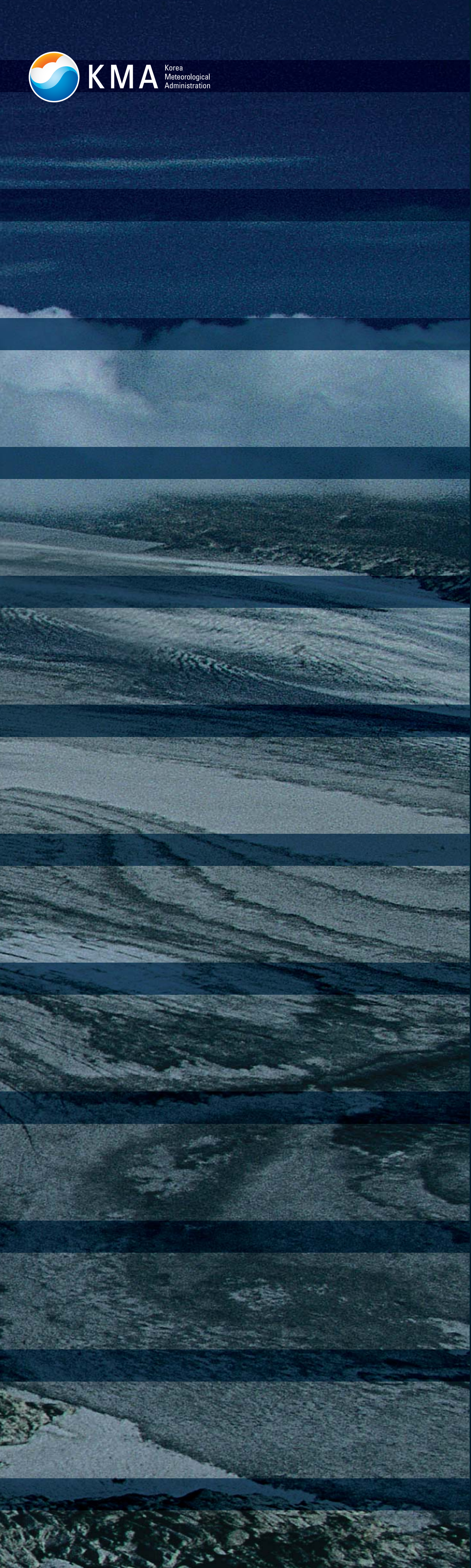
KMA Korea Meteorological Administration



Korea Climate Change Report

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Foreword

Abnormal weather events such as heavy rains, typhoons, drought, heavy snowfall and flooding have been occurring more frequently across the world in recent years, bringing the large-scale losses of human and economic damages from the natural disasters. The economic losses have also been steadily increasing.

According to the 2011 special report on 'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation' issued by the Intergovernmental Panel on Climate Change (IPCC), the possibility of increase of heat waves and heavy rains will be over 90% and 66% in the late 21st century, respectively. The increase of such extreme weather events will influence a broad range of fields and sectors such as water management, food security, health and industry.

According to the results of an analysis of observational data in the world, there are some differences among the local areas about the influences, vulnerabilities, and damages induced by the climate change so that the assessment of influences from the climate change is very important for the local areas.

Also, in light of the preparation of the large-scale natural disasters and the need to cope with the climate change effectively, the scientific and consistent information on the climate change should be provided for projecting the detailed regional climate change as well as a general projection on the future climate change over the Korean Peninsula.

In order to support the government ministries and local governments of South Korea in drawing up consistent measures for addressing climate change, projections of future climate change in the level of the city, county and borough should be provided.

The Korea Meteorological Administration has put together overall information for the Korean Peninsula as well as information organized by regions, so that the future trends of climate changes can be found in one place and be readily used for policy making. The report has been issued as 9 volumes divided by regions and also released as the collected report, 'Korea Climate Change Report', integrating all of these regions.

This report presents a comprehensive review of the rapidly changing climate conditions on the Korean Peninsula by examining the observational data from the past 30 years for both South Korea and North Korea, and the future projections of climate change for the 21st century on the basis of the new greenhouse gas scenarios.

It is hoped that this report will be of great use as a scientific resource in the advancement of measures addressing climate change and natural disasters across a broad spectrum of fields as well as in the establishment of adaptation policy for the climate change at the national and local government levels.

Administrator,
Korea Meteorological Administration (KMA)
30th November 2013

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This detailed climate change report for the Korean Peninsula in the 21st century has been compiled to support relevant actors in making provisions for large-scale natural disasters and ensure the establishment of well-informed climate change mitigation and adaptation policies.

◆ Climate Changes Observed on the Korean Peninsula

Change in Annual Mean Temperature

- The annual mean temperature of the Korean Peninsula has increased by 1.2℃ (0.41℃/decade) during the last 30 years (1981–2010), with the mean temperature increasing in all seasons.
  - The trend of change in annual mean temperature showed the greatest increase in autumn and winter and the smallest increase in spring and summer.
- The trend of change in annual mean temperature in North Korea (0.45℃/decade) was 1.3 times greater than that in South Korea (0.36℃/decade).
  - The difference in temperature increase between South and North Korea was greatest in the summer months, with North Korea showing a robust warming trend in summer temperatures.

Change in Annual Mean Precipitation

- While the annual mean precipitation has shown a slight increase of 78 ㎜ during the last 30 years it is not statistically significant as it accounts for less than 7% of the total annual precipitation.
  - The change is largely due to an increase in summer precipitation in South Korea, while the annual mean precipitation in North Korea even showed a slight decrease during the same period.

◆ Climate Change Projections for the Korean Peninsula

- Projections of future climate change for the Korean Peninsula indicate that the warming trend shown in observations for the past 30 years will continue consistently until 2100.
  - The low emissions scenario (RCP4.5) predicts a temperature increase of 0.33℃/decade until 2100: a more gradual rate of increase than that observed during the past 30 years.
  - The high emissions scenario (RCP8.5) predicts a more rapid temperature increase of 0.63℃/decade which is 1.6 times as large as the increase rate recorded in observations during the past 30 years.
  - The magnitude of the temperature increase projected by the RCP4.5 and RCP8.5 scenarios is 1.2 times as large as the global average and 1.4 time as the East Asian average for the same period (2071–2100).
- In the RCP4.5 scenario the rate of temperature increase is projected to slow down after the mid-21st century following the stabilization in the concentration of greenhouse gases. A temperature increase of 1.4℃ is predicted in the early 21st century (2011–2040), 2.4℃ in the mid-21st century (2041–2070) and 3.0℃ in the late 21st century (2070–2100).
  - The annual mean temperature of the Korean Peninsula in the late 21st century is projected to be 14.0℃ which is the current annual mean temperature in the southeast coastal region around Busan.
- In the RCP8.5 scenario the warming trend is predicted to accelerate after the mid-21st century,

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with the annual mean temperature reaching 16.7℃ by the late 21st century (2071–2100), by which time the annual mean temperature of Pyeongyang in North Korea would be similar to the current annual mean temperature of Seogwipo, Jeju Island (16.6℃).

- For the first part of the 21st century the trend of temperature increase projected by the RCP8.5 scenario is similar to that projected by RCP4.5.

● The projected rate of increase in annual mean temperature appears more severe in North Korea than in South Korea, coinciding with the overall trend of warming shown in observations during the past 30 years (1981–2010).

- The temperature increase predicted for the northern part of the Korean Peninsula is closely related with the overall warming of the Northeast Asian landmass projected to occur due to global warming.
- On a regional scale, the increase in ocean temperature and the northward shift of the warm current in the East Sea are predicted to cause a relatively distinct temperature increase in the eastern coastal region.

● A distinct increase in both annual mean daily maximum and minimum temperatures is also projected in both the RCP4.5 and RCP8.5 scenarios.

- Because of the greater increase in mean daily minimum temperatures, a gradual decrease is predicted in the daily temperature range.

● The annual mean precipitation is projected to increase over and above natural levels of fluctuation after the mid-21st century in both the RCP4.5 and RCP8.5 scenarios.

● In the RCP4.5 scenario the annual mean precipitation is predicted to increase up to 6.2% in the early 21st century, 10.5% in the mid-21st century and 16.0% in the late 21st century.

- The magnitude of the projected increase in precipitation over the Korean Peninsula for the late 21st century is 3.9 times as large as that predicted globally and 3.5 times the increase predicted in East Asia.

● In the RCP8.5 scenario the annual mean precipitation is predicted to increase by 3.3% in the early 21st century, 15.5% in the mid-21st century and 17.6% in the late 21st century.

- The magnitude of the projected increase in precipitation over the Korean Peninsula in the late 21st century corresponds to 3.0 times the average increase predicted globally and 2.9 times that predicted to occur in East Asia.

● The annual mean precipitation over the Korean Peninsula predicted for the late 21st century

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in the RCP4.5 and RCP8.5 scenarios corresponds with the current levels in Jeollanam-do, Gyeongsangnam-do and the central region of the Korean Peninsula.

- While wide regional variation is expected, the increase of precipitation is predicted to be more extreme in South Korea.
- The overall precipitation increase projected for the Korean Peninsula coincides with that for the East Asian region, being brought about by large-scale changes in monsoon circulation and the increase of water vapor transport from the ocean to the land.

- There are no significant changes in the annual mean wind speed, relative humidity, and cloud cover over the Korean Peninsula in both the RCP4.5 and RCP8.5 scenarios.

◆ Projections of Sea level height Change for the Korean Peninsula

- The sea level height is projected to rise along the entire coastline of the Korean Peninsula.
  - The trend of sea level height rise is predicted to be relatively more severe along the east coast than along the south and west coasts.
- In the RCP4.5 scenario the sea level height is predicted to rise 53㎝ on the south and west coasts and 74 ㎝ on the east coast by the late 21^{st} century (2071–2100).
  - The scale of this rise is comparable to the global sea level height rise of 70.6 ㎝ predicted for the same period.
- In the RCP8.5 scenario the extent of sea level height rise is predicted to reach 65 ㎝ on the south and west coasts and 99 ㎝ on the east coast in the late 21^{st} century.
  - The sea level height rise predicted for the east coast in this scenario is 1.1 times as much as the global average predicted for the same time period (88.5 ㎝).

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◆ Projections of Changes for Extreme Indices

- The subtropical climate region currently limited to the southern coastal area of the Korean Peninsula is predicted to extend gradually northward throughout the 21st century.
  - In the RCP4.5 scenario the subtropical climate region is predicted to extend along the west coast of Jeollanam-do, Jeollabuk-do and Chungcheongnam-do and up to the west coast of Gyeonggi-do and Hwanghae-do.
  - In the RCP8.5 scenario the majority of South Korea (except for Gangwon-do and the northwest of Gyeonggi-do) and the west of Hwanghae-do in North Korea are predicted to be classified as a subtropical climate region.

- Sharp increases are predicted in temperature-related extreme indices such as heat wave days and tropical nights in line with the general warming projected for the Korean Peninsula.

- The number of heat wave days is projected to increase in the RCP4.5 scenario from the current level of 7.3 day/year to 8.8 days in the early 21st century, 11.1 days in the mid-21st century and 13.1 days in the late 21st century.
  - In the RCP8.5 scenario the number is predicted to increase by 2.5 day/decade and reach 30.2 day/year in the late 21st century.

- The number of tropical nights is projected to increase rapidly in the RCP4.5 scenario from the current 2.8 day/year to 4.1 days in the early part of the 21st century, 9.0 days in the mid-21st century and 13.6 days in the late 21st century.
  - In the RCP8.5 scenario a more extreme increase of 3.8 day/decade is predicted, with the average annual number of tropical nights reaching 37.2 days in the late 21st century.

- The number of heavy precipitation days is projected to increase from the current level in both the RCP4.5 and RCP8.5 scenarios.
  - An increase in the number of heavy precipitation days of over 30% is predicted to occur in the late 21st century from the current level of 2.0 days to 2.8 day/year.

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01

Introduction

01 Introduction

Background to the Report

The Need for Detailed Climate Change Projections for the Korean Peninsula

- The record breaking floods, increasingly strong typhoons, severe heat waves and cold spells which are all now frequent occurrences on the Korean Peninsula are part of the global climate changes taking place due to increased greenhouse gas concentration in the atmosphere caused by human activity.
  - Such extreme climate and weather events are set to occur more frequently and severely in line with global warming.
- The trends of climate change taking place on the Korean Peninsula are already having tangible effects on a wide range of areas such as weather, ecology, environment and water resources (KMA, 2011a; 2011b), and progressing in various ways in different regions.
  - It is predicted that future climate change trends will occur in diverse ways in different regions.
- The use of systematic and scientific climate projections is crucial for the effective handling of climate change and making provisions for the natural disasters that are predicted to occur due to climate change.
  - In particular, the climate change projections presented in regional detail will be an important asset for the policy makers associated with the climate change.

Background of the Report and Objectives

- Recently the KMA published the 'White Paper on Climate Change in Korea' (KMA, 2011a) using South Korean climate data, and compiled data on North Korea to produce '30 Years of North Korean Weather' (KMA, 2011b), to provide information on climate change across the entire Korean Peninsula.
- The KMA in collaboration with the National Institute of Meteorological Research (NIMR) has compiled global and Korean Peninsula climate projections for the 21st century with a spatial resolution of 12.5 ㎞ (NIMR, 2011) based on the representative concentration pathways in the IPCC 'Fifth Assessment Report'.
  - To support the establishment of climate change adaptation policies by local governments, detailed regional climate projections have been produced to a spatial resolution of 1㎞.
- This report aims to bring together climate change information for South Korea and North Korea and make available data recorded on the trends of rapid change in weather and climate which have occurred on the Korean Peninsula in the last 30 years (1981–2010).
  - The report also presents observed and projected trends of climate change in spatial detail.

- Based on observed and projected data for the Korean Peninsula, this report presents the past and future trends of regional climate change and their space-time characteristics in a format which makes them easy to understand at a glance so that they can be applied to ensure climate change adaptation by local governments and in a range of sectors.

How this Report Differs to Previous Climate Change Reports

New Climate Change Scenarios for the Korean Peninsula

- Including the most recently released 'Fifth Assessment Report' (2013), the IPCC has been producing updated reports on global and regional climate change since 1990.
  - The report drafting process takes into account developments in climate science and climate modelling to maximize the reliability of the information.
- The 'Fifth Assessment Report' of the IPCC used a new set of greenhouse gas concentration scenarios called Representative Concentration Pathways (RCP).
  - Since 2011 the KMA has been creating climate change projections based on this new set of scenarios for the Korean Peninsula and the globe.
- The method of producing the new climate change projections presented here was different to that outlined in the previous 'Fourth Assessment Report' in the two main ways outlined below.

1) Greenhouse Gas Concentration Scenarios

- The new climate change projections in this report have been made by applying every aspect of the climate change modelling method outlined in the IPCC 'Fifth Assessment Report' (for details see section 2.2).
  - Going forward it will be possible to compare climate change projections produced by various meteorological agencies.
  - Also, when data produced by other agencies becomes available supplementation of previous projections will be possible by combining information from multiple models for the Korean Peninsula.
- The key inputs for the global climate model are based on the RCP in the new projection.
  - The RCP scenarios are similar to the SRES (Special Report on Emissions Scenarios) used in the fourth IPCC report in terms of the absolute values and trends of greenhouse gas concentration.

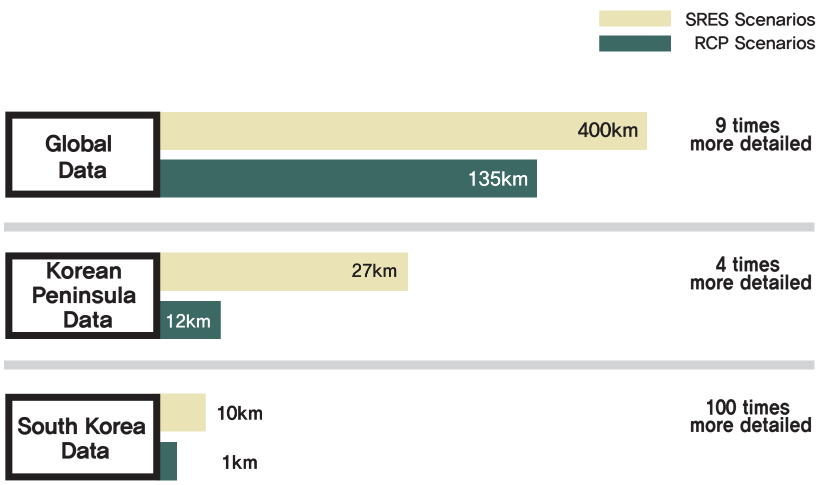
– The process of deducing the greenhouse gas concentrations of the new scenarios was simpler than methods used for previous scenarios which relied on complex socio–economic forecasting (see section 2.2 for details). The new scenarios allow for more efficient report drafting.

– Therefore, the global warming trends associated with the increase of the greenhouse gas concentration are the same qualitatively, but the projections are quantitatively different.

- This report presents the projections of climate change for the Korean Peninsula according to the RCP4.5 and RCP8.5 scenarios (assuming the direct greenhouse effect from the increase of greenhouse gas concentration by the year 2100 is 4.5 W/m² and 8.5 W/m², respectively).

  – In 2005, it was estimated there was a greenhouse effect of 1.6 W/m² associated with the increase of greenhouse gases (IPCC 2007).

Fig. 1.1
Comparison of the Spatial Resolution of the Climate Change Projection Models used by the KMA for the SRES and RCP based Scenarios



2) Improved Climate Projection Methods

- The HadGEM2-AO climate model used in this report was developed by the Hadley Centre at the UK Met Office. As a global climate model it provides detailed global climate projections until after 2100 to a spatial resolution of 135 ㎞.
  - Such a resolution reflects the constant development of high-capacity super computers and as the spatial resolution of climate models increases so will the general reliability of the data they produce.
  - To produce climate change projection data for East Asia the HadGEM3-RA regional climate model was developed and 12.5 ㎞ resolution climate data created for the region, this data was then fed back into the global model.
- In order to produce more detailed climate change projection data for the Korea Peninsula a statistical downscaling method has been used, applying GIS-based empirical analysis to create 1km spatial resolution data for South Korea (Fig. 1.1).

Reliability of the New Climate Change Projections

- The climate change projections in this report are different to those in the previous KMA (2011c) and National Institute of Environmental Research reports (2010).
  - This is due to differences in the prediction of greenhouse gases and the prediction methods (see the chapter 2, 'Data and Methodology').
- According to Reichler and Kim (2008), the HadGEM climate model used to produce the new climate change projections for the Korean Peninsula has an outstanding reproduction capability.
  - The reproduction capability of this model is particularly excellent for the East Asia and Pacific Rim regions in which the Korean Peninsula is located, therefore it is anticipated that these projections will provide relatively reliable predictions.
- However, considering the imperfect nature of climate models and the uncertainty of climate projection the information provided contains some degree of uncertainty.
  - For regional climate change projection data in particular there is a certain level of uncertainty.
  - Going forward such uncertainty should be gradually supplemented by climate data from various models produced for the IPCC 'Fifth Assessment Report'.

Climate Change Projections for the Globe and the East Asia

The New Projections for the Globe

- The concentration of carbon dioxide in the atmosphere is increasing consistently and in 2011 it was at a level of 392 ppm (US National Oceanic and Atmospheric Administration estimate).

  - In the RCP4.5 (low emissions) scenario the concentration of carbon dioxide in the atmosphere would be roughly 1.4 times the current level (540 ppm); and in the RCP8.5 (high emissions) scenario it would be 2.4 times the current amount (940 ppm) in 2100.

- The global mean surface temperature is projected to increase continuously in line with increasing greenhouse gas concentration (Fig. 1.2), and this increasing trend is predicted to be more obvious in the RCP8.5 scenario.

  - If greenhouse gas emissions are not reduced but continue to increase at the current rate (RCP8.5), by the end of the 21^{st} century (2081–2100) the global mean surface temperature is predicted to increase by 3.7℃ against the 1986–2005 average and sea level heights is predicted to rise by 63 ㎝. However, if a considerable reduction is realized (RCP4.5), the magnitude of increase in the mean temperature and sea level height rise is projected to be much smaller at 1.8℃ and 47 ㎝, respectively (Table 1.1).

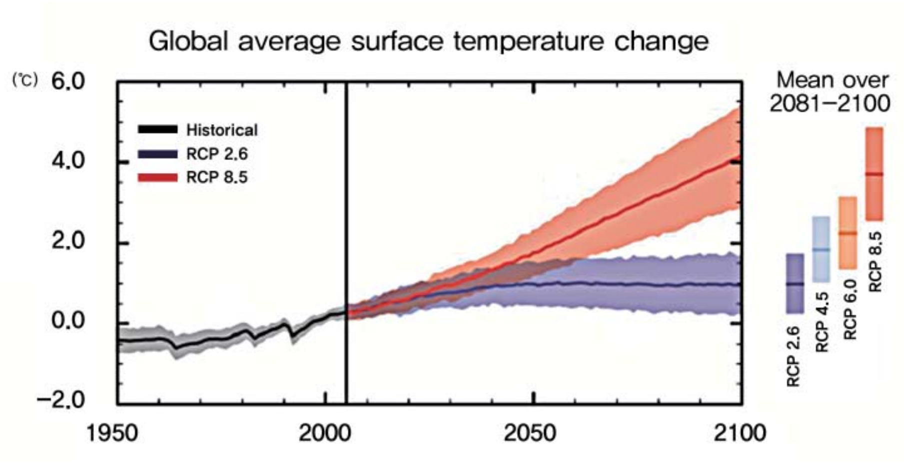
  - Although there may be regional exceptions, due to the warming of the climate it is highly likely that in most of the world the difference in precipitation according to season will widen in both wet and dry regions, and temperature difference between rainy seasons and dry seasons will increase; also in the high latitude and equatorial regions of the Pacific the precipitation is predicted to increase.

Table 1.1
Projection of Annual Mean Temperature and Sea level height Change in the Late 21st Century (2081–2100) Compared with Current Climate Conditions (1986–2005) by the IPCC 'Fifth Assessment Report'

RCP Scenario	RCP 4.5	RCP 8.5
CO_2 Concentration (by 2100)	540 ppm	940 ppm
Temperature	+1.8℃ (1.1 - 2.6℃)	+3.7℃ (2.6 - 4.8℃)
Rise in Sea level height	+47 cm (32 - 63cm)	+63 cm (45 - 82cm)

Fig. 1.2
Change in Annual Mean Global Temperature to 2100 in the RCP4.5/8.5 Scenarios

- The 'historical' run (black line) shows the climate model reproduction data for observed climate compared with the 1986–2005 average.
- The RCP2.6 (purple line) and RCP8.5 (red line) show the IPCC 'Fifth Assessment Report' projected global average surface temperature according to the respective greenhouse gas concentration rise of each scenario. The shaded area represents the range of uncertainty, and the numbers written on the graph indicate the number of models used in analysis.



Climate Change Projections for the East Asia Region

- The annual mean surface temperature for the East Asia region is predicted to increase by 2.2℃ in the RCP4.5 scenario and 4.2℃ in the RCP8.5 scenario by the late 21st century (2071–2100) compared to current conditions (1981–2010) (Fig. 1.3).
  - The East Asia region is predicted to see an increase in average precipitation of 4.6% in the RCP4.5 scenario and 6.0% in the RCP8.5 scenario (Fig. 1.4).
- In the East Asia region going further north to colder areas more severe trends of temperature increase are predicted (Fig. 1.3).
  - Regions such as Manchuria, Primorsky Krai and the coast of the Kamchatka Peninsula which are near the Korean Peninsula are set to experience a more extreme temperature increase.
  - The increasing trend of the temperature in the Tibetan Plateau is more severe than in other areas.
- While the RCP4.5 and RCP8.5 scenarios project similar regional distributions of temperature increases, the increasing temperature trend in RCP8.5 is more severe especially over the ocean.
- In the case of precipitation the East Asia region is predicted to see a general increase (Fig. 1.4).
  - Increases in precipitation are projected to be most prominent in middle and high latitude inland areas resulting from the increase in water vapor in the atmosphere and the intensified water vapor transport from the ocean to the land due to global warming.
- However, the increasing trend of precipitation is predicted to vary widely according to region with some regions even seeing an overall reduction in precipitation.
  - While the regional variation for precipitation is similar in both RCP4.5 and RCP8.5, in the RCP8.5 scenario the changes predicted are more extreme.
- According to the RCP8.5 scenario, China and the Korean Peninsula will see increasing amounts of precipitation while Japan will see a decrease.
  - In the RCP4.5 scenario also the precipitation over the Korean Peninsula is projected to increase.

Fig. 1.3
Temperature Change Projections (℃) for East Asia in the Late 21st Century (2071–2100)

– The deviation from the 1981–2010 mean climatology.

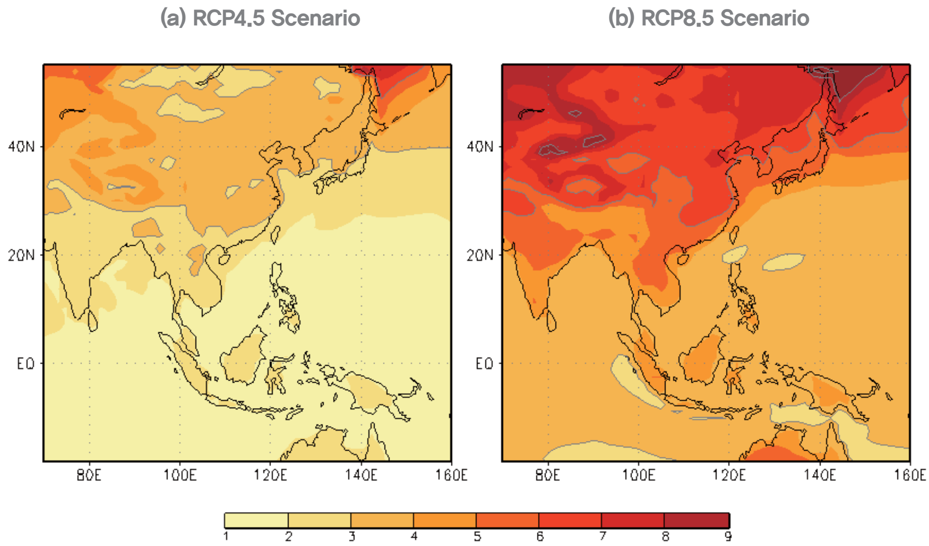
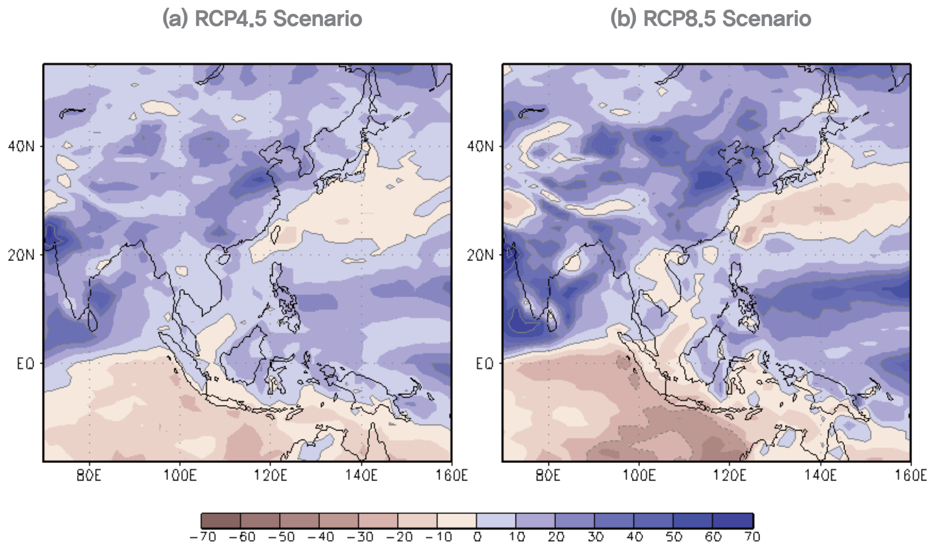


Fig. 1.4
Precipitation Change Projections (%) for East Asia in the Late 21st Century (2071–2100)

– The rate of precipitation change (%) from the 1981–2010 mean climatology.



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02

Data and Methodology

1. Observation Data
2. Climate Change Scenario Data

02 Data and Methodology

1. Observation Data

◆ Climate Data

Selection of Representative Observation Stations on the Korean Peninsula

- For this report 72 land weather observation stations (45 in South Korea, 27 in North Korea) were selected to depict the climate characteristics of the Korean Peninsula and the climatic changes which have occurred during the last 30 years (see chapter 3).
  - The topography of the Korean Peninsula and the location of the the 72 observation stations can be seen in Figure 2.1.
  - The World Meteorological Organization (WMO) station registration number, name, location coordinates and altitude above sea level height for each station are provided in Table 2.1.
- The 45 observation stations in South Korea were selected according to guidelines set by the KMA for effective calculation of the national averages of climate elements on the Korean Peninsula (KMA, 2011c).
- The 27 observation stations in North Korea correspond to the international synoptic surface observation stations from which data is provided to the World Meteorological Organization (KMA, 2011a).

Fig. 2.1
Location of 72 Weather Observation Stations on the Korean Peninsula used for Analyses

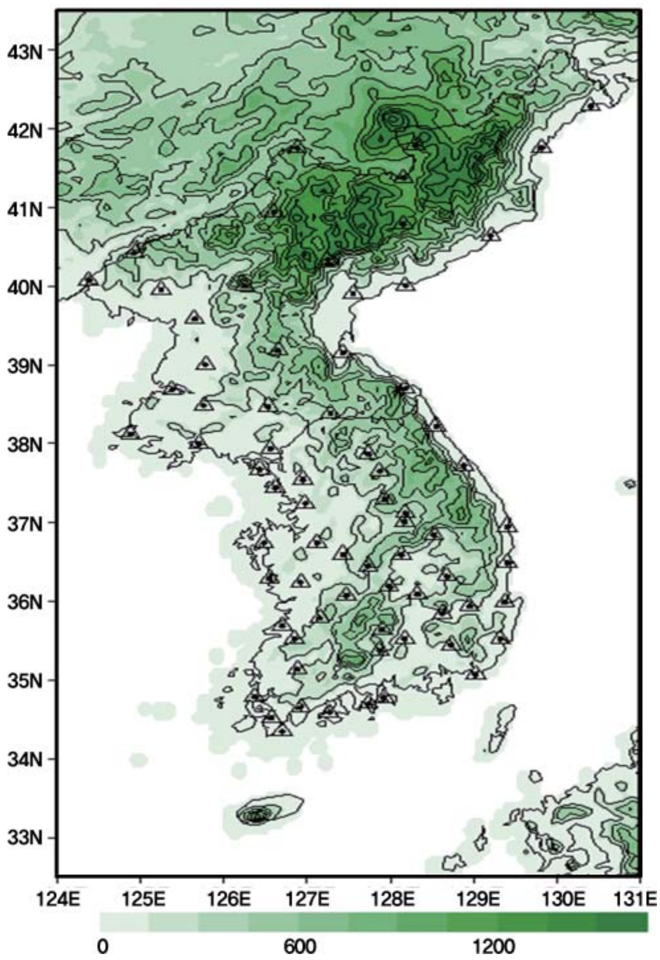


Table 2.1
Geographical Characteristics of Weather Observation Stations used for Analyses

Observation Station No.	Name	Lattitude(N)	Londitude(E)	Altitude(m)
3	Seonbong	42° 19′	130° 24′	3
5	Samjiyeon	41° 49′	128° 18′	1386
8	Cheongjin	41° 47′	129° 49′	43
14	Junggang	41° 47′	126° 53′	332
16	Hyesan	41° 24′	128° 10′	714
20	Ganggye	40° 58′	126° 36′	306
22	Pungsan	40° 49′	128° 09′	1206
25	Gimchaek	40° 40′	129° 12′	23
28	Supung	40° 27′	124° 56′	83
31	Jangjin	40° 22′	127° 15′	1081
35	Sinuiju	40° 06′	124° 23′	7
37	Guseong	39° 59′	125° 15′	99
39	Huicheon	40° 10′	126° 15′	155
41	Hamheung	39° 59′	127° 33′	38
46	Sinpo	40° 02′	128° 11′	19
50	Anju	39° 37′	125° 39′	27
52	Yangdeok	39° 13′	126° 39′	279
55	Wonsan	39° 11′	127° 26′	36
58	Pyeongyang	39° 02′	125° 47′	38
60	Nampo	38° 43′	125° 23′	47
61	Jeongjeon	38° 44′	128° 11′	35
65	Sariwon	38° 31′	125° 46′	52
67	Singye	38° 30′	126° 32′	100
68	Yongyeon	38° 09′	124° 53′	5
69	Haeju	38° 02′	125° 42′	81
70	Kaesong	37° 58′	126° 34′	70
75	Pyeonggang	38° 25′	127° 17′	371
90	Sokcho	38° 15′	128° 33′	18.1
101	Chuncheon	37° 54′	127° 44′	77.7
105	Gangneung	37° 45′	128° 53′	26.0
108	Seoul	37° 34′	126° 57′	85.8
112	Incheon	37° 28′	126° 37′	68.2
114	Wonju	37° 20′	127° 56′	148.6
119	Suwon	37° 16′	126° 59′	34.1
129	Seosan	36° 46′	126° 29′	28.9
130	Uljin	36° 59′	129° 24′	50.0
131	Cheongju	36° 38′	127° 26′	57.2
135	Chupungnyeong	36° 13′	127° 59′	244.7
138	Pohang	36° 01′	129° 22′	2.3
143	Daegu	35° 53′	128° 37′	64.1
146	Jeonju	35° 49′	127° 09′	53.4
152	Ulsan	35° 33′	129° 19′	34.6
156	Gwangju	35° 10′	126° 53′	72.4
159	Busan	35° 06′	129° 01′	69.6
165	Mokpo	34° 49′	126° 22′	38.0
168	Yeosu	34° 44′	127° 44′	64.6
170	Wando	34° 23′	126° 42′	35.2
201	Ganghwa	37° 42′	128° 02′	47.0
211	Inje	38° 03′	128° 10′	200.2

Table 2.1 (continued)

Observation Station No.	Name	Lattitude(N)	Londitude(E)	Altitude(m)
212	Hongcheon	37° 41′	127° 52′	140.9
221	Jecheon	37° 09′	128° 11′	263.6
226	Boeun	36° 29′	127° 44′	175.0
232	Cheonan	36° 46′	127° 07′	21.3
235	Boryeong	36° 19′	126° 33′	15.5
236	Buyeo	36° 16′	126° 55′	11.3
238	Geumsan	36° 06′	127° 28′	170.4
243	Buan	35° 43′	126° 42′	12.0
245	Jeongeup	35° 33′	126° 51′	44.6
260	Jangheung	34° 41′	126° 55′	45.0
261	Haenam	34° 33′	126° 34′	13.0
262	Goheung	34° 37′	127° 16′	53.1
272	Yeongju	36° 52′	128° 31′	210.8
273	Mungyeong	36° 37′	128° 08′	170.6
277	Yeongdeok	36° 31′	129° 24′	42.1
278	Uiseong	36° 21′	128° 41′	81.8
279	Gumi	36° 07′	128° 19′	48.9
281	Yeongcheon	35° 58′	128° 57′	93.6
284	Geochang	35° 40′	127° 54′	221.4
285	Hamcheon	35° 33′	128° 10′	33.1
288	Miryang	35° 29′	128° 44′	11.2
289	Sancheong	35° 24′	127° 52′	138.1
295	Namhae	34° 48′	128° 36′	45.0

Climate Data Processing

Climate Analysis Variables

- Climate analysis variables have been selected for land based observations including temperature (daily average, daily minimum and maximum), precipitation, wind (wind speed), relative humidity and cloud cover.
  - The units of the variables are as follows: temperature-℃, precipitation-㎜, daily precipitation-㎜/day, wind speed-m/s, relative humidity-%, cloud cover -%.
- Data for sea level height has been cited from the Korea Hydrographic and Oceanographic Administration.
  - The unit for change of sea level height is centimeters.

Definition of the Mean Climate and Analysis Period

- In this report, the standard climate values used for comparison with the future climate change projection data are defined as the mean climate values of the past 30 years (1981–2010).

Processing the Climate Data

- Daily observation data has been used in this report and in the case of North Korea where the collection rate is relatively low, monthly and yearly recorded data was only used when it represented a minimum 80% collection rate.

- The mean values for each climate element have been produced by calculating the daily data for the past 30 years into seasonal and yearly averages and then finally into the mean value for that period.

- The definition of the seasons used in the report is as follows: spring, March–May; summer, June–August; autumn, September–November; winter, December–February (the following year).

- Anomalies (the deviations from the mean climate) were used for calculating the climate change trends.
  - The normalization of the rate of precipitation change is defined as the anomalies divided by the mean climate.

- The trends of the variables are defined as the incline of the linear regression in which the annual mean for the past 30 years (1981–2010) is applied statistically.

Definition and Analysis of Extreme Indices

Definition of Extreme Indices

- In this report 6 extreme indices related to temperature (frost days, summer days, freezing days, tropical nights, length of growing season, heat wave days) and 2 extreme indices related to precipitation (precipitation intensity, heavy precipitation days) have been used (see Tables 2.2 and 2.3).

- Frost days are defined as days where the conditions for frost are observed, with implications for plant growth and cultivation.
  - In this report the number of frost days is defined as the number of days in a year when the minimum daily temperature drops below 0℃.
  - The number of freezing days is defined as the number of days in a year when the maximum daily temperature drops below 0℃.

- The number of summer days is defined as the number of days in a year when the maximum temperature rises above 25℃, with implications for agriculture, energy usage and leisure activities etc.
  - The number of tropical nights refers to the number of days in a year when the minimum daily temperature stays above 25℃; this indicator represents the occurrence of high temperatures overnight and has implications for night time energy use etc.
  - The number of heat wave days refers to the number of days in a year when the maximum daily temperature in the daytime rises above 33℃. This information is important for considerations related to health, atmospheric conditions and daytime energy usage in the event of hot weather.

- Length of growing season denotes the number of continuous days each year where conditions are suitable for the growing of crops and is defined by the daily mean temperature. This data is important for agriculture and the forecasting of crop conditions.

- In the observational data, when the precipitation on any given day exceeds 1 ㎜ it is classified as a precipitation day and when the precipitation on one day exceeds 80 ㎜ it is classified as a heavy precipitation day.

  – Precipitation intensity and number of heavy precipitation days are indices which indicate extreme amounts or intensity of precipitation and thus have implications for the forecasting of floods and water resource management.

Table 2.2
Definition of Extreme Indices Related to Temperature

Indicator	Definition	Unit of Measure
Frost Days	Number of days in a year when the minimum temperature is below 0℃	Day(s)
Summer Days	Number of days in a year when the maximum temperature is over 25℃	Day(s)
Freezing Days	Number of days in a year when the maximum temperature is below 0℃	Day(s)
Tropical Nights	Number of days in a year when the minimum temperature is over 25℃	Day(s)
Length of Growing Season	The number of days in a year where the daily average temperature is over 5℃ (counted from the first day the temperature is sustained for 6 days to the first day the temperature is lower for 6 continuous days)	Day(s)
Heat Wave Days	Number of days in a year when the maximum temperature is over 33℃	Day(s)

Table 2.3
Definition of Extreme Indices Related to Precipitation

Indicator	Definition	Unit of Measure
Precipitation Intensity	Total yearly precipitation divided by the number of wet days in a year (days when the precipitation is over 1.0 ㎜)	㎜/Day
Heavy Precipitation Days	Number of days in a year where the precipitation is over 80 ㎜	Day(s)

2. Climate Change Scenario Data and Analysis Methods

◆ Overview

Production of the Detailed Climate Change Projections for the Korean Peninsula

- To contribute to the IPCC 'Fifth Assessment Report' and produce detailed climate change projections for the Korean Peninsula, the KMA and NIMR (2011) produced climate change projection data for the Korea Peninsula using a multi-phase process combining a global climate model, regional climate model, and statistical downscaling method (Fig. 2.2).

- In this report the future climate change projections for the Korean Peninsula have been presented using data from the regional climate model with a spatial resolution of 12.5㎞ (chapter 4).
  - In addition, using the 1 ㎞ resolution data for South Korea produced using a statistical downscaling method, climate projections have been presented for the 16 provinces and metropolitan cities of South Korea (chapter 5).

- The detailed climate change projections for every administrative unit in South Korea–city/county/borough and town/township/district–are provided in the 9 regionally divided "Regional Climate Change Reports" which have been published alongside this report.
  - 9 regional divisions: Seoul/Incheon/Gyeonggi-do; Gangwon-do; Chungcheongbuk-do; Daejeon/Chungcheongnam-do; Daegu/Gyeongsangbuk-do; Busan/Ulsan/Gyeongsangnam-do; Jeollabuk-do; Gwangju/Jeollanam-do; Jeju-do.

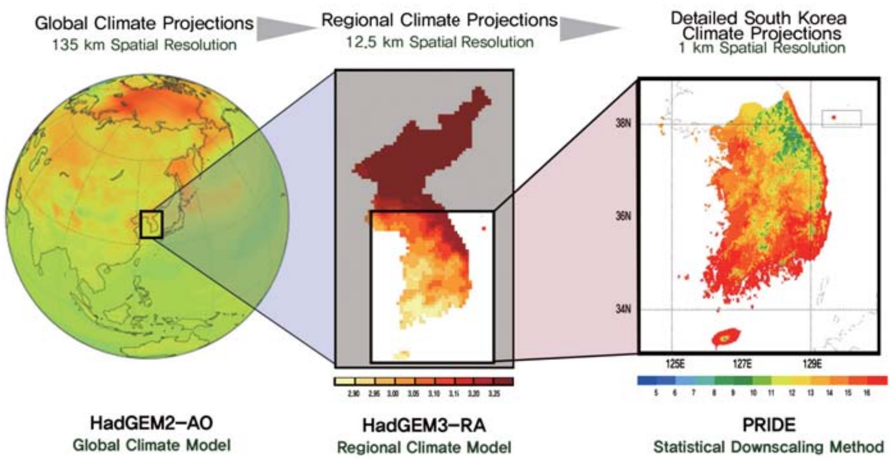


Fig. 2.2
Overview of the Process of Making Climate Change Projection Data for the Korean Peninsula

RCP Greenhouse Gas Concentration Scenarios

Greenhouse Gas Concentration Scenarios used in the IPCC 'Fifth Assessment Report'

- As greenhouse gas emissions will determine future climate change the future concentrations of greenhouse gases in the atmosphere are the key inputs for climate models simulating future climate change.

- In the IPCC 'Fifth Assessment Report' future greenhouse gas concentration has been calculated using the Representative Concentration Pathways (RCP) scenarios.
  - The RCP emission scenarios are different from the SRES (Special Report on Emission Scenarios) scenarios used in the IPCC 'Fourth Assessment Report' (2007) (Fig. 2.3).

- The SRES scenarios were decided on the basis of future socio-economic forecasting (Fig. 2.3a).
  - Once the emission scenarios were decided, long-term climate simulations were carried out using the climate model, applying radiative forcing in the atmosphere. Based on the data thus acquired future changes to the climate, need for adaptation measures and points of vulnerability could be identified and evaluated.

- In the case of the climate change projections based on the RCP scenarios a parallel method was adopted in consideration of the vast computation and running time of the super computers required for climate modelling.
  - Based on previous research a set of representative pathways for greenhouse gas concentration was decided on and then using this data the climate model simulations were carried out.
  - At the same time, new socio-economic forecasts have been developed and independent greenhouse gas emission scenarios produced accordingly.
  - After combining the projection data from climate models and the climate change and socio-economic scenarios made using emission information based on socio-economic outlooks to make an overall picture, the effects of climate change, need for adaptation, assessment of vulnerability and decisions on related policies can be considered.

- In the case of RCP the method for calculating greenhouse gas concentration scenarios has been simplified to ensure more efficient assessment report drafting.
  - While the climate change scenarios based on both RCP and SRES predict global warming induced by increasing greenhouse gas concentration in the atmosphere, there is a quantitative difference between RCP and SRES.

Types of RCP Scenarios and their Attributes

- Currently meteorological agencies around the world, including the KMA, are producing future climate change projections based on RCP scenarios.
    - Fig. 2.4 illustrates the change in greenhouse gas concentration for the period 1850–2100 as projected in each RCP scenario.
- Each RCP scenario proposes the effects of a different greenhouse gas concentration levelincline over time in correspondence with future socio-economic outlooks.
- This report describes the trends of future climate change over the Korean Peninsula basedon RCP4.5 and RCP8.5 by the year 2100 (assuming the additional warming effect by radiative forcing of 4.5 W/m^2 and 8.5 W/m^2 , respectively).
    - The greenhouse effect caused by anthropogenic greenhouse gases in 2005 was estimated to be 1.6 W/m^2 (IPCC, 2007).
    - RCP8.5, the high emission scenario, represents the rapid increase in greenhouse gas concentration that may occur if there are no efforts made to reduce the greenhouse gas emissions. It represents a middle ground between the SRES A2 and A1F scenarios of the IPCC 'Fourth Assessment Report' (but is a much higher emission scenario than A1B which was most widely used previously).
    - RCP4.5 represents a gradual stabilization of greenhouse gas concentration which could be brought about through effective implementation of emission reduction policies; it corresponds with SRES B1 (Table 2.4).
- In this report RCP8.5 is defined as the high emission scenario and RCP4.5 as the low emission scenario.

Fig. 2.3
Comparison of the Techniques used for the SRES and RCP based Climate Change Scenarios

– IPCC & Moss (2008).

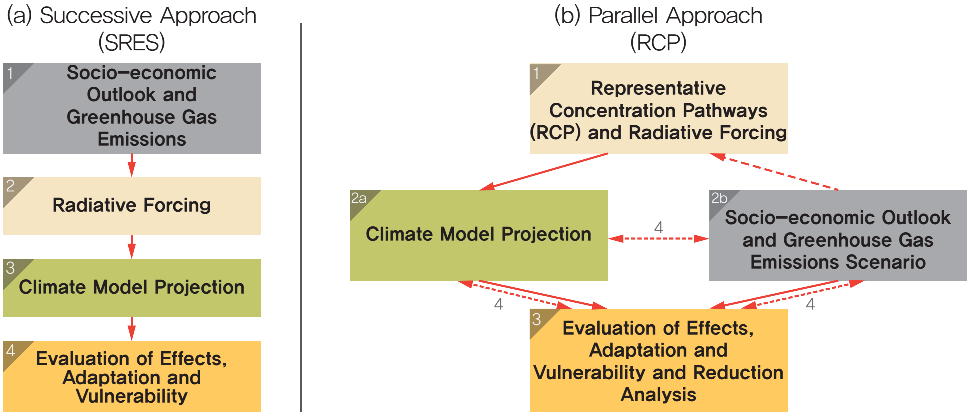


Fig. 2.4
Projection for Change in CO_2 Concentration based on the RCP Scenarios

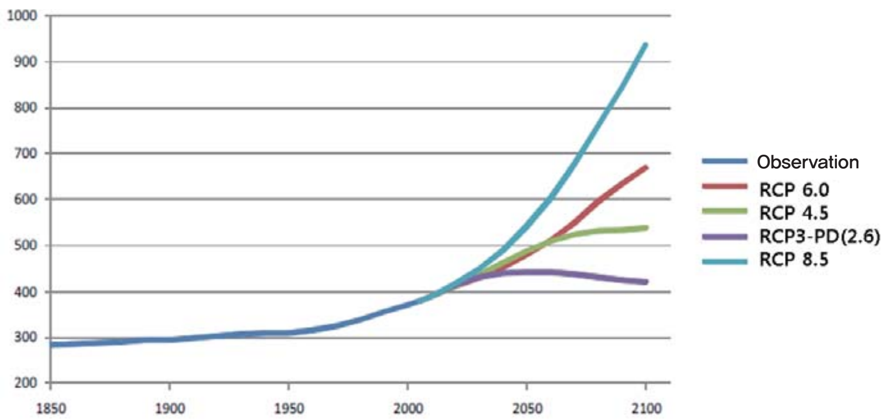


Table 2.4
Characteristics of RCP Scenarios

– Greenhouse gas concentrations are CO_2 equivalent concentrations. All contribution effects of greenhouse gas are converted to CO_2 concentrations.

Scenario	Radiative Forcing	Greenhouse Gas Concentration*	Trend	Comparison with SRES
RCP8.5	〉8.5 W/㎡ (2100)	〉1270 ppm (2100)	Increase	A2~A1F1
RCP6.0	~ 6 W/㎡(2100)	~ 850 ppm (2100)	Stable	A1B
RCP4.5	~ 4.5 W/㎡(2100)	~ 650 ppm (2100)	Stable	B1
RCP3–PD(2.6)	Before 2100–3 W/㎡ maximum and later decline	Before 2100–490 ppm maximum concentration and later decline	Reduction after Increase	

Production of Global Climate Change Projections

HadGEM2-AO Global Climate Model

- The climate model used for the production of the global climate change data is HadGEM2-AO (Hadley Center Global Environment Model version 2; Atmosphere-Ocean coupled model) which was developed by the Hadley Center at the UK Met Office, and is the most up-to-date climate model where atmospheric, ocean, thawing and aerosol processes are all combined reciprocally.

- While the spatial resolution of the atmospheric model is varied, the projections made for this report are based on a model with spatial resolution of 135 ㎞ and vertical resolution of 38 levels (the highest level being 40 ㎞ above the sea surface).

- The spatial resolution of the ocean model is also varied, and the projections used in this report were created using a model which has a grid system of 1° intervals east-west (360 in total) and 1/3° – 1° intervals north-south (216 in total) showing the highest density at the equator.
  - Vertically the model has dense layers at 5 m intervals around the surface level in consideration of the mixed layer process of the ocean, however the vertical resolution declines deeper into the water.

- The thawing model has the same grid system as the ocean model and encompasses the thermodynamic processes for calculating freezing and thawing phenomena and the dynamic processes that deal with the movement of sea ice.

- HadGEM2-AO includes aerosol processes and explicitly takes into account the spatial movement of man-made and natural aerosols such as sulfur dioxide, black carbon, organic carbon, combusted biomass, dust and sea salt particles.

Production of Global Climate Change Projections

- This report uses HadGEM2-AO to produce climate change projections based on the RCP4.5 and RCP8.5 scenarios to a spatial resolution of 135 ㎞.
  - The projections produced are then used as input data for the regional climate model with high resolution over the Korean Peninsula (Fig. 2.2).

- Land cover variation as well as aerosol variation is considered in the simulation of global climate change (NIMR, 2011).
  - The information on aerosol emissions (sulfur dioxide, black carbon, organic carbon, combusted biomass, etc.) was taken from Jones et al. (2011), with concentrations of dust and sea salt particles etc. explicitly calculated in the model.

- The land cover data produced by Loveland et al. (2000) and the History Database of the Global Environment 'Coupled Model Intercomparison Project 5' (HYDE3 CMIP5) were used.
  - According to the agricultural and industrial outlooks in place for each future scenario, RCP8.5 predicts an increase in the area of land used as pasture by the late 21st century, while RCP4.5 predicts a decrease.
- A historical run was first conducted with the global climate model using data collected for the period 1860–2005 and then a projection run was carried out for the period from 2006 onwards according to the RCP4.5 and RCP8.5 greenhouse gas emission scenarios.

Producing Climate Change Projections for the Korean Peninsula Using a Regional Climate Model

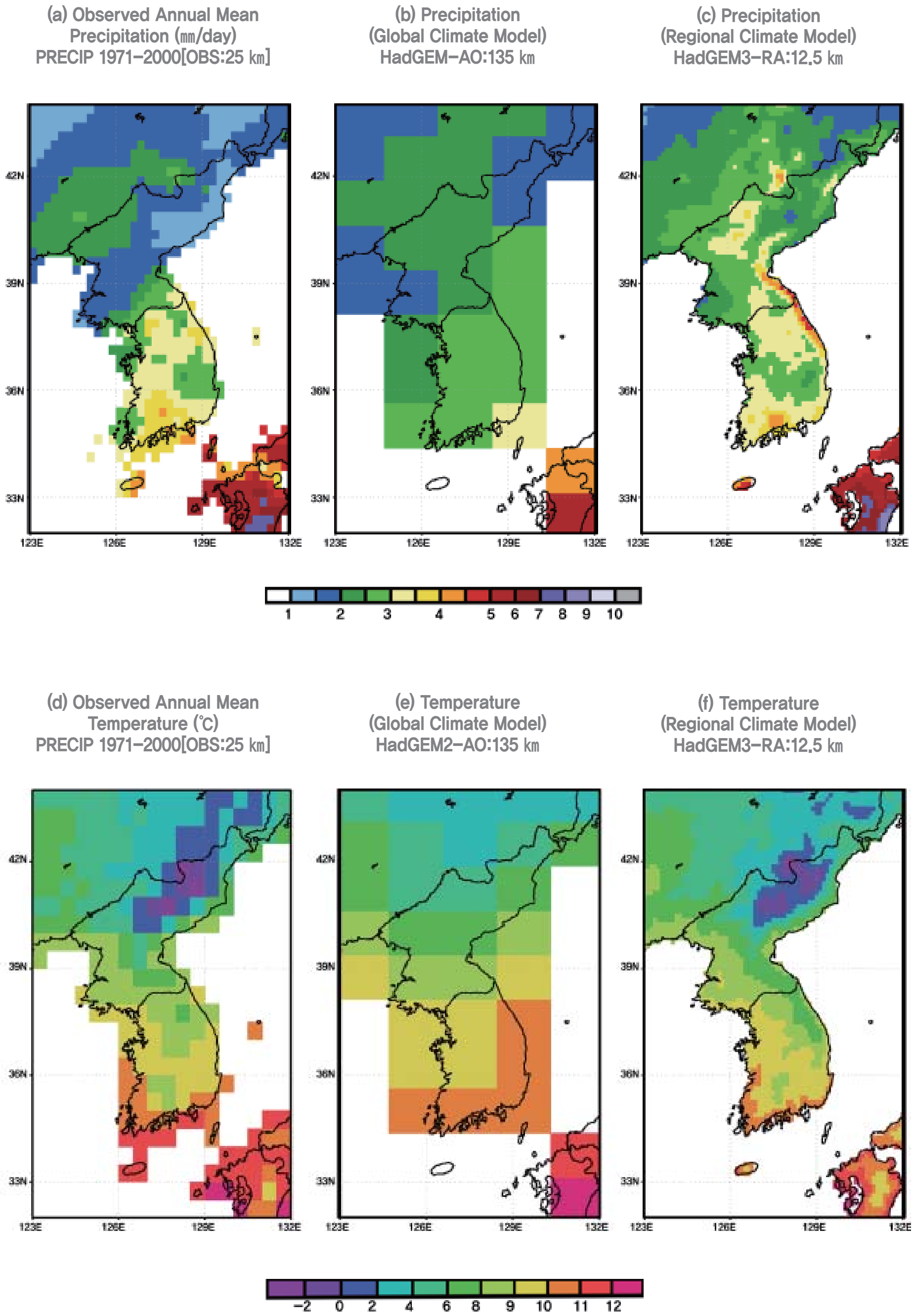
HadGEM3-RA Regional Climate Model

- HadGEM3-RA (Atmospheric Regional climate model of the Hadley Centre Global Environment Model 3) has been used to create the detailed climate change projections for the Korean Peninsula.
- By downscaling the global climate projection data of HadGEM2-AO, HadGEM3-RA has enabled the production of 12.5 km resolution regional climate change projections for the Korean Peninsula (with the benefit of providing insight into local climate characteristics caused by topographical features).
- HadGEM3-RA considered the interaction of atmospheric circulation processes and land surface processes, while for ocean processes it used the projected data of the global model.
  - The dynamic systems and physical processes of the regional climate model are basically the same as HadGEM2-AO.

Producing Regional Climate Change Projections

- The process of creating high resolution regional climate change projections is similar to that of the global climate modelling process as mentioned above; first a historical run for the period 1950–2005 is conducted, followed by a projection run for the period 2006–2100 based on the RCP4.5 and RCP8.5 emission scenarios.
- The high resolution data is created by applying a regional climate model to the low resolution data produced by the global climate model, this process is referred to as 'dynamical downscaling'.
  - In this process consistency between the projection trends of the global climate model and the regional climate model are maintained.
  - The results of comparison between the projection data of the global and regional climate models show that they both reproduce a very similar structure of climate averages for the Korean Peninsula; they also accurately reflect the observed data (Fig. 2.5).

Fig. 2.5
Comparison of the Simulation Capacities of the Global and Regional Climate Models for Reproducing the Current Climate



◆ Processing the Projection Data

Processing of Climate Model Projection Data

- To ensure the reliability of future climate projections it is best if the climate model reproduces observed climate characteristics as closely as possible.
  - Structural errors that may occur in the climate change model could be included unchanged in future climate change projections.
  - In order to eliminate structural errors, when eliminating the current reproduced climate value from the projected values acquired through the climate model, the information on future climate change caused by anthropogenic greenhouse gas increase is extracted in the form of anomaly.

- In this report, the data from the HadGEM3-RA historical run has been used in order to get rid of structural errors in the detailed 12.5 km climate change projection data from which the regional climate model for the Korean Peninsula is produced.
  - In this instance the average climate period for the model is the past 30 years (1981–2010), which is the same as that used for the analysis of the observed data (as the greenhouse gas concentrations for RCP4.5 and RCP8.5 are different from 2006 onwards, climate model data has been produced separately for each scenario for the period 2006–2010).

- In chapter 4, climate change projection data is presented divided into three time periods: early 21^{st} century (2011–2040), mid-21^{st} century (2041–2070) and late 21^{st} century (2071–2100).

- To produce the absolute prediction values for climatic variables provided in this report:
  1) The difference is calculated by removing the past climate values from the values predicted by the model.
  2) Then the observed average climate values are added to the difference.

- When computing trends in climate change using the same method as that used in the analysis for observed data, for temperature the difference from the climate value of the model is presented.
  - For precipitation, the difference from the average precipitation of the climate model is again divided by the average precipitation of the climate model and then presented as a percentage in comparison to the observed climate value.

- When analyzing the changing trends of climate elements over time, the trend is defined as the slope the yearly average values make when applied statistically to a linear regression straight line.

Calculating Extreme Indices

Climate Analysis Variables

- The trends of change in the extreme indices caused by climate change presented in chapter 4 and the appendix of this report may contain structural errors when the output values of the model are used as they are.
  - When the calculation method used in the analysis of observed data was applied unchanged to the data from the climate model, a portion of structural errors were found and these have been corrected.
- For temperature-related extreme indicators, the standards of absolute value used for observed data were applied as they were and differences were obtained after the indicators values were calculated in comparison with the current and future climates.
- In the case of precipitation-related extreme indicators, the same daily precipitation standard of 1 ㎜ was used to determine precipitation as was used in the observed data.
  - In the observed data a heavy precipitation day was defined as precipitation over 80 ㎜/day which corresponds to 60 ㎜/day in the climate model, therefore the latter has been used in analysis of the projected data in consideration of the structural tendency of the climate model.

Production of Climate Change Data for 16 Provinces and Metropolitan Cities of South Korea

Statistical Downscaling Method

- In Chapter 5 and Appendix 3 of this report climate change projection data is presented for each of the 16 provinces and metropolitan cities of South Korea.

- The 1㎞ resolution data of South Korea was created from the 12.5 ㎞ resolution data of the regional climate model by applying a statistical downscaling method (Fig. 2.2).
  - Using the statistical downscaling method low resolution climate model data is projected statistically into a 1 ㎞ grid system which contains high resolution local data such as altitude, topographical directivity and proximity to the coast.
  - Using the geographical information systems (GIS) technique the refined 1㎞ grid data has been rendered in finer detail into the data for administrative units–city, county, borough, town, township and district (Fig. 2.6).

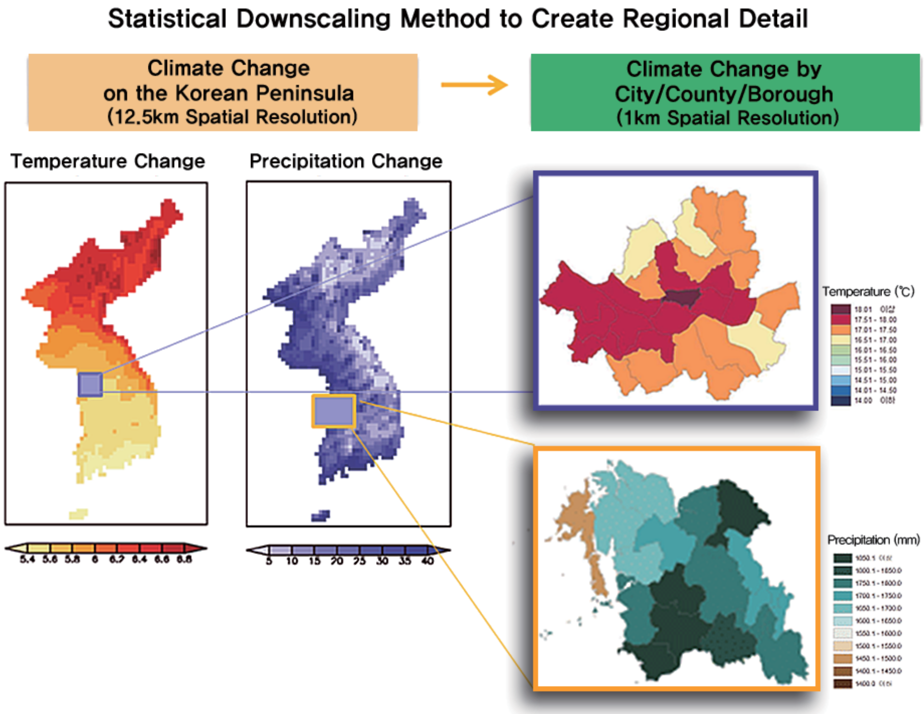


Fig. 2.6
Process of Producing Climate Projection Data for Administrative Areas in South Korea using GIS

More Climate Change Information for the Korean Peninsula

- Both the 12.5 ㎞ and 1 ㎞ resolution climate projection data based on the RCP4.5 and RCP8.5 scenarios are available for download via the KMA Climate Change Information Center website: http://www.climate.go.kr (Fig. 2.7).

Fig. 2.7
KMA Climate Change Information Center Website

Web-based Data Service

Korea Meteorological Administration Climate Change Information Center (https://www.climate.go.kr)

Korea
Climate Change Report

03

Characteristics of Observed Climate Change

03 Characteristics of Observed Climate Change

1. Spatial Patterns of Climate over the Korean Peninsula

Overview

Mean Climate Conditions on the Korean Peninsula (1981–2010)

- The annual mean temperature on the Korean Peninsula, encompassing both South Korea and North Korea, is 11.0℃ while the annual mean precipitation is 1,162.2 ㎜ (Table 3.1).
  - The climate of the Korean Peninsula has four distinct seasons, and for each of the seasons the mean temperature occurs in the following order: summer (22.7℃)〉 autumn (12.7℃)〉 spring (10.4℃)〉 winter (–1.7℃).
  - In the climate of the Korean Peninsula, the daily mean temperature range is around 10.4℃, and the maximum daily mean temperature variation occurs in spring (11.7℃).
- There is a large seasonal variation in precipitation with the mean for each season occurring in the following order: summer (655.5 ㎜) 〉 autumn (230.5 ㎜) 〉 spring (203.6 ㎜) 〉 winter (72.7 ㎜).
  - While summer precipitation accounts for 56.4% of the yearly total, winter precipitation makes up just 6.3%.
- The mean ground wind speed on the Korean Peninsula is around 1.7–2.1 m/s with little seasonal variation, and the annual mean wind speed is 1.9 m/s (6.8 ㎞/h).
- The annual mean relative humidity is around 70.2% with the highest levels of 78.8% in the summer occurring due to bands of warm oceanic air.
  - Relative humidity is lowest in the spring (64.7%) with the influence of cyclone and anticyclone fronts and in winter (65.5%) due to bands of cold air from the continent.
- On the Korean Peninsula the annual mean cloud cover is 52%, with the most coverage in the summer (69%) and the least in winter (39%).
  - In spring and autumn the mean cloud cover is around 50%.

Table 3.1
Annual and Seasonal Mean of Various Climate Elements for the Korean Peninsula (1981–2010)

Climate Element	Annual	Spring	Summer	Autumn	Winter
Mean Temperature (℃)	11.0	10.4	22.7	12.7	–1.7
Daily Maximum Temperature (℃)	16.6	16.5	27.5	18.6	3.8
Daily Minimum Temperature (℃)	6.2	4.8	18.8	7.7	–6.6
Precipitation (㎜)	1162.2	203.6	655.5	230.5	72.7
Wind Speed (m/s)	1.9	2.1	1.6	1.7	2.0
Relative Humidity (%)	70.2	64.7	78.8	71.7	65.5
Cloud Coverage (%)	52	51	69	48	39

The Climate of South Korea

- The annual mean temperature for South Korea is 12.5℃, with seasonal variation in the following order: summer (23.6℃)〉 autumn (14.1℃)〉 spring (11.7℃)〉 winter (0.6℃) (Table 3.2).
  - The annual mean daily temperature range in the South Korean climate is 10.4℃, with the largest variation occurring in spring (11.9℃) and the smallest in summer (8.7℃).
- The annual mean precipitation for South Korea is 1,307.7 ㎜ which is 12.5% more than the annual mean for the entire peninsula (1,162.2 ㎜) and 42.2% more than the annual mean for North Korea (919.7 ㎜).
  - In South Korea summer precipitation makes up around 55.3% of the annual mean amount corresponding with the trend for the peninsula.
  - The mean precipitation in each season occurs in the following order: summer (723.2 ㎜)〉 autumn (259.7 ㎜)〉 spring (236.6 ㎜)〉 winter (88.5 ㎜). Winter accounts for only 6.8% of the total annual mean amount.
- The mean ground wind speed for South Korea is around 1.8–2.3 m/s, a level somewhat higher than that of the entire peninula, and the annual mean wind speed is 2.0 m/s (7.2 ㎞/h).
- The annual mean relative humidity for South Korea is roughly 68.8% reaching the highest level in summer (77.0%) and lowest in spring (63.2%) and winter (63.5%).
- The annual mean cloud cover of South Korea is around 50% which is less than the mean for the peninsula, with maximum coverage in summer (65%) and minimum in winter (40%).

Table 3.2
Annual and Seasonal Mean of Various Climate Elements for South Korea (1981–2010)

Climate Element	Annual	Spring	Summer	Autumn	Winter
Mean Temperature (℃)	12.5	11.7	23.6	14.1	0.6
Daily Maximum Temperature (℃)	18.1	17.9	28.4	20.1	6.1
Daily Minimum Temperature (℃)	7.7	6.0	19.7	9.2	–4.1
Precipitation (㎜)	1307.7	236.6	723.2	259.7	88.5
Wind Speed (m/s)	2.0	2.3	1.8	1.8	2.2
Relative Humidity (%)	68.6	63.2	77.0	70.9	63.5
Cloud Coverage (%)	50	49	65	46	40

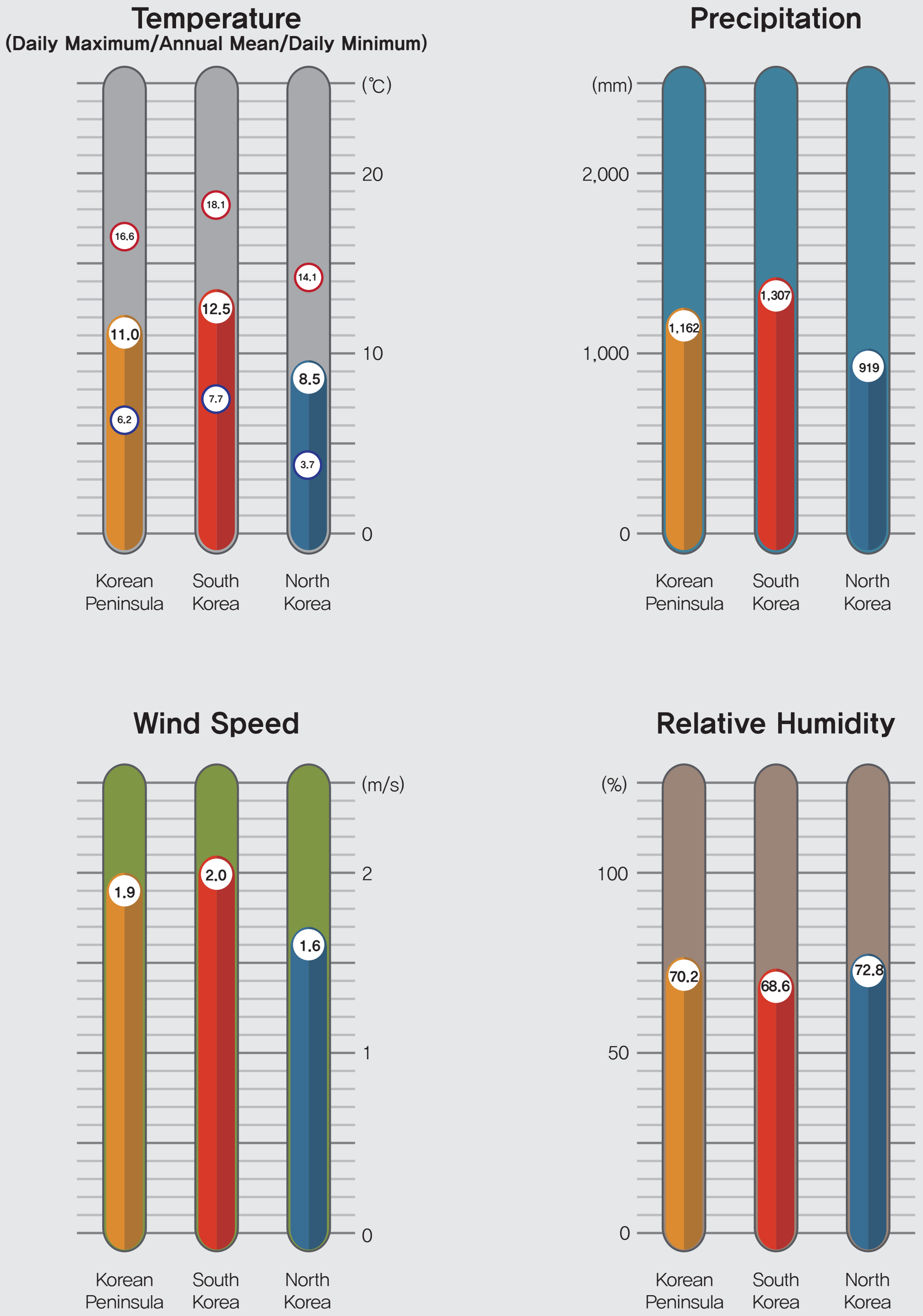
The Climate of North Korea

- The annual mean temperature for North Korea is 8.5℃ with seasonal variation occurring as follows: summer (21.2℃)〉 autumn (10.2℃)〉 spring (8.2℃)〉 winter (–5.6℃) (Table 3.3).
  - The annual mean daily temperature range in North Korea, like that of South Korea, is 10.4℃ with a maximum range of 11.4℃ in spring and minimum of 8.7℃ in summer.
- The annual mean precipitation in North Korea is 919.7 ㎜, 70.3% of the South Korean average.
  - Summer precipitation accounts for approximately 59% of the annual mean total, a higher level of concentration than that of South Korea.
  - Winter precipitation accounts for just 5% of the annual mean total, a relatively small proportion compared to that in South Korea.
  - The mean precipitation for each season occurs in the following order: summer (542.7 ㎜)〉 autumn (181.9 ㎜)〉 spring (148.6 ㎜)〉 winter (46.4 ㎜).
- The mean ground wind speed for North Korea varies according to the season within a range of 1.4–1.9 m/s with an annual mean wind speed of roughly 1.6 m/s (5.7 km/h), which is slightly lower than that in South Korea.
- The annual mean relative humidity in North Korea is around 72.8%, slightly higher than South Korea, with the maximum of 81.9% in the summer and minimum of 67.3% in the spring.
- The annual mean cloud cover in the climate of North Korea is 55% which is somewhat higher than the South Korean mean coverage. Maximum coverage is in the summer (75%) and minimum coverage in the winter (38%).
  - Variation in cloud cover according to the season is relatively greater than in South Korea.

Table 3.3
Annual and Seasonal Mean of Various Climate Elements for North Korea (1981–2010)

Climate Element	Annual	Spring	Summer	Autumn	Winter
Mean Temperature (℃)	8.5	8.2	21.2	10.2	–5.6
Daily Maximum Temperature (℃)	14.1	14.2	26.0	16.1	0.0
Daily Minimum Temperature (℃)	3.7	2.8	17.3	5.2	–10.7
Precipitation (mm)	919.7	148.6	542.7	181.9	46.4
Wind Speed (m/s)	1.6	1.9	1.4	1.5	1.6
Relative Humidity (%)	72.8	67.3	81.9	73.1	69.0
Cloud Coverage (%)	55	55	75	50	38

Annual Mean Value of Climate Variables for the Korean Peninsula, South Korea and North Korea



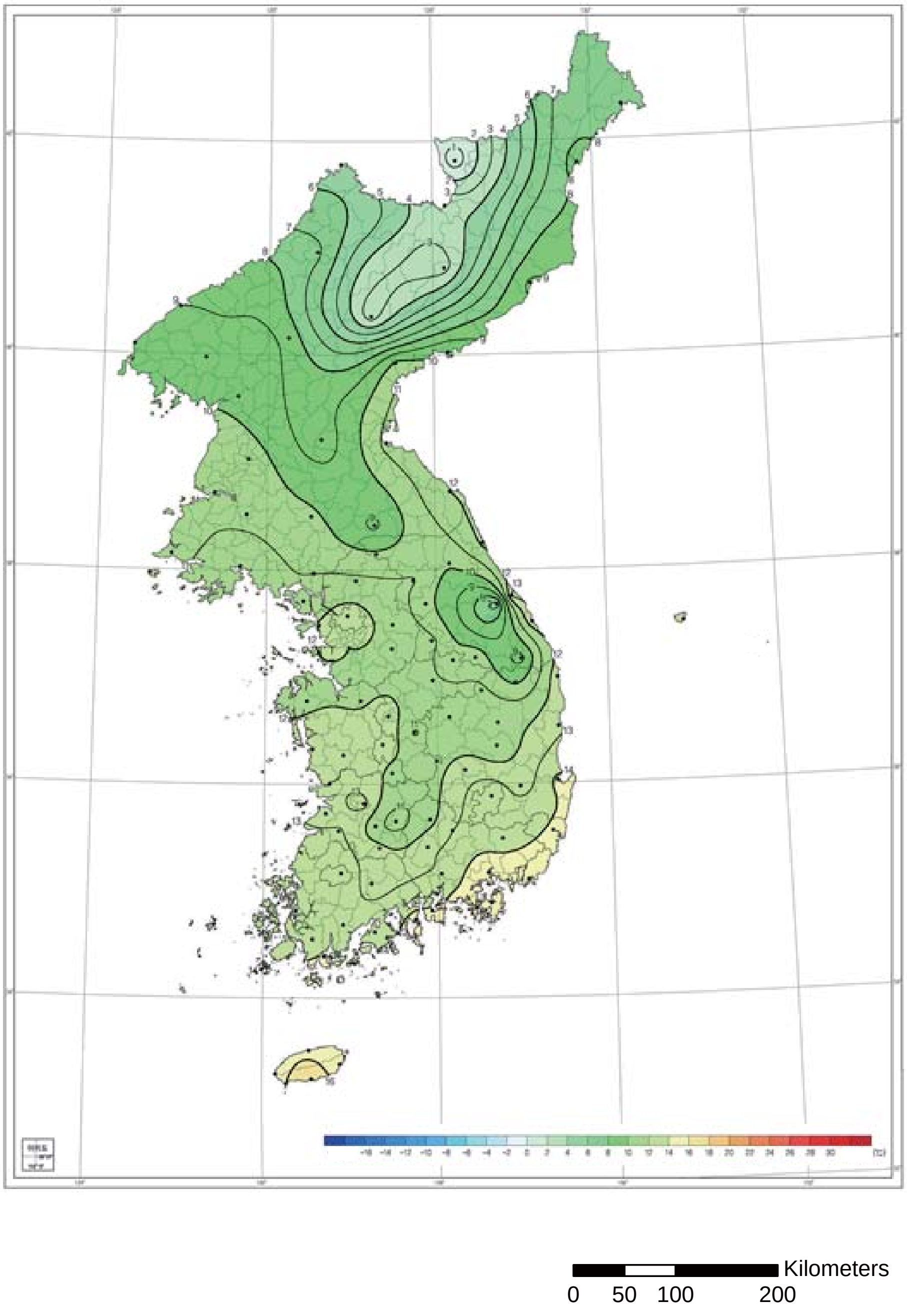
Spatial Patterns of Climate on the Korean Peninsula

Spatial Patterns of Annual Mean Temperatures on the Korean Peninsula

- The Korean peninsula is located in the northern hemisphere at mid–latitude of the northeast of the Eurasian continent. It is positioned at 124° - 132° east and 33° - 43° north.
  - While the peninsula is relatively narrow at 300 ㎞ from east to west, it is 1,100 ㎞ long from north to south with mean temperatures varying greatly according to latitude.
  - Factors such as altitude above sea level height and proximity to the coast also have an influence.
- Annual mean temperatures on the Korean peninsula depict a 'south high north low' pattern under the influence of latitude, and a 'west high east low' pattern in the central and northern regions according to the altitude above sea level height.
  - The place with the highest annual mean temperature is Seogwipo in the southern part of Jeju Island, while the place with the lowest is Samjiyeon at the north of the Gaema Plateau.
- The lowest temperature is recorded on the high altitude Gaema Plateau from which low temperatures spread southward along the Baekdudaegan, Taebaek and Sobaek mountain ranges.
  - In South Korea the lowest mean temperature is recorded in the high altitude Daegwallyeong area in northern Gangwon–do.
- Despite being at relatively high latitude, the south east coast of South Korea has a higher annual mean temperature than the south west coast.
  - Aside from Jeju Island the south east coastal region has the highest annual mean temperature on the Korean peninsula due to the influence of a warm oceanic current.

Fig. 3.1
Annual Mean Temperature on the Korean Peninsula (1981~2010)

– Source: Korea Climate Map



Spatial Patterns of the Annual Mean Precipitation on the Korean Peninsula

- The annual mean precipitation across the Korean Peninsula varies greatly in defferent regions with topography and predominant precipitation processes creating a complex picture.

- Precipitation tends to decrease northwards by latitude with the highest precipitation (over 1,600 ㎜) recorded on the south coast where southeasterly winds transport moisture inland during the summer.
  - The movement of the summer monsoon front and typhoons resulted in more precipitation in South Korea than in North Korea.
  - In South Korea the landlocked Yeongnam region surrounded by the Taebaek and Sobaek mountain ranges is the driest area, with less than 1,100 ㎜ of annual precipitation.
  - The places with the greatest annual precipitation on the Korean Peninsula are Seongsan and Seogwipo in Jeju Island (more than 1,900 ㎜).
  - The places with the least precipitation are Hyesan and Cheongjin to the north of the Gaema Plateau (less than 700 ㎜).

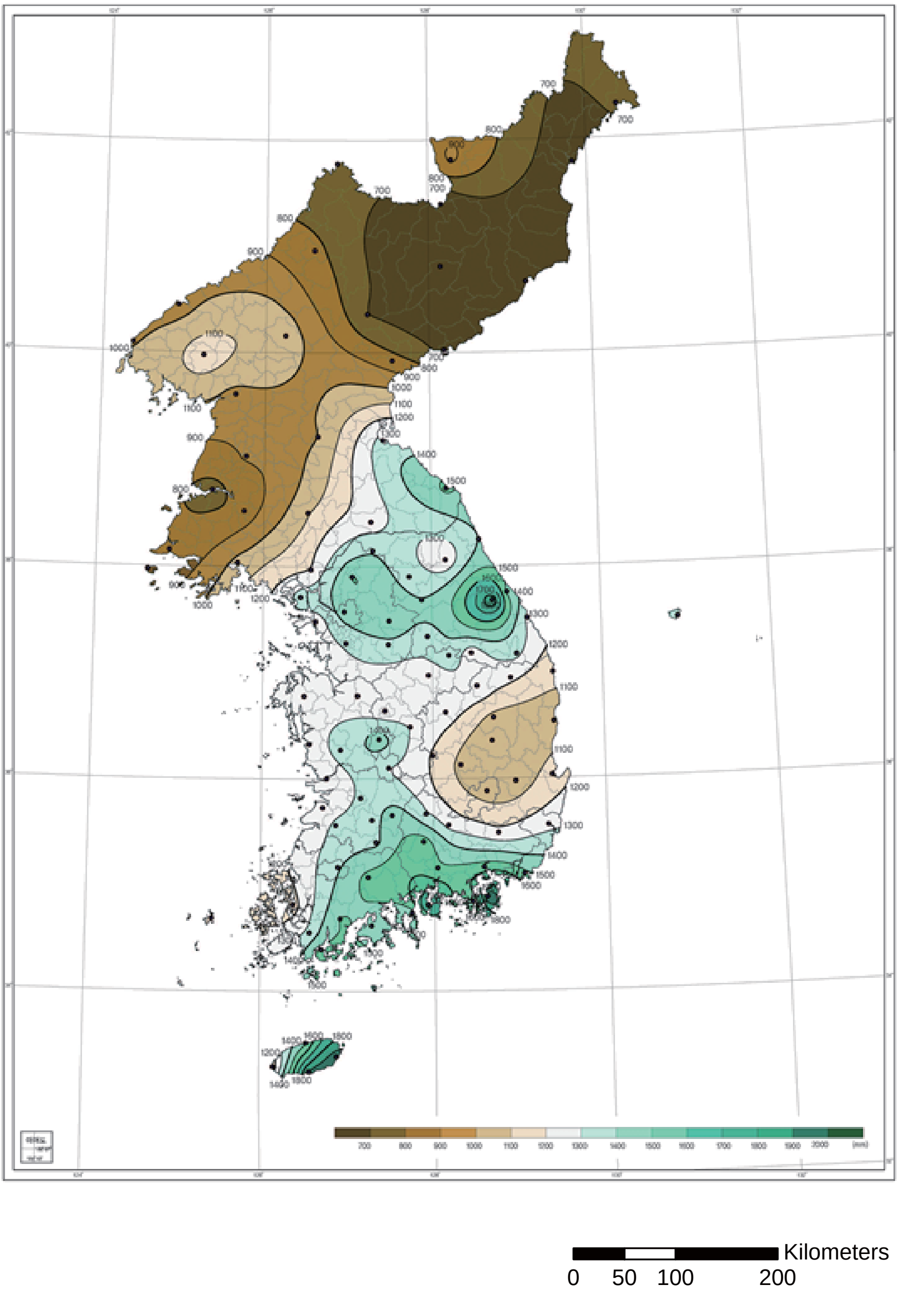
- Gangneung and Daegwalleong, located at the east of the Taebaek mountain range, are affected both by the ocean and by topography and thus show a high localized level of annual precipitation. This area, along with the central region of the Korean Peninsula around Seoul, forms an east–west precipitation zone.

- The annual mean precipitation for North Korea tends to decrease going further north and at higher altitude.
  - In the north of the Korean Peninsula there is a 'west high east low' pattern whereby Pyeonganbuk-do, which centers around Guseong and Sinuiju, has a much higher level of precipitation than the high altitude region of Hamgyeong-do.
  - Despite being at a low altitude and influenced by proximity to the sea, Pyeongan-do, centering around Nampo, and the northern region of Hwanghae-do show a low annual precipitation and this trend increases going inland.

- Affected both by topographical precipitation and oceanic currents, places such as Jangjeon and Wonsan on the east coast have the highest annual precipitation in North Korea.

Fig. 3.2
Annual Mean Precipitation on the Korean Peninsula (1981–2010)

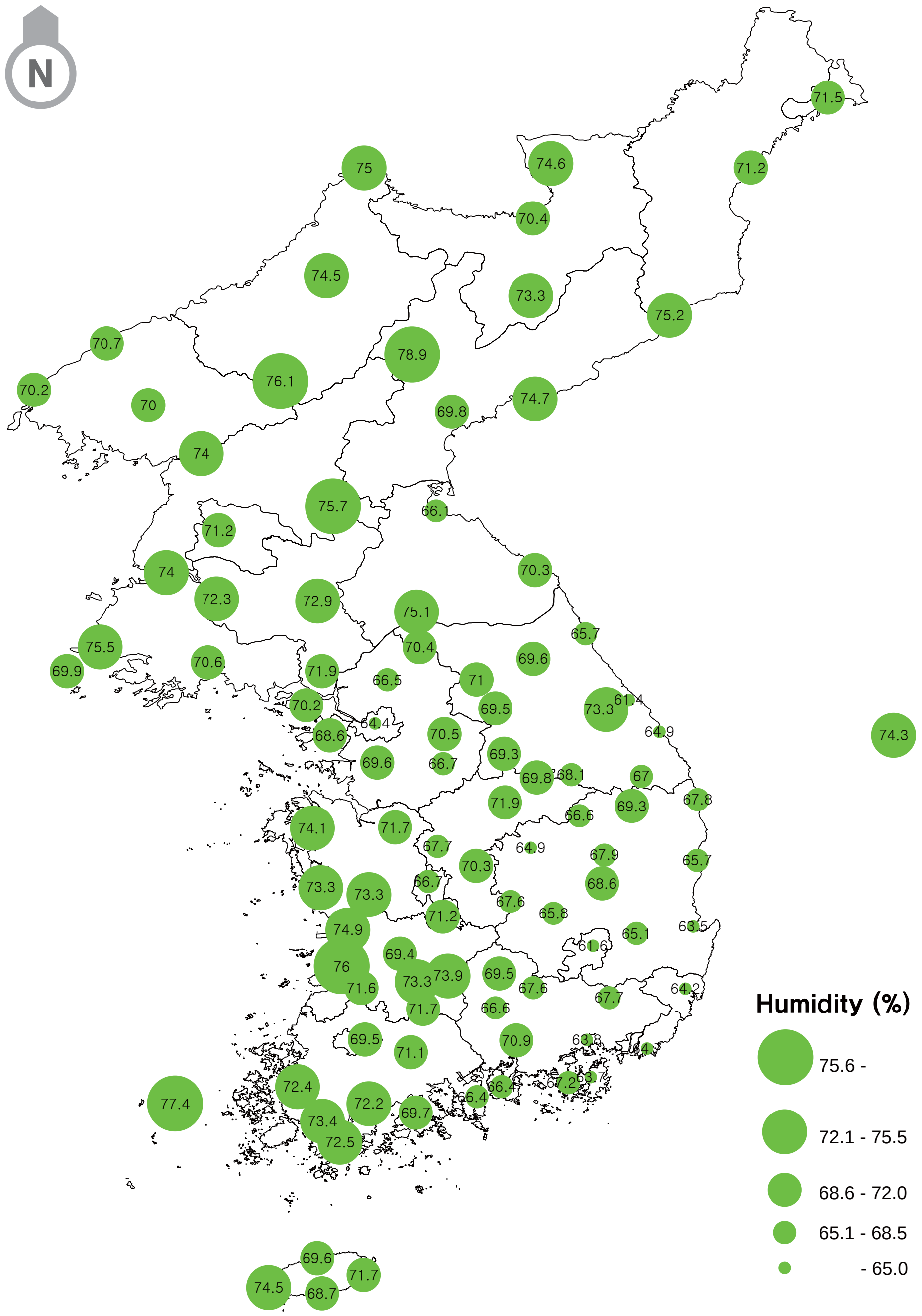
– Source: Korea Climate Map



Spatial Patterns of Annual Mean Relative Humidity on the Korean Peninsula

- The annual mean relative humidity on the Korean Peninsula is around 70% with fluctuation in the range of 60–80% according to region.
  - Relative humidity is highest in Jangjin on the Gaema Plateau (78.9%), and lowest in Gangneung on the east coast (61.4%).
- The relative humidity in North Korea is higher than in South Korean and characteristically relatively high in low–temperature and higher–altitude inland regions.
  - The lowest relative humidity in North Korea can be found in Wonsan on the east coast (66.1%).
- Typically, relative humidity levels in South Korea are higher in the west and lower in the east, with relatively high humidity on the west coast gradually decreasing further inland.
  - Humidity is particularly low in the characteristically arid inland Gyeongsangbuk–do and Yeongnam regions which stand in the shadow of the Taebaek and Sobaek mountain ranges.
- Coastal cities such as Busan, Ulsan, Pohang and Gangneung show low levels of relative humidity despite the influence of the sea.
  - Inland cities such as Daegu, Seoul, Gwangju and Jeonju show a lower level of relative humidity in comparison with observations in their vicinities. This is understood as characteristic of the localized dry climate conditions that can occur due to urbanization.
- In the case of North Korea, proximity to the coastline and urbanization seem to have littleimpact on relative humidity.

Fig. 3.3
Annual Mean Relative Humidity on the Korean Peninsula (1981–2010)



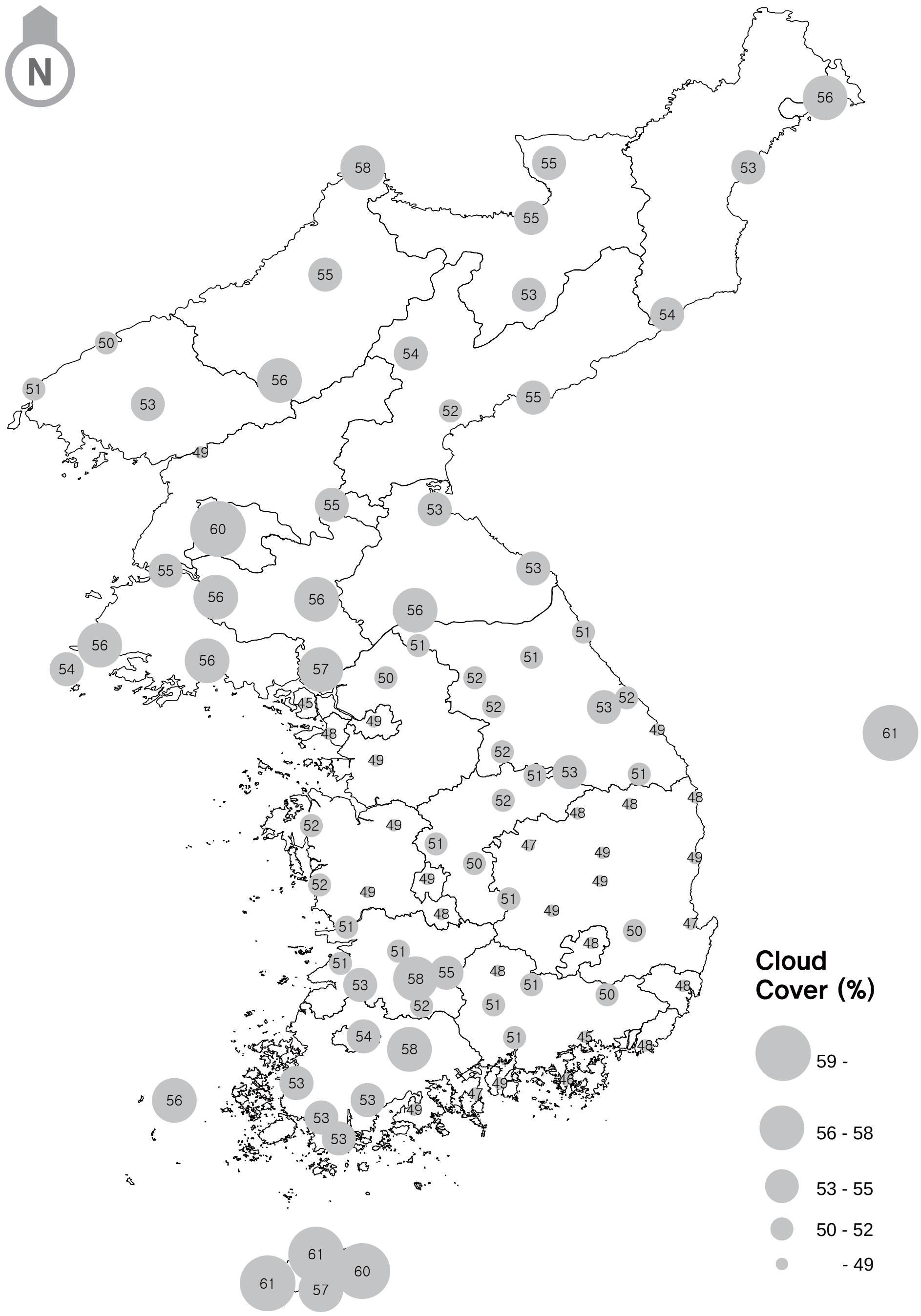
Spatial Patterns of Annual Mean Cloud Cover on the Korean Peninsula

- Spatial variation in annual mean cloud cover shows relatively high levels of coverage for islands such as Jeju-do and Ulleung-do.

- In the south of the Korean Peninsula, cloud cover follows the trends in relative humidity with a 'west high east low' pattern with high cloud coverage in the south west decreasing farther inland and towards the east.
  - Highly urbanized cities such as Seoul, Busan, Daegu, Gwangju, Ulsan, Incheon and Daejeon show a lower level of cloud cover than the areas surrounding them.
  - The lower relative humidity of these urban areas is seen to have an impact on the spatial pattern of cloud cover.
  - In the case of the central region of the Korean Peninsula, Gangwon-do and the east coast show a relatively high level of cloud cover.

- The annual mean cloud cover observed for North Korea is higher overall than that of South Korea.
  - In North Korea, Pyeongyang and the southern part of Hwanghae-do show a higher level of cloud cover while Sinuiju, Supung and Anju in Pyeonganbuk–do have relatively low coverage.

Fig. 3.4
Annual Mean Cloud Cover on the Korean Peninsula (1981-2010)



Spatial Patterns of Annual Mean Wind Speed on the Korean Peninsula

- The winds that blow over the Korean Peninsula show broad regional variation due to the influences of seasonal winds, geographical location, and land cover.
  - Coastal and mountain regions come under the influence of localized atmospheric circulation, such as land-sea breezes and mountain-valley winds caused by temperature difference, and the paths of typhoons and storms.
  - The wind speed on Jeju Island varies according to locations with an annual mean wind speed of 7 m/s in Gosan in the west and 2.9 m/s in Seogwipo in the south.
- The highest annual mean wind speed is observed at Gosan (7 m/s) on Jeju Island while the lowest is recorded in Junggang (0.3 m/s) in the northern inland region of North Korea.
- The annual mean wind speed on the Korean Peninsula is generally affected by proximity to the coast line, and typically high in coastal regions and lower further inland.
  - In the coastal region, the development of land–sea breezes contributes to the increase in wind speed, while inland complex topography and rough ground surfaces contribute to the decrease in wind speed.
  - Such characteristics occur more noticeably in South Korea than in North Korea.
- Annual mean wind speed is relatively higher in South Korea than in North Korea.

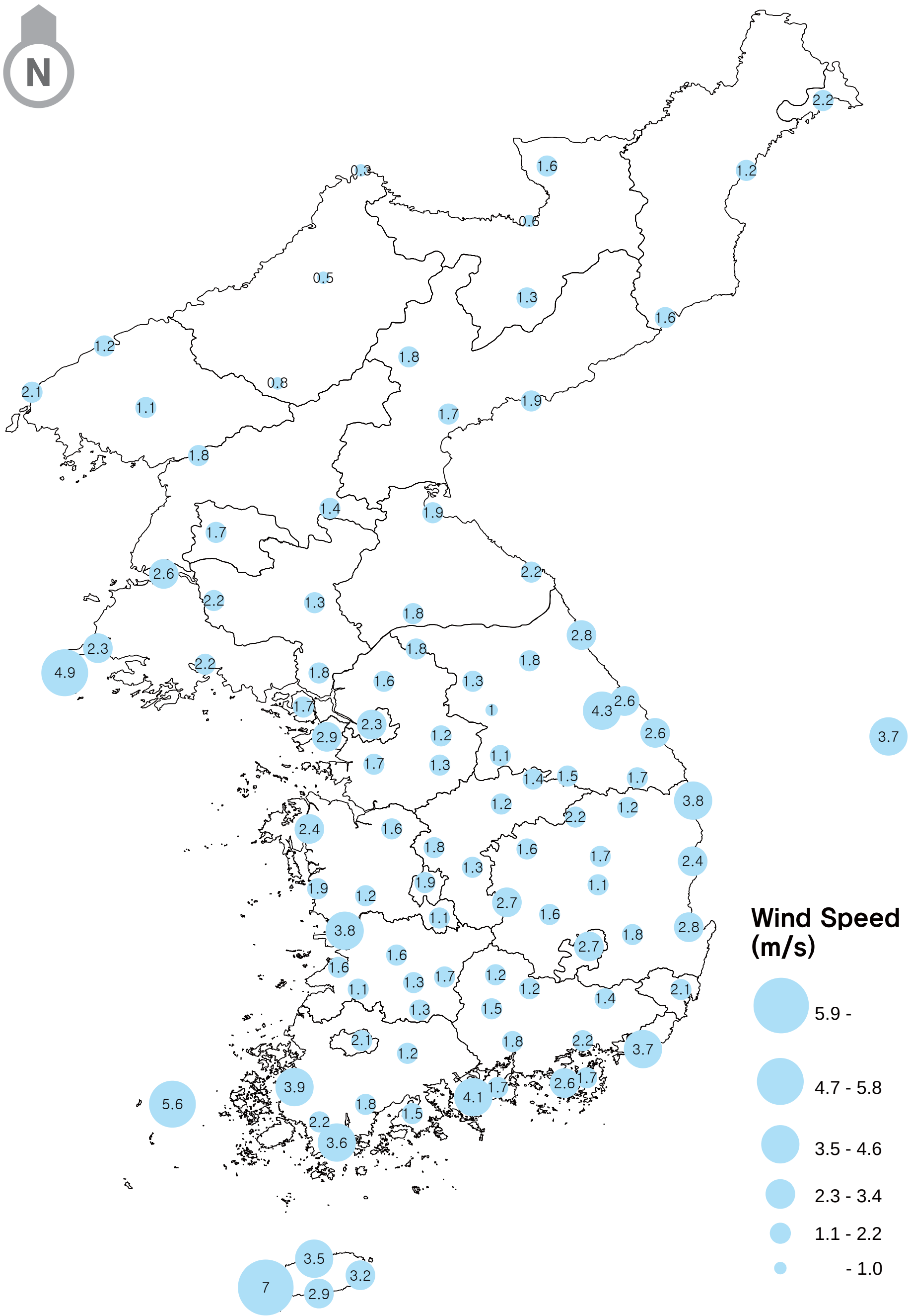


Fig. 3.5
Annual Mean Wind Speed on the Korean Peninsula (1981~2010)

Spatial Patterns of Extreme Indices

Spatial Patterns of the Annual Mean Number of Tropical Nights

- Tropical nights are defined as days when the minimum daily temperature is over 25℃. The number of tropical nights is higher in regions where nighttime temperatures are high.

- The annual mean number of tropical nights is higher in South Korea than in North Korea.

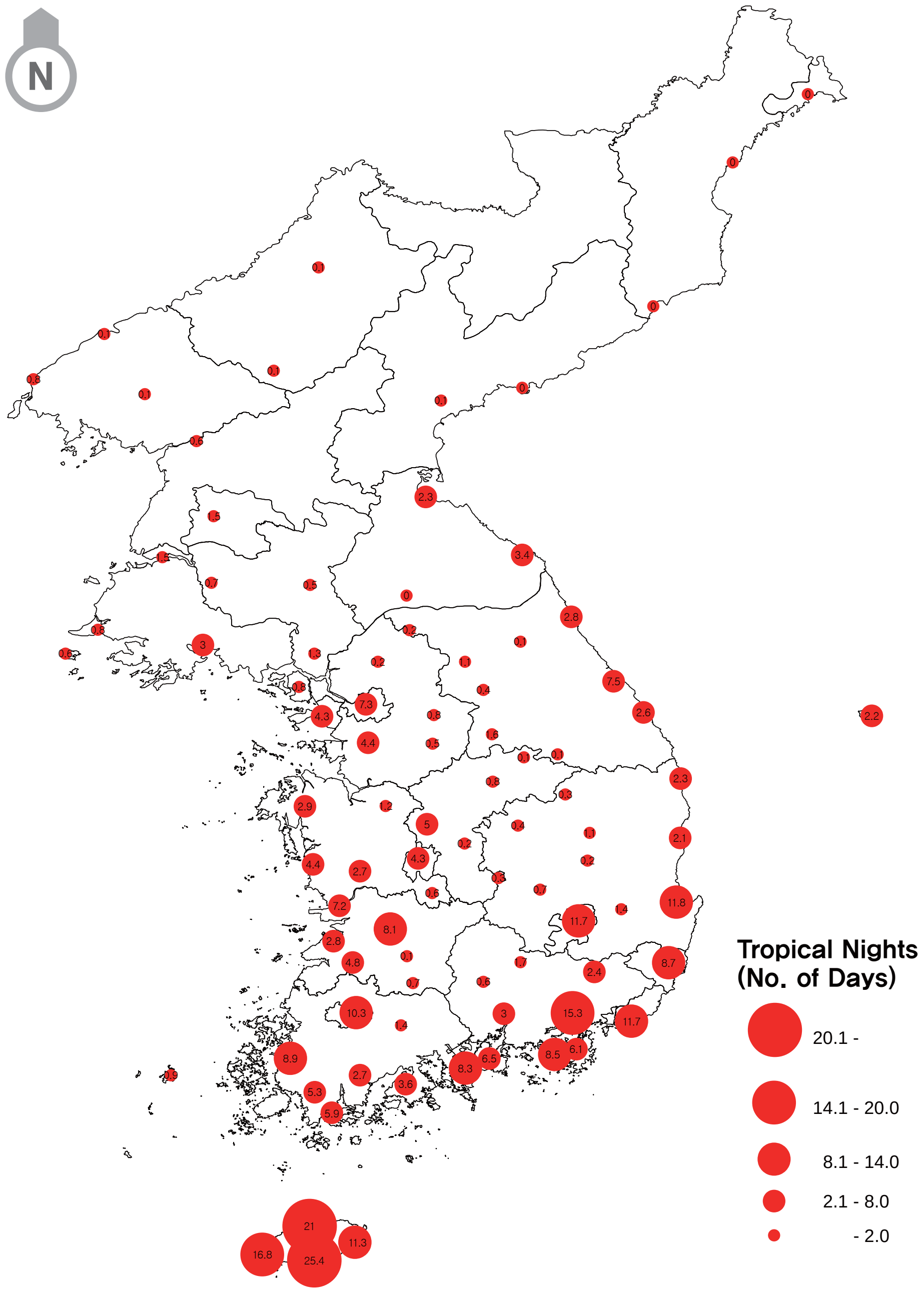
- In South Korea the highest number of tropical nights occurs in Seogwipo on Jeju Island at 25.4 days while inland the highest number occurs in Changwon with 15.3 and locations experiencing over 10 tropical nights a year include Pohang, Daegu, Busan and Gwangju.
  - Aside from those mentioned above, there are over 7 tropical nights per year in Mokpo, Jeonju, Gangneung and Seoul.

- The annual mean number of tropical nights in South Korea is high in the southern region and in urban areas where daily minimum temperatures remain high.
  - In urban areas a large difference can occur between minimum temperatures in city centers and those in the suburbs depending on the level of urbanization. Therefore data errors may occur due to the specific locations of observatories.

- The annual mean number of tropical nights occurring in North Korea is less than 1 day/year, in the north of Pyeongan-do and Hamgyeong-do.
  - Hwanghae-do and Gangwon-do, where temperatures are rising, show the highest occurrence of tropical nights in North Korea, with an average of 3.4 tropical nights per year in Jangjeon.
  - Haeju (3.0) and Wonsan (2.3) also experience more than 1 tropical night per year.

- The annual mean number of tropical nights in North Korea is relatively low because minimum daily temperatures stay lower than in South Korea and urbanization has little influence on nighttime temperatures.

Fig. 3.6
Annual Mean Number of Tropical Nights on the Korean Peninsula (1981–2010)



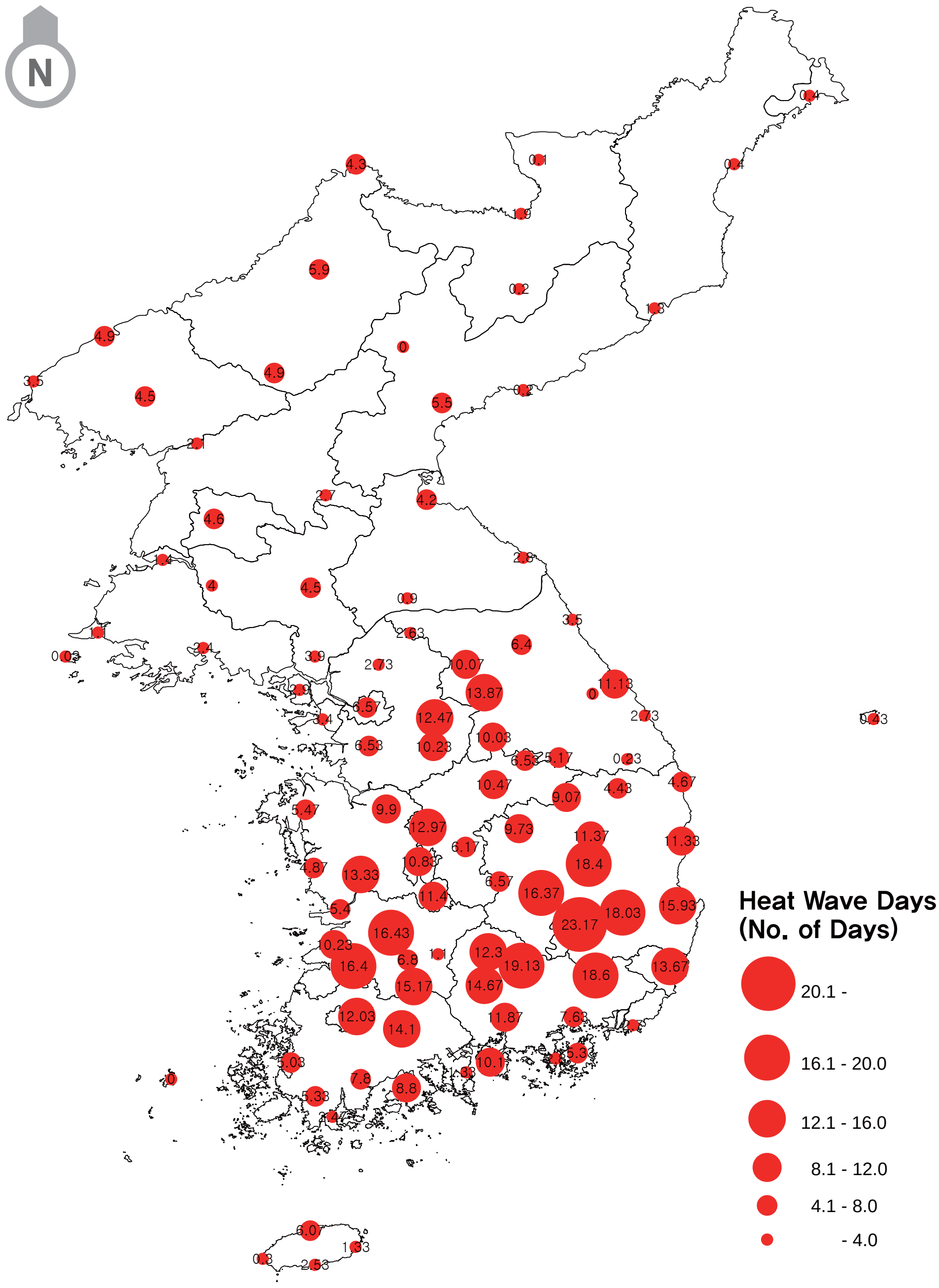
Spatial Patterns of Annual Mean Number of Heat Wave Days

- Heat wave days are defined as days when the maximum daily temperature rises above 33℃. The highest occurrences are in regions with high daytime temperatures.
  - The annual mean number of heat wave days is higher in South Korea where temperatures are generally higher than in North Korea.

- The highest annual mean number of heat wave days in South Korea is observed in Daegu with 23.2 day/year. Areas with more heat wave days include the inland regions of Jeollabuk-do, Gyeongsangnam-do and Gyeongsangbuk-do with around 16–23 day/year.
  - In the central Yeongseo region of South Korea (Chuncheon, Hongcheon, Wonju) a localized figure of over 10 heat wave day/year has been noted.
  - The data reflects the tendency for maximum daytime temperatures to be higher in inland areas, it is understood that the higher numbers of heat wave days in these areas is caused in part by the foehn effect.
  - In the densely populated Seoul metropolitan region the annual mean number of heat wave days is 6.6 day/year.

- While the annual number of heat wave days in North Korea increases further inland, in highland areas such as the Gaema Plateau the number is very low.
  - In North Korea the number of heat wave days is highest in Ganggye with 5.9 day/year, followed by Hamheung on the east coast with 5.5 days and 4.9 days in Supung and Huicheon in Pyeonganbuk-do.
  - In the northwest region of North Korea, which has a relatively low altitude, the number of heat wave days increases further inland.

Fig. 3.7
Annual Mean Number of Heat Wave Days on the Korean Peninsula (1981–2010)



Spatial Patterns of the Annual Mean Number of Heavy Precipitation Days

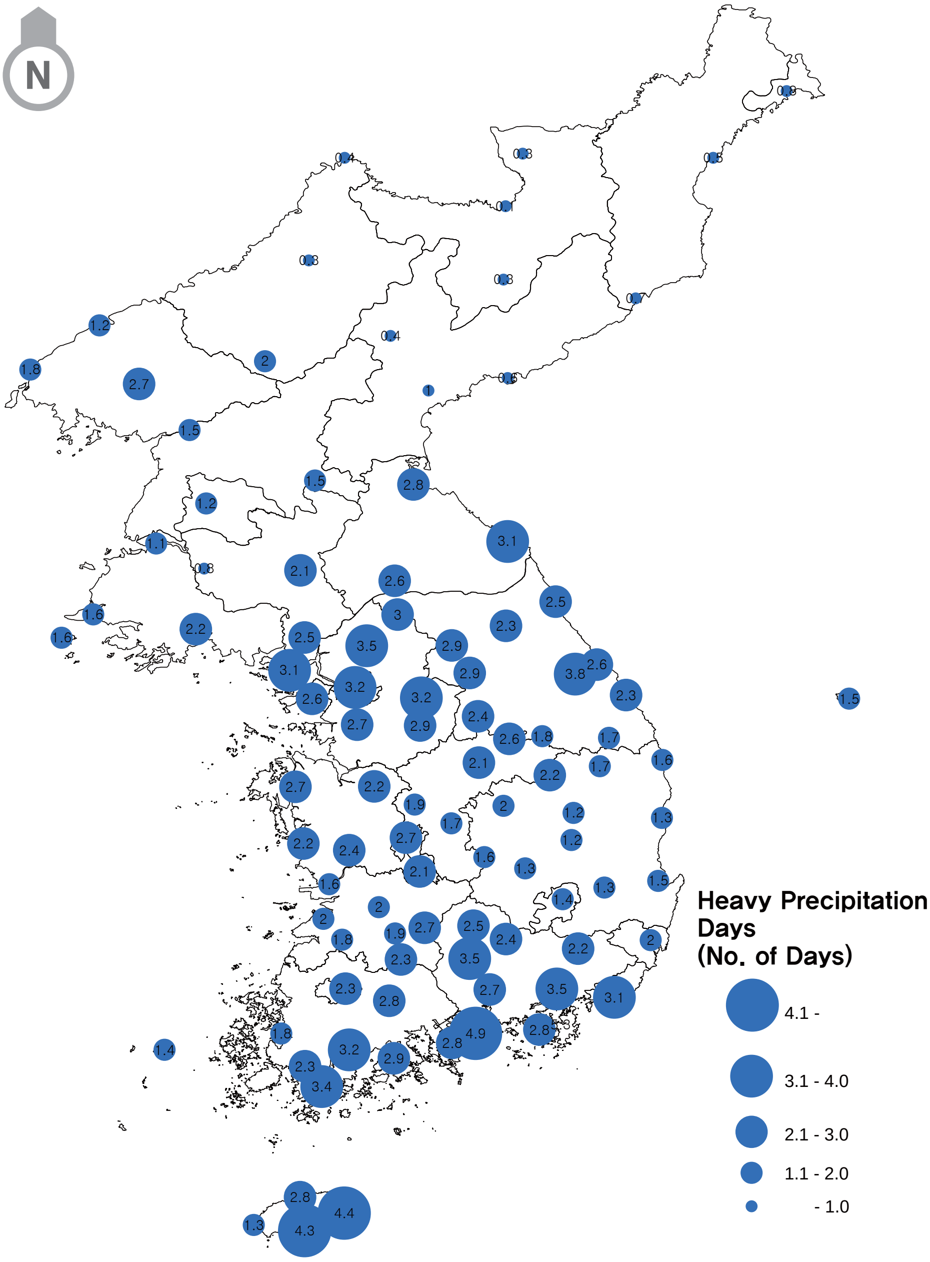
- The number of heavy precipitation days is defined as the number of days where the precipitation exceeds 80 ㎜.
  - The spatial pattern of heavy precipitation days on the Korean Peninsula coincides with the spatial pattern of annual mean precipitation.

- The place with the highest annual mean number of heavy precipitation day is Namhae in Gyeongsangnam-do with 4.9 day/year and the place with the lowest is Uiseong in Gyeongsangbuk-do with 1.2 day/year.
  - In Gyeongsangbuk-do, where annual mean precipitation is low, most of the region has a lower number of heavy precipitation days of around 1.5 day/year.

- The annual mean number of heavy precipitation days is higher in South Korea than in North Korea reflecting the higher precipitation in South Korea.
  - The difference in precipitation between east and west on the south coast and in Gyeongsangnam-do, and the central region around Seoul are distinctively apparent in the data.
  - The data shows that the localized intense precipitation during the summer wet season tends to move following an east–west divide.
  - Jeju Island which is located in the path of the summer monsoon front and typhoon routes shows a high level of precipitation.

- In North Korea the highest annual mean number of heavy precipitation days is 3.1 days occurring in Jangjin on the east coast followed by Guseong in Pyeonganbuk–do with 2.7 day/year.

Fig. 3.8
Annual Mean Number of Heavy Precipitation Days on the Korean Peninsula (1981–2010)



2. Temporal Patterns of Climate over the Korean Peninsula

Annual Mean Variation

Trend of Annual Mean Temperature Change over the Korean Peninsula

- Over the past 30 years (1981–2010) the annual mean temperature of the Korean Peninsula has shown a 1.2℃ increase (0.41℃/decade).
  - The increasing trend of temperature is clear in all seasons, with mean temperatures rising 1.7℃ for winter, 1.5℃ for autumn, 0.8℃ for spring and 0.7℃ for summer in the past 30 years.
- The annual mean temperature for North Korea has increased by 1.4℃ over the past 30 years (0.45℃/decade), compared with the 1.1℃ (0.36℃/decade) seen in South Korea.
- The difference in temperature increase between South Korea and North Korea is particularly prominent in the summer, with summer temperatures showing a sharper increase in North Korea (0.39℃/decade).

Trend of Annual Mean Precipitation Change over the Korean Peninsula

- The change in annual precipitation on the Korean Peninsula over the last 30 years shows a large annual fluctuation and therefore no statistically meaningful trend can be determined.
- Despite this, it can be noted that the annual mean precipitation on the Korean Peninsula has experienced a slight increase of around 78 ㎜ in the last 30 years (1981–2010) representing an increasing trend of 25.87 ㎜/decade (less than 7% of the average annual precipitation of the Korean Peninsula).
  - This increasing trend is due to an increased precipitation in South Korea.
  - In contrast, the precipitation in North Korea has shown a slight decrease in the same period.
- The trends of seasonal precipitation change on the Korean Peninsula show the largest increase in the summer and a slight decrease in the autumn.
  - Such tendencies are more related to the changes in South Korea where the mean precipitation is greater than in North Korea.

Table 3.4
Trend of Annual and Seasonal Mean Temperature and Precipitation change on the Korean Peninsula, South Korea and North Korea for 1981–2010

– Note: unit of measure for temperature is ℃/decade, for rainfall it is ㎜/decade (*95% reliability, **99% reliability).

		Annual	Spring	Summer	Autumn	Winter
Mean Temperature	Korean Peninsula	0.41**	0.25	0.24	0.49**	0.56*
	South Korea	0.36**	0.23	0.11	0.43**	0.57*
	North Korea	0.45**	0.28	0.39	0.52**	0.47
Precipitation	Korean Peninsula	25.87	10.34	28.07	–7.70	2.20
	South Korea	54.28	16.95	46.26	–11.85	1.99
	North Korea	–25.19	–3.20	–5.54	–3.24	–1.40

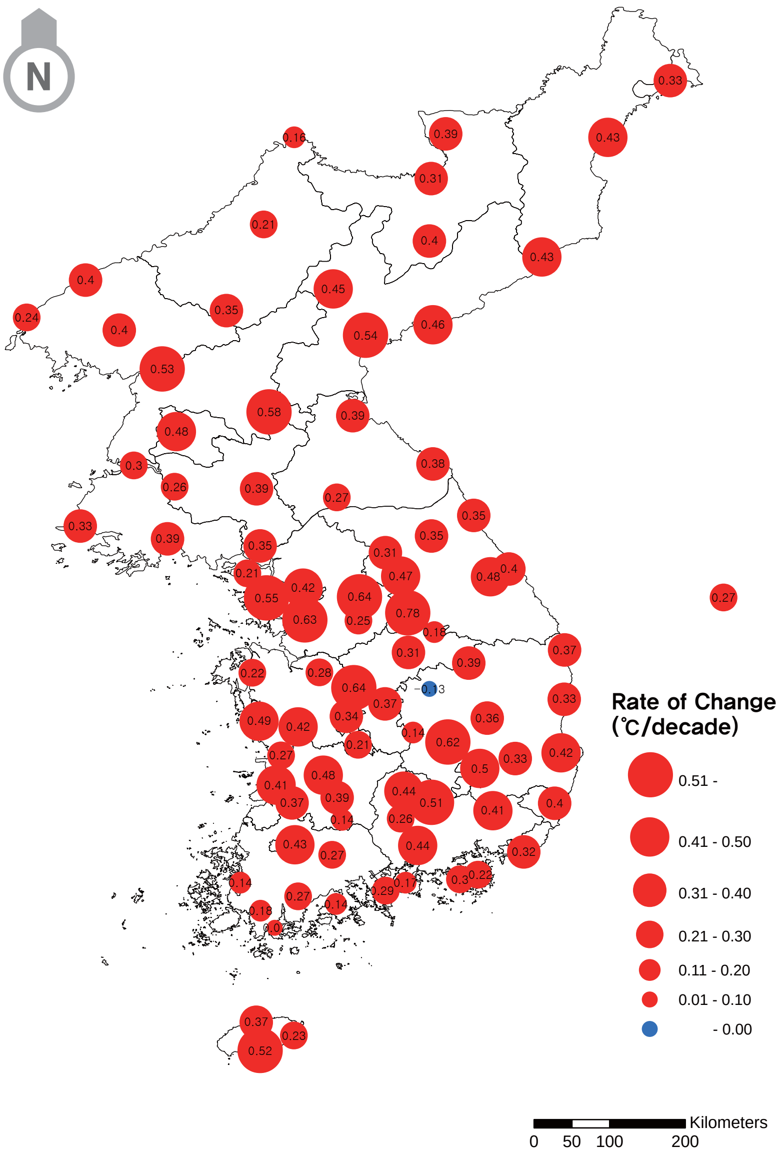
Spatial Pattern of Annual Trends of Change in Each Region

Spatial Pattern of the Rate of Annual Mean Temperature Change over the Korean Peninsula

- The increasing trend in annual mean temperature was noted at all observation stations except for one (Mungyeong).
  - However, the scale of this temperature increase varies greatly depending on location.
- In the case of South Korea, temperatures are increasing more drastically in the capital metropolitan area, as well as in the inland Yeongnam and Yeongseo regions, while in the south west Honam coastal region the increase trend is marginal.
- In the case of North Korea, relatively large temperature increases are occurring in the inland areas of Pyeongan–do and the coastal region of Hamgyeong–do centered around Wonsan.

Fig. 3.9
The Rate of the Mean Temperature Change on the Korean Peninsula (1981–2010)

– Unit of Measure : ℃/decade



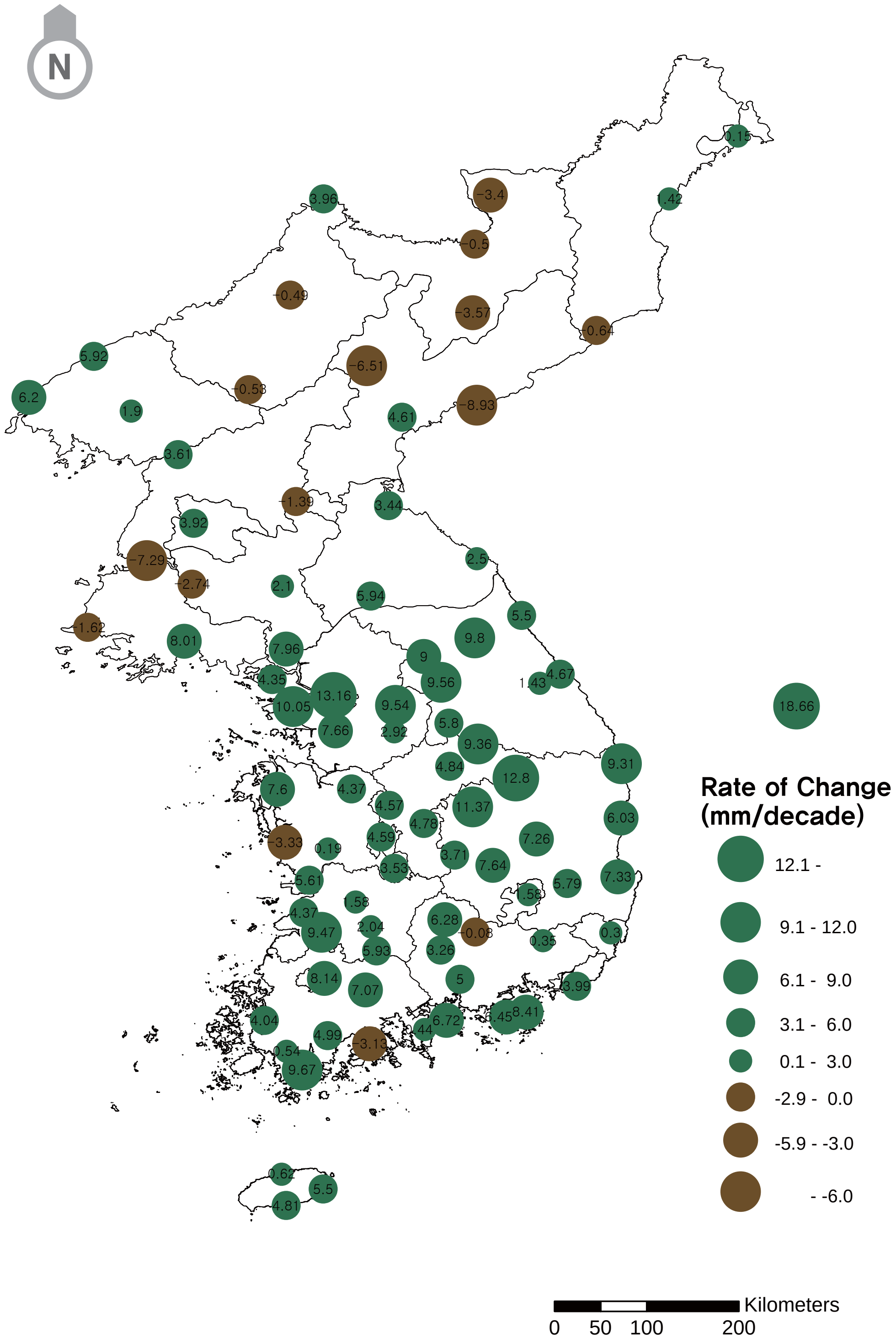
Spatial Pattern of the Rate of Annual Mean Precipitation Change over the Korean Peninsula

- While most of South Korea shows an increasing trend in the annual mean precipitation, there is considerable regional variation.
  - The increasing trends for precipitation are particularly prominent in the metropolitan and central regions.
  - Compared to the Yeongdong region, the central Yeongseo region has a relatively high annual precipitation, which is mainly due to the summer wet season and concentrated precipitation.
  - Also in the typically dry region of Gyeongsangbuk-do, the precipitation has shown a clear increase in the past 30 years.
  - On the other hand in the southern part of Chungcheong-do and the south west coastal regions, the annual mean precipitation has shown either only a slight increase or even a decreasing trend.
- In North Korea there is a mix of regions showing an increase in the precipitation and those showing a decrease.
  - In areas such as Hamgyeong-do, the Gaema Plateau and western Pyeongan-do, the annual mean precipitation shows a decreasing trend.

Changes in Sea level height around the Korean Peninsula

- In the past 43 years (1964–2006) the sea level height of the coast around the Korean Peninsula has shown an almost 8 ㎝ rise, representing a 1.9 ㎜/year rate of increase which is slightly greater than the global average.
  - In particular Jeju Island showed a high annual mean rate of sea level height rise of 5.1 ㎜/year, meaning an approximately 22 ㎝ rise in the aforementioned period (Korea Hydrographic and Oceanographic Administration, 2008).
- By coastal region, sea level height rise has been recorded as 14.6 ㎝ (3.4 ㎜/year) for the south coast, 6.0 ㎝ (1.4 ㎜/year) for the east coast, and 4.3 ㎝ (1.0 ㎜/year) for the west coast, with the south coast showing a more robust rise.
  - This characteristic is related to the relatively high increase in sea surface temperature of the South Sea.

Fig. 3.10
The Rate of the Annual Mean Precipitation Change on the Korean Peninsula (1981–2010)



Korea
Climate Change Report

04

Future Climate Change Projections for the Korean Peninsula

04 Future Climate Change Projections for the Korean Peninsula

1. Spatial Patterns of Climate Change Projections

◆ Climate Change Projections for the Korean Peninsula

Projection of Annual Mean Temperature Change for the Korean Peninsula

- Projections to the end of the 21st century show that the annual mean temperature of the Korean Peninsula will continue to increase steadily in line with increasing greenhouse gas concentration.

- In the RCP4.5 scenario, the annual mean temperature is projected to increase by 1.4℃ in the early 21st century, 2.4℃ in the mid-21st century and 3.0℃ in the late 21st century (Table 4.1).
  - In the RCP4.5 scenario the increasing trend projected is similar to that for RCP8.5 during the early 21st century, with the rate of increase slowing during the mid-21st century as greenhouse gas concentration stabilizes.
  - In the RCP4.5 scenario the annual mean temperature in the late 21st century is projected to be 14.0℃, corresponding to the current average in the southeast coastal region (Ulsan/Busan/Gyeongsangnam-do).

- The RCP8.5 scenario projects an acceleration in climate warming, with mean temperature increasing by 1.5℃ from the current value (11.0℃) in the early 21st century, 3.4℃ in the mid-21st century and 5.7℃ in the late 21st century.
  - By the late 21st century the annual mean temperature is predicted to reach 16.7℃, corresponding to the current mean temperature in the southern part of Jeju Island.

- The magnitude of the increase in the annual mean temperature of the Korean Peninsula, according to the RCP4.5 and RCP8.5 scenarios, will be 1.2 times as large as that of the entire globe and 1.4 times as large as that for East Asia in the same period (2071–2100).

- The daily maximum and minimum temperatures also show a robust increasing trend in both the RCP4.5 and RCP8.5 scenarios.
  - In the RCP8.5 scenario the daily maximum temperature is projected to increase by 1.5℃ from the current 16.6℃ in the early 21st century, 3.3℃ in the mid-21st century, and 5.6℃ in the late 21st century.
  - In the RCP8.5 scenario the daily minimum temperature is projected to rise by 1.5℃ from the current level of 6.2℃ in the early 21st century, 3.5℃ in the mid-21st century and 5.8℃ in the late 21st century.
  - The increase rate for the daily minimum temperature is greater than that of the daily maximum, therefore the daily temperature range is predicted to gradually decrease in the future climate.

Projection of Annual Mean Precipitation Change for the Korean Peninsula

- The annual mean precipitation on the Korean Peninsula in the late 21st century is projected to be 1,348.1 ㎜ in the RCP4.5 scenario and 1,366.9 ㎜ in the RCP8.5 scenario. These figures correspond to the annual mean precipitation levels of Jeollanam-do, Gyeongsangnam-do and the central part of the peninsula in the current climate.
  - In the RCP4.5 (RCP8.5) scenario the increase rate for precipitation from the current climate is projected to be 3.9 (3.0) times, that for the globe and 3.5 (2.9) times that for the East Asia region respectively.
  - The precipitation increase on the Korean Peninsula corresponds to the overall trend in East Asia caused by changes in monsoon circulation and water vapor transport from the ocean to the land (Fig. 1.4).

- In the RCP4.5 scenario the annual mean precipitation is projected to increase from the current level by 6.2% in the early 21st century, 10.5% in the mid-21st century and 16.0% in the late 21st century.
  - The increasing trend is more obvious in the early 21st century in RCP4.5 than in RCP8.5 but in the late 21st century the rate of increase is predicted to slow.
  - While an overall trend of increase in precipitation is projected in both scenarios, during the 21st century the precipitation change is expected to follow a non-linear variation.

- In the RCP8.5 scenario, the annual mean precipitation is set to increase by 3.3% against the current level in the early 21st century, 15.5% in the mid-21st century and 17.6% in the late 21st century.
  - The characteristics of this trend show precipitation increasing rapidly toward the mid-21st century, and then a slowdown in the rate of increase towards the late 21st century.
  - In both the RCP4.5 and RCP8.5 scenarios, the annual mean number of heavy precipitation days is projected to increase by over 30% from 2.0 days in the current climate to 2.8 days in the late 21st century.

Trends of Change for Other Climate Elements

- No substantial change is projected in either the RCP4.5 or RCP8.5 scenarios for the annual mean values of other climate elements such as wind speed, relative humidity, and cloud cover.
  - However, in a warmer climate extreme indices such as heat wave days and tropical nights are expected to become more frequent.
- The annual number of heat wave days is projected in the RCP4.5 scenario to increase from the current level of 7.3 day/year to 8.8 days in the early 21st century, 11.1 days in the mid-21st century and 13.1 days in the late 21st century.
  - In the RCP8.5 scenario the number of heat wave days is projected to increase more rapidly by 2.54 day/decade, rising to 10.2 days in the early 21st century, 15.2 days in the mid-21st century and 30.2 days in the late 21st century.
- The number of tropical nights is projected in the RCP4.5 scenario to increase from the current annual mean level of 2.8 days to 4.1 days in the early 21st century, 9.0 days in the mid-21st century and 13.6 days in the late 21st century.
  - In the RCP8.5 scenario a more drastic increase of 3.82 day/decade is projected; meaning the number of tropical nights would reach 37.2 day/year in the late 21st century.
- The number of heavy precipitation days, which indicates the intensity of precipitation, is projected to increase in both the RCP4.5 and RCP8.5 scenarios, however there is no significant difference between the two scenarios.
  - In both the RCP4.5 and RCP8.5 scenarios, the annual mean number of heavy precipitation days is projected to increase by over 30% from the current level of 2.0 days to 2.8 days in the late 21st century.

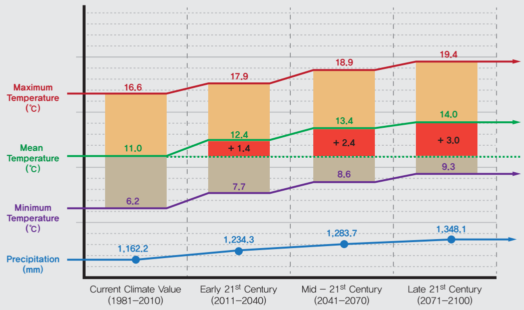
Table 4.1
21st Century Climate Change Projections for the Korean Peninsula based on RCP4.5 (8.5)

- Units of Measure: temperature – ℃; precipitation – ㎜; wind speed – m/s; relative humidity – %; cloud cover – %; heat wave days, tropical nights, heavy precipitation days – number of days per year.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

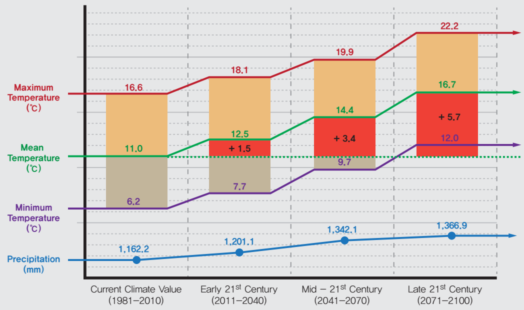
Climate Element	Current Climate Value (1981–2010)	Early 21st Century (2011–2040)		Mid-21st Century (2041–2070)		Late 21st Century (2071–2100)		Decadal Rate of Change	
Mean Temperature	11.0	12.4	(12.5)	13.4	(14.4)	14.0	(16.7)	0.33	(0.63)
Daily Maximum Temperature	16.6	17.9	(18.1)	18.9	(19.9)	19.4	(22.2)	0.31	(0.62)
Daily Minimum Temperature	6.2	7.7	(7.7)	8.6	(9.7)	9.3	(12.0)	0.34	(0.64)
Precipitation	1162.2	1234.3	(1201.1)	1283.7	(1342.1)	1348.1	(1366.9)	20.66	(22.74)
Wind Speed	1.9	1.9	(1.9)	1.9	(1.9)	1.8	(1.9)	–0.01	(0.00)
Relative Humidity	70.2	70.1	(70.0)	69.8	(70.4)	70.4	(70.3)	0.02	(0.01)
Cloud Cover	52	52	(52)	52	(52)	52	(52)	0.00	(0.00)
Heat Wave Days	7.3	8.8	(10.2)	11.1	(15.2)	13.1	(30.2)	0.64	(2.54)
Tropical Nights	2.8	4.1	(5.7)	9.0	(16.6)	13.6	(37.2)	1.20	(3.82)
Heavy Precipitation Days	2.0	2.3	(2.1)	2.6	(2.8)	2.7	(2.8)	0.08	(0.09)

Projections of Change in Temperature and Precipitation in the 21st Century Based on the RCP Scenarios for the Korean Peninsula, South Korea and North Korea

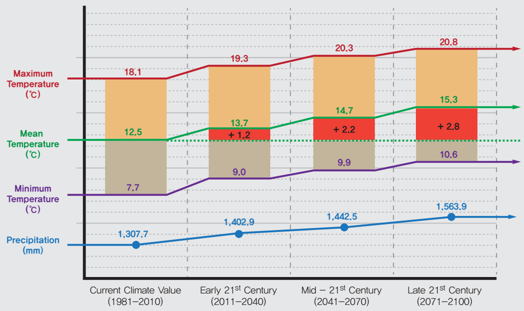
Korean Peninsula (RCP4.5)



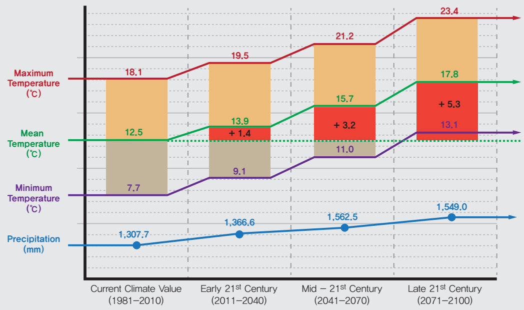
Korean Peninsula (RCP8.5)



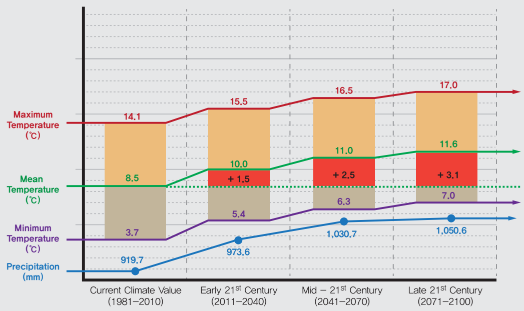
South Korea (RCP4.5)



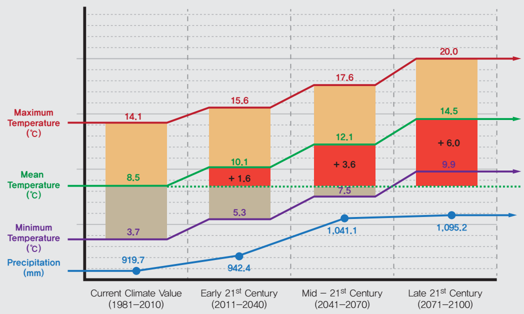
South Korea (RCP8.5)



North Korea (RCP4.5)



North Korea (RCP8.5)



◆ Climate Change Projections for South Korea

- The annual mean temperature of South Korea is projected to increase steadily in line with the increasing trend of temperature of the entire peninsula (Table 4.2).
  - In the RCP8.5 scenario, the annual mean temperature is projected to increase from the current annual mean level of 12.5℃ by 1.4℃ in the early 21st century, 3.2℃ in the mid-21st century, and 5.3℃ in the late 21st century.
  - This rate of increase is slightly lower than the annual mean temperature increase rate projected for the entire peninsula.
- In the RCP8.5 scenario the annual mean temperature of South Korea is projected to reach 17.8℃ by the late 21st century, this is higher than any annual mean temperature observed on the entire peninsula (including Jeju Island) in the current climate.
- In the RCP4.5 scenario a smaller increase in temperature is projected than in RCP8.5, increasing by 1.2℃ in the early 21st century, 2.2℃ in the mid-21st century and 2.8℃ in the late 21st century.
  - In comparison with the temperature increasing rate in the same scenario for the entire peninsula, the increase rate for South Korea is relatively low.
  - In RCP4.5, the annual mean temperature in the late 21st century is projected as 15.3℃, which is the current annual mean temperature of Jeju Island.

Table 4.2
21st Century Climate Change Projections for South Korea based on RCP4.5 (8.5)

- Units of Measure: temperature – ℃; precipitation – ㎜; wind speed – m/s; relative humidity – %; cloud cover – %; heat wave days, tropical nights, heavy precipitation days – number of days per year.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal incrementsproviding a rate of change.

Climate Element	Current Climate Value (1981–2010)	Early 21st Century (2011–2040)		Mid-21st Century (2041–2070)		Late 21st Century (2071–2100)		Decadal Rate of Change	
Mean Temperature	12.5	13.7	(13.9)	14.7	(15.7)	15.3	(17.8)	0.31	(0.59)
Daily Maximum Temperature	18.1	19.3	(19.5)	20.3	(21.2)	20.8	(23.4)	0.30	(0.59)
Daily Minimum Temperature	7.7	9.0	(9.1)	9.9	(11.0)	10.6	(13.1)	0.32	(0.60)
Precipitation	1307.7	1402.9	(1366.6)	1442.5	(1562.5)	1563.9	(1549.0)	28.47	(26.81)
Wind Speed	2.0	2.0	(2.0)	1.9	(2.0)	1.9	(2.0)	–0.01	(0.00)
Relative Humidity	68.6	68.9	(68.5)	68.6	(69.4)	69.1	(69.7)	0.06	(0.12)
Cloud Cover	50	50	(50)	50	(50)	50	(50)	0.00	(0.00)
Heat Wave Days	10.1	11.7	(13.9)	15.3	(20.7)	17.9	(40.4)	0.87	(3.37)
Tropical Nights	3.8	6.1	(8.9)	14.8	(25.5)	22.1	(52.1)	2.03	(5.37)
Heavy Precipitation Days	2.3	2.6	(2.3)	2.8	(3.3)	3.3	(3.2)	0.11	(0.10)

- The daily maximum and minimum temperatures show a clear increase in both the RCP4.5 and RCP8.5 scenarios.
  - In the RCP8.5 scenario the daily maximum temperature is projected to increase by 5.3℃ from the current level by the late 21st century.
  - The daily minimum temperature is projected to increase by 5.4℃, representing a slightly higher rate of increase than the daily maximum.
- The annual mean precipitation is projected in the RCP8.5 scenario to increase by 4.5% in the early 21st century, 19.5% in the mid-21st century and 18.5% by the late 21st century representing a rapid increase until the mid-21st century followed by relative stability until the end of the century.
  - In the RCP8.5 scenario the annual mean precipitation of South Korea in the late 21st century is projected to be 1,549 ㎜, which corresponds to the current mean amount for the southern coastal region of the peninsula which is classified as a wet region.
  - In the RCP4.5 scenario an annual mean precipitation of 1,563.9 ㎜ is projected for South Korea by the late 21st century which is more than that projected in the RCP8.5 scenario.
  - The overall precipitation increase projected for South Korea is understood as being due to increased water vapor transports from the south in the warmer climate.
- For the other climate elements of South Korea, such as wind speed, humidity and cloud cover, little variation from the current values is predicted.
- The number of heat wave days in South Korea is projected to increase rapidly in the RCP8.5 scenario from the current 10.1 day/year to 13.9 days in the early 21st century, 20.7 days in the mid-21st century and 40.4 days in the late 21st century representing an increase rate of 3.4 day/decade, much faster than that projected for the entire peninsula.
- The number of tropical nights is projected to increase rapidly in the RCP8.5 scenario from the current 3.8 day/year to 8.9 days in the early 21st century, 25.5 days in the mid-21st century and 52.1 days in the late 21st century.
  - In the RCP4.5 scenario the number of tropical nights is also projected to increase, reaching 22.1 day/year in the late 21st century, representing a more rapid rate of increase than that projected for the entire peninsula.
- The number of heavy precipitation days is projected to increase from the current level in both the RCP4.5 and RCP8.5 scenarios.
  - The number of heavy precipitation days is projected to increase from the current level of 2.3 days to 3.3 days in the RCP4.5 scenario and 3.2 days in the RCP8.5 scenario in the late 21st century.

Climate Change Projections for North Korea

- The annual mean temperature of North Korea is projected to increase steadily in line with the increasing trend projected for the entire peninsula (Table 4.3).
  - In the RCP8.5 scenario the annual mean temperature is projected to increase steadily from the current 8.5℃ by 1.6℃ in the early 21st century, 3.6℃ in the mid-21st century and 6.0℃ in the late 21st century.
  - This projected increase rate is higher than the trend projected for the peninsula as a whole.
- The annual mean temperature of North Korea is projected in the RCP8.5 scenario to increase to approximately 14.5℃ by the late 21st century, which corresponds to the current annual mean temperature of the Busan region.
  - In the RCP4.5 scenario the temperature is projected to reach 11.6℃ by the late 21st century, which corresponds to the current annual mean temperature of northern Gyeonggi-do.
- The rate of temperature increase projected in the RCP4.5 scenario is slower than that of RCP8.5, increasing by 1.5℃ in the early 21st century, 2.5℃ in the mid-21st century and 3.1℃ by the late 21st century
  - The projected temperature increase for North Korea is higher than that of the peninsula as a whole in the same scenario.
- The daily maximum and minimum temperatures are projected to increase in both the RCP4.5 and RCP8.5 scenarios.
  - The daily maximum temperature is projected to increase by 5.9℃ from the current level by the late 21st century in the RCP8.5 scenario.
  - In the same scenario the daily minimum temperature is projected to increase by 6.2℃ representing a greater increase than that for the daily maximum.
- The annual mean precipitation is projected in the RCP8.5 scenario to increase from the current level by 2.4% in the early 21st century, 13.1% in the mid–21st century and 19.0% in the late 21st century.
  - Compared with the trend for the entire peninsula, the projection for North Korea shows a relatively small increase in the early and mid-21st century, but a larger increase in the late 21st century.
- The annual mean precipitation of North Korea is projected in the RCP8.5 scenario to reach 1,095.2 ㎜ by the late 21st century, which corresponds to the current value for rainy regions in southern North Korea and Pyeonganbuk-do.
  - In the RCP4.5 scenario an increase to 1,050.6 ㎜ is projected.

Table 4.3
21st Century Climate Change Projections for North Korea based on RCP4.5 (8.5)

- Units of Measure: temperature – ℃; precipitation – ㎜; wind speed – m/s; relative humidity – %; cloud cover – %; heat wave days, tropical nights, heavy precipitation days – number of days per year.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal incrementsproviding a rate of change.

Climate Element	Current Climate Value (1981–2010)	Early 21st Century (2011–2040)		Mid-21st Century (2041–2070)		Late 21st Century (2071–2100)		Decadal Rate of Change	
Mean Temperature	8.5	10.0	(10.1)	11.0	(12.1)	11.6	(14.5)	0.34	(0.67)
Daily Maximum Temperature	14.1	15.5	(15.6)	16.5	(17.6)	17.0	(20.0)	0.32	(0.66)
Daily Minimum Temperature	3.7	5.4	(5.3)	6.3	(7.5)	7.0	(9.9)	0.37	(0.69)
Precipitation	919.7	973.6	(942.4)	1030.7	(1041.1)	1050.6	(1095.2)	14.54	(19.50)
Wind Speed	1.6	1.6	(1.6)	1.6	(1.6)	1.5	(1.6)	–0.01	(0.00)
Relative Humidity	72.8	72.5	(72.6)	72.0	(72.5)	72.7	(72.2)	–0.01	(–0.07)
Cloud Cover	55	55	(55)	55	(55)	54	(55)	–0.01	(0.00)
Heat Wave Days	2.8	4.2	(5.0)	5.5	(8.6)	7.0	(19.9)	0.47	(1.90)
Tropical Nights	0.6	1.1	(1.7)	3.1	(8.1)	5.5	(24.0)	0.54	(2.60)
Heavy Precipitation Days	1.3	1.6	(1.4)	2.1	(1.9)	1.8	(2.0)	0.06	(0.08)

- No significant change from current conditions is projected for other elements of the North Korean climate such as wind speed, humidity and cloud cover.

- The number of heat wave days in North Korea is projected to increase rapidly in the RCP8.5 scenario from the current level of 2.8 day/year to 5.0 days in the early 21st century, 8.6 days in the mid-21st century and 19.9 days in the late 21st century.

- The number of tropical nights is projected to increase rapidly in the RCP8.5 scenario, from the current annual mean number of 0.6 days to 1.7 days in the early 21st century, 8.1 days in the mid-21st century and 24.0 days in the late 21st century.
  - In the RCP4.5 scenario the number of tropical nights is projected to increase to 5.5 day/year by the latter half of the 21st century.

- The number of heavy precipitation days is projected to increase in both the RCP8.5 and RCP4.5 scenarios.
  - The number of heavy precipitation days is projected to increase from the current level of 1.3 days to 1.8 days in the RCP4.5 scenario and 2.0 days in the RCP8.5 scenario by the late 21st century.

Spatial Patterns of Climate Change Projected for the Korean Peninsula

Spatial Patterns of the Annual Mean Temperature Change

- The annual mean temperature is projected to increase across all parts of the Korean Peninsula throughout the entire 21st century (Fig. 4.1).

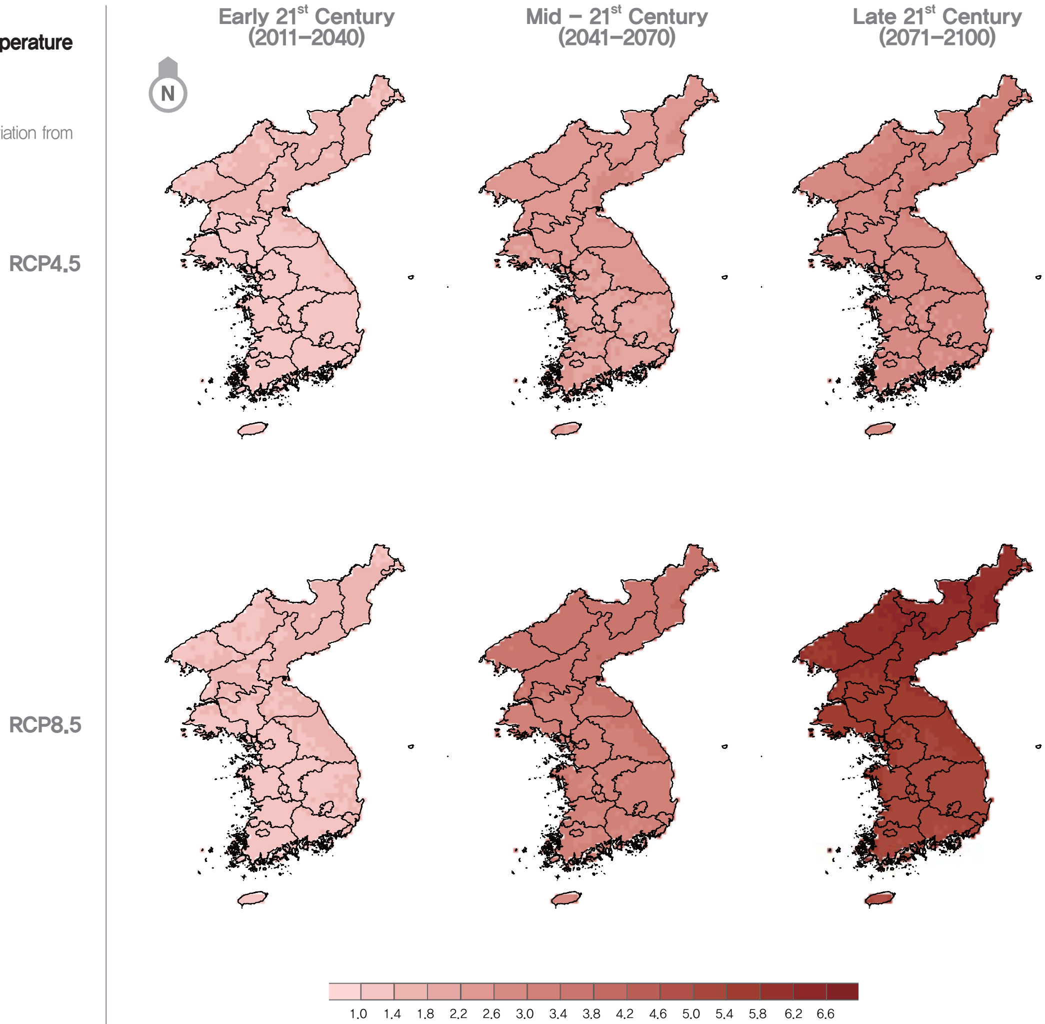
- The spatial patterns of annual mean temperature change projected by both the RCP4.5 and RCP8.5 scenarios are about the same; however, a more rapid warming trend is projected in the RCP8.5 high emissions scenario.
  - Geographically, more extreme temperature increases are expected in the mountainous northern part of the Korean Peninsula including the Gaema Plateau and the northeastern coastal area.

- The warming of the northern part of the Korean Peninsula, a region connected to the Asian continent, corresponds to the overall trend projected for Northeast Asia as a whole (Fig. 1.3).
  - Also apparent is a projected increase in sea surface temperature and surface temperature on the eastern coast due to the movement of a warm ocean current in the East Sea.

- The predicted rapid warming of the northern mountainous region may increase the vulnerability of the alpine ecosystem and create difficulties for water resource management due to decreasing levels of snowfall and changes to the thawing season.

Fig. 4.1
Projection of Annual Mean Temperature on the Korean Peninsula in the RCP4.5/8.5 Scenarios

– Change value is calculated as deviation from the 1981–2010 climate (℃).



Spatial Patterns of the Annual Mean Precipitation Change

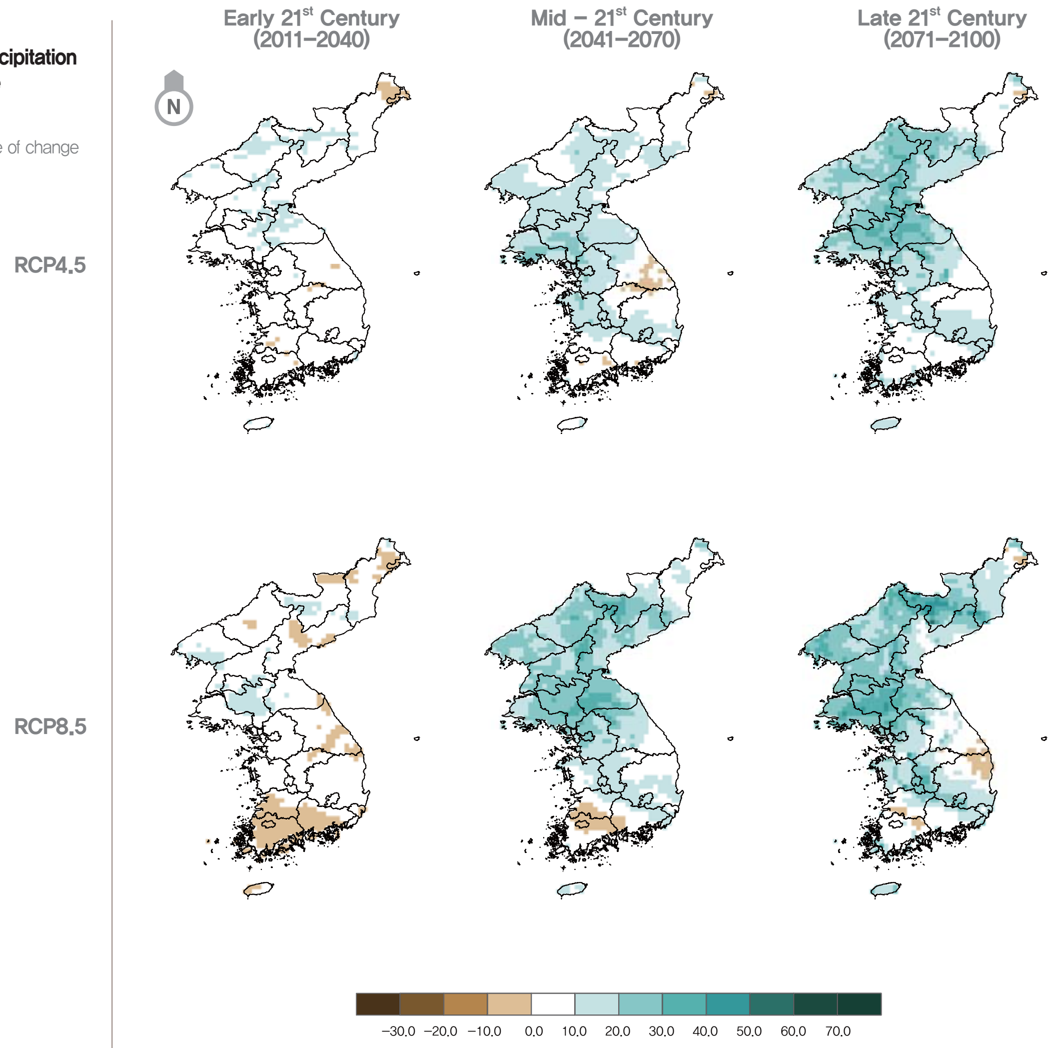
- The annual mean precipitation is projected to rise consistently in the central inland region and the northern part of the peninsula following the general warming trend.
  - A maximum increase of 50% from the current precipitation is projected in the northeastern highland area, which is currently the most arid part of the peninsula.

- In the RCP4.5 scenario, a slight increase in precipitation is projected for mort parts of the peninsula especially in North Korea in the early 21st century. This is followed by a conspicuous increase in the mid-21st century in areas such as the central region of the peninsula, Chungcheong-do, the southwestern part of North Korea, and the Gaema Plateau.
  - Precipitation is projected to decrease locally in the Yeongdong region.
  - The change projected in precipitation for the late 21st century shows a distinct increase in North Korea and a general increase in most parts of the peninsula.

- In the RCP8.5 scenario, a mix of regions with increasing precipitation and others with decreasing precipitation is projected in the early 21st century.
  - Precipitation is projected to decrease in the southwestern part of the peninsula, and increase in Hwanghae-do.
  - Compared with the RCP4.5 scenario a more significant increase of precipitation is projected for North Korea in the mid-21st century with a more moderate increase projected for most parts of the peninsula excluding the southwestern region of South Korea where precipitation is set to decrease.
  - In the late 21st century, the increasing trend in precipitation is more conspicuous in North Korea and the central region of the peninsula, while the decreasing trend is more extreme in Gyeongsangbuk-do and the coastal region of Gangwon-do.

Fig. 4.2
Projection of Annual Mean Precipitation on the Korean Peninsula in the RCP4.5/8.5 Scenarios

– Change value is calculated as rate of change from the 1981–2010 climate (%).



Change in Sea level height around the Korean Peninsula

- Sea level height is projected to rise along the entire coastline of the peninsula.

  - The rise in sea level height is projected to be relatively more extreme on the east coast than the rest of the peninsula while there is little difference between the projections for the south and west coasts (Fig. 4.3).

- The rise in sea level height around the Korean Peninsula, according to the RCP4.5 (8.5) scenario, is projected to reach 53 ㎝ (65 ㎝) along the south and west coasts, and 74 ㎝ (99 ㎝) along the east coast in the late 21st century (2071–2100).

  - These figures are comparable with the rise in sea level height of 70.6 ㎝ (88.5 ㎝) projected to take place globally in the same period.

- The sea level height is projected to rise more rapidly as time goes on. According to the RCP4.5 (8.5) scenario sea level heights are projected to have risen by as much as 65 ㎝ (85 ㎝) along the south and west coasts, and 90 ㎝ (130 ㎝) along the east coast by 2100.

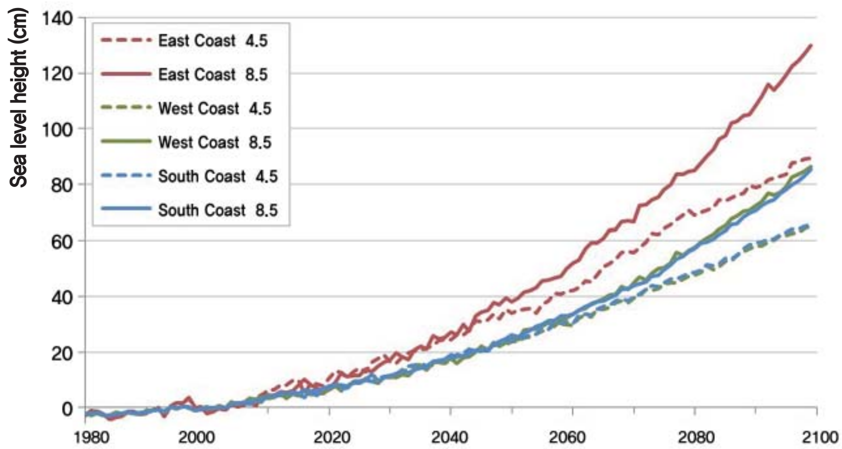
  - The relatively extreme sea level height rise projected on the east coast is mainly attributable to the increasing heat transport from the warm Kuroshio Current caused by global warming and the subsequent increase in temperature predicted in the warm current which passes through the East Sea of Korea.

- The HadGEM2-AO model used for this climate change report takes into account both heat expansion and the effect of freshwater inflow due to the melting of inland glaciers (NMRI, 2011). The findings predict that the glacier-melting effect caused by global warming will contribute more significantly to rising sea level heights after the mid-21st century.

  - The rapid rise in sea level height is expected to expose the vulnerability of coastal areas to climate change, resulting in coastal erosion and the destabilization of coastal structures, etc.

Fig. 4.3
Projection of Sea level height Change around the Korean Peninsula in the RCP4.5/8.5 Scenarios

- Sea level height change (㎝) is shown as deviation from the 1981–2010 climate value.

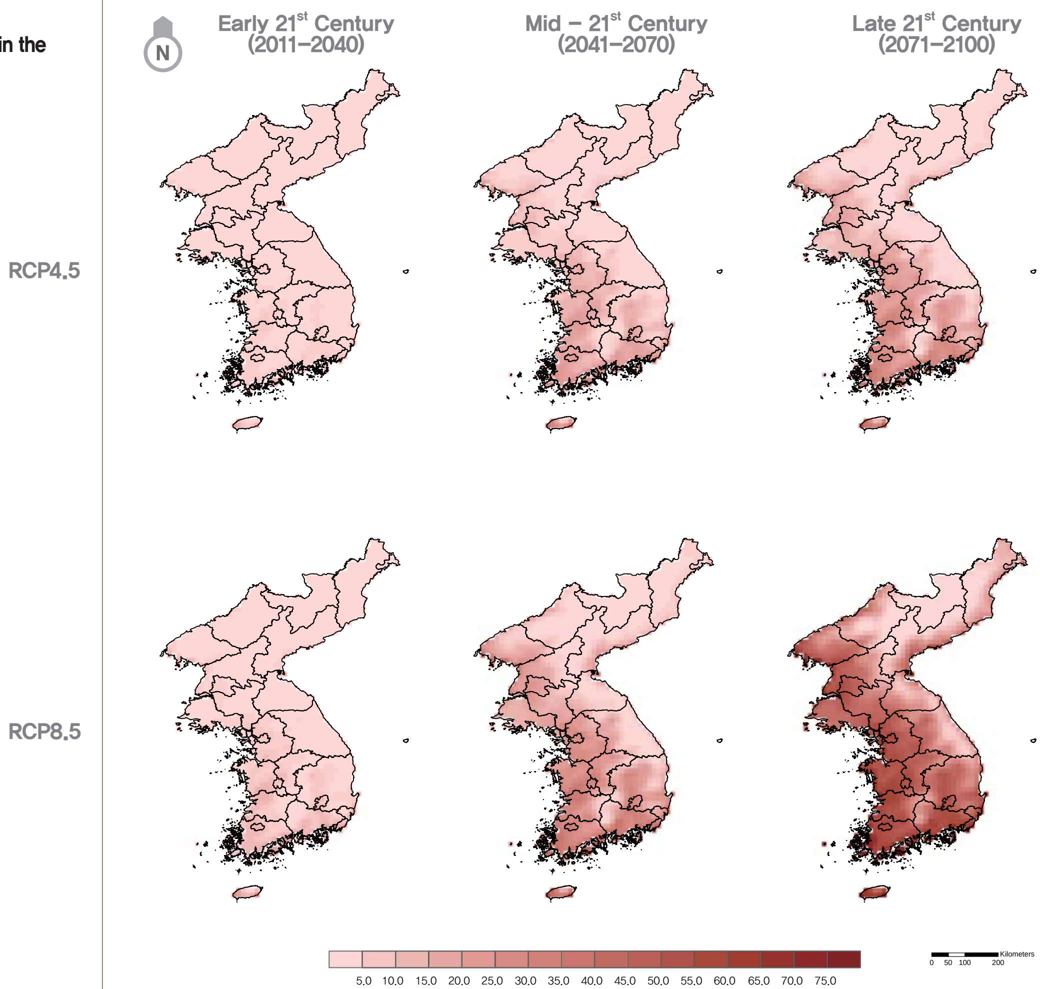


Spatial Patterns of Projected Change to Extreme Indices on the Korean Peninsula

The Rate of Increase in the Number of Tropical Nights

- The increasing trend in the number of tropical nights is projected to be more rapid in the RCP8.5 scenario.
  - The number of tropical nights is projected to increase at a faster rate in the lower altitude areas where the daily minimum temperature is higher.
- As climate change worsens, it is predicted that the area in which tropical nights occur will expand, gradually encroaching on the high altitude mountainous regions (Fig. 4.4).

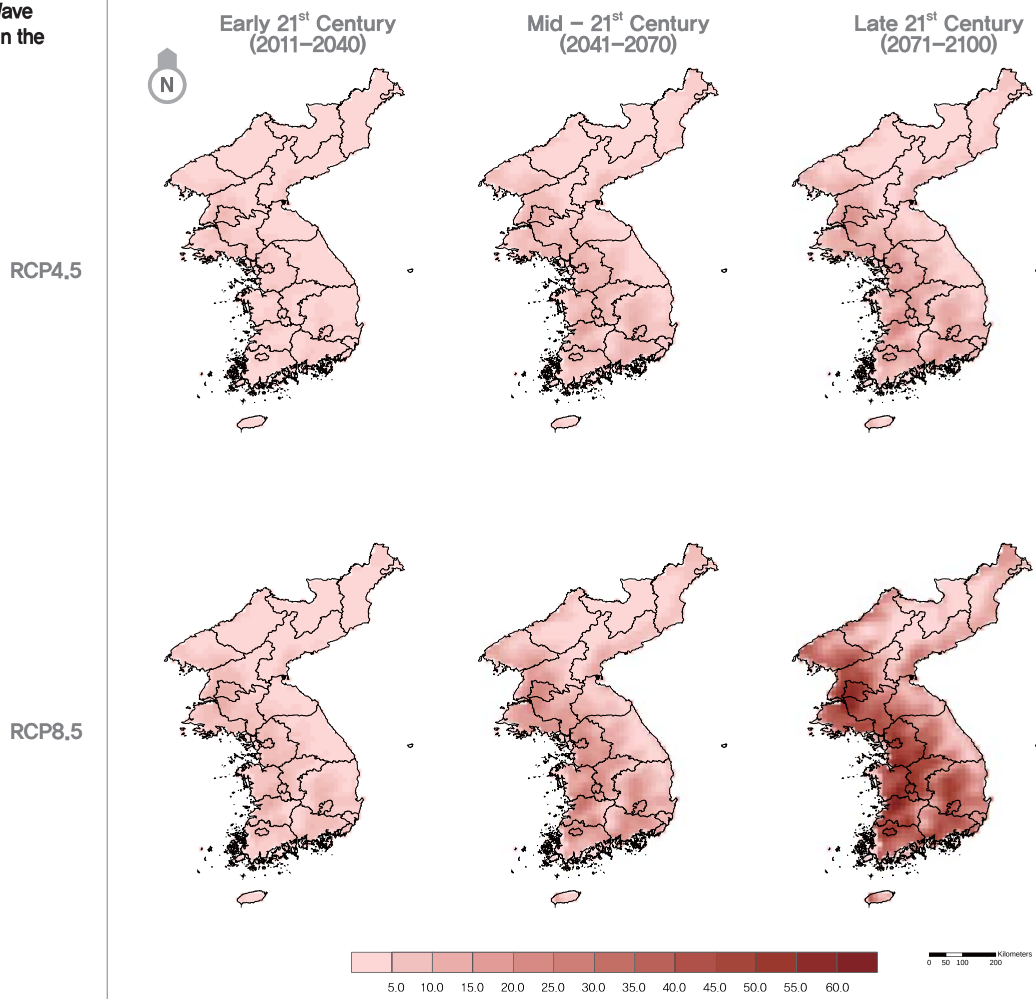
Fig. 4.4
Projection of Number of Tropical Nights on the Korean Peninsula in the RCP4.5/8.5 Scenarios



Spatial Patterns of Change in Number of Heat Wave Days

- The increasing rate in the number of heat wave days is projected to be more rapid in the RCP8.5 scenario.
    - The number of heat wave days is projected to increase more rapidly in the lower altitude areas where the daily maximum temperature is relatively high.
- As climate change worsens, the number of heat wave days is projected to increase in all regions in line with increases in maximum daily temperatures in the high altitude mountainous regions (Fig. 4.5).

Fig. 4.5
Projection of Number of Heat Wave Days on the Korean Peninsula in the RCP4.5/8.5 Scenarios



Spatial Patterns of Change in Heavy Precipitation Days

- The change in the number of heavy precipitation days is projected to vary widely with season, region and scenario.

- In the RCP4.5 scenario, change in the number of heavy precipitation days shows either an increasing or decreasing trend in the early 21st century, however toward the mid-21st century the increasing trend is dominant in most regions.

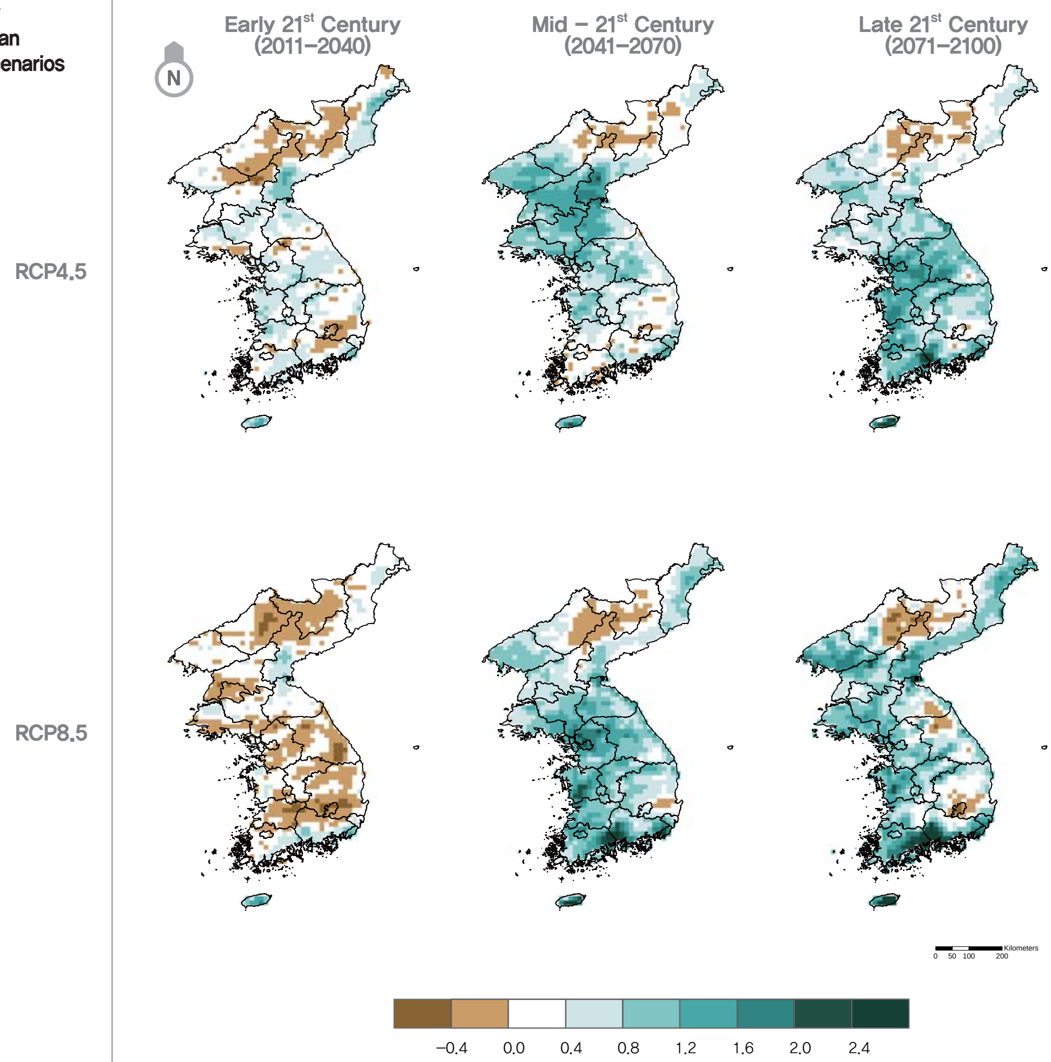
  - In the late 21st century the number of heavy precipitation days is projected to increase across the entire peninsula with only a few regional exceptions, such as the Gaema Plateau and the inland area of Gyeongsangnam-do.

- In the RCP8.5 scenario the number of heavy precipitation days is projected to decrease slightly in most regions in the early 21st century, with two exceptions being the southern coast and the coastal area of Wonsan Bay.

  - The RCP4.5 and RCP8.5 scenarios project similar changes in the number of heavy precipitation days after the mid-21st century, including an increase in the southern coastal region.

- Both the RCP4.5 and RCP8.5 scenarios project similar changes in the number of heavy precipitation days after the mid-21st century; in particular an increase in the number of heavy precipitation days in the southern coastal region.

Fig. 4.6
Projection of Number of Heavy Precipitation Days on the Korean Peninsula in the RCP4.5/8.5 Scenarios



2. Temporal Patterns of Climate Change Projections

Temporal Changes in Mean Temperature and Precipitation on the Korean Peninsula

Temporal Changes in Temperature and Precipitation on the Korean Peninsula

- In the RCP8.5 scenario the decadal mean temperature of the Korean Peninsula is projected to increase steadily at a rate of 0.7%/decade (Fig. 4.7a), corresponding with the increase of greenhouse gas concentration (see Fig. 2.4).

- In the RCP4.5 scenario temperatures are projected to increase rapidly until the 2040s in line with the stabilization of greenhouse gas concentration in the mid-21st century, and then the increasing rate is predicted to slow (see Fig. 2.4).

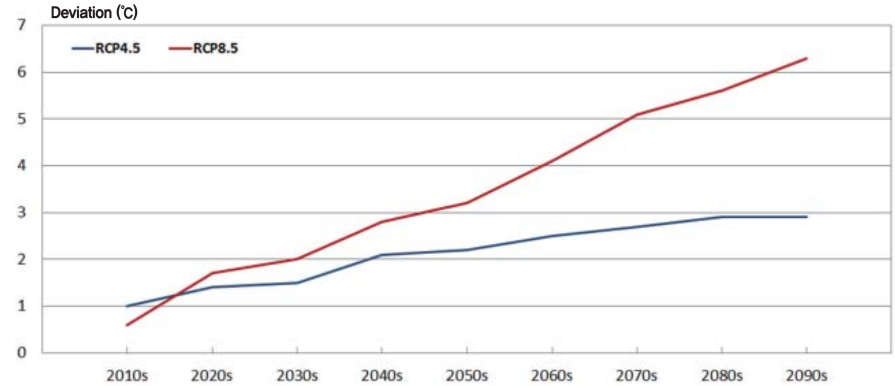
- The change in precipitation on the Korean Peninsula, unlike the trend of increasing temperature, appears complex with a pattern of cyclic change lasting several decades as well as an increase overall (Fig. 4.7b).
  - According to the RCP4.5 scenario, precipitation is projected to increase steadily from the 2020s onwards, accompanied by long-term cyclic changes in precipitation.
  - According to the RCP8.5 scenario, after a rapid increase of precipitation in the 2010s, a gradual decrease is projected to occur until the late 21st century.

- The two RCP scenarios project different trends of change in precipitation for the early 21st century, but they both predict an overall increase in precipitation from the current climate value by the late 21st century.
  - The absolute value of increase in precipitation varies only slightly between the two scenarios with a slightly greater increase in the RCP8.5 scenario (see Table 4.1).

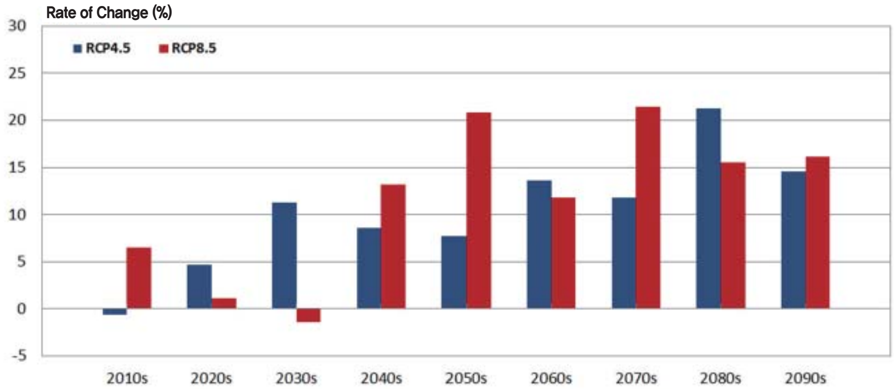
Fig. 4.7
Projection of Temperature and Precipitation on the Korean Peninsula during the 21st Century

- Mean temperature and precipitation are shown as deviation (℃) and rate of change (%) from the 1981–2010 climate in decadal increments.

(a) Mean Temperature



(b) Precipitation

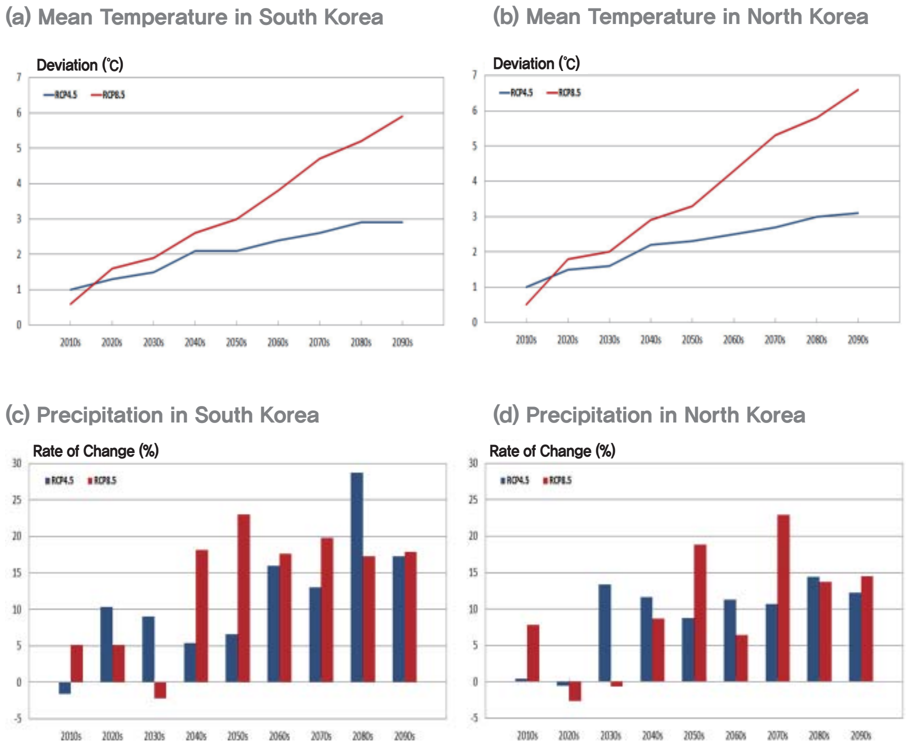


Comparing the Patterns of Temporal Change between South and North Korea

- The increasing trend of mean temperature is relatively greater in North Korea with this difference appearing more conspicuously in the RCP8.5 scenario (see Fig. 4.8a, 4.8b).
  - The decadal trends of temperature change for both South Korea and North Korea are almost the same; this is understood as being due to the wider scope of long-term trends of temperature change.
- The increasing trend of precipitation is projected more robustly for South Korea (see Fig. 4.8c, 4.8d).
- The increasing trend of precipitation is not progressive but rather appears complex with long-term cyclic change.
  - When comparing the changes in precipitation predicted in South and North Korea, unlike temperature only a slight correlation is detected, indicating that changes in precipitation due to climate change will be influenced by geographical characteristics.

Fig. 4.8
Projection of Temperature and Precipitation for South and North Korea during the 21st Century

- Mean temperature and precipitation are shown as deviation (℃) and rate of change (%) from the 1981–2010 climate in decadal increments.



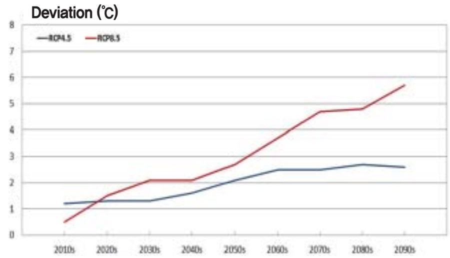
Comparing Characteristics of Seasonal Change in Mean Temperature and Precipitation

- The mean temperature of the Korean Peninsula is projected to increase in all seasons and this trend is predicted to be more severe in the RCP8.5 scenario.
  - The temperature increase is predicted to be relatively greater in winter and autumn, and the rate of increase appears more conspicuous after the 2030s and 2050s.
  - In contrast, the temperature increase appears relatively minor in the summer.
- The difference in temperature increase between the two scenarios appears greatest in winter, which reflects that change in winter temperatures will be highly dependent on the future greenhouse gas concentration.
- The change in precipitation in comparison with the current climate is projected to be greatest in winter, the driest season, where the effects of climate change are expected to be most tangible.
  - In the RCP4.5 scenario the change in wintertime precipitation displays a greater increase towards the late 21^{st} century.
  - In the RCP8.5 scenario however the change shows a more linear increment.
- Projections for springtime precipitation show either a slight increasing trend (RCP4.5) or an overall increase with wide fluctuation in rates of change from plus to minus (RCP8.5).

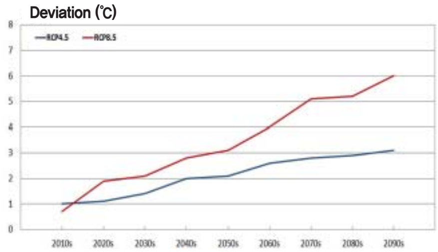
Fig. 4.9
Projection of Temperature and Precipitation for the Korean Peninsula during the 21st Century by Season

- Mean temperature and precipitation are shown as deviation (℃) and rate of change (%) from the 1981–2010 climate in decadal increments.

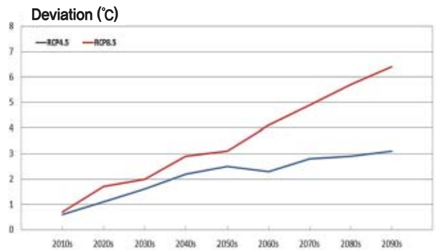
(a) Spring Mean Temperature



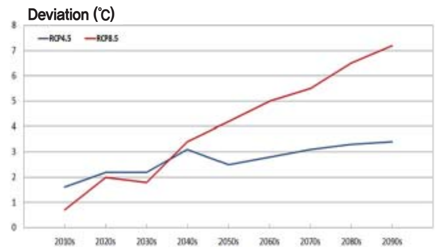
(b) Summer Mean Temperature



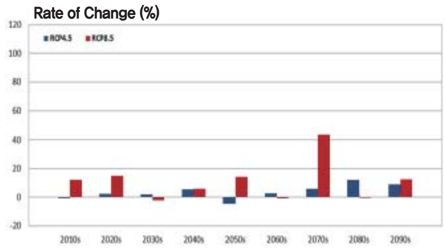
(c) Autumn Mean Temperature



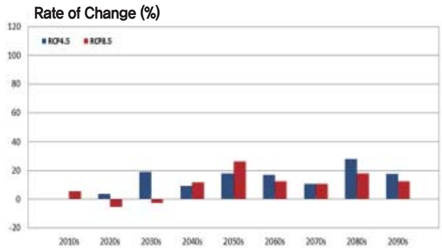
(d) Winter Mean Temperature



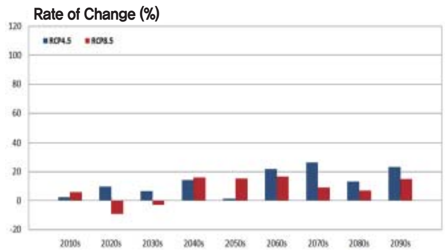
(e) Spring Precipitation



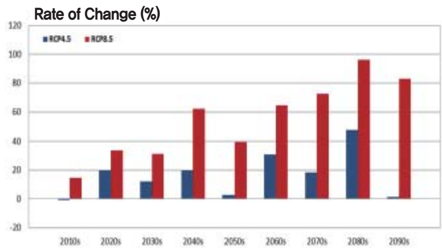
(f) Summer Precipitation



(g) Autumn Precipitation



(h) Winter Precipitation



What is Trewartha's Subtropical Climate Region?

This classification applies to areas where, while the average temperature of the coldest month is below 18℃, the number of months each year with an average temperature above 10℃ exceeds 8.

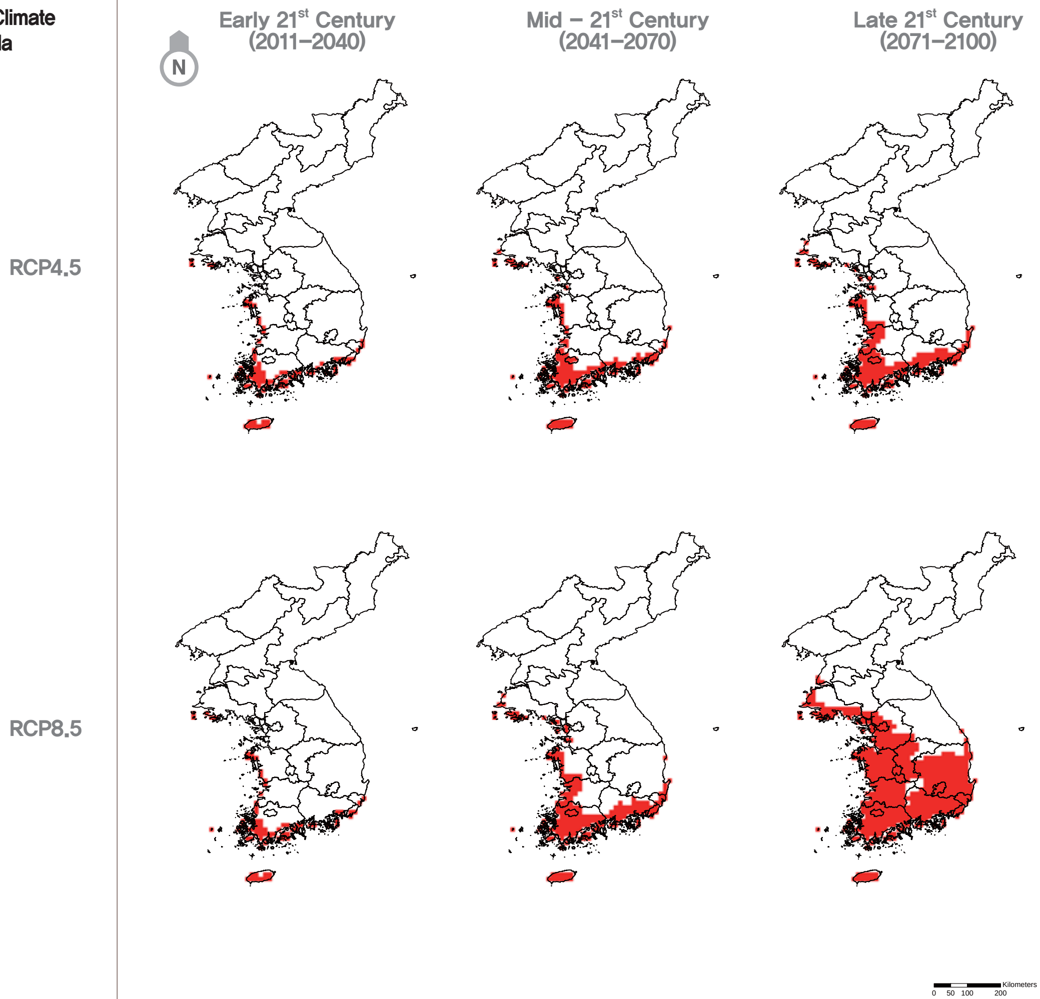
Change in the Subtropical Climate Region

- According to Trewartha's climate classification the southern coast of the Korean Peninsula including Jeju Island, Busan and Mokpo is classified as part of a humid subtropical climate region while the rest of the peninsula is part of a continental climate region.
  - As global warming accelerates, the boundary of the subtropical climate region is expected to gradually move north.

- According to the projection of the RCP4.5 scenario, in the late 21st century the subtropical climate region will move northward along the west coast of Jeollanam-do, Jeollabuk-do and Chungcheongnam-do, as well as the west coast of Gyeonggi–do and Hwanghae-do, and Gyeongsangnam-do in the southeast.

- According to the projection of the RCP8.5 scenario most of South Korea, except for the mountainous region of Gangwon-do, will become part of this subtropical climate region in the late 21st century.

Fig. 4.10
Projection of the Subtropical Climate Region of the Korean Peninsula



Korea
Climate Change Report

05

Climate Change Projections for the Administrative Areas of South Korea

05 Climate Change Projections for the Administrative Areas of South Korea

Overview

- This chapter presents detailed climate change projections for the 16 provinces and metropolitan cities of South Korea using the 1㎞ resolution data refined using a statistical downscaling method.

- The exact projection values are presented in Tables A1–A10 in Appendix 3.

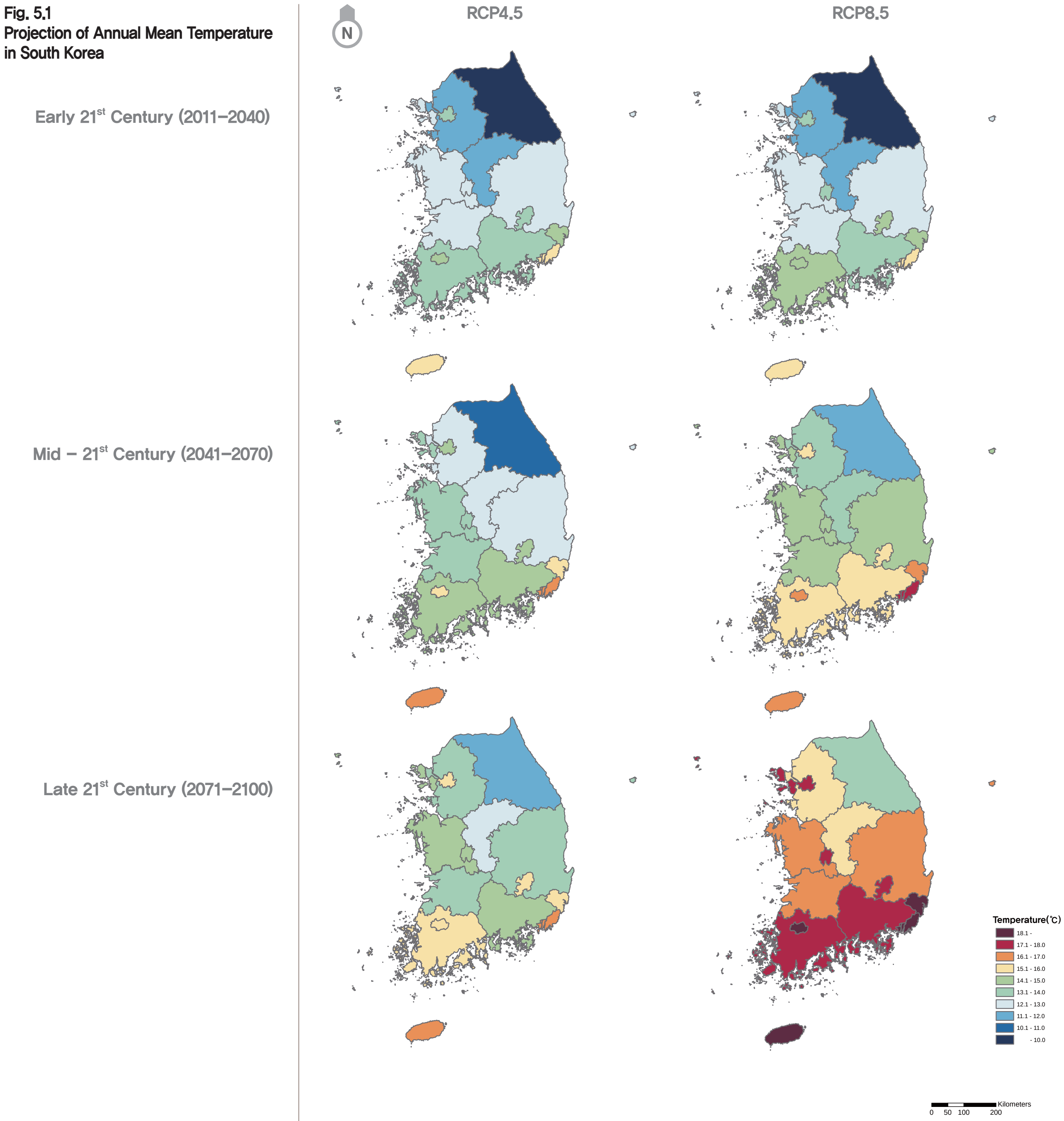
Projection of Annual Mean Temperature for the 16 Provinces and Metropolitan Cities of South Korea

- The maximum annual mean temperature in the current climate (2001–2010) is observed in Jeju-do and Busan (14.4℃) and the minimum in Gangwon-do (7.9℃).
  - The annual mean temperature is projected to increase in all 16 administrative areas in the 21st century.

- According to the RCP4.5 scenario, in the late 21st century (2071–2100) the mean temperature for Jeju-do and Busan will reach 16.7℃, and 11.2℃ for Gangwon-do.
  - The largest increases in the annual mean temperature are forecast to occur in Incheon and Ulsan (0.3℃/decade) and the smallest increases in Gwangju and Daejeon (0.26℃/decade), displaying no significant regional difference.

- In the RCP8.5 scenario, the maximum annual mean temperature is projected to reach 19.2℃ in Busan in the late 21st century with an increase rate of 0.6℃/decade.

Fig. 5.1
Projection of Annual Mean Temperature in South Korea



◆ Projections for Annual Mean Precipitation for the 16 Administrative Areas of South Korea

- In the current climate (2001–2010), the maximum annual mean precipitation occurs in Jeju-do (2,168.1 ㎜), and the minimum in Incheon (1,199.2 ㎜).
  - The annual mean precipitation is projected to increase in all 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean precipitation is projected tobe maximum in Jeju–do with 2,709.7 ㎜/year, and minimum in Daegu with 1,546.1 ㎜/year.
  - The greatest increase in annual mean precipitation is projected to occur in Gwangju with 76.64 ㎜/decade, and the smallest increase in Daegu with 40.16 ㎜/decade.
- In the RCP8.5 scenario in the late 21st century the annual mean precipitation is projected to be maximum in Jeju-do (2,924.5 ㎜) with an increase rate of 94.55 ㎜/decade.

Fig. 5.2
Projection of Annual Mean Precipitation in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)

Projections for Annual Mean Number of Frost Days for the 16 Administrative Areas of South Korea

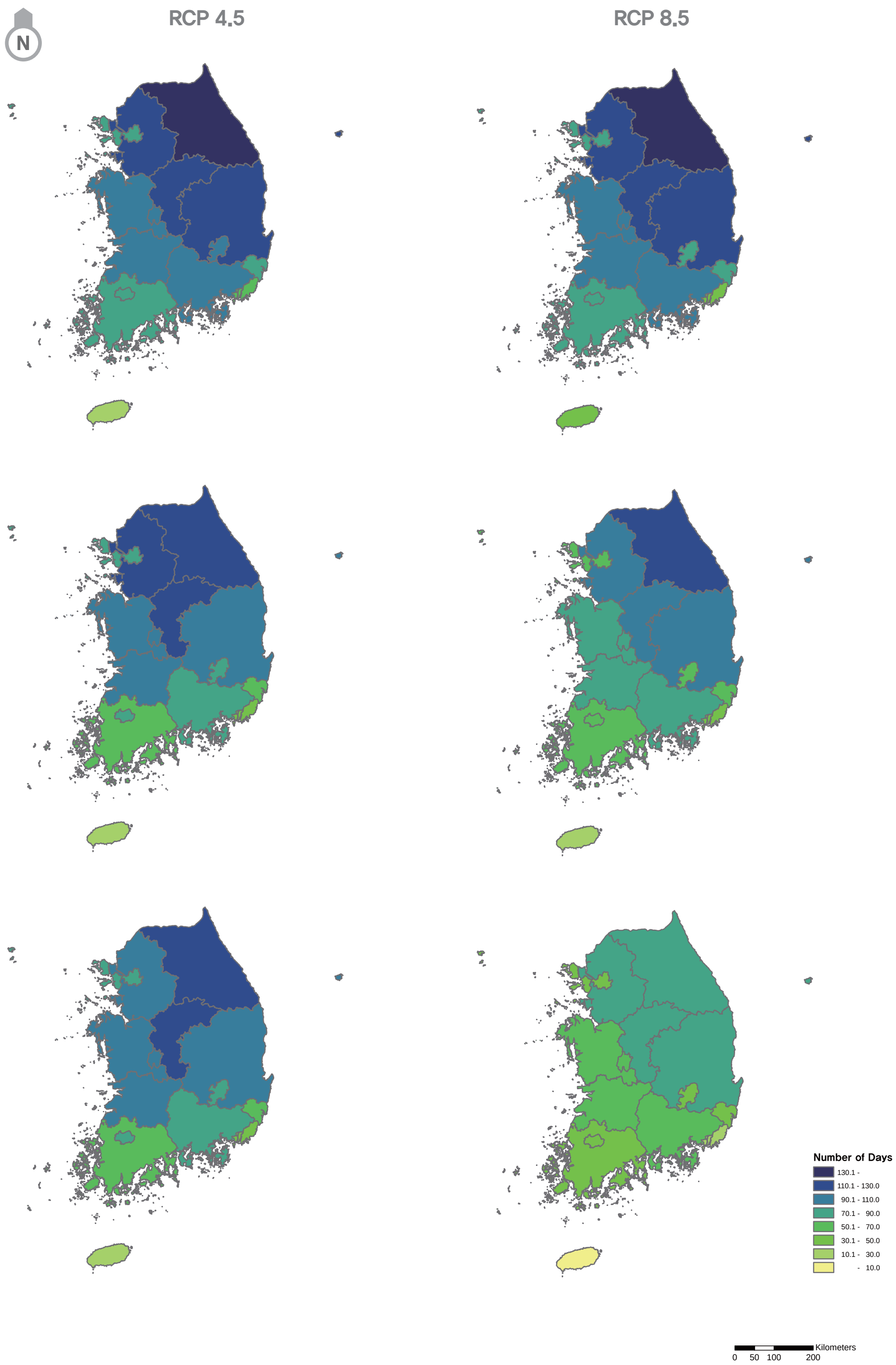
- In the current climate the number of frost days is highest in Gangwon-do (144.1 day/year) and lowest in Jeju-do (35.1 day/year).
  - The annual number of frost days is projected to decrease in all 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean number of frost days is projected to be maximum in Gangwon–do with 117.5 day/year, and minimum in Jeju–do with 18.1 day/year.
  - The greatest decrease in the annual mean number of frost days is projected to occur in Gangwon-do (–3.33 day/decade) and the smallest decrease in Seoul (–1.48 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean number of frost days is projected to be maximum in Gangwon-do (89.2 day/year) with a decrease rate of –6.86 day/decade.

Fig. 5.3
Projection of Annual Mean Number of Frost Days in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



◆ Projections for Annual Mean Number of Summer Days for the 16 Administrative Areas of South Korea

- In the current climate (2001–2010), the maximum number of summer days occurs in Gwangju (130.5 day/year), and the minimum in Gangwon-do (74.6 day/year).
  - The annual number of summer days is predicted to increase in all 16 administrative areas in the 21st century.

- In the RCP4.5 scenario in the late 21st century the annual mean number of summer days is projected to be maximum in Gwangju with 154.9 day/year, and minimum in Gangwon-do with 99.1 day/year.
  - The greatest increase in the annual mean number of summer days is projected to occur in Busan (5.08 day/decade), and the lowest increase in Seoul and Gwangju (3.05 day/decade).

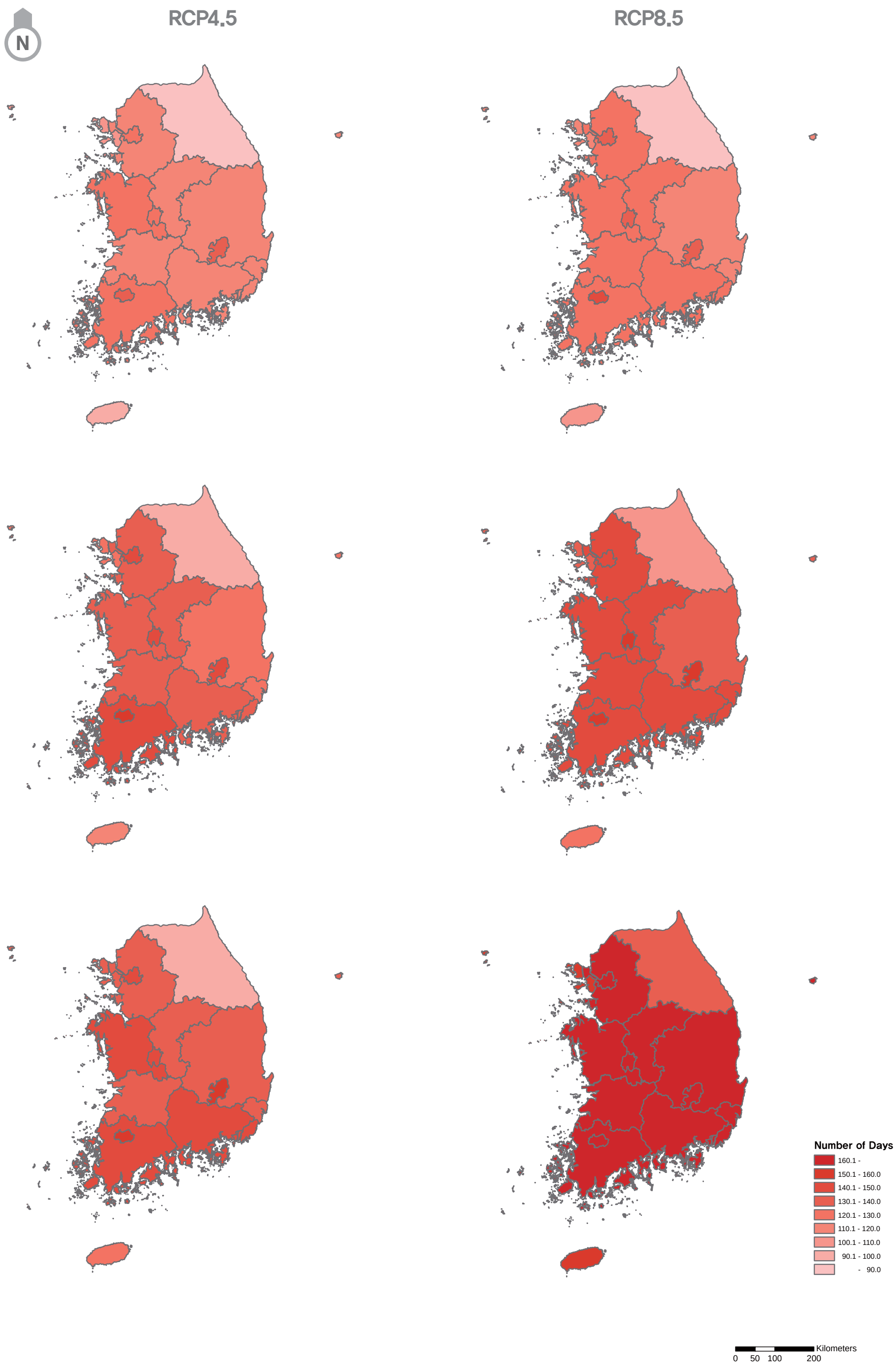
- In the RCP8.5 scenario in the late 21st century the annual mean number of summer days is projected to be maximum in Gwangju (177.7 day/year) with an increase rate of 5.9 day/decade.

Fig. 5.4
Projection of Annual Mean Number of Summer Days in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



Projections for Annual Mean Number of Freezing Days for the 16 Administrative Areas of South Korea

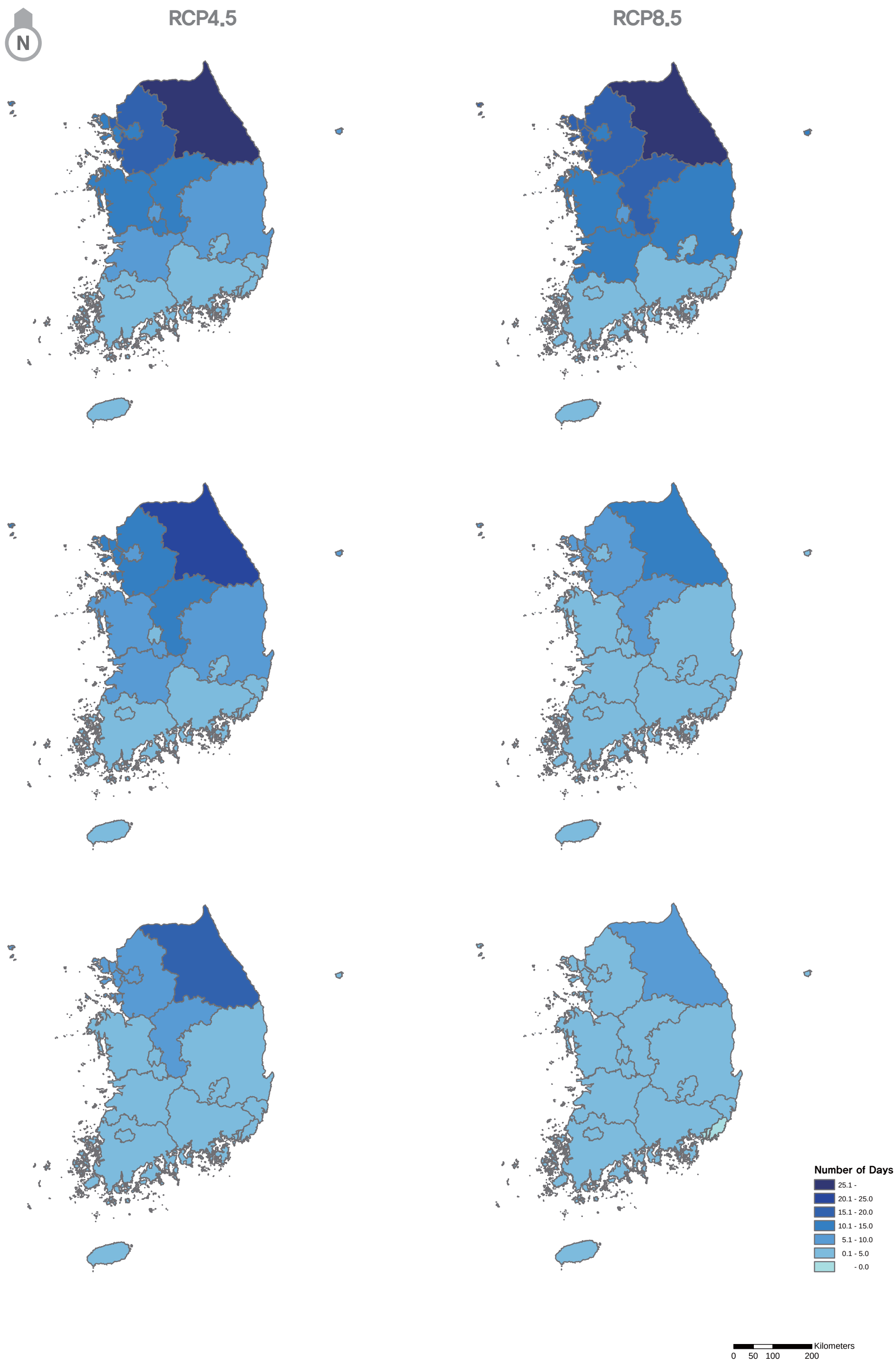
- The highest number of freezing days in the current climate (2001–2010) occurs in Gangwon–do (36.4 day/year), and the lowest number in Busan (1.4 day/year).
  - The annual number of freezing days is predicted to decline in all 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean number of freezing days is projected to be maximum in Gangwon–do with 17.4 day/year, and minimum in Busan with 0.1 day/year.
  - The greatest decrease in the annual mean number of freezing days is projected to occur in Gangwon-do (–2.38 day/decade), and the smallest decrease in Busan (–0.16 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean number of freezing days is projected to be maximum in Gangwon-do (6.3 day/year) with a decrease rate of –3.76 day/decade.

Fig. 5.5
Projection of Annual Mean Number of Freezing Days in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



Projections for Annual Mean Number of Tropical Nights for the 16 Administrative Areas of South Korea

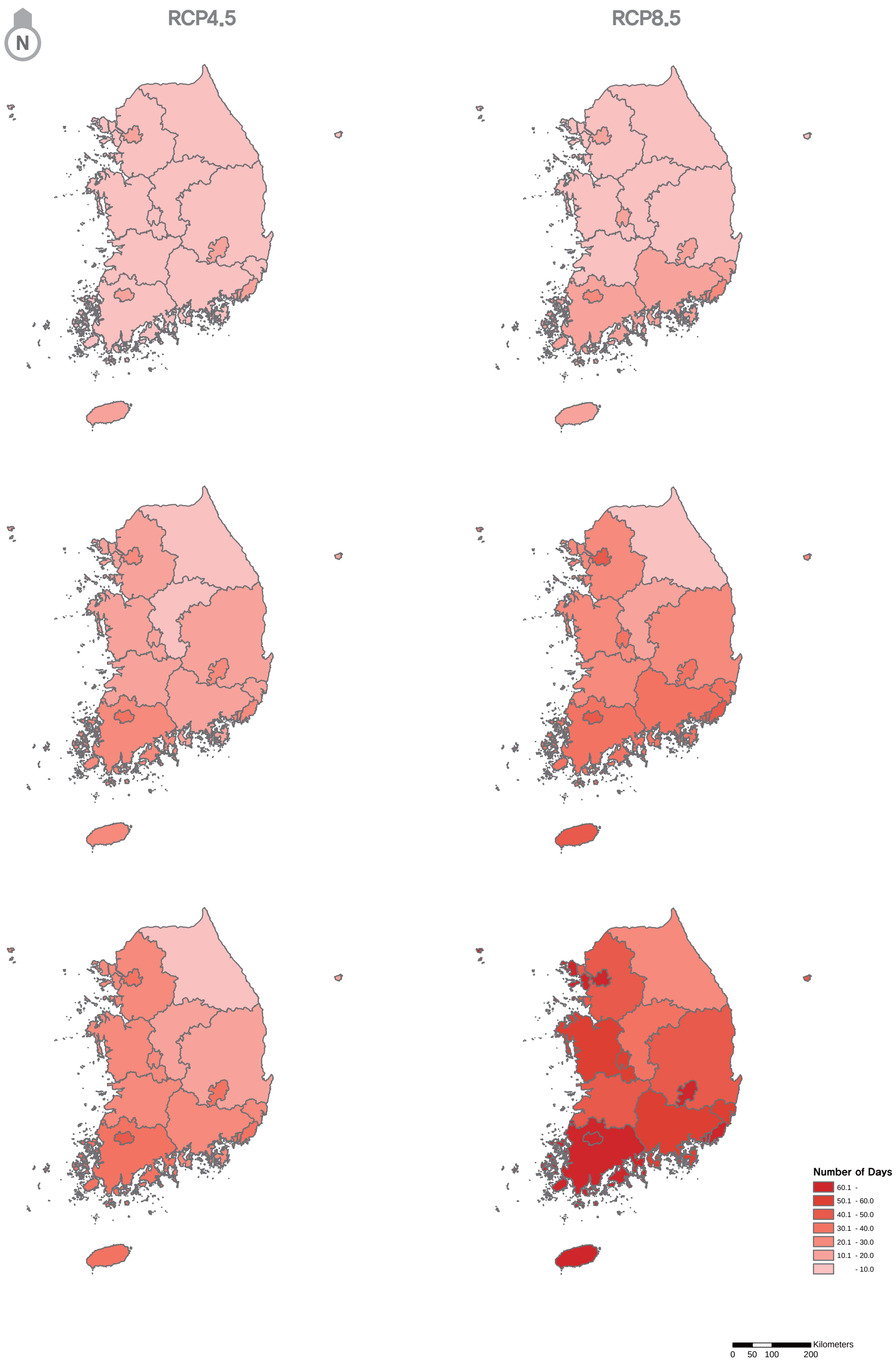
- In the current climate (2001–2010) the maximum annual mean number of tropical nights occurs in Jeju (9.5 day/year), and the minimum in Gangwon-do (0.2 day/year).
  - In the 21st century the annual mean number of tropical nights is projected to increase in all 16 administrative areas.
- In the RCP4.5 scenario in the late 21st century the annual mean number of tropical nights is projected to be maximum in Gwangju with 41.9 day/year, and minimum in Gangwon-do with 6.2 day/year.
  - The greatest increase in the annual mean number of tropical nights is projected to occur in Gwangju (4.33 day/decade), and the lowest increase in Gangwon-do (0.75 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean number of tropical nights is projected to be maximum in Busan (72.3 day/year) with an increase rate of 8.06 day/decade.

Fig. 5.6
Projection of Annual Mean Number of Tropical Nights in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



Projections for Annual Mean Length of Growing Season for the 16 Administrative Areas of South Korea

- The annual mean length of the growing season in the current climate (2001–2010) is longest in Jeju-do (322.9 day/year), and shortest in Gangwon-do (230.1 day/year).
  - The annual mean length of the growing season is forecast to increase in all 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean length of the growing season is projected to be maximum in Jeju-do with 344.5 day/year, and minimum in Gangwon-do with 251.5 day/year.
  - The greatest increase in the annual mean length of the growing season is projected to occur in Busan (3.30 day/decade), and the lowest increase in Gwangju (1.70 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean length of the growing season is projected to be maximum in Jeju-do (354.9 day/year) with an increase rate of 4.0 day/decade.

Fig. 5.7
Projection of Annual Mean Length of Growing Season in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)

Projections for the Annual Mean Number of Heat Wave Days for the 16 Administrative Areas of South Korea

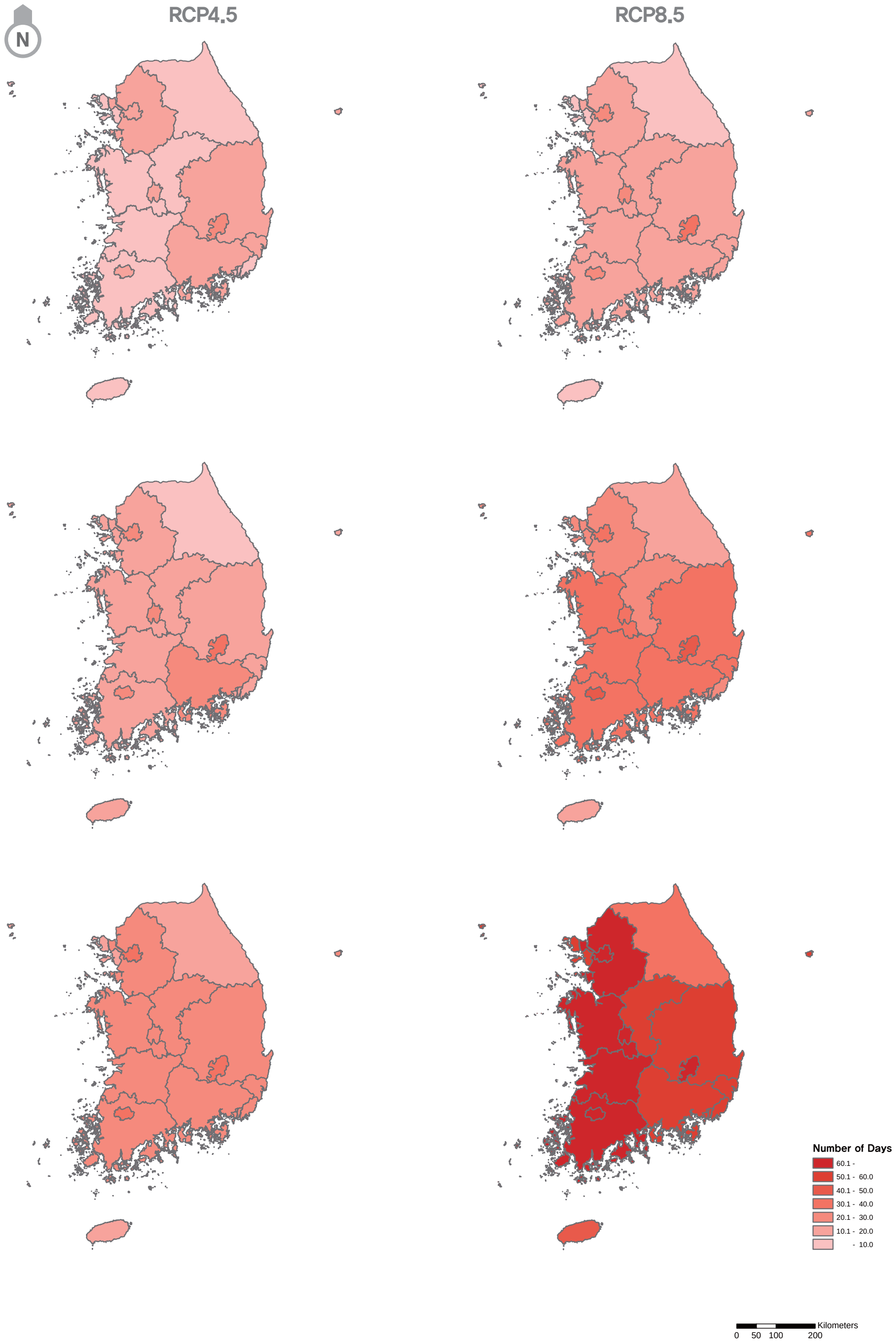
- In the current climate (2001–2010), the maximum annual mean number of heat wave days occurs in Daegu (22 day/year), and the minimum in Jeju-do (1.6 day/year).
  - The annual mean number of heat wave days is projected to increase in all 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean number of heat wave days is projected to be maximum in Daegu with 37.2 day/year, and minimum in Gangwon-do with 10.4 day/year.
  - The greatest increase in the annual mean number of heat wave days is projected to occur in Seoul (2.59 day/decade), and the lowest increase in Gangwon-do (0.86 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean number of heat wave days is projected to be maximum in Gwangju (77.3 day/year) with an increase rate of 7.66 day/decade.

Fig. 5.8
Projection of Annual Mean Number of Heat Wave Days in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



Projections for the Annual Mean Precipitation Intensity for the 16 Administrative Areas of South Korea

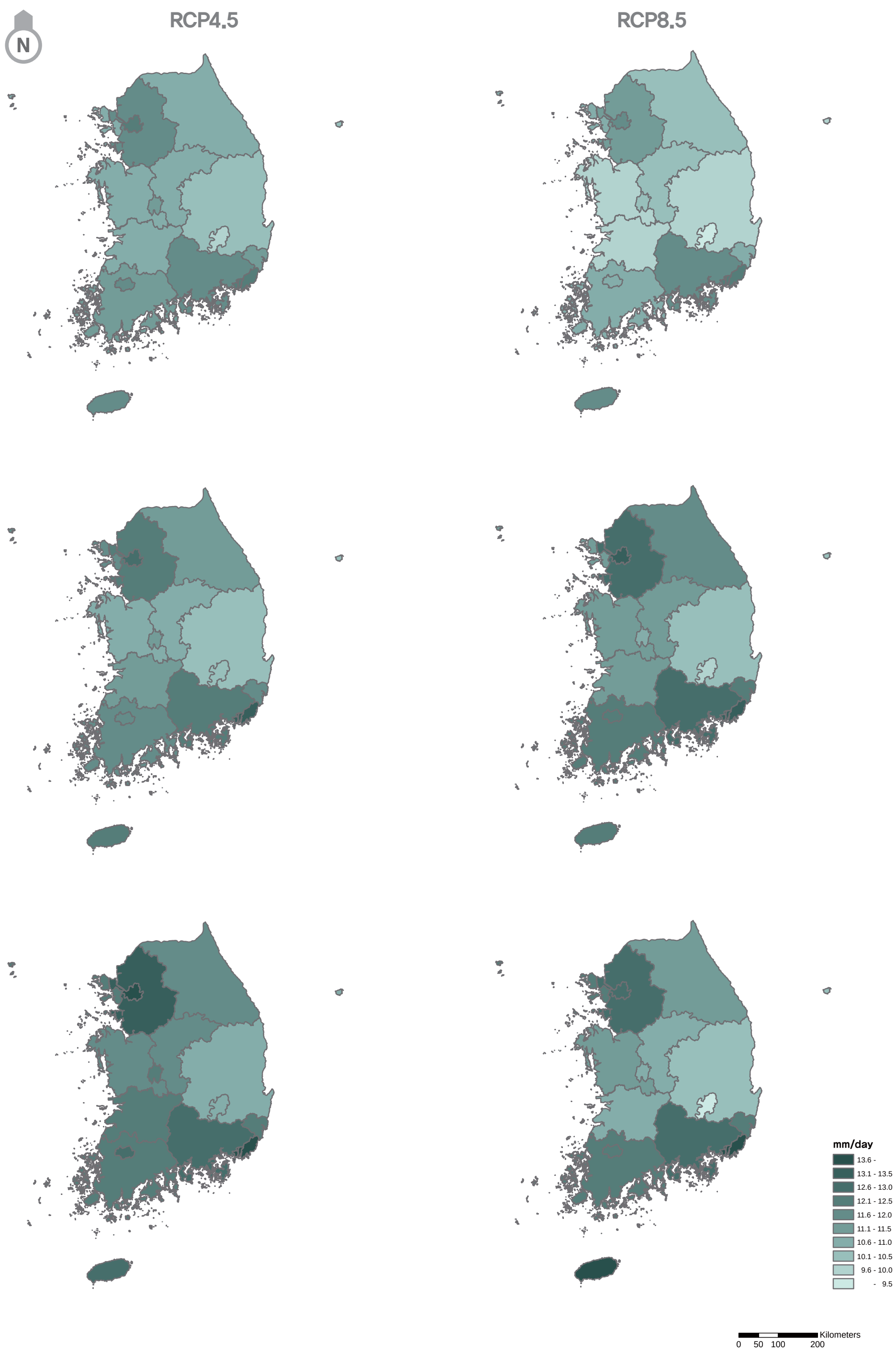
- In the current climate (2001–2010), the annual mean precipitation intensity is 9.3–11.3 ㎜/day.
  - The annual mean precipitation intensity is projected to increase in most of the 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean precipitation intensity is projected to be maximum in Seoul with 13.8 ㎜/day, and minimum in Daegu with 10.7 ㎜/day.
  - The projected rate of increase in annual mean precipitation intensity for Daegu is 0.18 ㎜/day and for Seoul the projected rate is 0.38 ㎜/day.
- In the RCP8.5 scenario in the late 21st century the annual mean precipitation intensity is projected to be maximum in Busan (14.0 ㎜/day) and Jeju-do (13.8 ㎜/day).
  - The annual mean precipitation intensity is projected to be minimum in Daegu (9.5 ㎜/day) and Gyeongsangbuk-do (10.1 ㎜/day).

Fig. 5.9
Projection of Annual Mean Precipitation Intensity in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



◆ Projections for the Annual Mean Number of Heavy Precipitation Days for the 16 Administrative Areas of South Korea

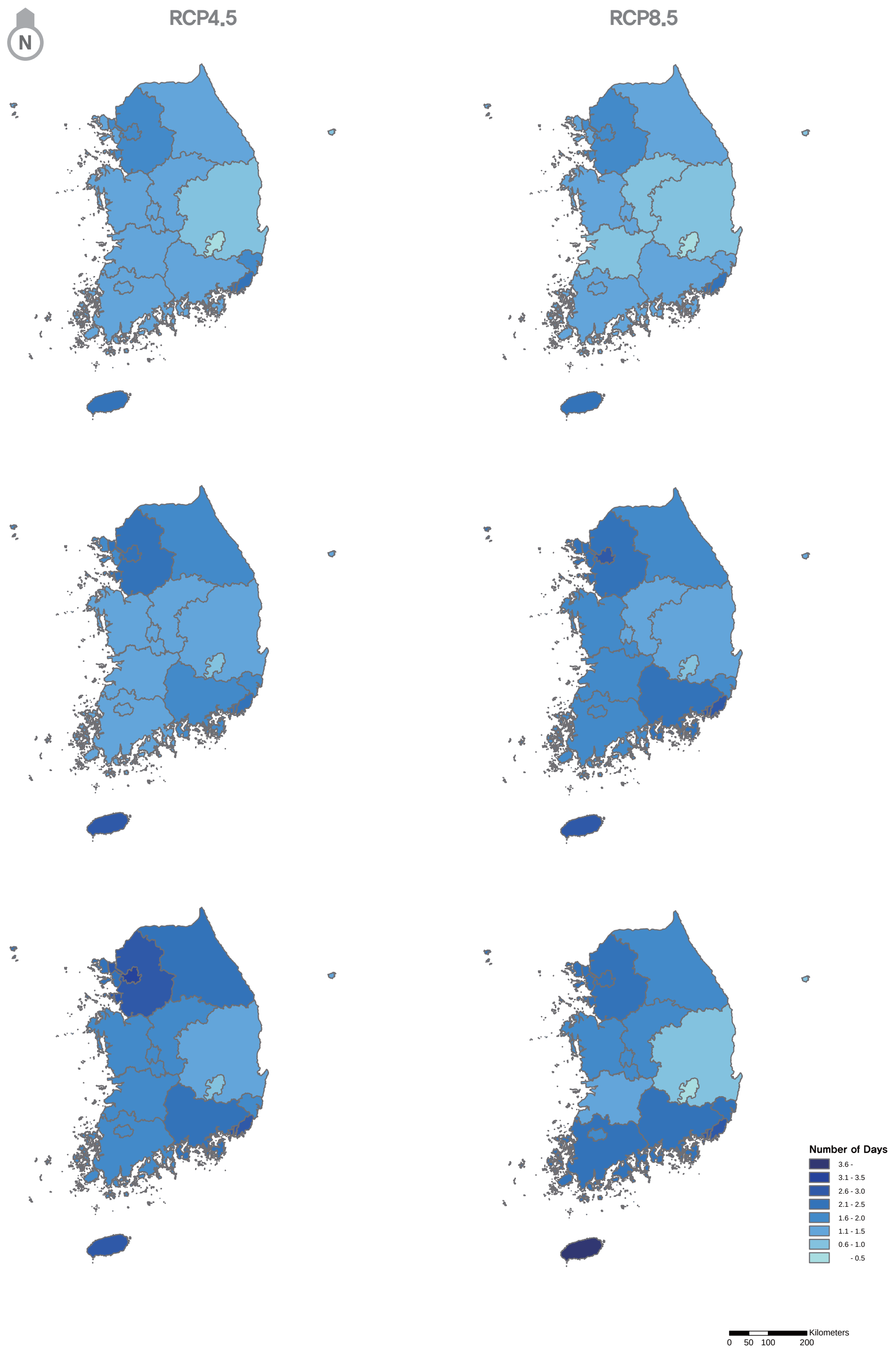
- The annual mean number of heavy precipitation days in the current climate (2001–2010) is between 0.6 – 1.9 day/year.
  - The annual mean number of heavy precipitation days is projected to increase in most of the 16 administrative areas in the 21st century.
- In the RCP4.5 scenario in the late 21st century the annual mean number of heavy precipitation days is projected to be maximum in Seoul with 3.2 day/year, and minimum in Daegu with 0.7 day/year.
  - The greatest increase in the annual mean number of heavy precipitation days is projected to occur in Seoul (0.25 day/decade), and a slight decrease is projected for Daegu (–0.01 day/decade).
- In the RCP8.5 scenario in the late 21st century the annual mean number of heavy precipitation days is projected to be maximum in Jeju-do (3.8 day/year) with an increase rate of 0.34 day/decade.

Fig. 5.10
Projection of Annual Mean Number of Heavy Precipitation Days in South Korea

Early 21st Century (2011–2040)

Mid – 21st Century (2041–2070)

Late 21st Century (2071–2100)



Korea Climate Change Report

06

Application of the Climate Change Projections

06 Application of the Climate Change Projections

Limits and Uncertainties of the Climate Change Projections

Limits of the Climate Change Projections

- The future greenhouse gas concentration scenario, a major element of climate modelling, involves uncertainties caused by potential changes in socio-economic activity, patterns of energy usage and the effectiveness or absence of greenhouse gas reduction policies.
  - International agreements on greenhouse gas reduction have faced many challenges, that is, developed countries are reluctant to set a second-phase pledge period for reduction as long as the main greenhouse gas emitting countries remain unburdened by obligatory reduction treaties; meanwhile developing countries have called for the continuation of the dual system which is the obligatory reduction in developed countries and voluntary reduction in developing countries.

- Due to the inherent characteristics of climate modelling, the projections for some climate elements may have been underestimated in the data due to statistical errors or the limitations of spatial resolution etc.
  - The projection data for change in the extreme indices provided in this report may be less reliable in terms of the quantitative data values but the qualitative aspects of the projections are considered to be more reliable.

Uncertainties due to the Use of a Single Climate Model

- The global climate model used to produce the data presented in this report was described as having an outstanding level of reliability in the latest comparative assessment of climate models.
  - For the East Asia and Pacific Rim regions in which the Korean Peninsula is located the reproduction capacity of this model is considered particularly outstanding, therefore it is anticipated that the climate change projections will have a high level of reliability.

- Most climate models are imperfect and may be incomplete with inherent structural errors.
  - Accordingly the multiple model ensemble technique, which combines climate data produced by many climate models, is applied to create more reliable climate projections and assess the uncertainties.

- Going forwards the uncertainty of the projections presented in this report should gradually be supplemented through the gathering of data from further climate models used in compiling the IPCC 'Fifth Assessment Report'.

Application of the Climate Change Projections

- While the climate change projections for the Korean Peninsula provided in this report are largely in alignment with the trends of change observed during the past 30 years (1981–2010), it is predicted that with ongoing global warming these trends will become more noticeable and more extreme.

- It is anticipated that the data provided in this report will become the basis of assessments of vulnerability to climate change and the establishment of adaptation policies for the 7 target areas designated by the Ministry of Environment in 2010 (health, disasters, agriculture, forestry, ocean/fisheries, water management and ecosystems), as well as the establishment of climate change adaptation measures for industry and energy.

Health

- As the mean temperature on the Korean Peninsula increases, extreme climate events such as heat waves and tropical nights are predicted to occur more frequently.
  - As extreme climate events become more common, particularly in the large and densely populated metropolitan cities, this report can be applied for the establishment of measures to safeguard vulnerable members of society (such as healthcare guidelines, heat wave response manuals and hot weather refuges) and healthcare policies.
  - The detailed projections for temperature as well as tropical nights and heat wave days provided for each metropolitan city can be applied as the basis for the design of buildings adapted to climate change and environmentally friendly urban planning systems.
  - From the projections of precipitation change and the gradual transition to a subtropical climate, tropical diseases such as malaria are predicted to become more prevalent and thus the data provided in this report should be used in the preparation of appropriate healthcare policies at the local government level.

Disasters

- In both of the RCP scenarios presented in this report an increase is projected in precipitation, precipitation intensity and number of heavy precipitation days on the Korean Peninsula.
  - The detailed projection data provided for each region can be used by local governments as information for the classification of which areas are potentially vulnerable to storm and flood damage.
  - The projections for precipitation can be used as key input data for forecasting watershed hydrology. The data may also be applied to various tasks such as the preparation of guidelines for sewer improvement and storm runoff reduction to minimize flooding, and the promotion of storm damage insurance.
  - The climate projection data can also contribute to the formation of climate change adaptation measures through usage in analyzing typhoon routes, coastal erosion and the vulnerability of infrastructure, as well as in the designation of landslide hazard zones etc.

Agriculture

- The detailed regional projection data for seasonal changes in temperature, precipitation, length of growing season and frost days provided in this report can be used as the basis for decision making in relation to crop management and irrigation, prevention of crop damage and estimation of agricultural yields.
  - In particular it is anticipated that the projection data will be used in the development and dissemination of crops adjusted to climate change.
  - It may also be used in research into outbreaks of agricultural pests and infectious diseases among livestock as well as the effects of increasing temperature on agricultural produce etc.

Forestry

- The projections of temperature and precipitation can be of use as base data in evaluating the vulnerability of forest resources and predicting their productivity.
  - As distinct warming trends are projected to occur in the mountainous regions of the Korean Peninsula it is anticipated that the data provided will be used as the basis for assessing the vulnerability of forest resources in high mountain areas.
  - The data may be of use in research into the prevention of forest fire and outbreaks of subtropical pests, as well as the estimation of changes in tree species etc.

Ocean/Fisheries

- The climate projections presented in this report predict a continual rise in sea level heights all around the coast of the Korean Peninsula as well as an increasing trend in the number of heavy precipitation days on the south coast and in the central and capital metropolitan regions.
  - Rising sea level heights pose the long-term threat of coastal erosion and when coupled with typhoon conditions or intense precipitation the flooding and waterlogging of lower altitude areas may occur as a result.
  - The detailed projection data provided in this report can be used in the classification of areas at high risk of flooding in the near future, the creation of disaster prevention standards and construction guidelines for coastal disaster prevention facilities, and structures such as embankments, sea walls and bridges.
  - Due to the increase of the sea surface temperature around the Korean Peninsula cold water fish species are likely to decrease while warm water species begin to appear and grow in number; the information provided in this report can be of use in estimating such changes.
  - Changes in the marine products that can be farmed and gathered on the south, west and east coasts can be estimated using this data.
  - The data can be of positive use to the fishing industry by helping to predict the emergence of new fish species and develop new fishing techniques before changes occur.

Water Management

- The 12.5 ㎞ resolution precipitation data presented in this report and the 1㎞ resolution data provided in the "Regional Climate Change Reports" can be used as vital input data in the estimation of the inflow and outflow of water for the major rivers and streams on the Korean Peninsula.

  - While this report does not provide any projection for snowfall, the seasonal temperature and precipitation can be used to make predictions for future amounts of snowfall.
  - According to the results of this report, a reduction in snowfall in high mountainous regions is predicted, and the subsequent decrease in the melting snow along with changes in the thawing season is expected to have a major effect on the volume of inflow to rivers.
  - It is anticipated that the data provided here will be used in the assessment of the vulnerability of water resources having implications for their management.
  - In addition, the projections for precipitation intensity and number of heavy precipitation days can be used for the establishment of a flood warning system, provision for disasters and emergencies resulting from flooding, and facilities management of safety equipment etc.

Ecosystems

- The projections for future temperature and precipitation presented here should become important input data in the monitoring of various ecosystems and indicator species, as well as in the evaluation of their vulnerability to future climate change.

  - The data can be used in research into how and when plants flower and amphibians spawn.
  - Also, predictions of changes in forest ecosystems based on the projections may assist planners in the selection of appropriate tree species for planting.
  - Research into the damage and loss of sand dunes in coastal regions and changes in the structure and overall construction of marine life due to rising sea level heights can also make use of this report.

Industry/Energy

- The projections of temperature, heat wave days and tropical nights will be useful for the establishment of appropriate mid-and long-term plans regarding energy usage for heating and air conditioning, the purchase of raw materials, management of facilities and resources and provision for emergencies etc.

  - Annual and seasonal projections of precipitation and heavy precipitation days can be of use in drafting plans for the management and supply of water resources.
  - Projection data related to seasonal temperatures such as number of summer days and number of freezing days may be used as basic information in predicting the demand for seasonal facilities such as ski resorts, swimming pools and amusement facilities.
  - The data can be used in the analysis of sensitivity to climate change in sectors such as the domestic appliance and clothing industries which are closely connected to the climate, and in the creation of new market sectors.
  - The data may also assist in encouraging increasing demands for 'warmbiz' and 'coolbiz' initiatives, landscaping industries and weather services to help businesses adapt to climate change efficiently.

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Appendices

Appendices

Appendix 1 Spatial Distribution of the Climate on the Korean Peninsula

◆ Spatial Patterns of Seasonal Mean Climate Values on the Korean Peninsula (1981–2010)

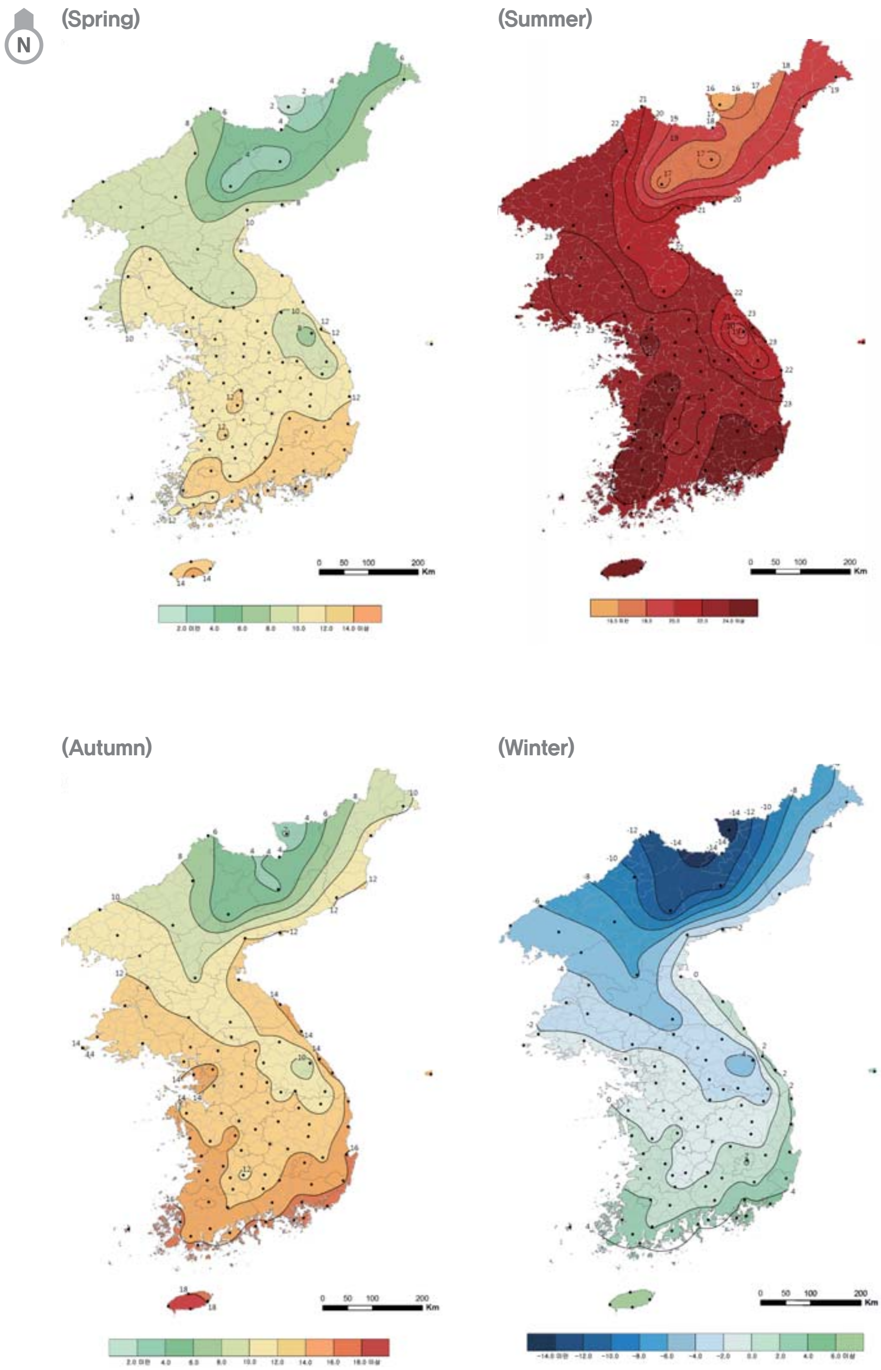


Fig. A1.1
Seasonal mean Temperatures on the Korean Peninsula (1981–2010)

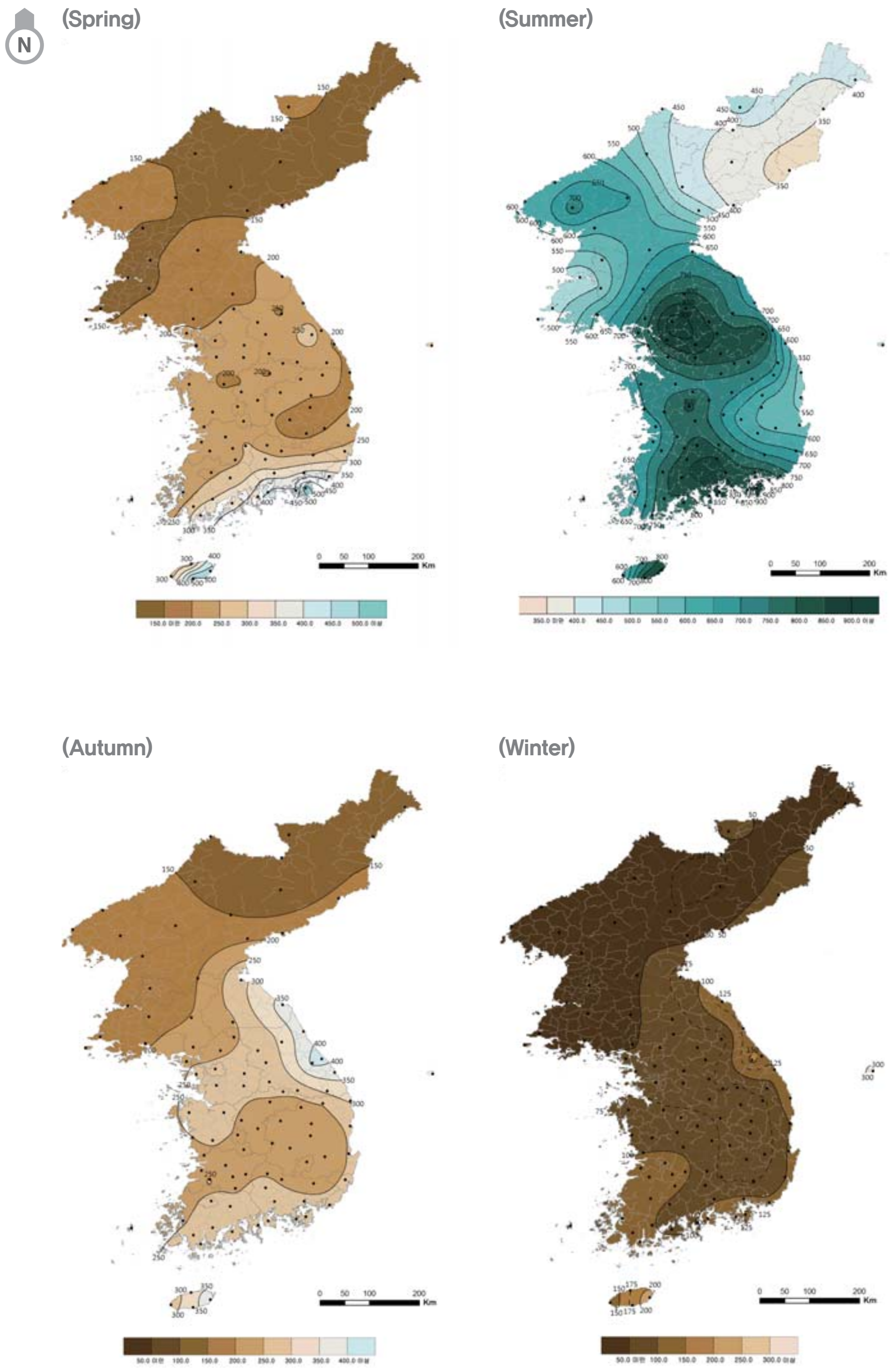


Fig. A1.2
Seasonal Mean Precipitation on the Korean Peninsula (1981–2010)

Fig. A1.3
Seasonal Mean Relative Humidity on the Korean Peninsula (1981–2010)

Fig. A1.4
Seasonal Mean Cloud Cover on the Korean Peninsula (1981–2010)

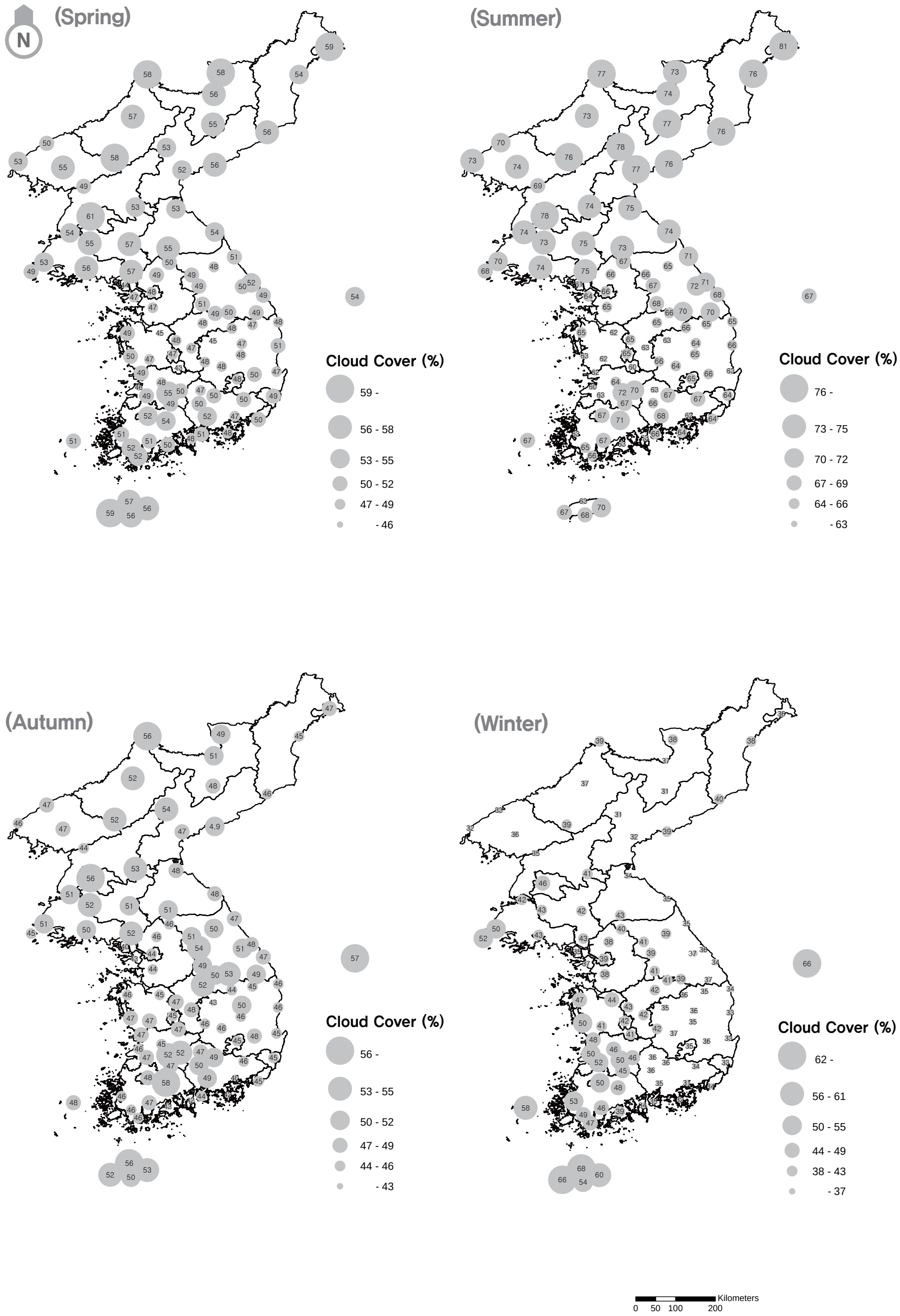
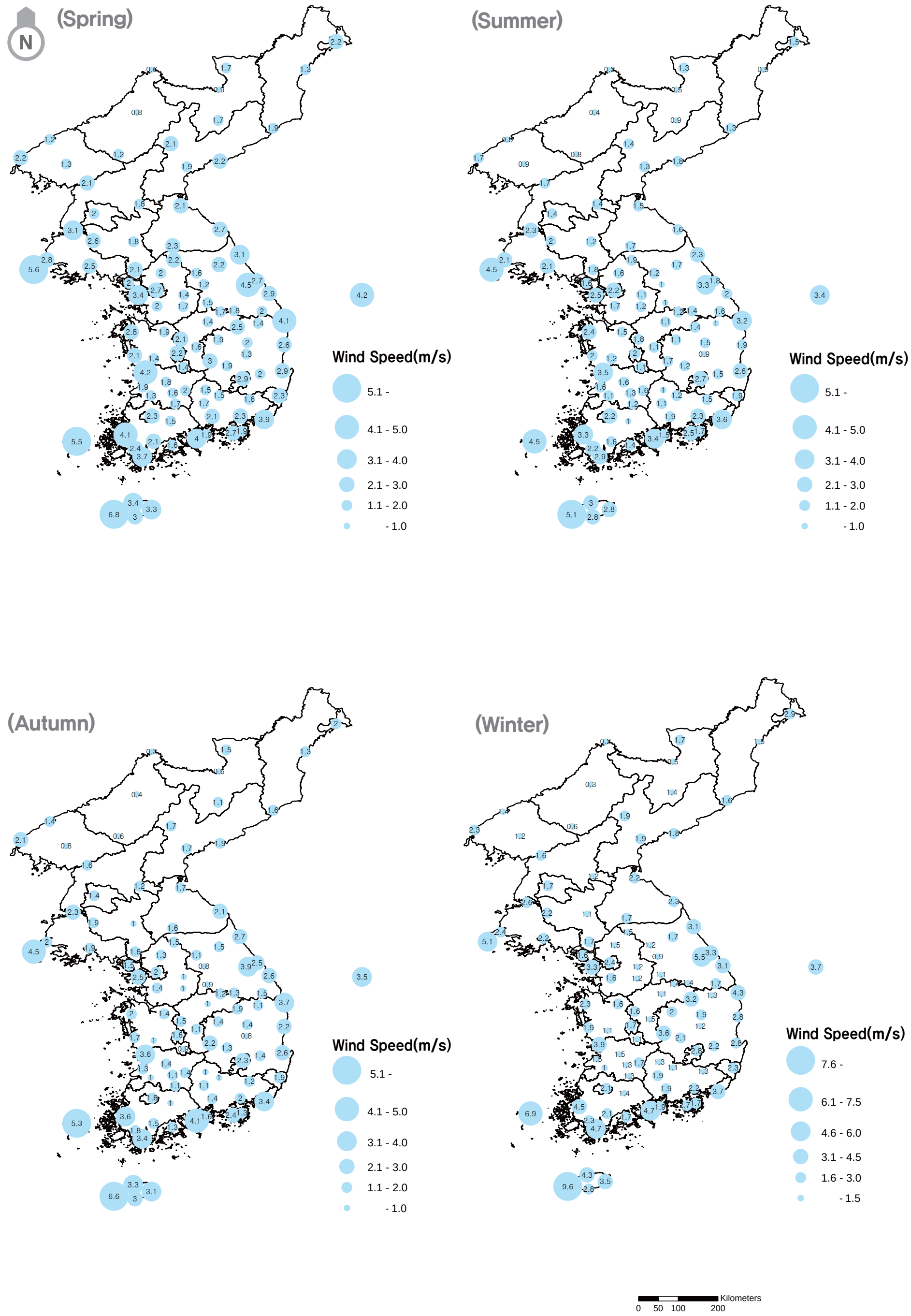


Fig. A1.5
Seasonal Mean Wind Speed on the Korean Peninsula (1981~2010)

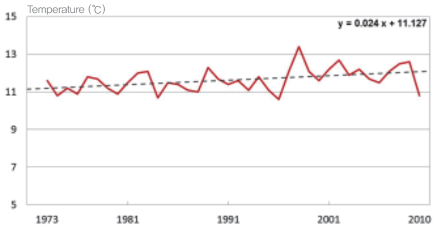


Annual Change in Seasonal Mean Temperature and Precipitation in South Korea

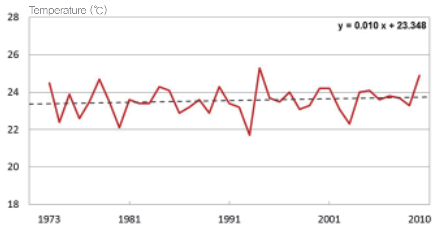
Fig. A1.6
Annual Change in Mean Temperature and Precipitation by Season in South Korea

– Annual Change in Mean Temperature in South Korea by Season (1973–2010)

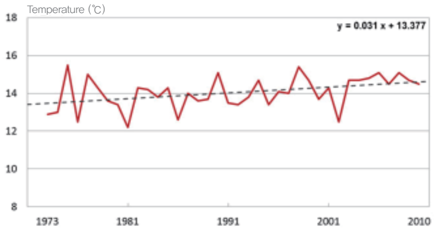
(a) Spring



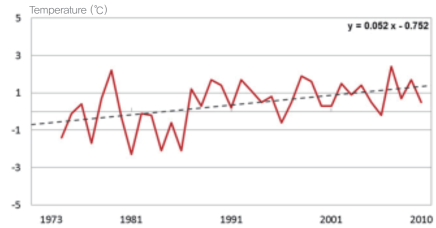
(b) Summer



(c) Autumn

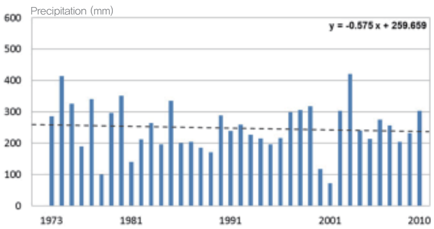


(d) Winter

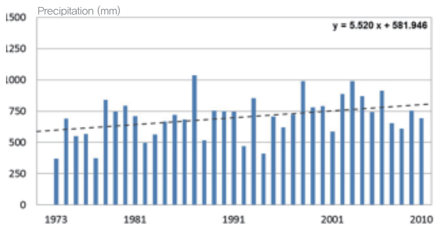


– Annual Change in Mean Precipitation in South Korea by Season (1973–2010)

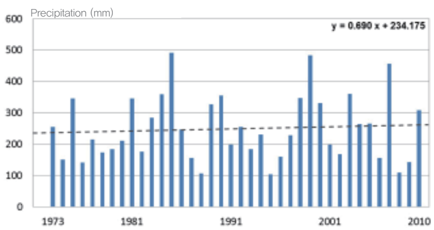
(a) Spring



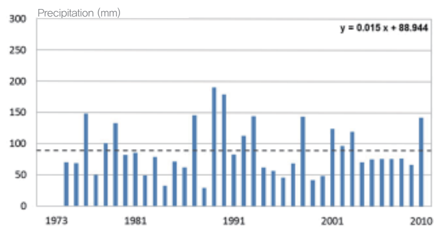
(b) Summer



(c) Autumn



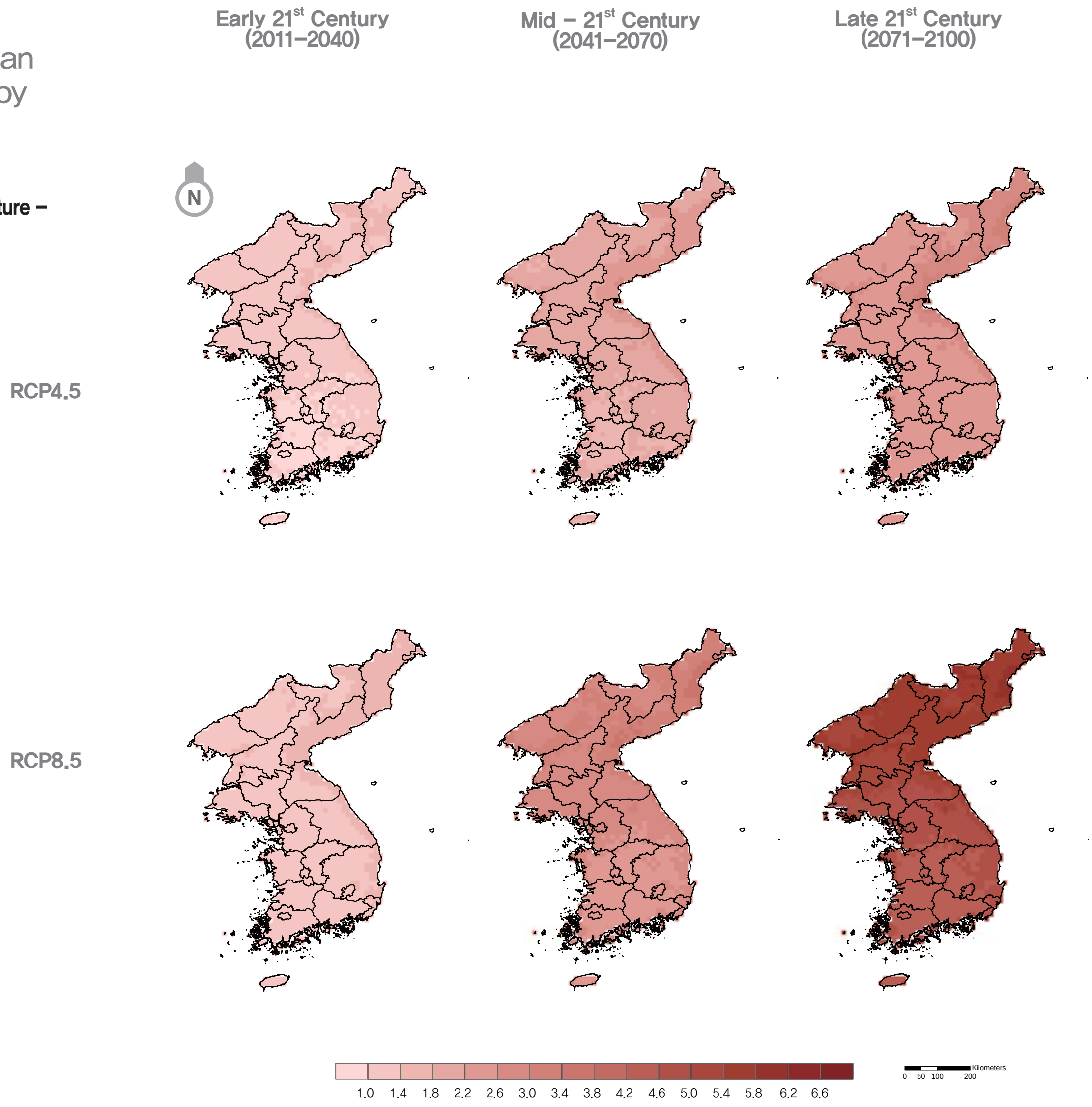
(d) Winter



Appendix 2 Climate Change Projections for the Korean Peninsula

Projections for Increase in Mean Temperatures by Season

Fig. A2.1
Projection of Mean Temperature – Spring



Explanation of the Data

- In this appendix projections for climate elements and extreme indices are presented using the 12.5 ㎞ RCP scenario data for the Korean Peninsula.
- The temperature change values represent deviation from the current climate (1981–2010), change in precipitation is presented as the rate of change (%) from the current climate (1981–2010).

Fig. A2.2
Projection of Mean Temperature – Summer

Early 21st Century (2011–2040) | Mid – 21st Century (2041–2070) | Late 21st Century (2071–2100)

RCP4.5

RCP8.5

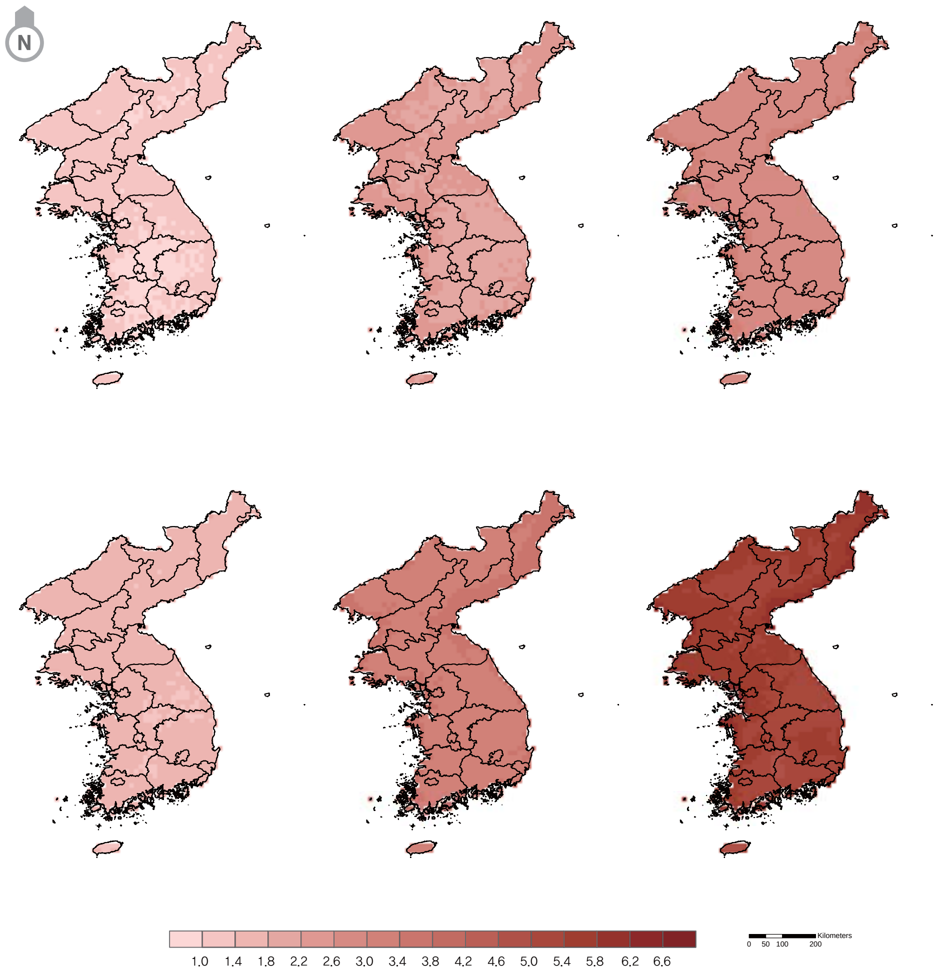


Fig. A2.3
Projection of Mean Temperature – Autumn

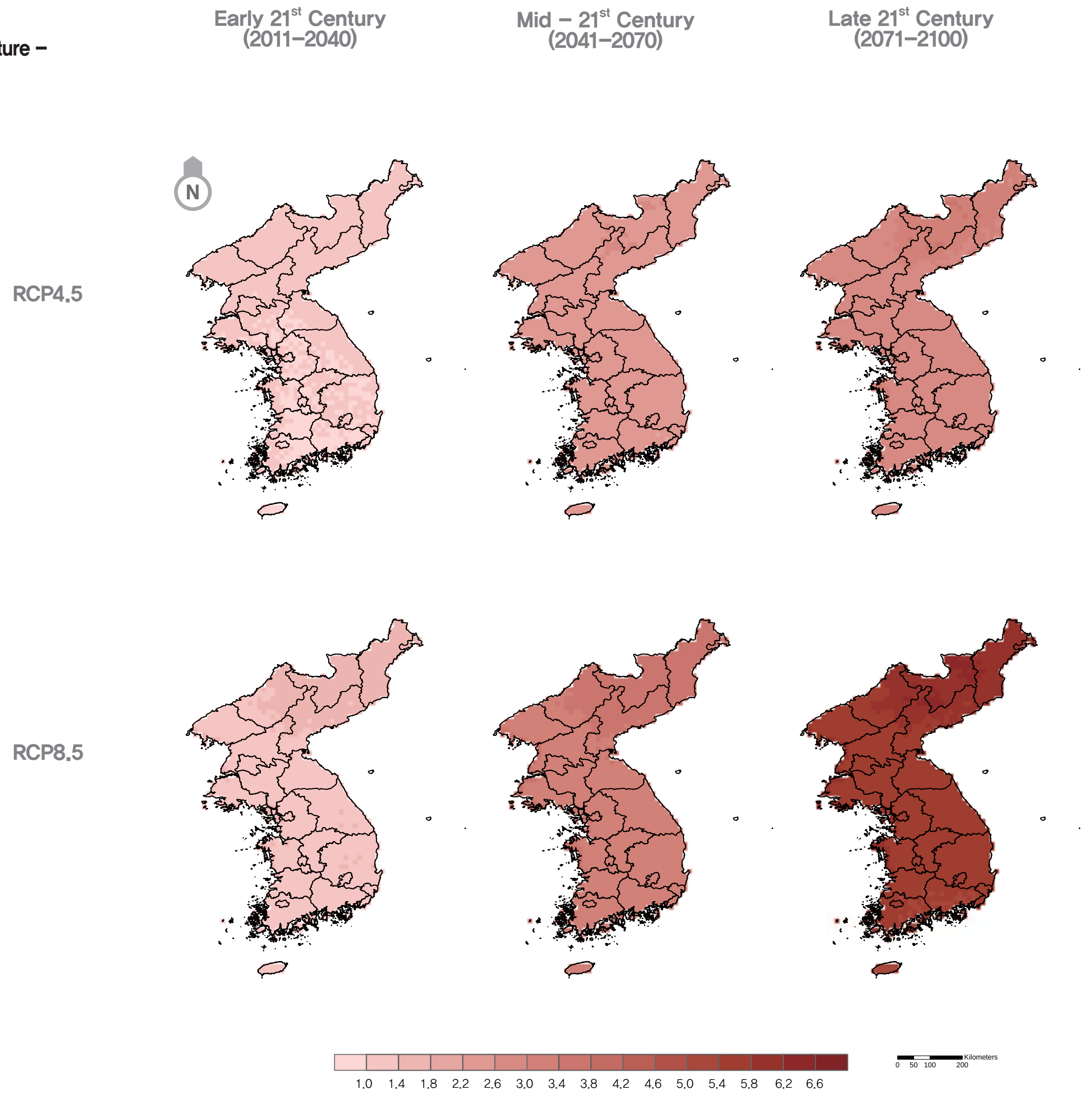


Fig. A2.4
Projection of Mean Temperature – Winter

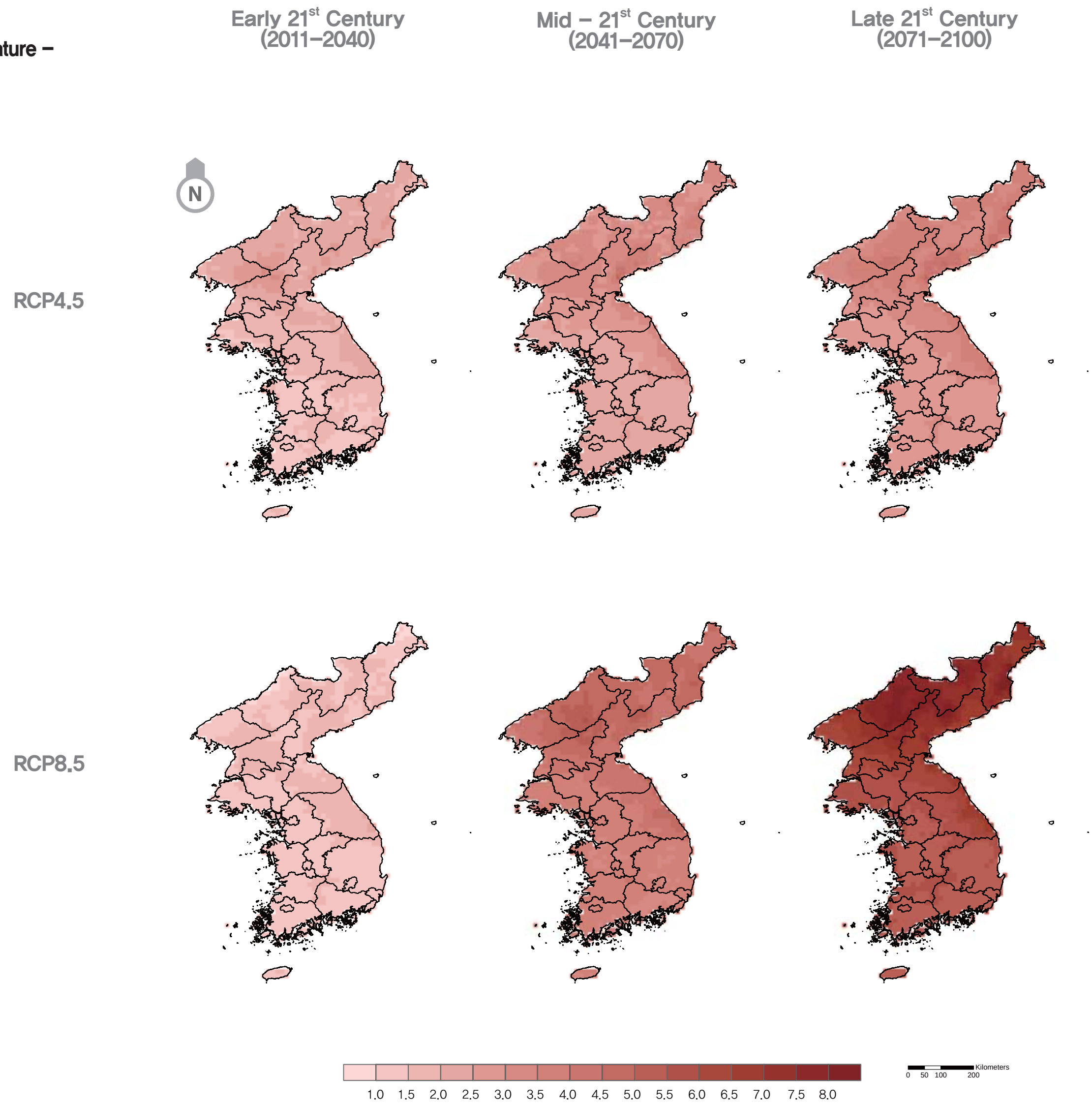


Fig. A2.5
Projection of Annual Mean Maximum Daily Temperature

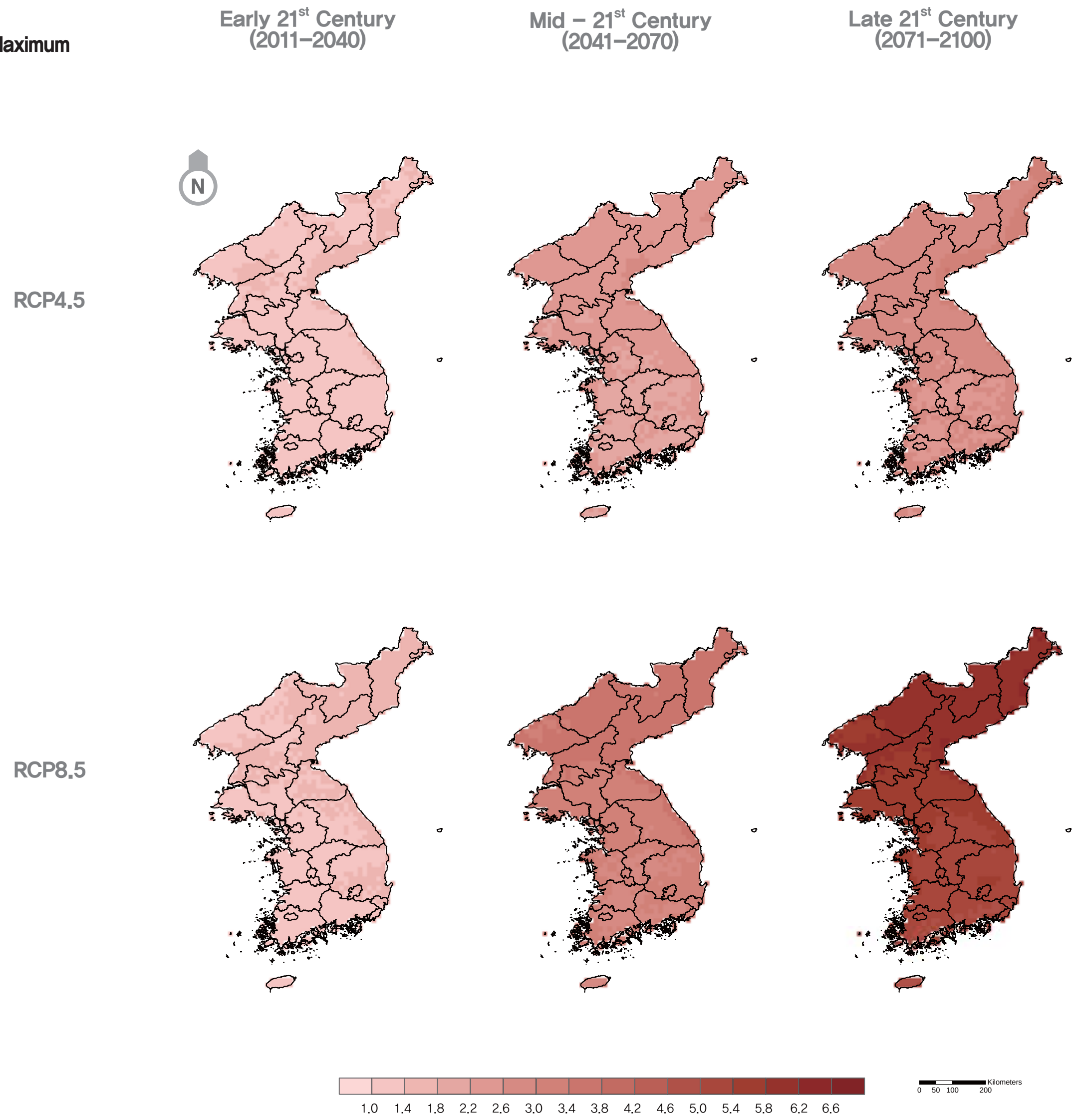


Fig. A2.6
Projection of Mean Maximum Daily Temperature – Summer

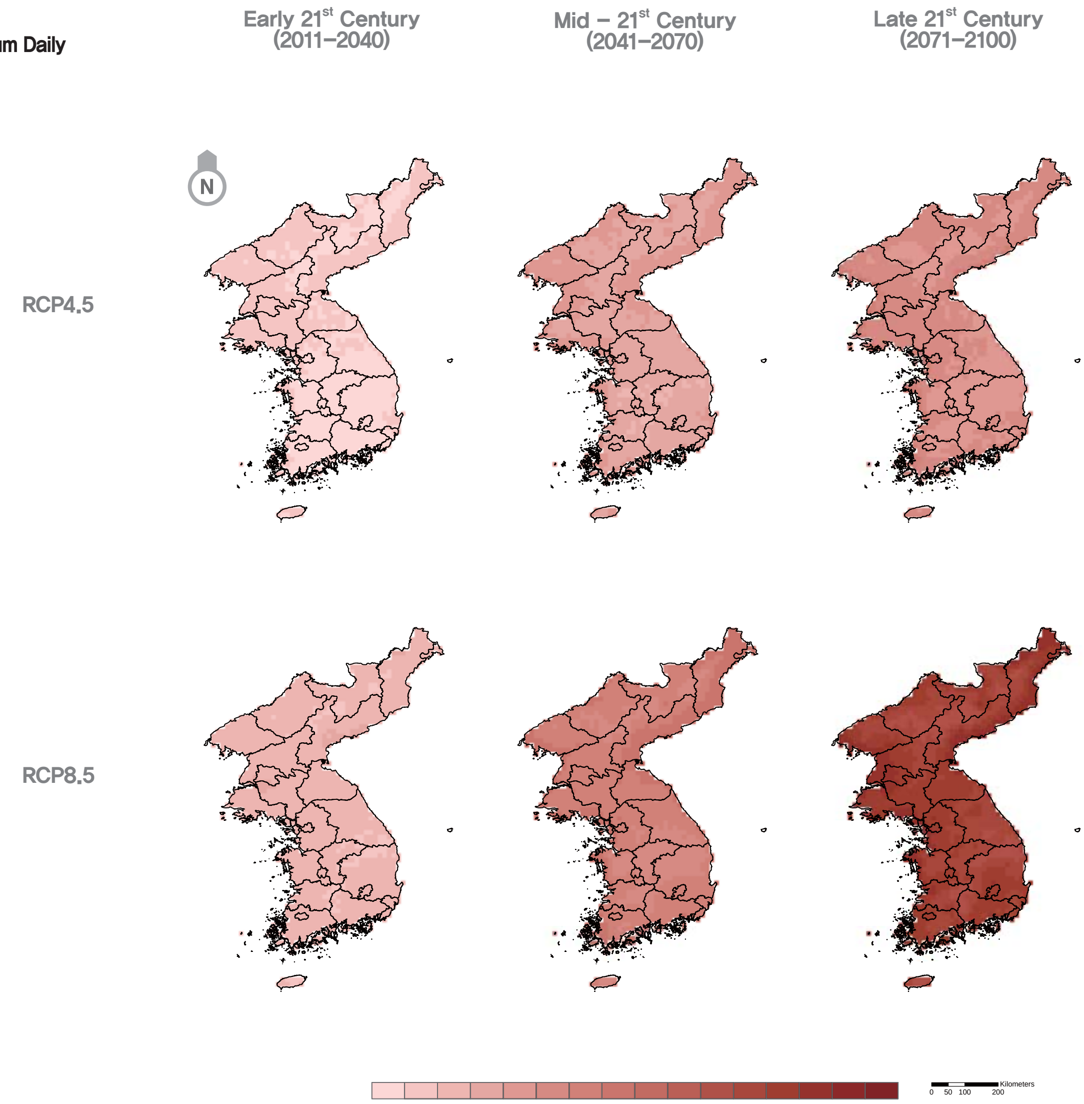


Fig. A2.7
Projection of Mean Maximum Daily Temperature – Winter

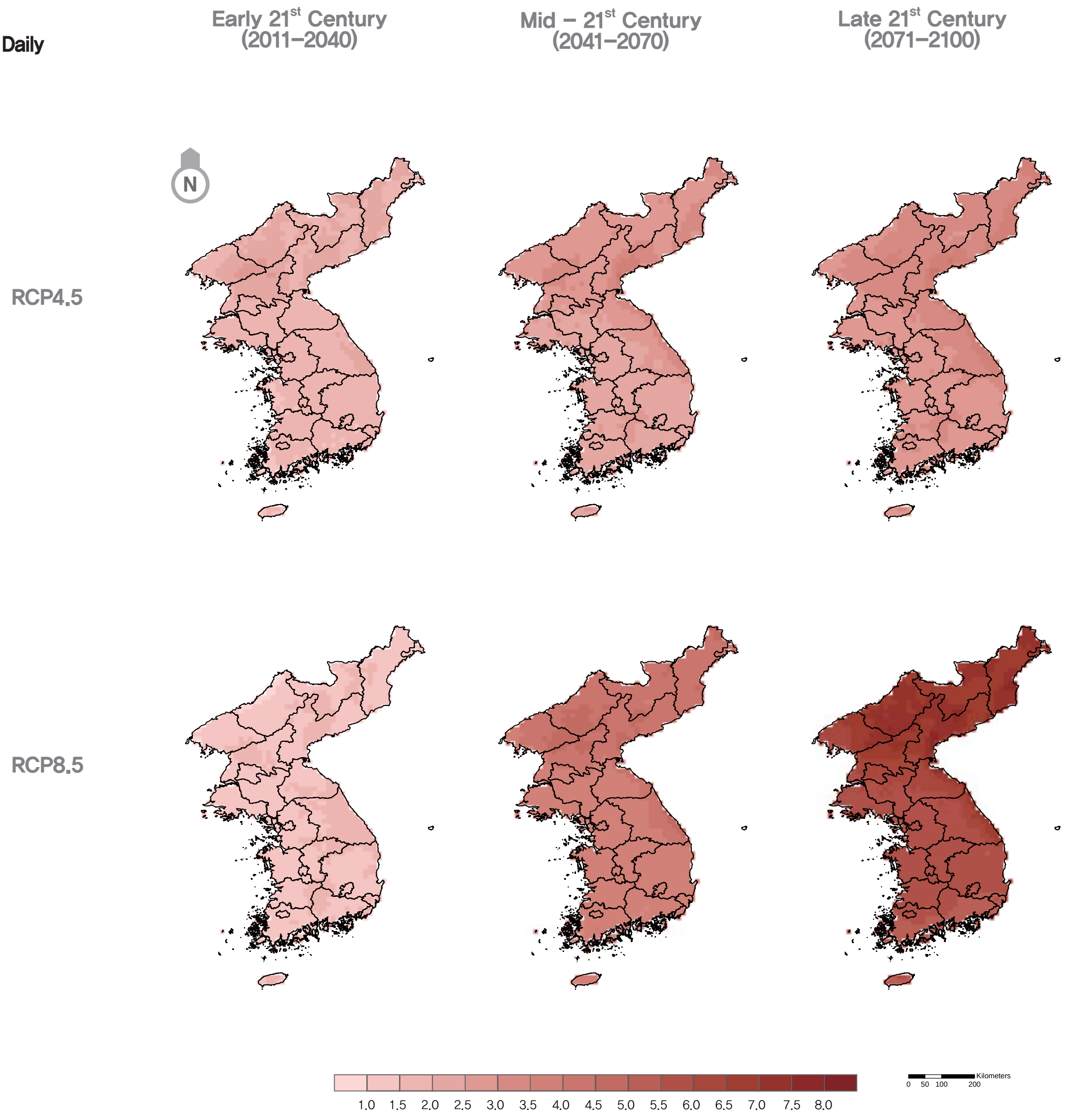


Fig. A2.8
Projection of Annual Mean Minimum Daily Temperature

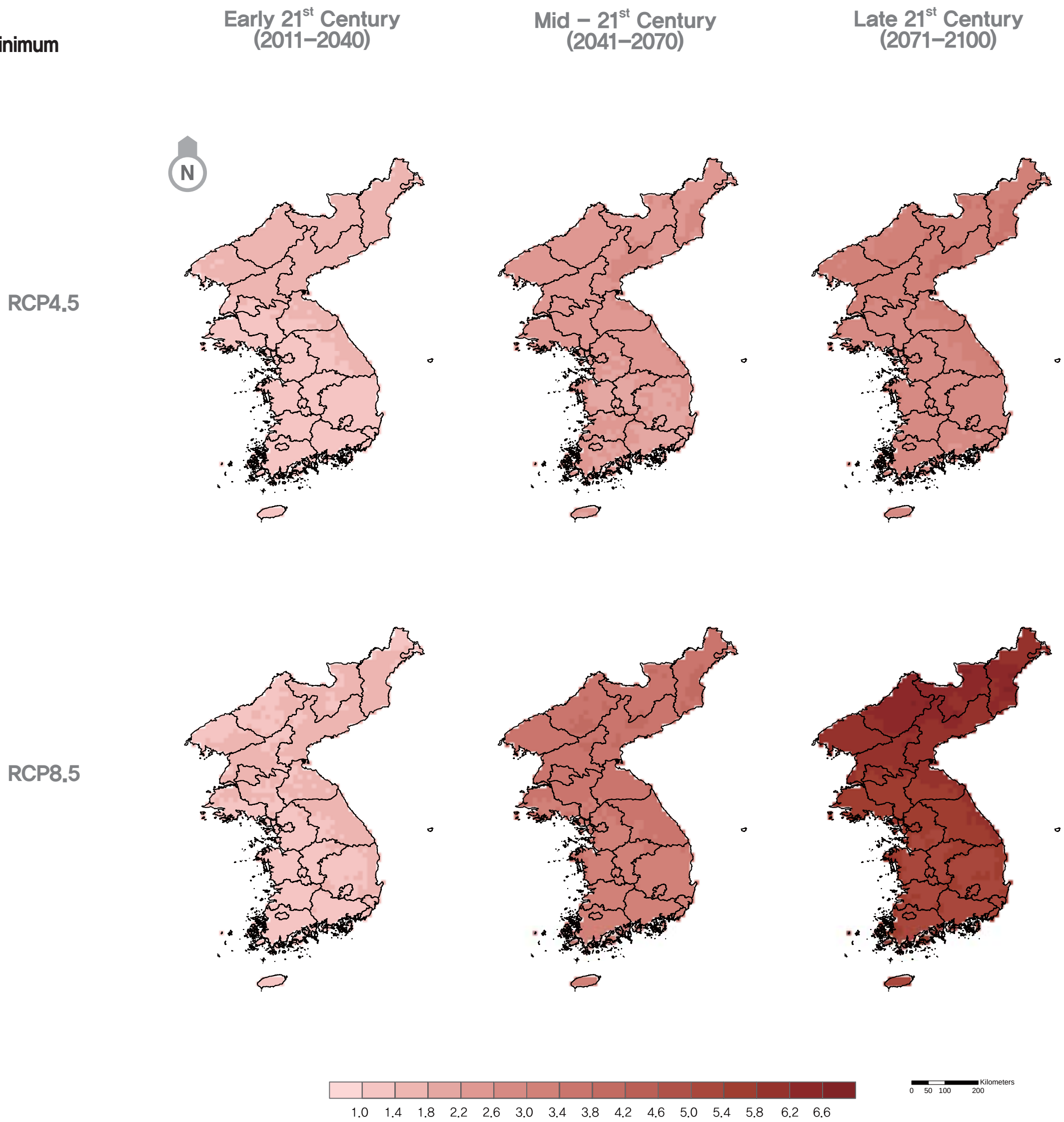


Fig. A2.9
Projection of Mean Minimum Daily Temperature – Summer

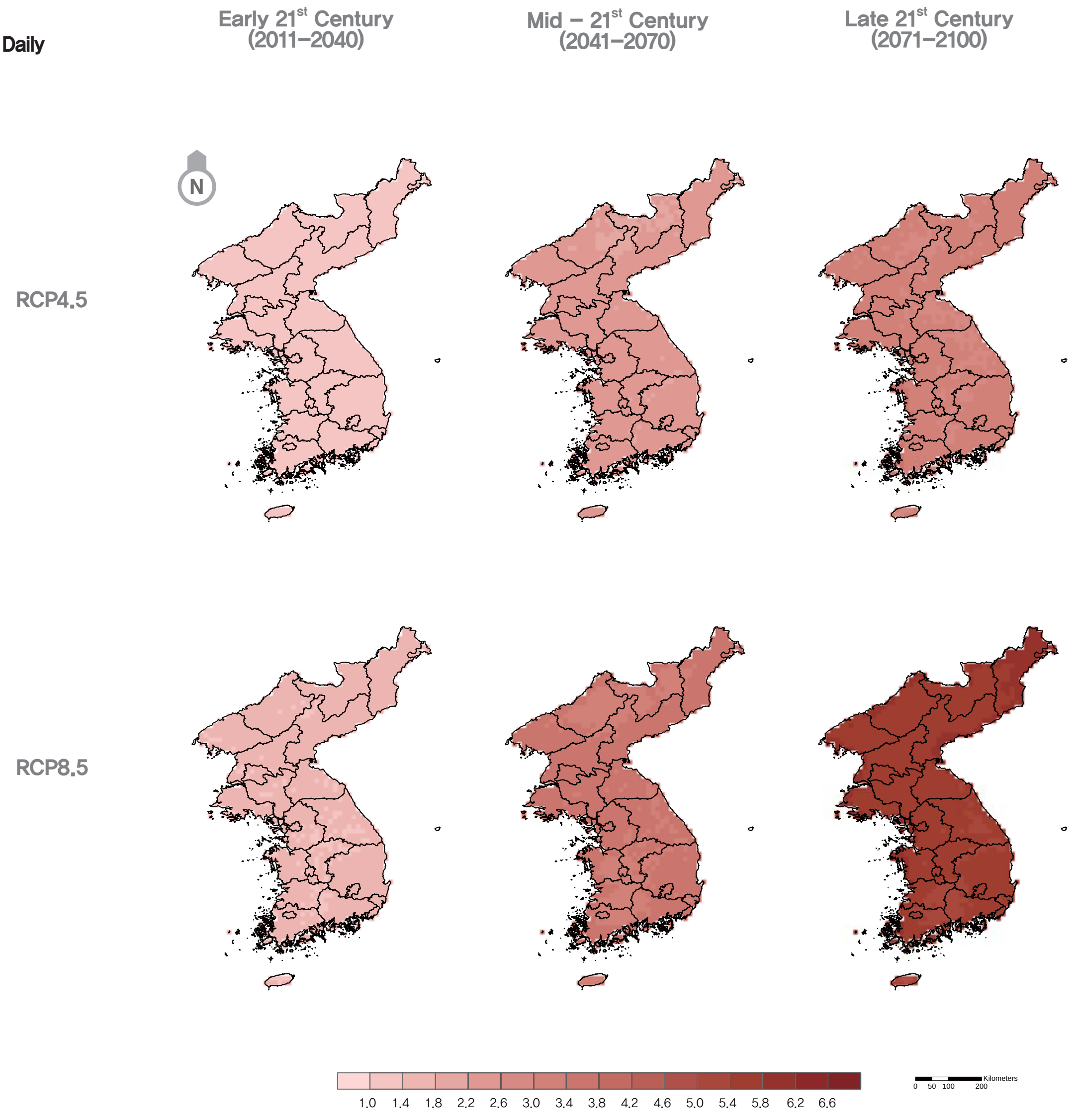
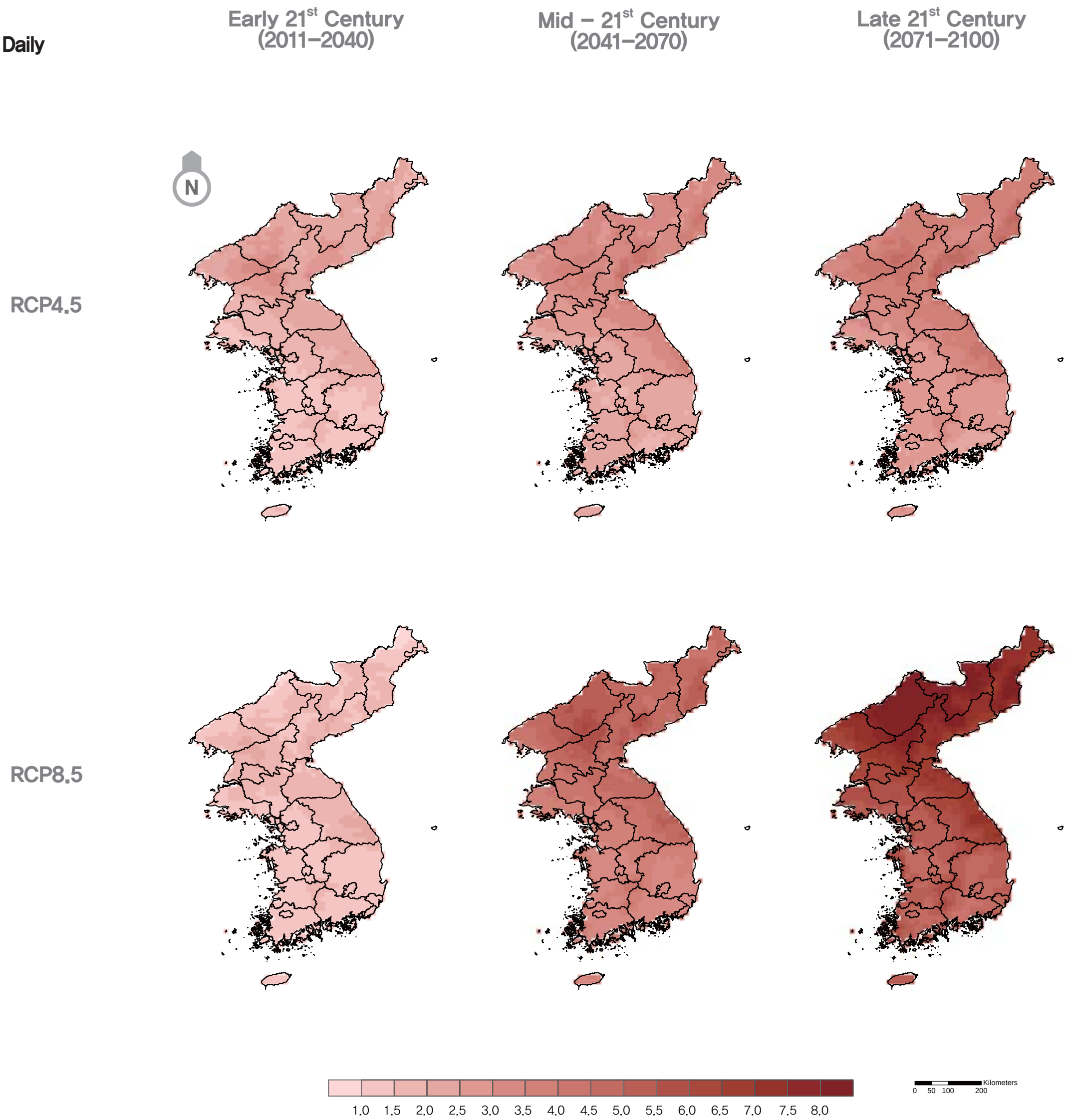


Fig. A2.10
Projection of Mean Minimum Daily Temperature – Winter



Projection of Mean Precipitation by Season

Fig. A2.11
Projection of Mean Precipitation – Spring

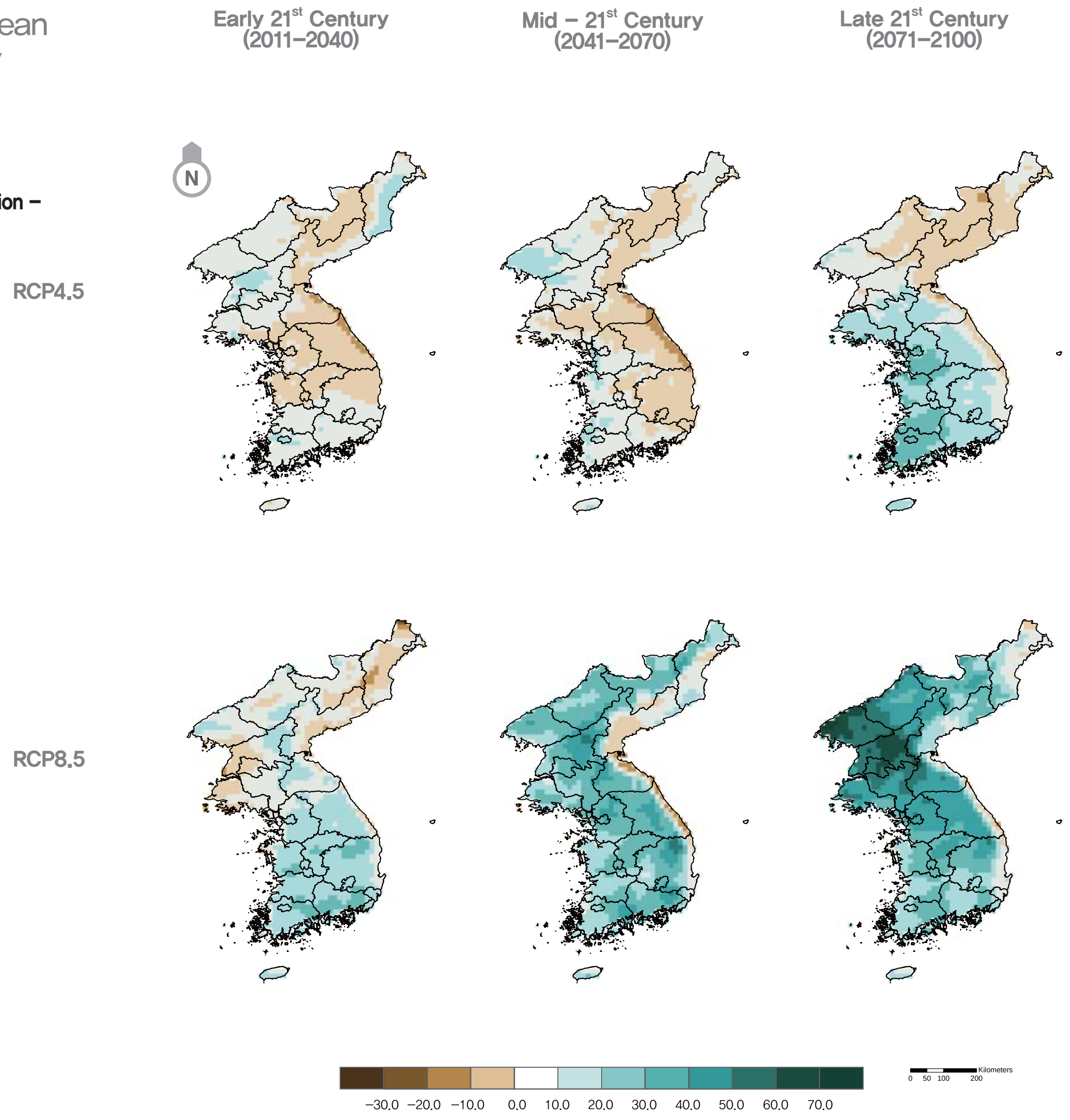


Fig. A2.12
Projection of Mean Precipitation – Summer

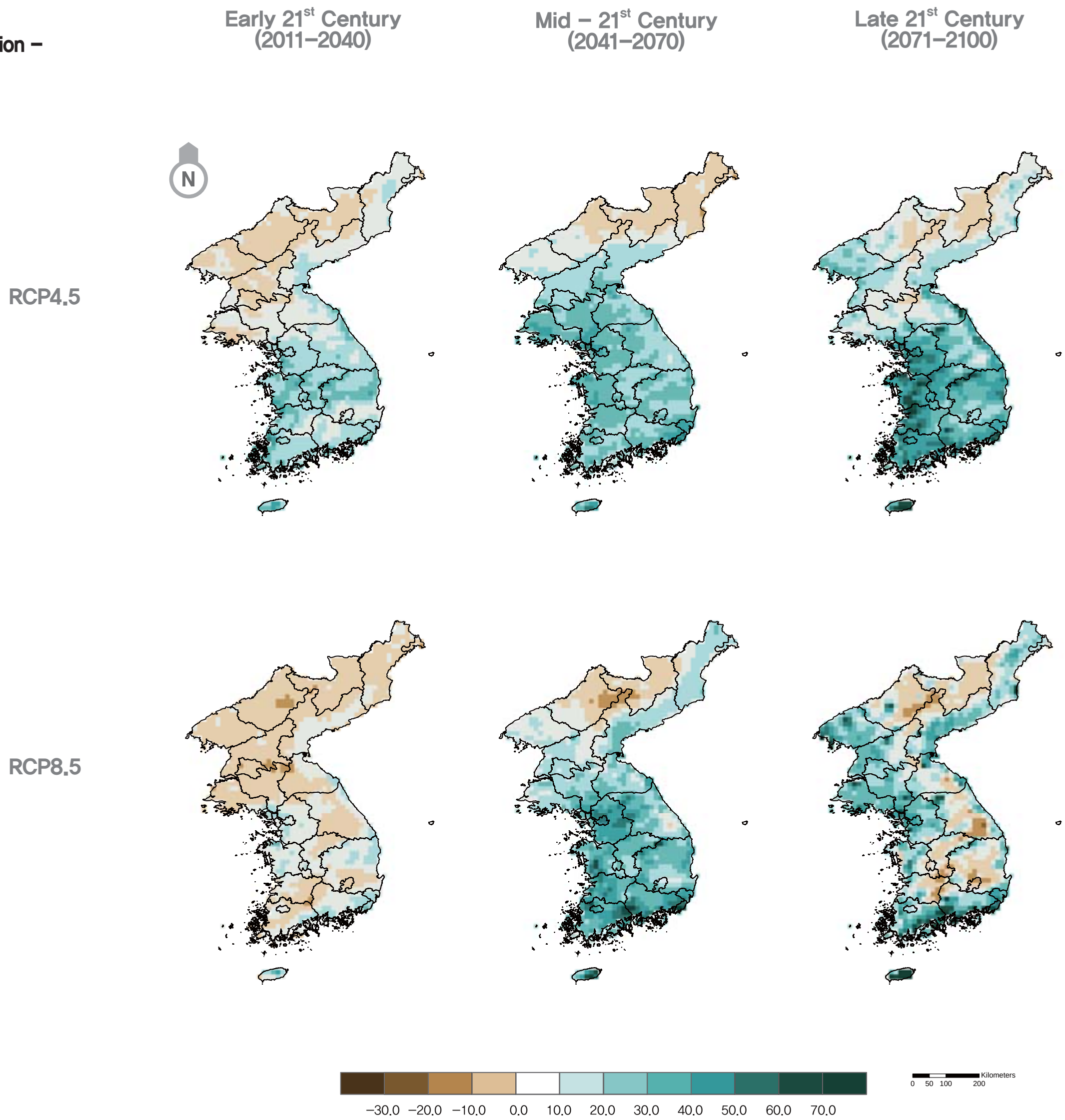


Fig. A2.13
Projection of Mean Precipitation – Autumn

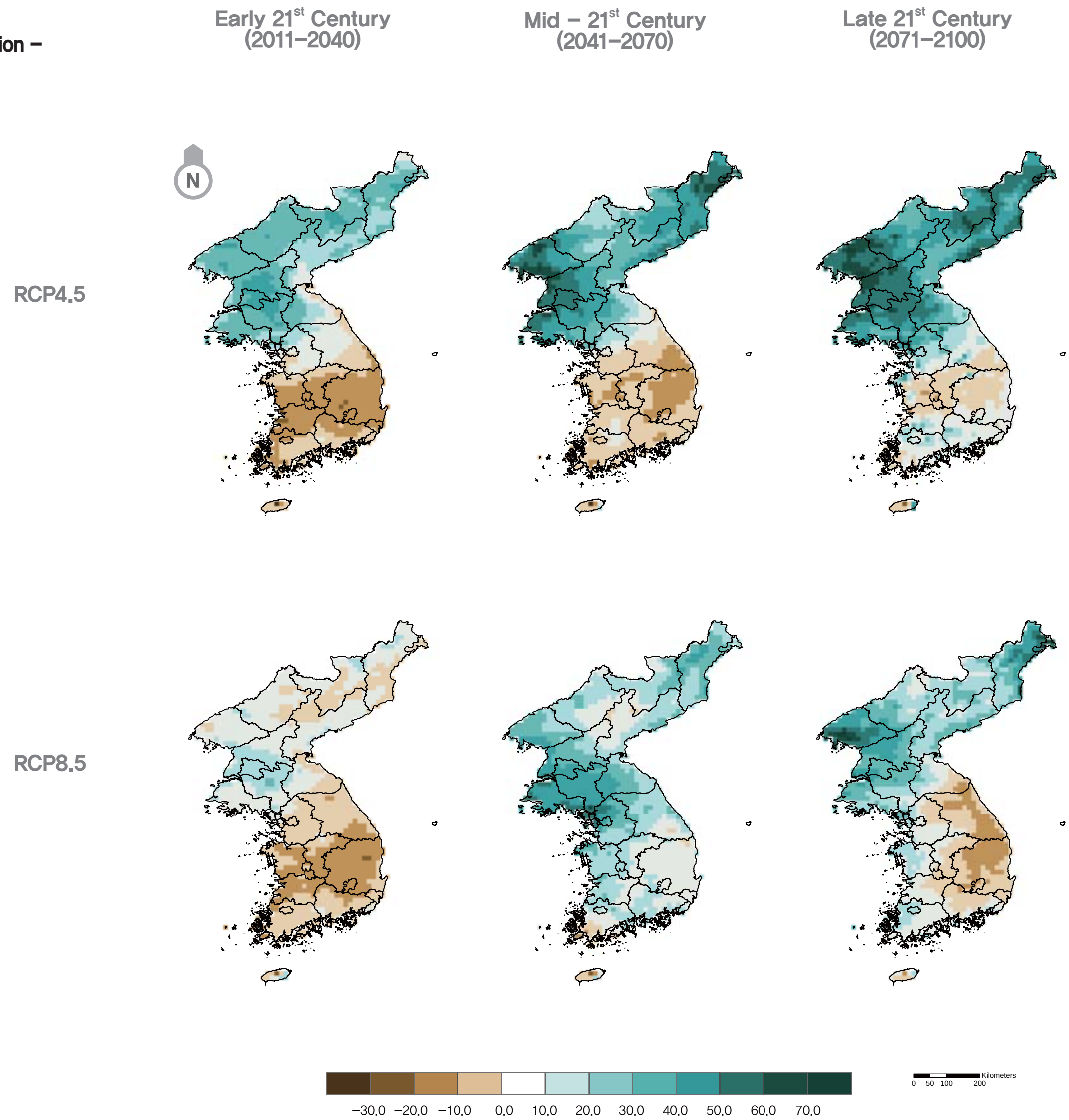
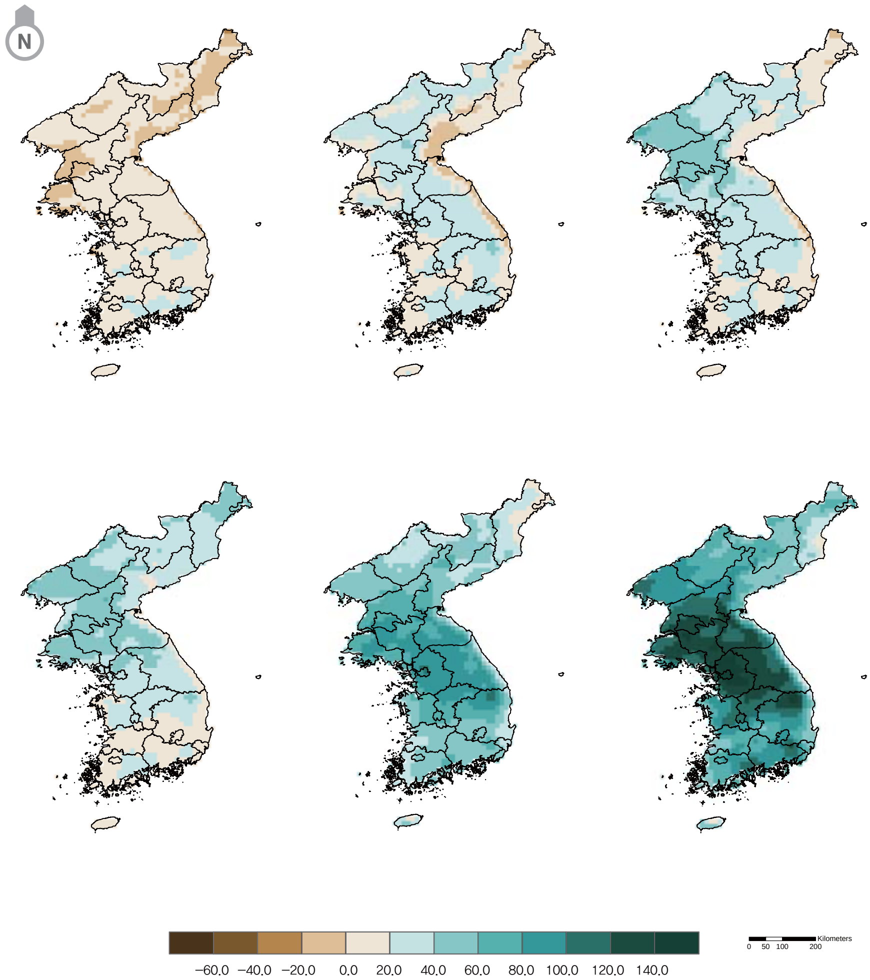


Fig. A2.14
Projection of Mean Precipitation – Winter

Early 21st Century (2011–2040) | Mid – 21st Century (2041–2070) | Late 21st Century (2071–2100)

RCP4.5

RCP8.5



Spatial Patterns of Extreme Indices on the Korean Peninsula

Fig. A2.15
Projection of Annual Mean Number of Frost Days

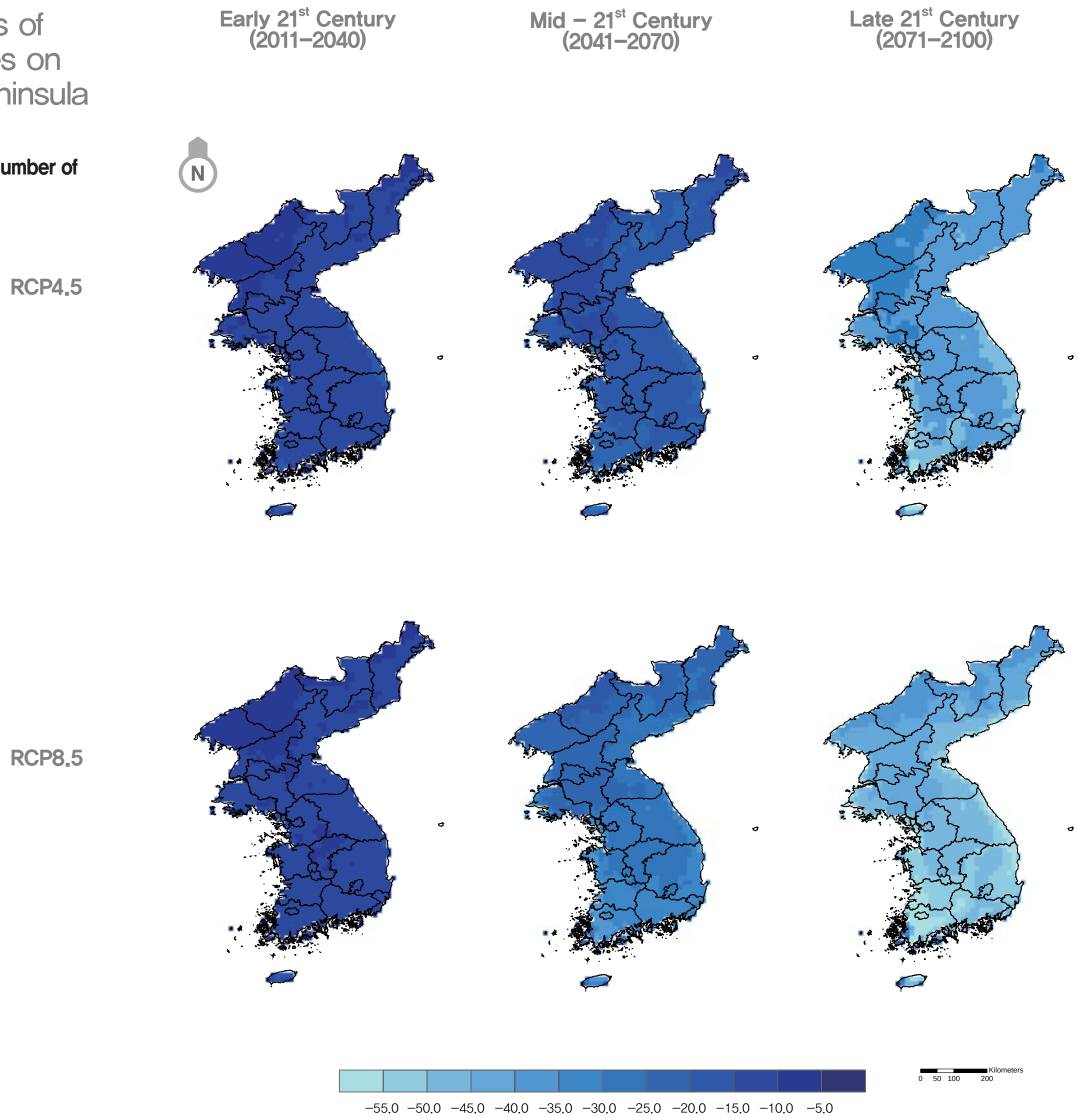


Fig. A2.16
Projection of Annual Mean Number of Summer Days

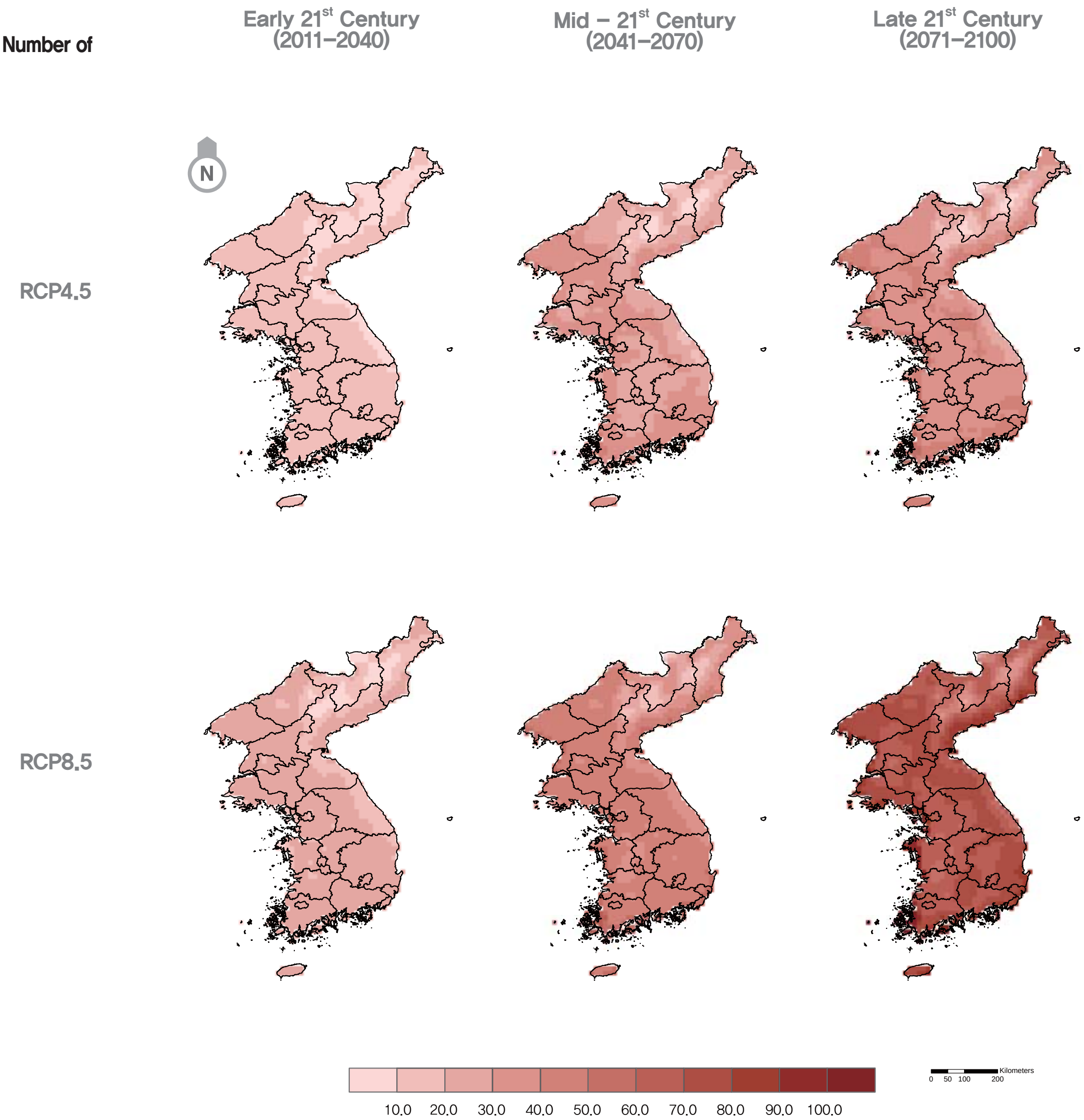


Fig. A2.17
Projection of Annual Mean Number of Freezing Days

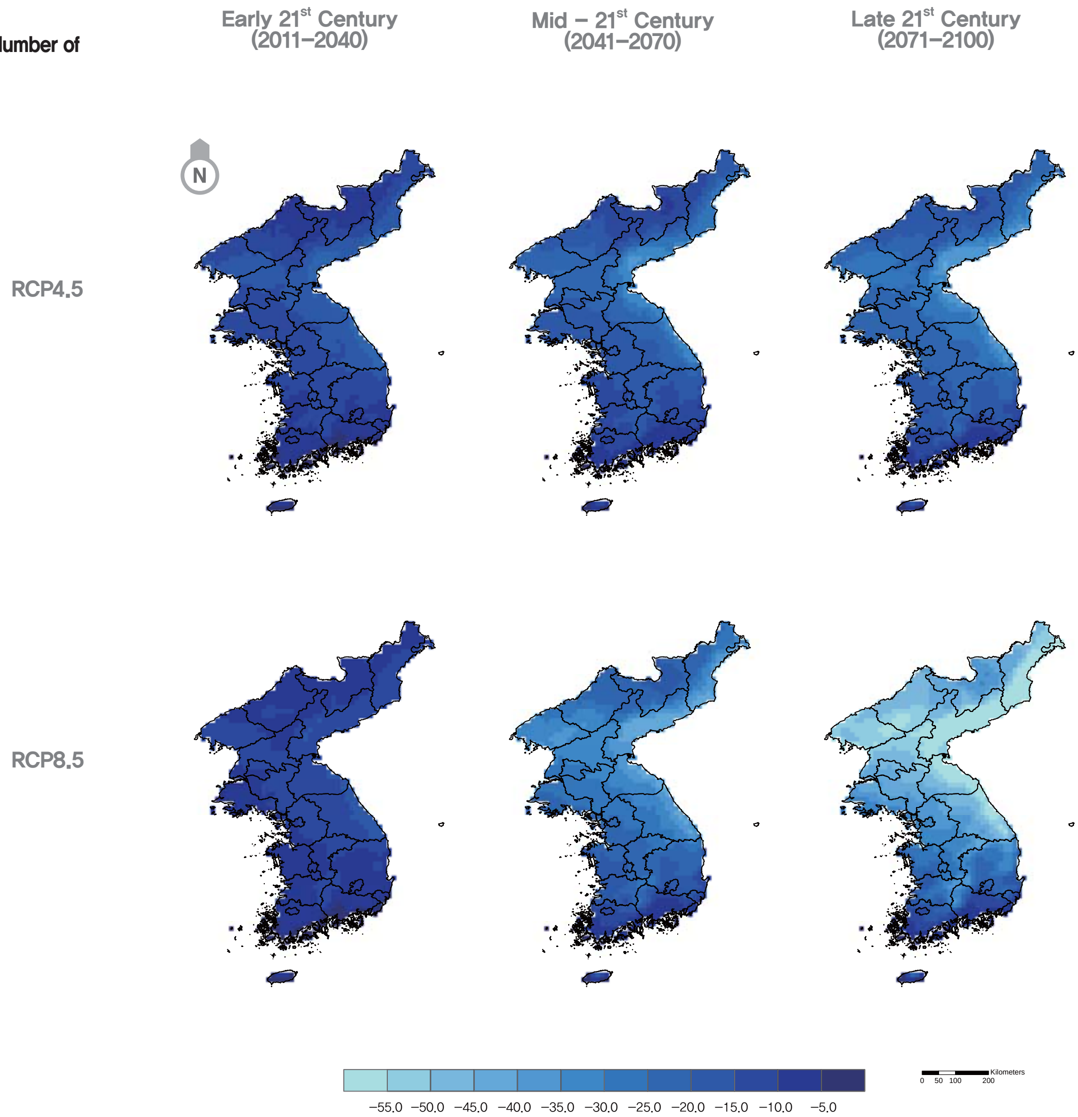


Fig. A2.18
Projection of Annual Mean Length of Growing Season

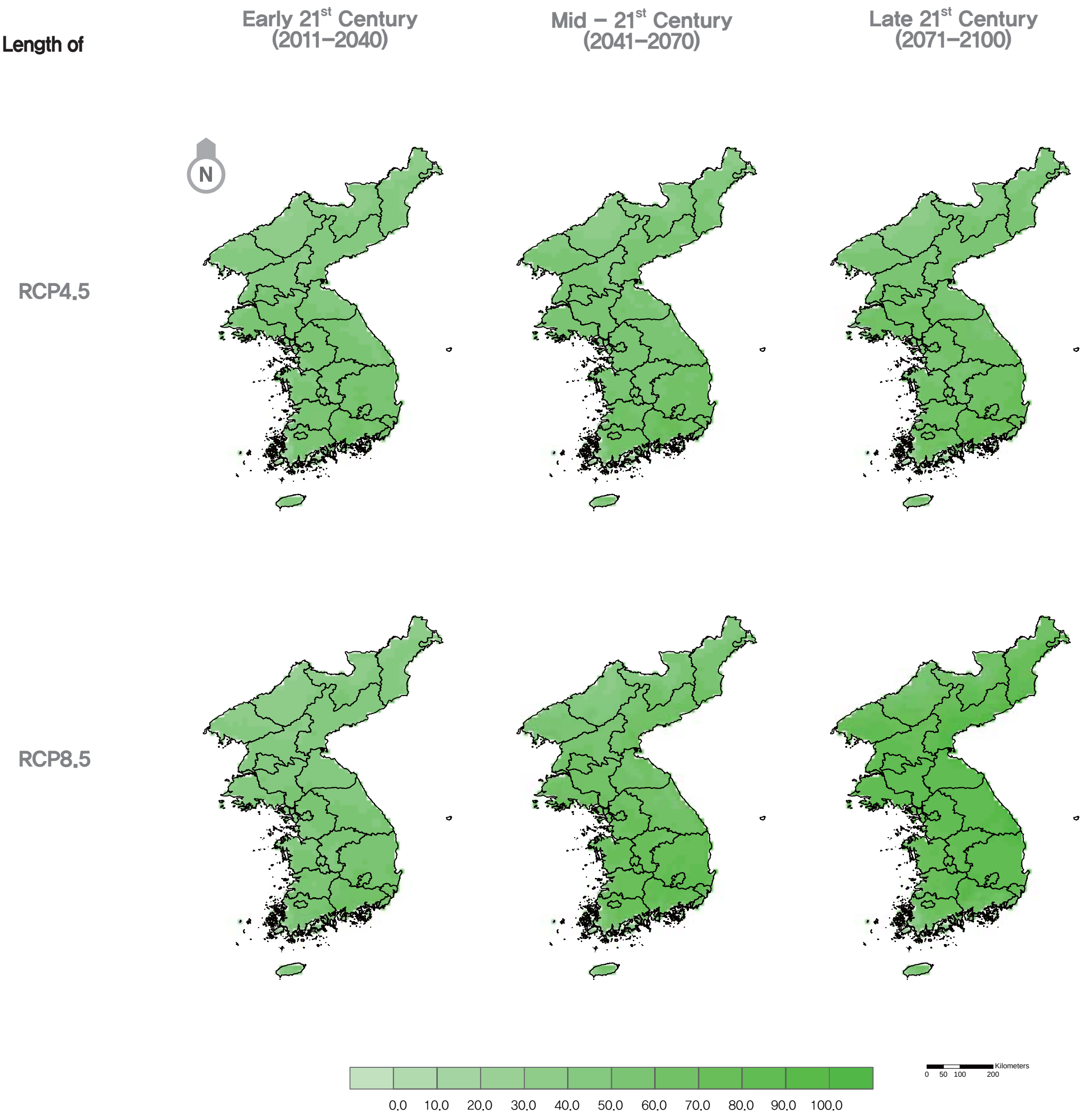
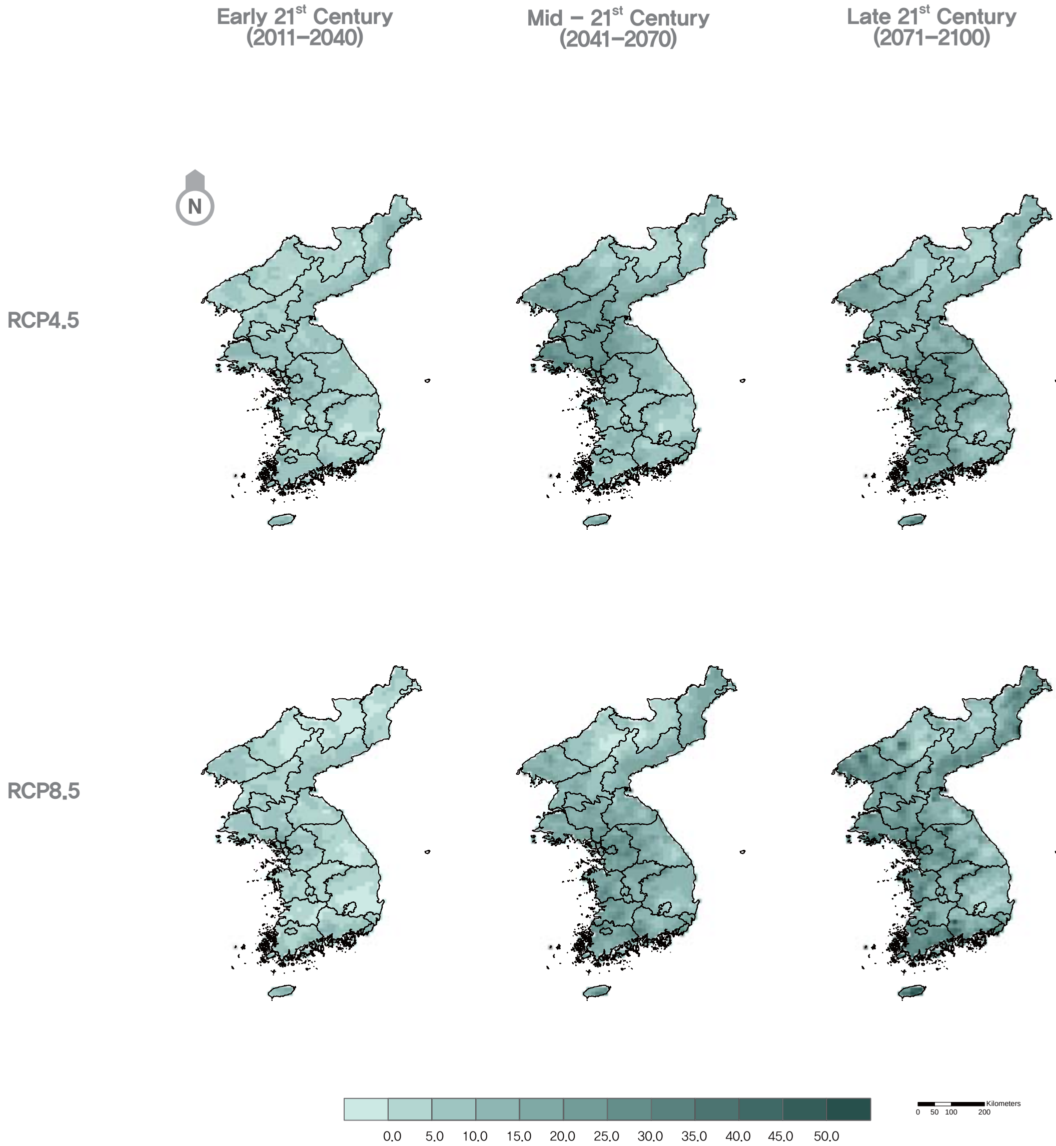


Fig. A2.19
Projection of Annual Mean Precipitation Intensity



Appendix 3 Climate Change Projections for Each Administrative Area of South Korea

Explanation of the Data

- In this appendix future climate change projections and projections for changes to the extreme indices are presented for the 16 administrative areas and metropolitan cities of South Korea using the 1㎞ resolution RCP scenario data for the Korean Peninsula.
- For the spatial patterns of climate change trends refer to chapter 5 'Climate Change Projections for the Administrative Areas of South Korea'.

Table A1
Projection of Annual Mean Temperature for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Future Climate	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (℃/decade)	
Seoul	13.0	Absolute Value	13.6	(13.8)	14.6	(15.7)	15.2	(17.9)	0.28	(0.61)
		Variation	+0.6	(+0.8)	+1.6	(+2.7)	+2.2	(+4.9)		
Busan	14.4	Absolute Value	15.1	(15.4)	16.1	(17.2)	16.7	(19.2)	0.29	(0.60)
		Variation	+0.7	(+1.0)	+1.7	(+2.8)	+2.3	(+4.8)		
Daegu	13.2	Absolute Value	13.9	(14.2)	14.8	(15.9)	15.4	(18.0)	0.28	(0.60)
		Variation	+0.7	(+1.0)	+1.6	(+2.7)	+2.2	(+4.8)		
Incheon	12.0	Absolute Value	12.8	(12.8)	13.8	(14.8)	14.4	(17.1)	0.30	(0.64)
		Variation	+0.8	(+0.8)	+1.8	(+2.8)	+2.4	(+5.1)		
Gwangju	13.6	Absolute Value	14.2	(14.4)	15.1	(16.1)	15.7	(18.2)	0.26	(0.58)
		Variation	+0.6	(+0.8)	+1.5	(+2.5)	+2.1	(+4.6)		
Daejeon	12.4	Absolute Value	13.0	(13.3)	13.9	(15.0)	14.5	(17.1)	0.26	(0.59)
		Variation	+0.6	(+0.9)	+1.5	(+2.6)	+2.1	(+4.7)		
Ulsan	13.4	Absolute Value	14.2	(14.5)	15.2	(16.3)	15.8	(18.3)	0.30	(0.61)
		Variation	+0.8	(+1.1)	+1.8	(+2.9)	+2.4	(+4.9)		
Gyeong gi–do	11.2	Absolute Value	11.8	(12.0)	12.8	(13.9)	13.4	(16.0)	0.28	(0.60)
		Variation	+0.6	(+0.8)	+1.6	(+2.7)	+2.2	(+4.8)		
Gang won–do	8.9	Absolute Value	9.7	(9.9)	10.7	(11.7)	11.2	(13.9)	0.29	(0.63)
		Variation	+0.8	(+1.0)	+1.8	(+2.8)	+2.3	(+5.0)		
Chung cheong buk–do	10.9	Absolute Value	11.5	(11.7)	12.4	(13.5)	13.0	(15.6)	0.26	(0.59)
		Variation	+0.6	(+0.8)	+1.5	(+2.6)	+2.1	(+4.7)		
Chung cheong nam–do	12.0	Absolute Value	12.6	(12.8)	13.6	(14.6)	14.2	(16.8)	0.28	(0.60)
		Variation	+0.6	(+0.8)	+1.6	(+2.6)	+2.2	(+4.8)		
Jeolla buk–do	11.8	Absolute Value	12.4	(12.6)	13.4	(14.4)	14.0	(16.5)	0.28	(0.59)
		Variation	+0.6	(+0.8)	+1.6	(+2.6)	+2.2	(+4.7)		
Jeolla nam–do	13.2	Absolute Value	13.9	(14.1)	14.8	(15.8)	15.4	(17.9)	0.28	(0.59)
		Variation	+0.7	(+0.9)	+1.6	(+2.6)	+2.2	(+4.7)		
Gyeong sangbuk–do	11.4	Absolute Value	12.1	(12.4)	13.0	(14.1)	13.6	(16.2)	0.28	(0.60)
		Variation	+0.7	(+1.0)	+1.6	(+2.7)	+2.2	(+4.8)		
Gyeong sangnam–do	12.8	Absolute Value	13.5	(13.8)	14.4	(15.5)	15.0	(17.5)	0.28	(0.59)
		Variation	+0.7	(+1.0)	+1.6	(+2.7)	+2.2	(+4.7)		
Jeju–do	14.4	Absolute Value	15.1	(15.3)	16.1	(17.0)	16.7	(19.0)	0.29	(0.58)
		Variation	+0.7	(+0.9)	+1.7	(+2.6)	+2.3	(+4.6)		

Table A2
Projection of Annual Mean Precipitation for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Future Climate	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (mm/decade)	
Seoul	1387.0	Absolute Value	1627.7	(1628.0)	1712.7	(1905.8)	1850.9	(1843.4)	57.99	(57.05)
		Variation	+17.4	(+17.4)	+23.5	(+37.4)	+33.4	(+32.9)		
Busan	1532.1	Absolute Value	1917.9	(1950.2)	2031.3	(2142.5)	2122.6	(2249.8)	73.81	(89.71)
		Variation	+25.2	(+27.3)	+32.6	(+39.8)	+38.5	(+46.8)		
Daegu	1224.8	Absolute Value	1418.7	(1331.4)	1481.8	(1479.2)	1546.1	(1421.3)	40.16	(24.56)
		Variation	+15.8	(+8.7)	+21.0	(+20.8)	+26.2	(+16.0)		
Incheon	1199.2	Absolute Value	1393.7	(1430.1)	1528.0	(1578.2)	1617.1	(1658.0)	52.24	(57.35)
		Variation	+16.2	(+19.3)	+27.4	(+31.6)	+34.8	(+38.3)		
Gwangju	1415.5	Absolute Value	1800.8	(1708.9)	1853.1	(1958.9)	2028.6	(1922.4)	76.64	(63.36)
		Variation	+27.2	(+20.7)	+30.9	(+38.4)	+43.3	(+35.8)		
Daejeon	1286.7	Absolute Value	1587.0	(1547.0)	1614.2	(1695.9)	1747.6	(1668.4)	57.61	(47.71)
		Variation	+23.3	(+20.2)	+25.5	(+31.8)	+35.8	(+29.7)		
Ulsan	1447.8	Absolute Value	1761.5	(1751.4)	1849.4	(1929.9)	1915.5	(1975.4)	58.46	(65.95)
		Variation	+21.7	(+21.0)	+27.7	(+33.3)	+32.3	(+36.4)		
Gyeong gi-do	1437.3	Absolute Value	1700.8	(1678.2)	1775.2	(1920.1)	1922.9	(1881.6)	60.70	(55.54)
		Variation	+18.3	(+16.8)	+23.5	(+33.6)	+33.8	(+30.9)		
Gang won-do	1491.5	Absolute Value	1736.7	(1684.7)	1772.3	(1869.8)	1885.3	(1793.9)	49.23	(37.80)
		Variation	+16.4	(+13.0)	+18.8	(+25.4)	+26.4	(+20.3)		
Chung cheong buk-do	1351.4	Absolute Value	1615.9	(1547.5)	1633.0	(1740.1)	1785.2	(1668.9)	54.23	(39.69)
		Variation	+19.6	(+14.5)	+20.8	(+28.8)	+32.1	(+23.5)		
Chung cheong nam-do	1264.2	Absolute Value	1564.9	(1526.1)	1614.9	(1703.7)	1764.5	(1691.1)	62.54	(53.36)
		Variation	+23.8	(+20.7)	+27.7	(+34.8)	+39.6	(+33.8)		
Jeolla buk-do	1417.4	Absolute Value	1719.8	(1618.0)	1786.8	(1868.7)	1923.5	(1785.8)	63.26	(46.05)
		Variation	+21.3	(+14.2)	+26.1	(+31.8)	+35.7	(+26.0)		
Jeolla nam-do	1476.0	Absolute Value	1835.5	(1759.0)	1868.2	(1989.4)	2034.1	(2055.9)	69.76	(72.49)
		Variation	+24.4	(+19.2)	+26.6	(+34.8)	+37.8	(+39.3)		
Gyeong sangbuk-do	1291.6	Absolute Value	1528.7	(1473.5)	1559.7	(1635.7)	1661.3	(1581.7)	46.21	(36.26)
		Variation	+18.4	(+14.1)	+20.8	(+26.6)	+28.6	(+22.5)		
Gyeong sangnam-do	1596.8	Absolute Value	1954.7	(1921.5)	2014.2	(2139.8)	2131.0	(2168.8)	66.78	(71.50)
		Variation	+22.4	(+20.3)	+26.1	(+34.0)	+33.5	(+35.8)		
Jeju-do	2168.1	Absolute Value	2479.2	(2456.1)	2561.1	(2642.6)	2709.7	(2924.5)	67.70	(94.55)
		Variation	+14.3	(+13.3)	+18.1	(+21.9)	+25.0	(+34.9)		

Table A3
Projection of Annual Mean Number of Frost Days for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	87.7	86.8	(85.3)	81.2	(65.4)	75.9	(44.4)	–1.48	(–5.41)
Busan	54.4	50.5	(49.5)	44.0	(30.2)	38.8	(15.9)	–1.95	(–4.81)
Daegu	94.9	90.7	(89.3)	84.5	(69.3)	79.1	(49.0)	–1.98	(–5.74)
Incheon	96.3	89.3	(87.7)	81.9	(66.4)	76.2	(43.3)	–2.51	(–6.63)
Gwangju	89.8	84.9	(84.2)	76.2	(60.6)	70.4	(34.6)	–2.43	(–6.90)
Daejeon	110.8	104.5	(103.2)	98.7	(84.2)	92.4	(60.4)	–2.30	(–6.30)
Ulsan	80.1	73.4	(71.7)	67.0	(51.5)	61.3	(33.3)	–2.35	(–5.85)
Gyeonggi–do	123.7	116.9	(116.6)	111.8	(99.7)	105.5	(77.6)	–2.28	(–5.76)
Gangwon–do	144.1	131.9	(132.9)	124.1	(113.5)	117.5	(89.2)	–3.33	(–6.86)
Chungcheongbuk–do	133.8	125.1	(125.1)	119.4	(107.5)	112.7	(83.6)	–2.64	(–6.28)
Chungcheongnam–do	114.5	106.6	(106.0)	99.6	(86.0)	92.9	(61.5)	–2.70	(–6.63)
Jeollabuk–do	117.7	108.1	(108.2)	100.2	(86.7)	93.8	(61.3)	–2.99	(–7.05)
Jeollanam–do	87.9	78.1	(78.0)	69.1	(54.4)	62.6	(31.8)	–3.16	(–7.01)
Gyeongsangbuk–do	122.9	113.0	(112.9)	107.0	(93.5)	100.3	(70.1)	–2.83	(–6.60)
Gyeongsangnam–do	100.6	92.6	(92.2)	85.9	(72.1)	80.5	(51.4)	–2.51	(–6.15)
Jeju–do	35.1	29.8	(30.1)	22.6	(15.7)	18.1	(6.8)	–2.13	(–3.54)

Table A4
Projection of Annual Mean Number of Summer Days for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	121.8	126.0	(131.3)	142.7	(149.9)	146.2	(169.3)	3.05	(5.94)
Busan	100.8	113.8	(124.1)	134.2	(144.6)	141.4	(170.1)	5.08	(8.66)
Daegu	122.2	130.3	(139.2)	149.0	(155.6)	152.4	(177.3)	3.78	(6.89)
Incheon	99.2	109.1	(112.8)	128.3	(135.3)	133.3	(157.0)	4.26	(7.23)
Gwangju	130.5	135.1	(142.9)	152.8	(158.7)	154.9	(177.7)	3.05	(5.90)
Daejeon	123.4	128.0	(136.7)	145.8	(153.1)	149.8	(173.0)	3.30	(6.20)
Ulsan	100.7	110.4	(119.6)	129.1	(140.7)	136.0	(166.0)	4.41	(8.16)
Gyeonggi–do	113.7	117.7	(124.4)	135.0	(143.3)	139.1	(163.9)	3.18	(6.28)
Gangwon–do	74.6	75.7	(83.7)	91.8	(105.8)	99.1	(133.6)	3.06	(7.38)
Chungcheongbuk–do	110.4	113.8	(122.8)	131.6	(141.3)	136.9	(163.7)	3.31	(6.66)
Chungcheongnam–do	114.5	120.8	(127.4)	138.7	(145.5)	142.9	(165.6)	3.55	(6.39)
Jeollabuk–do	112.5	115.8	(125.1)	134.0	(143.4)	138.8	(164.7)	3.29	(6.53)
Jeollanam–do	113.5	120.9	(129.5)	140.5	(148.1)	144.7	(169.5)	3.90	(7.00)
Gyeongsangbuk–do	104.5	110.2	(119.8)	128.3	(138.7)	134.1	(163.3)	3.70	(7.35)
Gyeongsangnam–do	111.0	117.7	(127.3)	136.8	(145.9)	142.4	(169.0)	3.93	(7.25)
Jeju–do	89.4	99.2	(105.4)	118.3	(128.2)	125.0	(156.2)	4.45	(8.35)

Table A5
Projection of Annual Mean Number of Freezing Days for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by 10 year increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	18.3	11.9	(14.1)	9.2	(5.0)	5.9	(1.3)	–1.55	(–2.13)
Busan	1.4	0.7	(0.7)	0.2	(0.1)	0.1	(0.0)	–0.16	(–0.18)
Daegu	6.8	4.6	(4.8)	2.8	(1.5)	1.7	(0.4)	–0.64	(–0.80)
Incheon	19.6	13.5	(15.8)	10.5	(5.8)	6.8	(1.5)	–1.60	(–2.26)
Gwangju	5.4	3.8	(4.5)	2.3	(1.4)	1.0	(0.2)	–0.55	(–0.65)
Daejeon	12.3	7.7	(8.3)	4.9	(2.8)	2.8	(0.6)	–1.19	(–1.46)
Ulsan	4.3	3.1	(3.3)	2.0	(1.1)	1.3	(0.3)	–0.38	(–0.50)
Gyeonggi–do	22.9	16.4	(18.5)	13.5	(7.9)	9.4	(2.7)	–1.69	(–2.53)
Gangwon–do	36.4	26.1	(28.7)	21.7	(14.7)	17.4	(6.3)	–2.38	(–3.76)
Chungcheongbuk–do	20.4	14.2	(15.7)	10.9	(6.5)	7.5	(2.2)	–1.61	(–2.28)
Chungcheongnam–do	14.7	10.2	(11.0)	7.1	(3.9)	4.2	(0.9)	–1.31	(–1.73)
Jeollabuk–do	13.6	9.5	(10.5)	6.7	(4.4)	4.2	(1.3)	–1.18	(–1.54)
Jeollanam–do	5.6	3.6	(4.0)	2.3	(1.4)	1.2	(0.3)	–0.55	(–0.66)
Gyeongsangbuk–do	13.8	9.1	(10.3)	6.7	(4.0)	4.5	(1.3)	–1.16	(–1.56)
Gyeongsangnam–do	6.1	4.0	(4.2)	2.8	(1.7)	1.8	(0.6)	–0.54	(–0.69)
Jeju–do	4.5	2.5	(2.7)	1.7	(1.1)	1.0	(0.3)	–0.44	(–0.53)

Table A6
Projection of Annual Mean Number of Tropical Nights for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided, the unit of measure is ℃.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by 10 year increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	8.2	13.6	(17.9)	26.8	(41.9)	37.2	(72.0)	3.63	(7.98)
Busan	7.8	11.8	(20.4)	27.2	(43.7)	37.6	(72.3)	3.73	(8.06)
Daegu	6.1	13.2	(18.2)	24.3	(38.3)	32.5	(60.5)	3.30	(6.80)
Incheon	2.0	6.1	(7.4)	17.1	(29.3)	25.6	(61.6)	2.95	(7.45)
Gwangju	7.3	15.7	(20.5)	31.1	(43.1)	41.9	(68.6)	4.33	(7.66)
Daejeon	1.6	7.0	(11.6)	19.5	(31.9)	26.9	(58.0)	3.16	(7.05)
Ulsan	4.0	7.9	(12.4)	19.1	(32.1)	27.8	(58.6)	2.98	(6.83)
Gyeonggi–do	1.4	5.1	(7.4)	13.7	(23.9)	20.4	(48.7)	2.38	(5.91)
Gangwon–do	0.2	1.1	(1.7)	3.8	(8.3)	6.2	(21.4)	0.75	(2.65)
Chungcheongbuk–do	0.3	2.7	(4.5)	9.7	(17.9)	14.6	(39.6)	1.79	(4.91)
Chungcheongnam–do	1.8	5.8	(8.7)	17.1	(27.9)	24.9	(55.5)	2.89	(6.71)
Jeollabuk–do	2.3	6.9	(9.3)	16.5	(24.8)	23.1	(48.5)	2.60	(5.78)
Jeollanam–do	4.9	9.5	(14.3)	23.4	(35.6)	32.6	(62.6)	3.46	(7.21)
Gyeongsangbuk–do	0.8	4.2	(6.5)	11.0	(20.6)	16.7	(41.2)	1.99	(5.05)
Gyeongsangnam–do	2.7	7.7	(12.1)	18.3	(30.4)	26.0	(53.5)	2.91	(6.35)
Jeju–do	9.5	16.1	(20.0)	29.8	(40.5)	38.6	(65.8)	3.64	(7.04)

Table A7
Projection of Annual Mean Length of Growing Season for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Unit of measure: number of days.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	268.5	273.5	(276.3)	279.5	(299.0)	282.9	(318.3)	1.80	(6.23)
Busan	312.8	324.6	(326.7)	333.3	(348.7)	339.2	(352.2)	3.30	(4.93)
Daegu	278.7	284.7	(284.9)	291.0	(314.7)	297.4	(331.1)	2.34	(6.55)
Incheon	256.6	267.9	(269.9)	276.1	(294.8)	280.7	(317.5)	3.01	(7.61)
Gwangju	290.5	294.1	(291.5)	298.6	(324.4)	304.1	(339.8)	1.70	(6.16)
Daejeon	265.2	268.3	(272.3)	275.0	(295.6)	279.1	(317.9)	1.74	(6.59)
Ulsan	293.8	304.7	(307.7)	311.0	(333.2)	319.2	(342.2)	3.18	(6.05)
Gyeonggi–do	250.2	252.4	(254.4)	256.8	(273.5)	263.5	(298.2)	1.66	(6.00)
Gangwon–do	230.1	237.6	(235.3)	242.3	(257.9)	251.5	(284.0)	2.68	(6.74)
Chungcheongbuk–do	248.0	249.5	(252.0)	253.8	(273.2)	261.7	(299.3)	1.71	(6.41)
Chungcheongnam–do	258.1	262.9	(267.5)	269.7	(290.8)	277.7	(315.3)	2.45	(7.15)
Jeollabuk–do	261.7	265.6	(269.0)	273.4	(297.5)	281.0	(318.7)	2.41	(7.13)
Jeollanam–do	286.3	294.6	(295.1)	303.6	(325.7)	311.0	(339.9)	3.09	(6.70)
Gyeongsangbuk–do	254.8	262.1	(263.3)	268.8	(289.6)	276.2	(312.9)	2.68	(7.26)
Gyeongsangnam–do	277.8	286.4	(287.3)	294.5	(316.6)	301.2	(332.4)	2.93	(6.83)
Jeju–do	322.9	329.9	(330.8)	340.7	(348.3)	344.5	(354.9)	2.70	(4.00)

Table A8
Projection of Annual Mean Number of Heat Wave Days for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Unit of measure: number of days.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)	Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	11.1	15.1	(22.0)	24.4	(38.6)	31.8	(73.4)	2.59	(7.79)
Busan	7.5	9.7	(14.3)	15.7	(28.7)	21.5	(54.3)	1.75	(5.85)
Daegu	22.0	22.8	(30.7)	32.1	(47.3)	37.2	(77.0)	1.90	(6.88)
Incheon	3.3	5.6	(8.3)	11.3	(22.2)	16.9	(53.7)	1.70	(6.30)
Gwangju	16.0	15.1	(24.0)	25.4	(42.0)	32.6	(77.3)	2.08	(7.66)
Daejeon	11.9	12.4	(20.5)	22.0	(37.2)	29.0	(71.6)	2.14	(7.46)
Ulsan	11.8	13.8	(18.9)	19.8	(31.9)	25.2	(55.4)	1.68	(5.45)
Gyeonggi–do	8.3	11.2	(15.8)	18.2	(29.5)	24.0	(62.0)	1.96	(6.71)
Gangwon–do	3.5	4.9	(6.7)	8.4	(13.9)	10.4	(30.3)	0.86	(3.35)
Chungcheongbuk–do	8.9	9.1	(14.1)	16.1	(26.8)	21.0	(57.4)	1.51	(6.06)
Chungcheongnam–do	7.9	9.6	(15.5)	17.2	(30.4)	23.7	(63.6)	1.98	(6.96)
Jeollabuk–do	8.4	9.2	(15.6)	17.1	(30.5)	22.8	(60.4)	1.80	(6.50)
Jeollanam–do	8.5	8.5	(13.9)	16.4	(30.4)	22.7	(60.9)	1.78	(6.55)
Gyeongsangbuk–do	11.9	13.0	(18.5)	19.7	(30.5)	23.5	(56.4)	1.45	(5.56)
Gyeongsangnam–do	12.4	13.4	(18.6)	20.6	(33.3)	25.5	(59.5)	1.64	(5.89)
Jeju–do	1.6	4.8	(7.2)	10.8	(19.5)	15.6	(41.2)	1.75	(4.95)

Table A9
Projection of Annual Mean Precipitation Intensity for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided; the unit of measure is mm/day.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)		Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	11.2	(10.8)	12.2	(11.6)	12.7	(13.3)	13.8	(12.9)	0.38	(0.21)
Busan	11.3	(11.0)	12.5	(12.3)	13.2	(13.5)	13.7	(14.0)	0.34	(0.34)
Daegu	9.6	(9.3)	10.0	(9.1)	10.4	(10.0)	10.7	(9.5)	0.18	(–0.01)
Incheon	9.9	(9.6)	10.7	(10.6)	11.7	(11.5)	12.5	(12.1)	0.36	(0.28)
Gwangju	10.4	(10.1)	11.7	(10.9)	12.0	(12.3)	12.9	(12.2)	0.35	(0.23)
Daejeon	10.6	(9.7)	11.1	(10.1)	11.4	(11.0)	12.3	(10.9)	0.33	(0.04)
Ulsan	10.9	(10.4)	11.5	(11.0)	12.0	(12.1)	12.3	(12.2)	0.24	(0.16)
Gyeonggi–do	10.6	(10.6)	11.9	(11.4)	12.3	(12.8)	13.3	(12.6)	0.34	(0.25)
Gangwon–do	10.0	(10.0)	11.0	(10.5)	11.2	(11.6)	11.8	(11.2)	0.23	(0.15)
Chungcheongbuk–do	10.1	(9.7)	10.9	(10.1)	11.0	(11.1)	12.0	(10.8)	0.29	(0.09)
Chungcheongnam–do	9.9	(9.3)	10.7	(10.0)	11.0	(11.1)	12.0	(11.2)	0.34	(0.16)
Jeollabuk–do	10.0	(9.4)	10.8	(9.8)	11.3	(11.2)	12.1	(10.8)	0.34	(0.10)
Jeollanam–do	10.2	(10.1)	11.3	(10.7)	11.6	(12.1)	12.4	(12.5)	0.29	(0.29)
Gyeongsangbuk–do	9.7	(9.3)	10.3	(9.6)	10.5	(10.5)	11.0	(10.1)	0.21	(0.05)
Gyeongsangnam–do	11.0	(10.9)	11.9	(11.6)	12.3	(12.8)	12.8	(12.9)	0.24	(0.24)
Jeju–do	10.8	(10.7)	11.9	(11.6)	12.3	(12.5)	13.0	(13.8)	0.29	(0.38)

Table A10
Projection of Annual Mean Number of Heavy Precipitation Days for 16 Administrative Areas and Metropolitan Cities in South Korea based on RCP4.5 (8.5)

- (RCP8.5 is given in brackets.) Both the absolute value and variation are provided; the unit of measure is number of days.
- The decadal trend is calculated by dividing the difference between the current climate value (1981–2010) and that for the late 21st century by decadal increments providing a rate of change.

Area	Current Climate Value (2001–2010)		Early 21st Century (2011–2040)		Mid – 21st Century (2041–2070)		Late 21st Century (2071–2100)		Trend (per decade)	
Seoul	1.5	(1.2)	1.9	(1.9)	2.2	(2.7)	3.2	(2.4)	0.25	(0.11)
Busan	1.9	(1.3)	2.1	(2.2)	2.5	(2.7)	3.0	(3.0)	0.21	(0.14)
Daegu	0.9	(0.8)	0.5	(0.4)	0.8	(0.9)	0.7	(0.5)	–0.01	(–0.05)
Incheon	1.2	(1.1)	1.4	(1.5)	1.9	(2.1)	2.5	(2.3)	0.18	(0.14)
Gwangju	1.2	(0.7)	1.5	(1.2)	1.5	(1.9)	2.0	(1.7)	0.16	(0.06)
Daejeon	0.9	(0.6)	1.3	(1.2)	1.2	(1.5)	1.7	(1.6)	0.14	(0.09)
Ulsan	1.6	(1.3)	1.6	(1.5)	1.9	(1.8)	1.8	(2.1)	0.06	(0.06)
Gyeonggi–do	1.2	(1.1)	1.8	(1.7)	2.1	(2.5)	2.8	(2.3)	0.21	(0.14)
Gangwon–do	1.1	(0.9)	1.5	(1.4)	1.8	(1.9)	2.1	(1.7)	0.15	(0.08)
Chungcheongbuk–do	1.0	(0.8)	1.4	(1.0)	1.3	(1.4)	1.9	(1.6)	0.14	(0.08)
Chungcheongnam–do	1.1	(0.7)	1.4	(1.2)	1.5	(1.6)	2.0	(1.9)	0.16	(0.10)
Jeollabuk–do	0.8	(0.6)	1.2	(1.0)	1.3	(1.7)	1.8	(1.4)	0.15	(0.08)
Jeollanam–do	1.2	(0.7)	1.4	(1.2)	1.5	(1.9)	2.0	(2.2)	0.16	(0.13)
Gyeongsangbuk–do	0.9	(0.8)	1.0	(0.8)	1.1	(1.2)	1.4	(1.0)	0.08	(0.01)
Gyeongsangnam–do	1.4	(1.2)	1.5	(1.4)	1.6	(2.2)	2.1	(2.1)	0.11	(0.09)
Jeju–do	1.1	(1.3)	2.1	(2.1)	2.6	(2.8)	2.7	(3.8)	0.18	(0.34)

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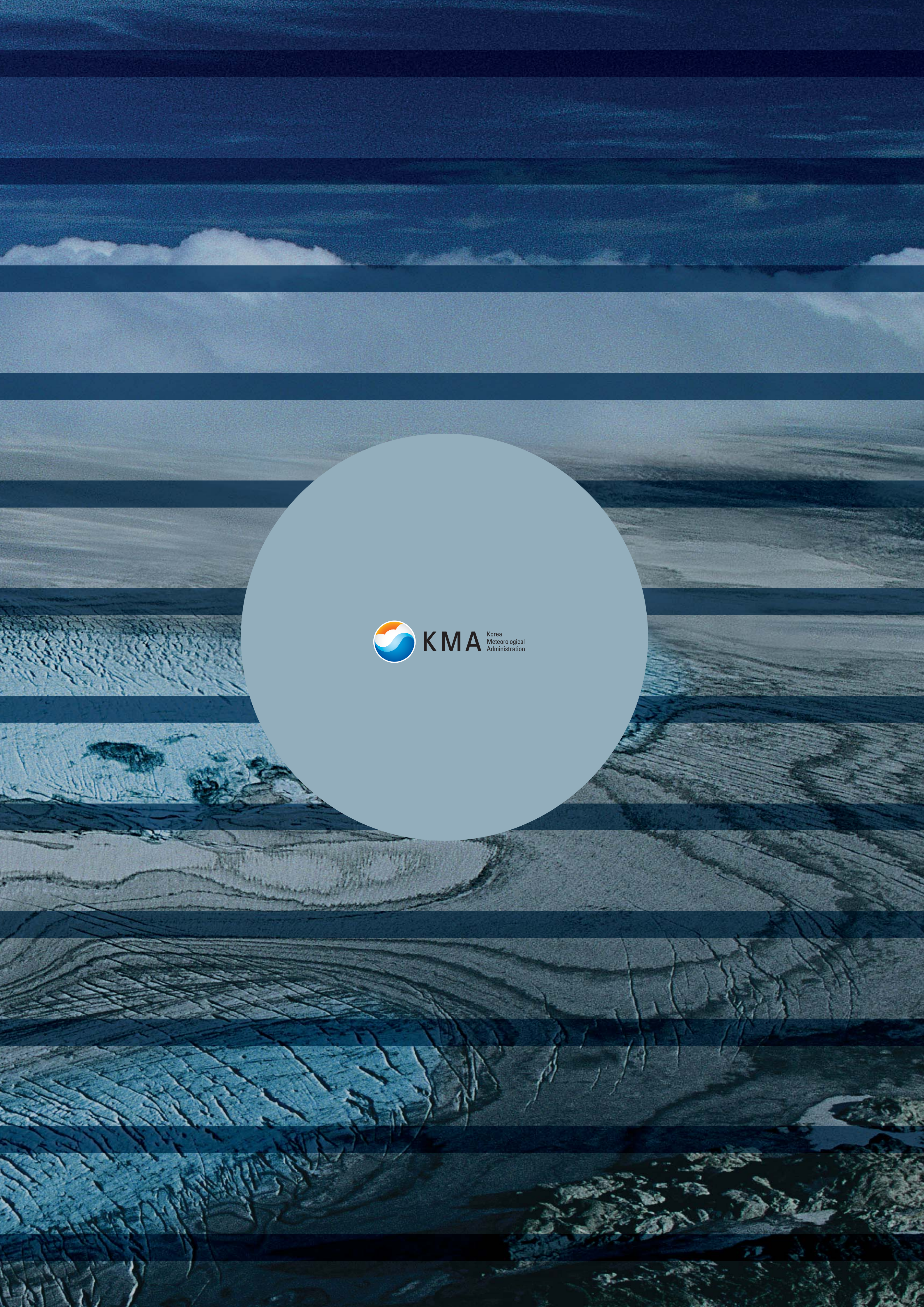
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