW04 : outermost domain → CTRL36
innermost domain → replaced with that of the outermost domain using bilinear interpolation

2) CTRL04 (04km grid-spacing, 30-sec resolution topography)
LOW04 (04km grid-spacing, 5-min resolution topography)
CTRL36 (36km grid-spacing, 5-min resolution topography)

We assumed that higher model resolution would cause
(1) greater extreme precipitation intensity
(2) increased short-duration precipitation due to smaller scale weather events
(3) increased orographic precipitation

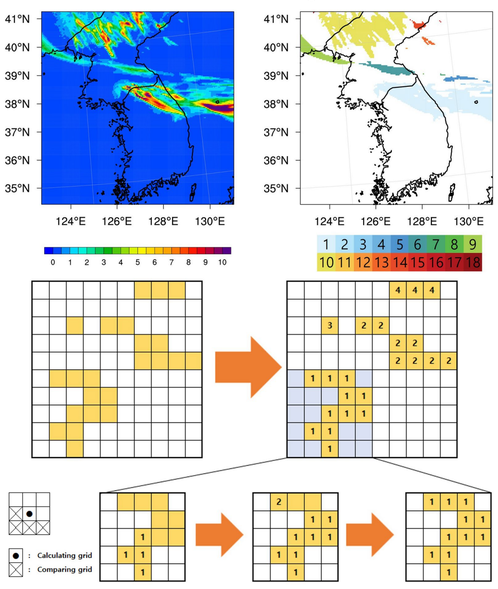
(a) **Fine-mesh effect (**LOW04 vs. CTRL36) : the grid spacing impacts on the precipitation intensity and the rain cell size

(b) **Detailed topographic effect (**CTRL04 vs. LOW04) : the effect of the topographies on the spatial distribution

• Analytical Methods

- Daily precipitation > 1mm/day was sampled for analysis.
- Rain cells at 3-hour intervals as closed contours with rainfall intensity exceeding 0.1mm for 3 hours.

Rain Cell Numbering Method



We numbered these rain cells as follows :

1. Sequential Assignment : Rain cells exceeding the 0.1 mm threshold were sequentially assigned group numbers, starting from 1. This was based on comparisons with rainfall values from four surrounding grids.
2. Grid Comparison : We checked only four of the eight surrounding grids, moving eastward and northward.
3. New Assignment : If none of the comparing grids exceeded the threshold, a new group number was assigned.
4. Assignment Based on Comparison : When at least one comparing grid exceeded the threshold, we assigned the group number of the corresponding grids.
5. Handling Multiple Exceedances : If multiple cells exceeded the threshold, we assigned the smallest group number to the current cell, updating all comparing cells' group numbers.

This process systematically numbered rain cells based on their characteristics and surrounding grid values.

Spectral method

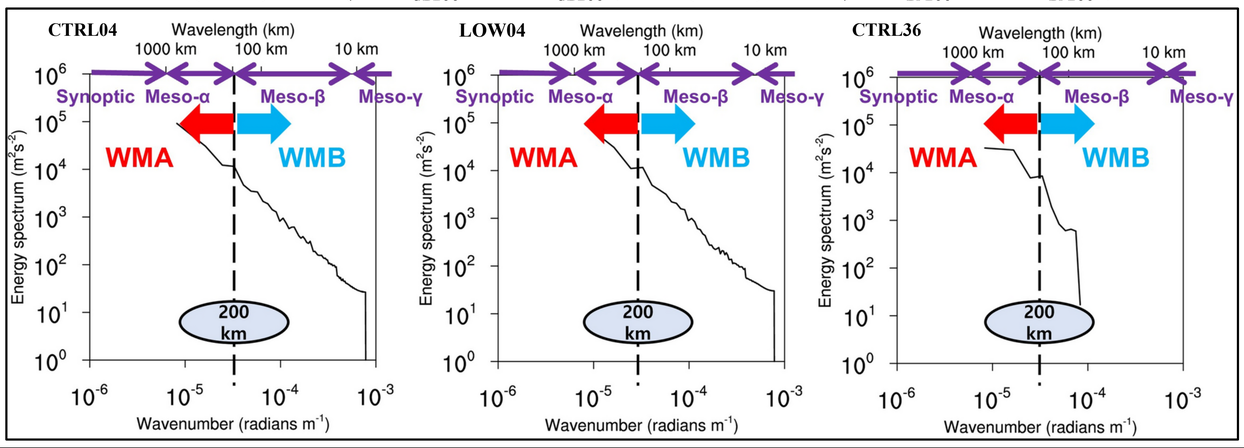
Spectral method was used to examine the model performance for kinetic energy depending on model resolution and its association with simulated precipitation in assumptions. We used kinetic energy at 850 hPa (TOTAL), which showed the highest temporal correlation with precipitation at various vertical levels.

$$TOTAL(m^2s^{-2}) = 0.5 \cdot (ua850^2 + va850^2)$$

Length of d03 is 856km · 856km . Only meso-α to meso-γ can be simulated.

New wind component with wavelengths of meso-α (WMA), meso-β (WMB)

$$WMA(m^2s^{-2}) = 0.5 \cdot ({ua850_{GE200}}^2 + {va850_{GE200}}^2),\ WMB(m^2s^{-2}) = 0.5 \cdot ({ua850_{LT200}}^2 + {va850_{LT200}}^2)$$

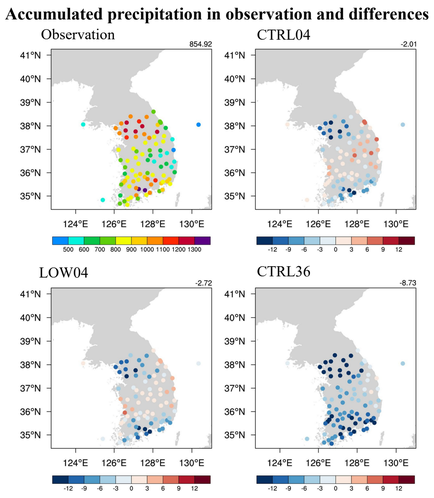


3. Results

• Validation of Precipitation

- Validations with 95 stations observation
- CTRL36 : underestimated in most regions (especially on northwestern & southern regions)
- CTRL04 & LOW04 : greatly reduced negative biases, although not improved significantly in spatial distribution.
- When detailed topographic data were used (CTRL04), the bias pattern was like that of LOW04 but showed slight differences depending on the region.
- Even, CTRL04 moderately overestimated precipitation in the mountainous eastern part, it decreased mean biases by increasing overall precipitation compared to LOW04.

Accumulated precipitation in observation and differences

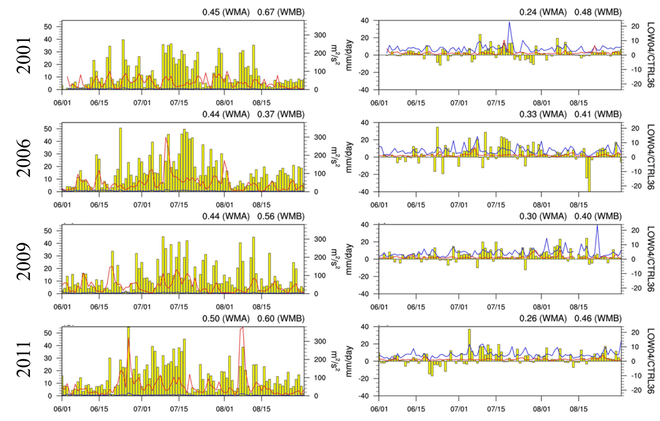


• Fine-mesh effects (grid-spacing only) LOW04 vs. CTRL36

Precipitation and KE of LOW04 and Changes

- In most days, precipitation, WMA, WMB increased.
- WMB increased significantly, but WMA was not.
- WMB increased 4.57 times.
- WMA increased 1.31 times.
- Mean precipitation increased : 3.47mm/day
- Kinetic Energy: WMA > WMB
- KE changes between LOW04 vs. CTRL36, WMA < WMB
Smaller grid makes smaller scale precipitation increased.
- Likewise, the t test results demonstrated significant changes in precipitation and WMB but not in WMA.

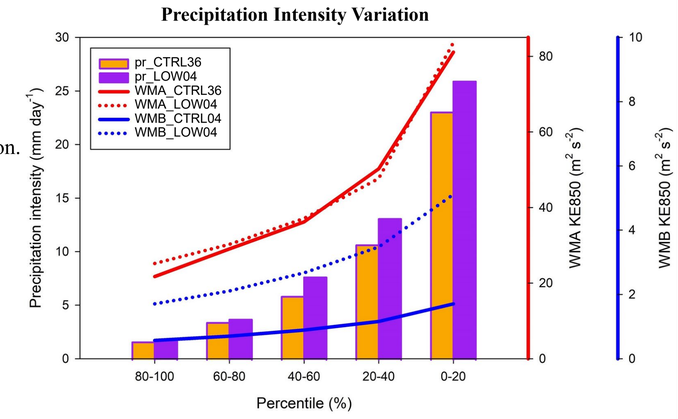
Time series of precipitation, WMA, WMB / **Time series of difference of precipitation, WMA, WMB**



Variation of Precipitation Intensities (Quantiles)

- 5 groups for each 20 percentiles
- Precipitation difference between CTRL36 and LOW04 increased as precipitation intensity increased.
- Extreme precipitation intensity was enhanced at high resolution.
- WMA does not show big difference between CTRL36 and LOW04.
- WMB shows higher wind component on LOW04 (even higher on extreme precipitation intensity)

Precipitation Intensity Variation



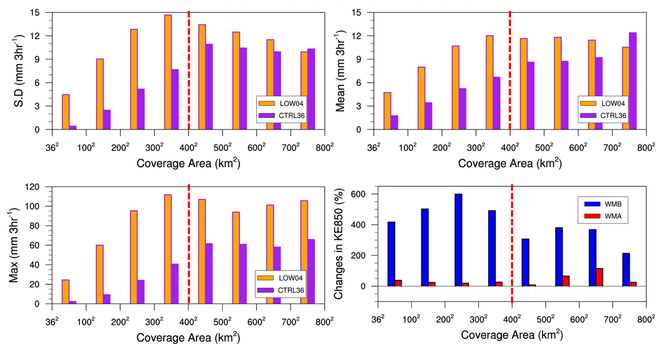
Variation of Precipitation Intensities (Size of the Rain Cell)

$$36^2 km^2 = Grid\ size < minimum\ rain\ cell\ size$$

$$small\ size\ cell < 400^2\ km^2 < big\ size\ cell$$

- Small size rain cell show significant difference on spatial standard deviation (S.D.), mean, and max precipitation between LOW04 and CTRL36.
- Higher resolution model (LOW04) show higher mean, max precipitation, and S.D. (→ higher intensity precipitation.)
- Large size rain cell showed less differences between experiments
- WMB has higher KE850 changes than WMA in most areas. Still, WMA become larger on larger rain cell size.

Variation in Precipitation Intensities as a Function of Rain Cell Size

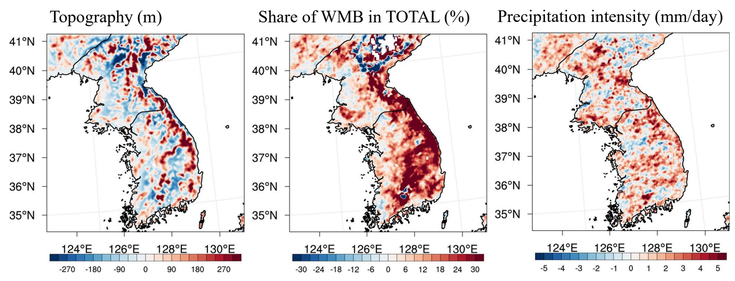


• Detailed topographic effects (same grid-spacing) LOW04 vs. CTRL04

Different Precipitation Intensities on the Topography

- CTRL04 express more detailed topography, especially in the mountainous regions.
- LOW04 mountain height range : 500-700m
CTRL04 mountain height range : 800-1000m
- Share of WMB in TOTAL has been increased on mountainous regions.
- Precipitation intensity has been increased.

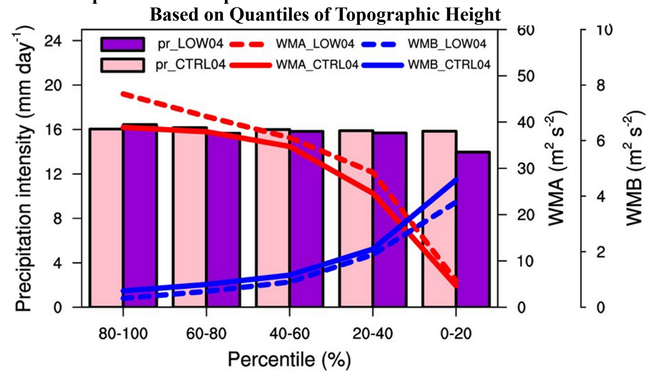
LOW04 - CTRL04



Precipitation Intensities, WMA, and WMB on Quantiles of Topographic Height

- 5 groups for each 20 percentiles depending on topographic height
- Highest height (0~20%) group shows significant higher precipitation on CTRL04 than LOW04
- No significant difference between experiment on other percentile group.
- However, each percentile groups' WMA do not show significant correlation between CTRL04 and LOW04.
- WMB shows highest difference between CTRL04 and LOW04 on highest height group.
- We can infer that higher elevation group's WMB increase made CTRL04's precipitation increase.

Comparison of Precipitation Intensities between WMA and WMB Based on Quantiles of Topographic Height



4. Summary

1. **Assessing Model Resolution** : Our study focused on evaluating the impact of increasing model resolution on regional climate simulations, particularly for heavy precipitation events.
2. **Fine-Mesh Effects** : Changes in grid spacing, leading to finer meshes, resulted in higher extreme precipitation intensity on smaller grids. This also led to increased mean and maximum precipitation in smaller rain cells.
3. **Topographic Influence** : Detailed topographic representation had a significant influence on precipitation, particularly in mountainous regions, where higher resolution led to increased precipitation.
4. **Precipitation Increase** : The combined effects of fine-mesh and topographic representation resulted in an overall increase in precipitation.
5. **Scale-Dependent Kinetic Energy** : This precipitation increase was not directly correlated with meso-α or larger-scale kinetic energy but was influenced by meso-β or smaller-scale kinetic energy.
6. **Resolution Impact** : Increasing model resolution notably affected precipitation via meso-β and smaller-scale phenomena.
7. **Variable Impact** : Model resolution alone, without fixed settings, increased precipitation, highlighting detailed topography's importance.

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