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Climate Projections for the Philippine Climate Change Adaptation Project (PhilCCAP)

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Copyright and disclaimer

Important disclaimer

Acknowledgment

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Foreword

Climate change has been recognized as one of the greatest challenges of the 21st Century. The Intergovernmental Panel on Climate Change (IPCC) has concluded that a continued increase in global mean surface air temperature is *virtually certain*, and proportional to the greenhouse gas emissions. The IPCC Fifth Assessment Report (IPCC, 2013) indicated that the projected temperature increases derived from the CMIP5 model simulations for 2081–2100 relative to 1986–2005 are likely be in the range of 0.3°C to 1.7°C for RCP2.6 (the lowest emissions scenario), 1.1°C to 2.6°C for RCP4.5 and 1.4°C to 3.1°C for RCP6.0 (intermediate emissions scenarios), and 2.6°C to 4.8°C for RCP8.5 (the scenario with the highest level of emissions). This is likely to be associated with changes to weather patterns and sea-level rise, which will impact on sectors including ecosystems, water resources, agriculture, forests, fisheries, industries, urban and rural settlements, energy, tourism, health, and disaster/emergency management.

The Philippines is highly vulnerable to current climate risks and future climate change. On average, twenty tropical cyclones enter the Philippine area of responsibility each year, with eight or nine crossing at least part of the country. The country is also periodically affected by the El Niño-Southern Oscillation (ENSO) phenomenon, which causes prolonged wet and dry seasons that contribute to a contraction in GDP and a dramatic drop in agricultural production (Philippines Initial National Communication, 1999). From 1990 to 2003, the estimated damage due to ENSO-related drought was more than US$370 million.

Recent studies have shown that water resources, natural ecosystems and local communities are highly vulnerable to climate change. The amount of seasonal water supply from watersheds could alter, leading to flooding in the rainy season and water deficit in the dry season (Cruz et al., 2006). In addition, forest ecosystems could change, leading to the loss of current forest types (Lasco et al., 2007). The poorest of the poor are expected to bear the brunt of these impacts (Pulhin et al., 2007).

The objective of Component 3 of the *Philippine Climate Change Adaptation Plan (PhilCCAP) Enhanced Provision of Scientific Information for Climate Risk Management* is to improve the access of end users, especially in the agriculture and natural resources sectors, to more reliable scientific information that would enable more rapid and accurate decision making for climate risk management. More specifically, it would provide data support for the mainstreaming activities in Component 1 of PhilCCAP and the adaptation interventions to be carried out at the local level under Component 2, by improving mechanisms for data gathering, integration, dissemination and interpretation, and through general strengthening of the capabilities of the institutions having responsibilities in this area—including the Philippines Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA). This Consultant will advise on the detailed structures and the facilitation of Component 3 in relation to Components 1 and 2 and an expert international institute will be identified to aid with the project to ensure that activities parallel the international state-of-the-art. The Consultant will be tasked with creating a design that considers the sustainability of all activities. PAGASA will mainly be responsible for the provision and analysis of climate data.

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Acknowledgments

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for the Coupled Model Intercomparison Project (CMIP), and we thank the climate modelling groups for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and has led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals. This report is a contribution to the Commonwealth Scientific Industrial Research Organization (CSIRO) Oceans and Atmosphere business unit.

The Government of the Republic of the Philippines has received for financing from the Global Environment Facility (GEF) through the World Bank toward the cost of the Philippine Climate Change Adaptation Project (PhilCCAP), from which this project was funded.

Executive summary

Climate change has been recognized as one of the greatest challenges facing our planet, not only for the environment, but also for economic development, with changes occurring in physical, ecological and socio-economic systems. Atmospheric greenhouse gas concentrations increased rapidly in the past century and are almost certain to continue increasing in the future (IPCC, 2013). Four emission scenarios are being used for climate projections: RCP2.6 (low emissions), RCP4.5 and RCP6.0 (intermediate emissions) and RCP8.5 (high emissions). Global climate model experiments indicate a global warming of 0.3-1.7 °C (RCP2.6), 1.1-2.6 °C (RCP4.5), 1.4-3.1 °C (RCP6.0) and 2.6-4.8 °C (RCP8.5) for 1981-2100 relative to 1986-2005 (IPCC, 2013). This is likely to be associated with changes to weather patterns, sea-level rise and impacts on sectors including ecosystems, water resources, agriculture, forests, fisheries, industries, urban and rural settlements, energy, tourism, health, and disaster/emergency management.

Located in South East Asia, with a tropical monsoon climate and a coastline of more than 3200 km, the Philippines is one of the most disaster-prone countries in the world (DFAT, 2012). Most of the disasters that occur in the country are related to weather and climate, and consequently climate change and climate variability are likely to pose increasing threats to the Philippines and its inhabitants in the near and long-term future. The purpose of the related *High-resolution Climate Projections for Viet Nam* project, completed in 2014, was to further climate science research and capacity building and to produce high-resolution climate projections for Southeast Asia. These new projections incorporated new climate science information released by the Intergovernmental Panel on Climate Change and provided more detailed projections at a regional level, enabling more effective adaptation planning. This report uses the results of the Viet Nam project and provides information needed for the new projections at the regional level for the Philippines.

Climate change projections are inherently uncertain. The future climate will be determined by a combination of factors, including levels of greenhouse gas and aerosol emissions, unexpected events (e.g. volcanic eruptions), a range of human activities, and sensitivity of the climate system to greenhouse gases and aerosols, as well as natural variability such as ENSO. Based on our knowledge of the laws of physics plus a number of plausible assumptions, some of these factors can be explored using models.

There are over 40 global climate model simulations of the past and future available from PCMDI. Climate models have different internal dynamics and parameterisations, and thus respond somewhat differently to the same inputs, producing a range of possible futures. This concern is partly addressed in the study by selecting CMIP5 Global Climate Models (GCMs) that reproduce current climate reasonably well before downscaling. In addition, multi-model means of variables such as temperature and rainfall are assessed to capture the central estimates of possible futures.

The Philippines has a diversity of regional climate zones in a relatively small region, and GCMs can't resolve many of the regional features relevant to the country. Also, GCMs have some imperfections in their simulation of the climate of the region, which can be at least partly improved through downscaling. These factors mean that there is significant potential for 'added value' from downscaling in the region, providing the motivation for the detailed downscaling using the regional climate models presented here.

Downscaled projections of future climate for the Philippines show a wide range of changes in temperature and rainfall. It is important to note that emissions make a significant difference to the amount of climate change projected to be experienced by the end of the century. Climate changes under a lower emissions scenario are likely to be similar in character, but lower in magnitude, than under the high emissions scenario. The multi-model median or mean changes are presented, along with the 10^{th} and 90^{th} percentiles in order to capture the spread among the model projections. This will provide some measure of uncertainty in the projections.

The model used for downscaling in this study was CSIRO's Conformal-Cubic Atmospheric Model (CCAM). The two-step method used to generate the high-resolution regional climate simulations is known as dynamical downscaling. First, data from the GCMs (approximately 200 km resolution) are used as input into CCAM, which is run globally at finer resolution (50 km). Then data from this simulation are used as input into the high-resolution simulation (25 km over the Philippines).

CCAM is a variable-resolution model, which means it can be run globally on an even grid or on a stretched grid with high resolution over the area of interest. In the projections generated here, only sea surface temperature and sea ice information from CMIP5 GCMs were used as inputs. These inputs were bias-corrected to improve their representation in the current climate, but preserve the projected climate change signal and the internal variability. CCAM simulations were completed for a continuous period from 1970-2099. Two sets of projections were completed, using two of the most recent IPCC Representative Concentration Pathways: RCP 4.5 (intermediate level of emissions) and RCP 8.5 (high emissions).

This report summarises the results generated using this data in order to help PAGASA provide regional climate projections. It describes the procedures used to generate the various data and presents some of the results in graphic form. The results present the various risks associated with various climate change indices, with uncertainty levels presented using the 10^{th}, 50^{th} and 90^{th} percentile change values among the model results.

The results show that the Philippines is likely to become warmer with fewer (and less intense) typhoons. This is associated with generally less rainfall, humidity and wind-speed, and an increase in solar radiation (sunshine). Uncertainties are large, so caution should be used when interpreting these results.

1 Introduction

The Government of the Republic of the Philippines has received financing in the amount of US$4.974 million from the Global Environment Facility (GEF) through the World Bank toward the cost of the Philippine Climate Change Adaptation Project (PhilCCAP).

The results from scientific research worldwide and in the Philippines have shown that climate change is having increasing impacts on the activities of socio-economic development and environmental protection in all regions, which has become a great challenge to sustainable development.

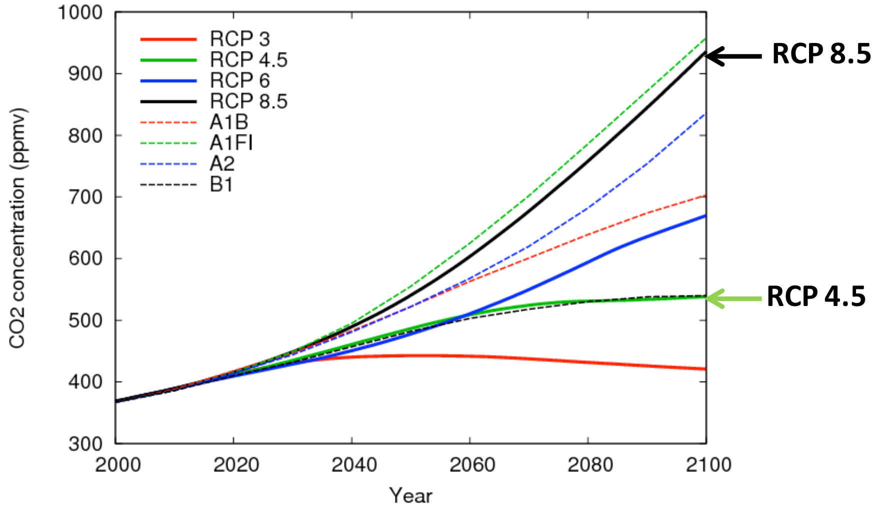
The project aims to support the building of awareness of and institutional, scientific and technical capacity of PAGASA in providing climate projection information. In order to achieve the project objectives, there is a need for technical services from an institution with advanced scientific knowledge, experience, and capability in climate modelling and in the production of credible climate change projections.

PAGASA is preparing information about Philippines's future climate from a number of downscaling models. Climate projections for the Philippines have been generated using several different regional climate modelling systems, including a number of different GCM and downscaling combinations. The spread of simulations gives some estimate of the range of possible future climates under various emissions scenarios. However, different projections are given different confidence ratings based on various lines of evidence. The physical understanding of the drivers of change, an evaluation of the simulation by models, the agreement between different models and the consistency between modelled trends and observations all feed into this confidence assessment. Once model simulations are produced, there is still a need to assess the confidence and sources of uncertainty in projections, and also to convert raw data into more useful impact-relevant indices.

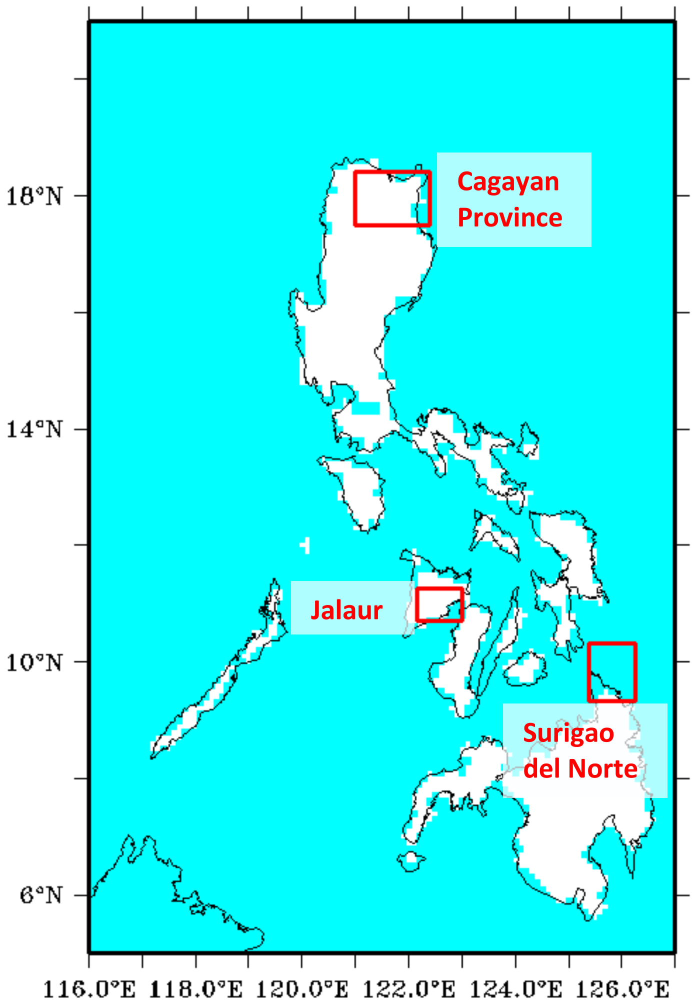
A recently completed Australian Department of Foreign Affairs and Trade (DFAT) funded project, *High-resolution Climate Projections for Viet Nam, 2012-2013*, a collaborative project between CSIRO, IMHEN and Hanoi University of Science (HUS), produced a range of high-resolution (10 km) dynamically downscaled data for Southeast Asia. The downscaling model used in this study was based upon the CSIRO's Conformal-Cubic Atmospheric Model (CCAM). These data were analysed and presented in a summary, seven regional reports and a Technical Report (available at http://vnclimate.vn). The *Development of Climate Scenarios for the Philippines*, funded by the World Bank through the PhilCCAP program, is the subject of this report and uses the high-resolution data from the Viet Nam project to further analyse projected climate change in the Philippines.

The report provides high-resolution climate projection information for the Philippines from data generated by the CCAM model simulations produced for Vietnam, but extracted for the Philippines (with resolution of about 25 km). Data used in this consultancy are from the six CCAM simulations from 1970 to 2005 for the historical period and for two sets of six simulations from 2006 to 2099 using RCP8.5 and RCP4.5. The CO_2 concentrations for the various RCPs sued in IPCC are shown in Figure 1-1. The two scenarios used in this study are indicated. Note that the concentrations stop increasing with RCP4.5 after about year 2070. Vuuren et al (2011) and Peters et al. (2013) note that for the past decade, CO2 emissions have been tracking RCP8.5 (Fuss et al., 2014).

Results were generated for the whole of the Philippines as well as for the three sub-regions indicated in (Figure 1-2). The masks used only land points in computation of the regional means.



1-1: Comparison of equivalent CO_2 concentrations (ppmv) from SRES (A1B, A1FI, A2, B1) and RCP (3[1], 4.5, 6.0, 8.5) approaches (adapted from Meinshausen *et al.* 2011).



1-2: Map of Philippine land area (white areas) from the model simulations with the three sub-regions (red labelled boxes) for which time series data is presented in this report.

[1] Note that for the lowest emission scenario, called RCP 2.6 in this report, the radiative forcing peaks at 3 Watts m^{-2} then declines to 2.6 Watts m^{-2} by the end of the 21st century.

2 Computation of ensemble median and percentiles to capture the range of future climate change projections

2.1 Procedure

For this project, climate projection results came from the CCAM model. The CCAM ensemble had six members, driven by sea surface temperatures from six different GCMs (ACCESS1-0, CCSM4, CNRM-CM5, GFDL-CM3, MPI-ESM-LR and NorESM1-M) which performed well in for the current climate (see Katzfey et al., 2014). The sea surface temperatures were bias and variance corrected before used in CCAM. Sea ice distribution from the GCMs were also used in the CCAM simulations.

Although results were generated in this project for both RCP4.5 and RCP8.5 for the full time series (1970 to 2099) for all of the Philippines, and the three sub-regions, this report will focus on results for two time periods: mid-century (2046-2065) and end of century (2080-2099) for spatial maps. Changes from the 1986-2005 baseline mean are presented for the full time series (1970 to 2099) for the regional averages over the Philippines and the three subregions. The full set of data has been provided to PAGASA.

In order to present the range of possible future changes, the mean of the six ensemble members was calculated, along with the 10^{th} and 90^{th} percentiles. Note with six members, the 10^{th} and 90^{th} percentiles will be the smallest and largest change values. This quantifies one measure of uncertainty, but it should be noted that other uncertainties have not been quantified, e.g. results from downscaling a larger ensemble of models, or changes in natural decadal variability.

3 Surface variables

In this section, a summary of the results for surface variables is presented. Although data have been generated seasonally, as well as annually, only annual results will be presented in this report. Plots are given for the current climate, as well as the ensemble mean, 10^{th} and 90^{th} percentile changes for RCP4.5 and RCP8.5 based upon the six CCAM simulations.

3.1 Procedure

The procedure used to calculate the variables is summarized here. Initially, the daily data for each variable (2 metre daily maximum air temperature (Tmax), 2 metre daily minimum air temperature (Tmin), 2 metre daily average air temperature (Tave), rainfall, mean sea-level pressure, 10 metre wind speed, 2 metre relative humidity and downward solar radiation) were extracted from each of the six CCAM simulations for the whole region and concatenated into a time series. This analysis was done for both RCP8.5 and RCP4.5.

For the above variables, averages (annual and seasonally) were computed for the base period (1986-2005) using the cdo software package (https://code.zmaw.de/projects/cdo/embedded/index.html). Using these averages, a time series was computed by subtracting the 1986-2005 means to get the time-evolving changes for each of the six model simulations for both RCPs.

A range of extreme indices were computed (see Table 3-1 for a summary). These indices were chosen to explore a range of extremes indices for both temperature and rainfall.

Care must be taken in using these results partly because only one model was used for downscaling 6 GCMs, although there are more than 40 GCMs available. The larger ensemble, based upon more GCMs and other downscaling, could provide a greater range of possible futures than from one RCM downscaling just six GCMs. In addition, due to significant spatial variability of some of the projected values, care must be taken in using data from just one region, especially if that region is small, to ensure that the climate change signal is representative of the region. In addition, assessing the accuracy of the simulations' ability to capture current climate is important (see Katzfey et al., 2014, for more discussion of this and other issues related to using projections). Finally, some measure of statistical significance should be used in order to ensure that the climate change signal is robust. This was not done in this report, though some measure of significance can be assessed by comparing the change values relative to the spread of the ensemble members. If the change signal is larger than the spread, it is very likely the changes will be significant, even with the relatively small sample size.

One other potential area of interest is the change in the spread of the simulated change signal in the ensemble. The spread is a measure of uncertainty in the projections for a given parameter, but also a measure of the risk for larger changes than just the median change value. Increase in the magnitude of this spread could indicate the risk of more extreme annual events than in the past. This could have significant impacts on the risk of a certain event, even though the ensemble mean of the simulations does not change much.

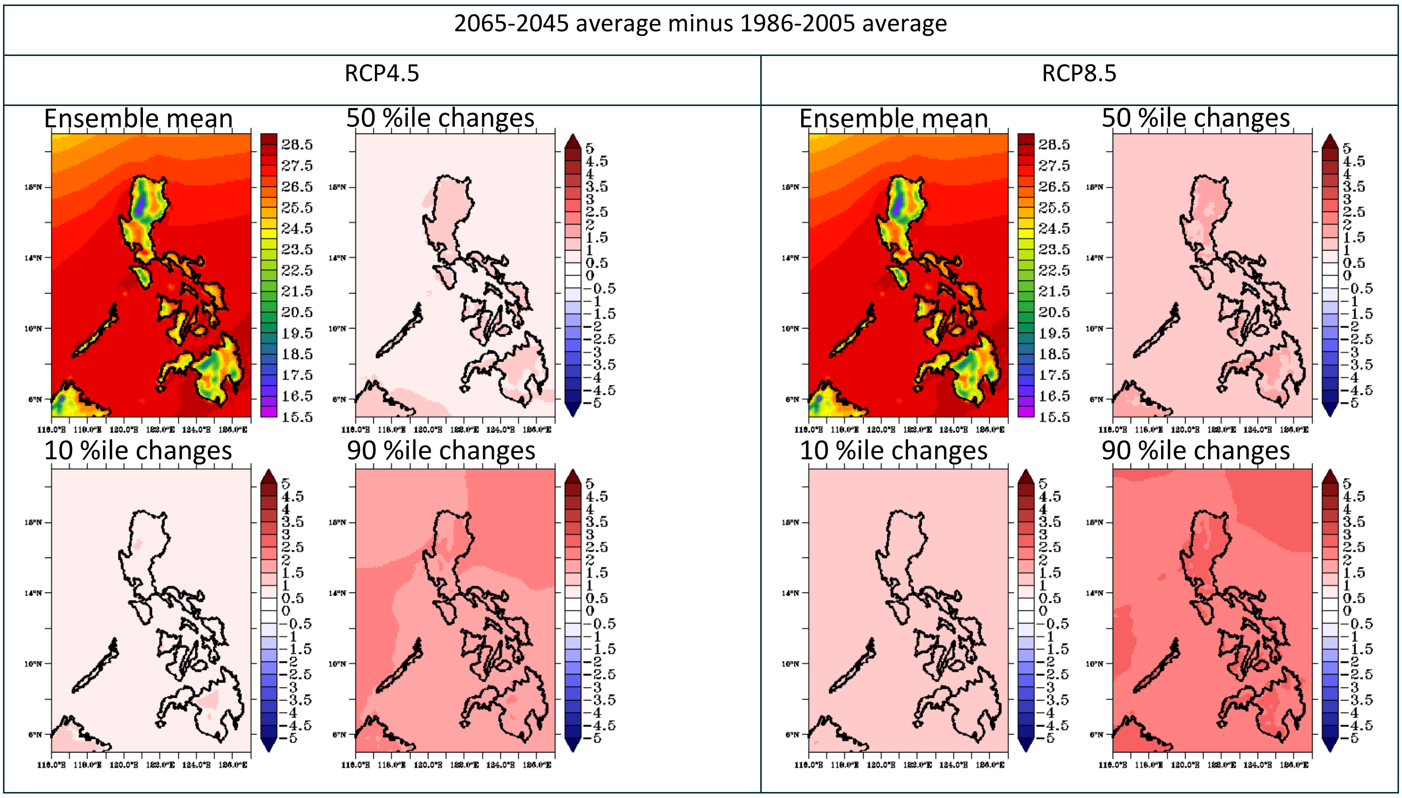
Table 3-1 Indices used in this study

TX90p	Temperature at the 10th percentile of the minimum temperature (°C)
TN10p	Temperature at the 90th percentile of the maximum temperature (°C)
TA10p	Temperature at the 10th percentile of the daily average temperature (°C)
T35	Days with Tmax greater than 35°C
T13	Days with Tave less than 13°C
RX1day	Maximum 1-day precipitation (mm)
RX5day	Highest annual consecutive 5-day precipitation amount (mm)
	Number of 5-day high precipitation events with greater than 50 mm
CDD	Annual maximum period with more than 5 days of rainfall less than 1 mm/day (days)
	Annual number of periods with more than 5 days of rainfall less than 1 mm/day
CWD	Annual maximum period with more than 5 days of rainfall greater than 1 mm/day (days)
	Annual number of periods with more than 5 days of rainfall total greater than 50 mm
SDII	Average daily rainfall for days with greater than 1 mm
PD1	Number of days with rainfall greater than 1 mm
R10mm	Number of days with rainfall greater than 10 mm
R20mm	Number of days with rainfall greater than 20 mm
PD50	Number of days with rainfall greater than 50 mm
PD100	Number of days with rainfall greater than 100 mm

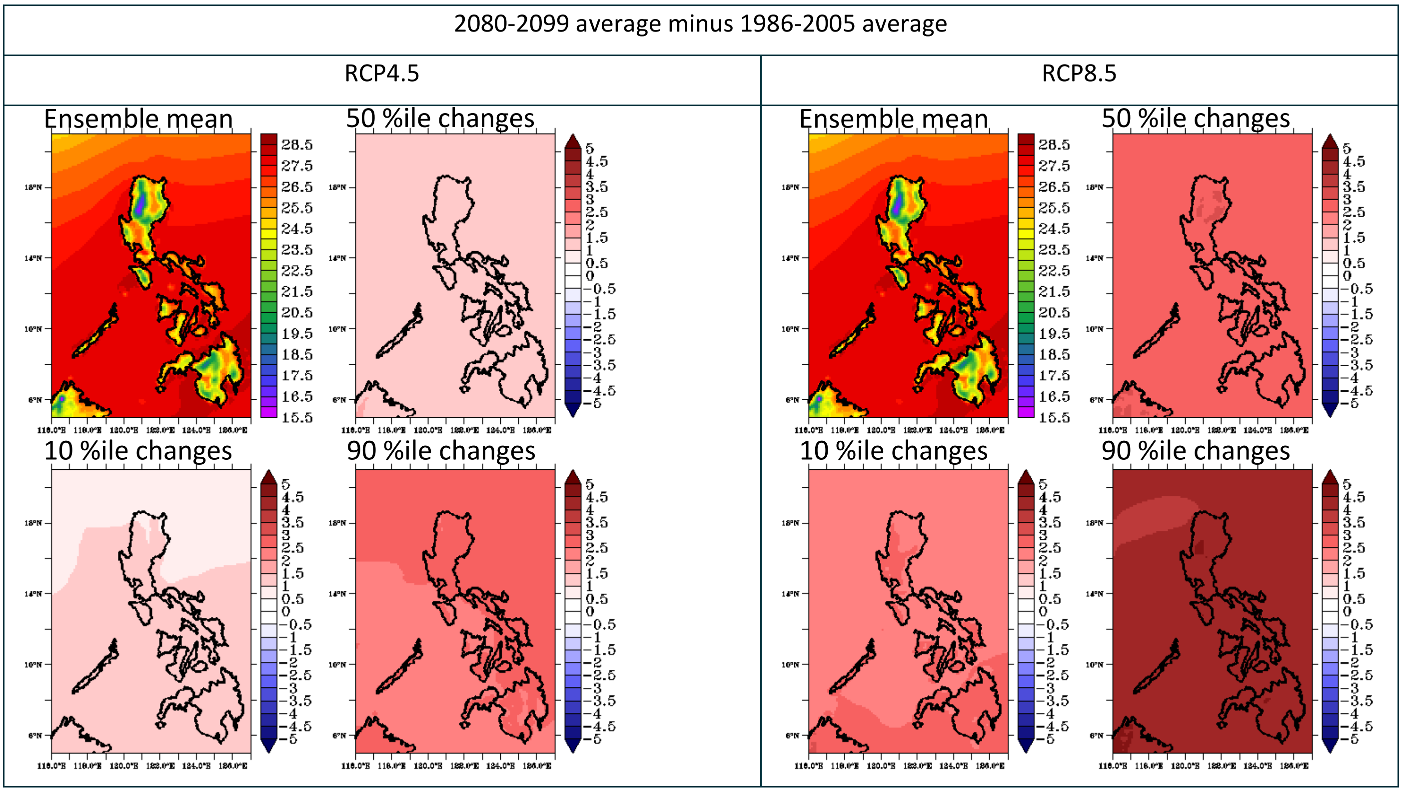
3.2 Tave: Average air temperature

The average annual surface temperature shows a large amount of warming by the end of the century, with all models agreeing on warming, as evidenced in both the maps for mid-century and the end of century (Figures 3-1 and 3-2) and the time series plots (Figure 3-3), especially with higher greenhouse gas concentrations (RCP8.5). The 90th percentile warming approaches 5 °C in northern Philippines by end of the century with RCP8.5.

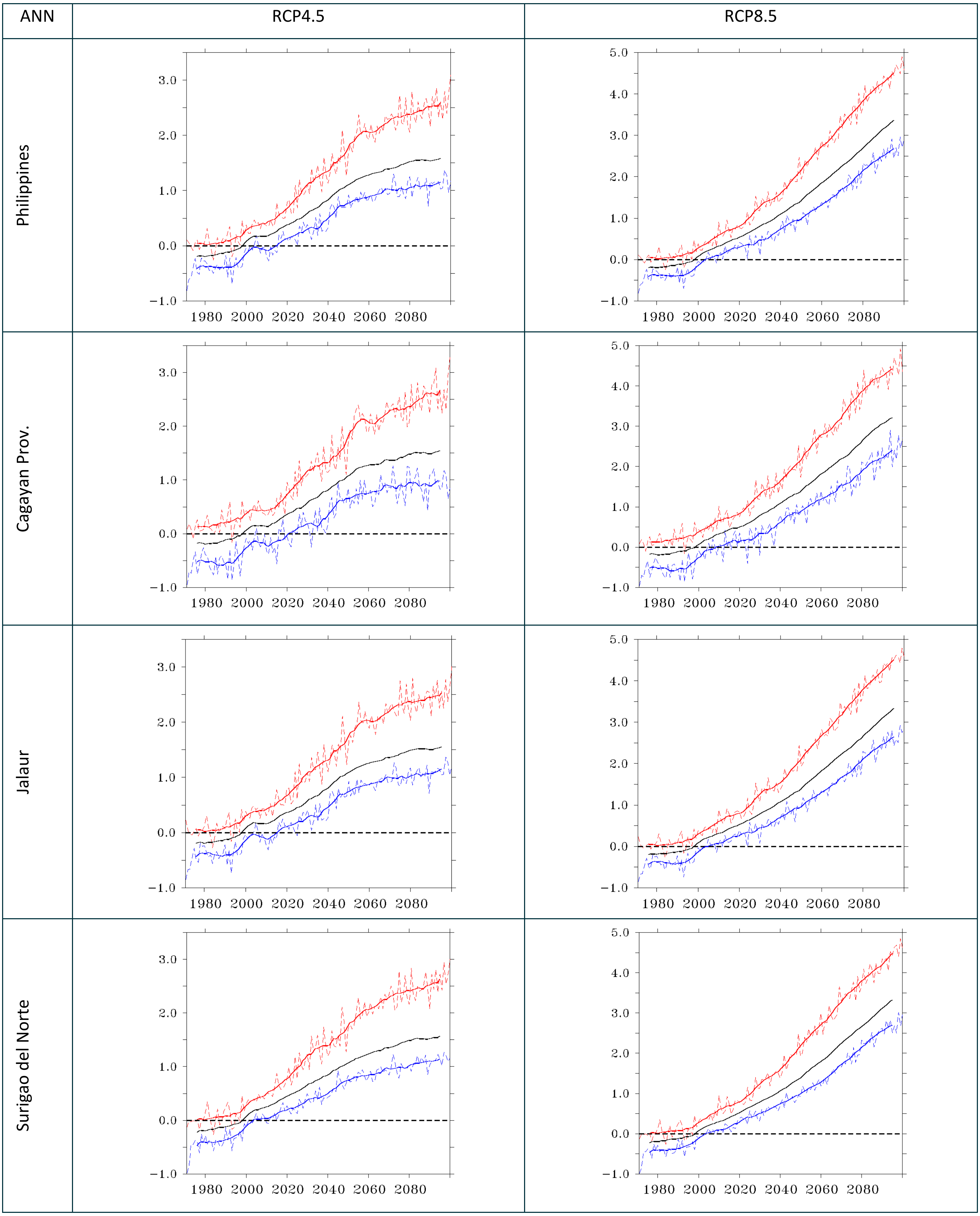
The time series suggests that, under RCP4.5, the rate of warming decreases after mid-century. There is steady warming under RCP8.5. These are consistent with the expected radiative forcing resulting from the CO_2 concentrations for the two RCPs (see Figure 1-1).



3-1: Average air temperature 2 metres above the surface (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



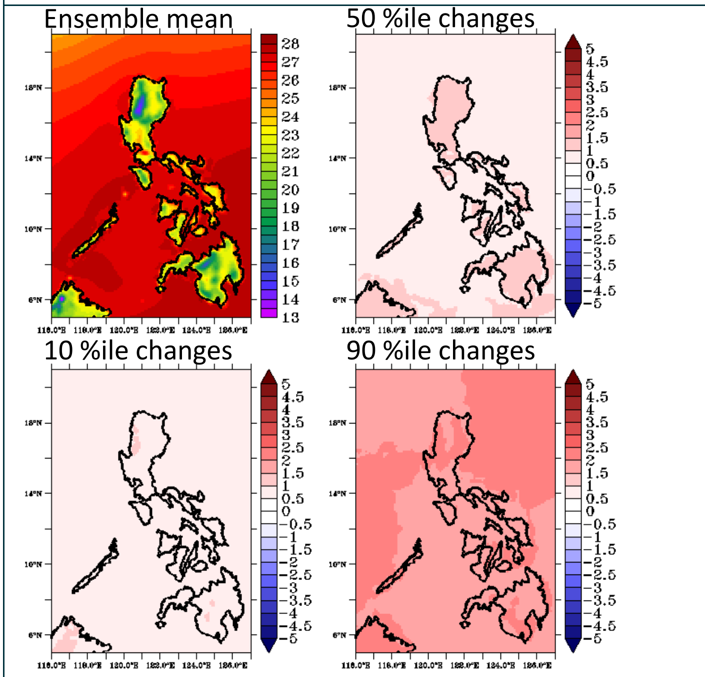
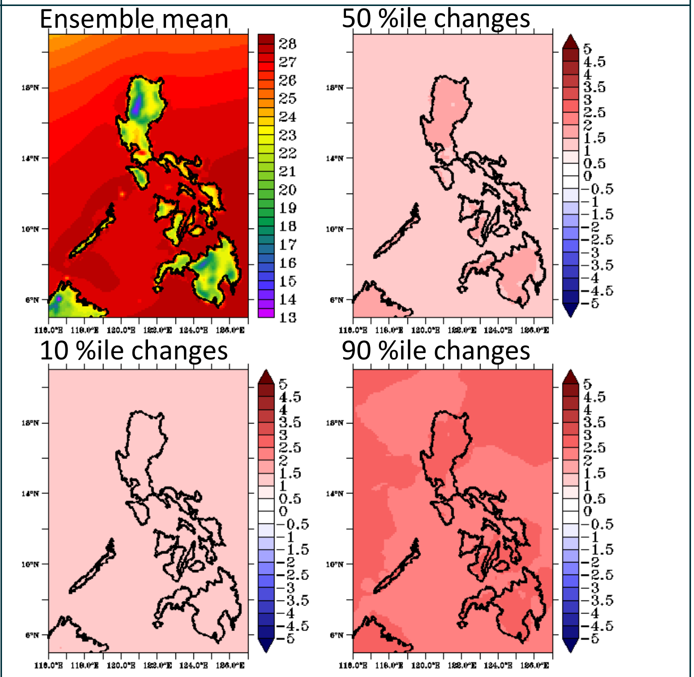
3-2: Average air temperature 2 metres above the surface (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-3: Time series plots of change in the annual average air temperatures (°C) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean while dashed lines show annual values. Dashed black line is zero mark.

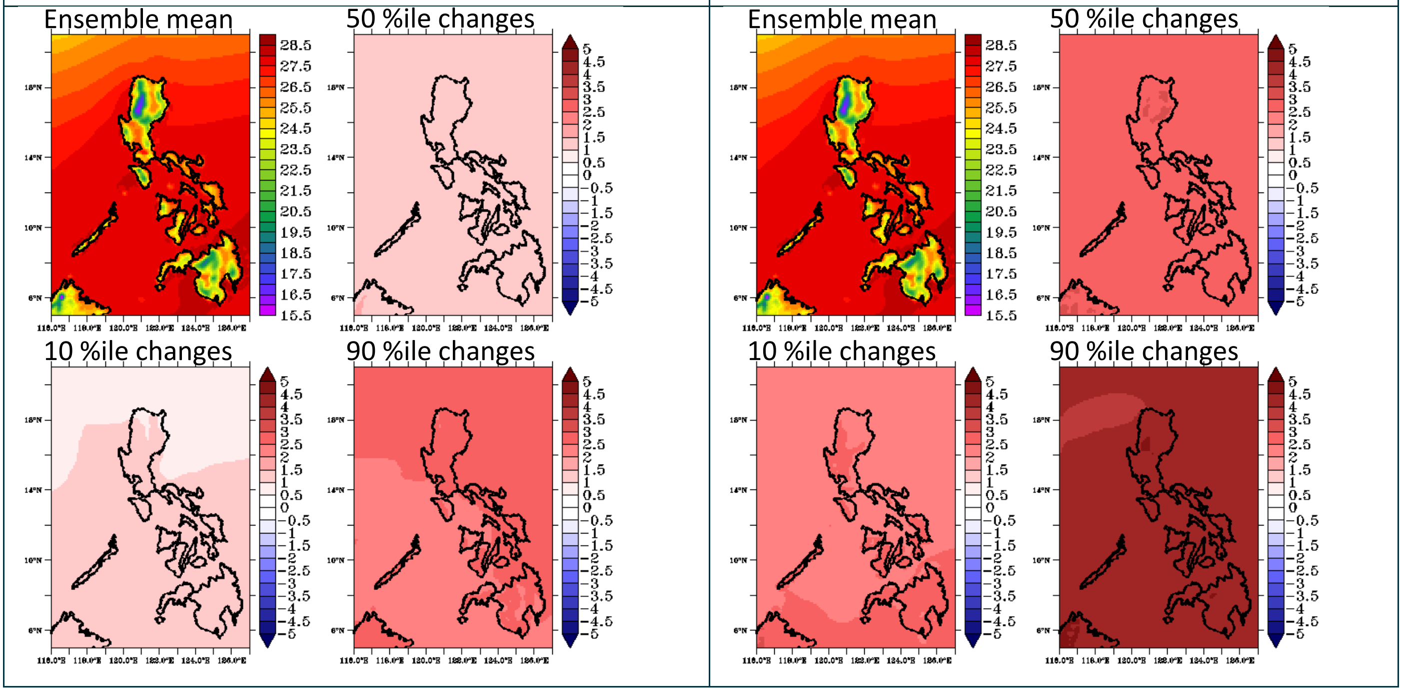
3.3 Tmin: Average daily minimum air temperature

Similar to the average 2 metre air temperature, the daily minimum air temperature shows strong warming by the end of the century for RCP8.5 (Figures 3-4, 3-5 and 3-6). The magnitude and pattern of warming is very similar to average air temperature. The warming is steady for RCP8.5, but the rate of warming decreases after mid-century with RCP4.5.

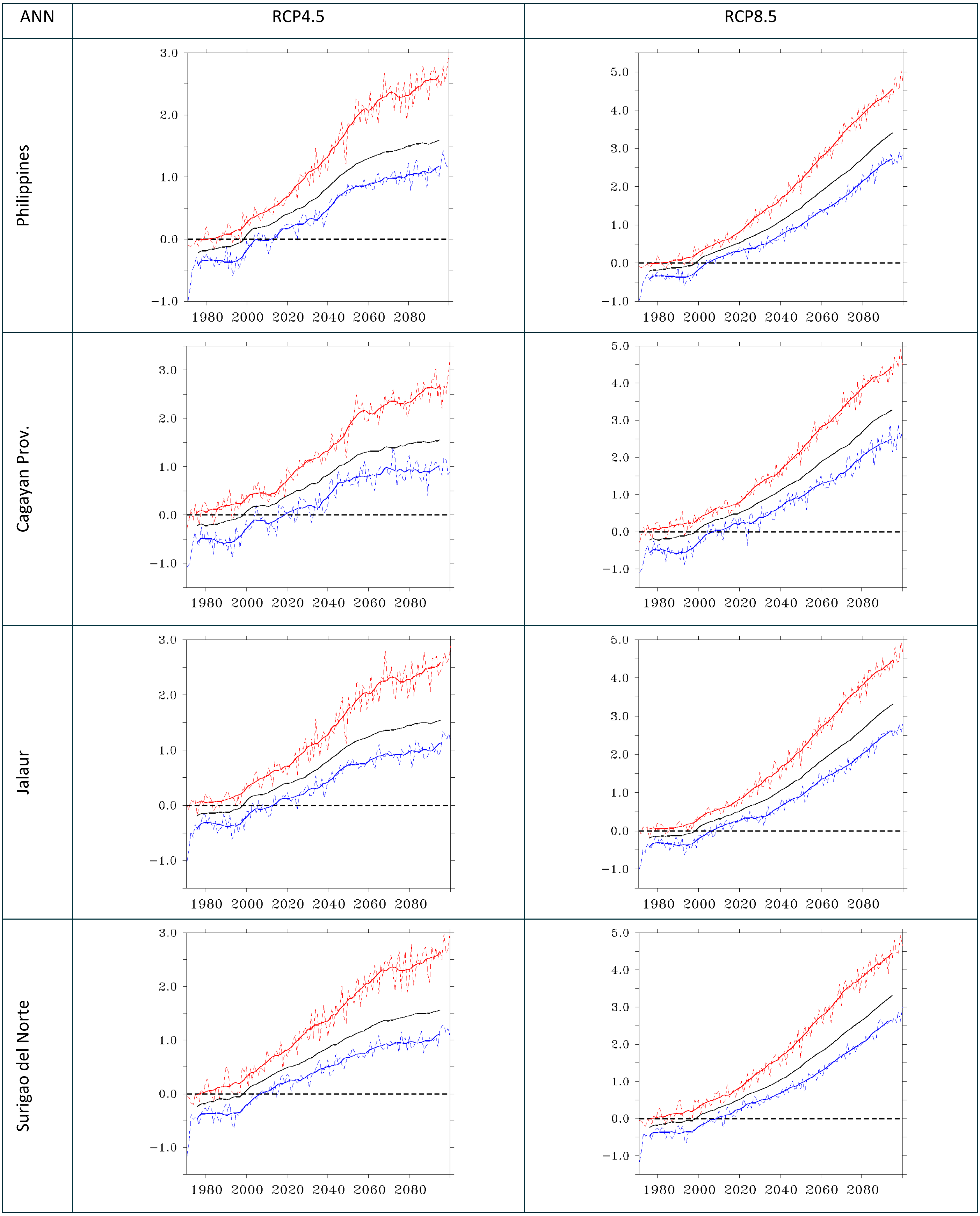
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5
	

3-4: Average daily minimum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5



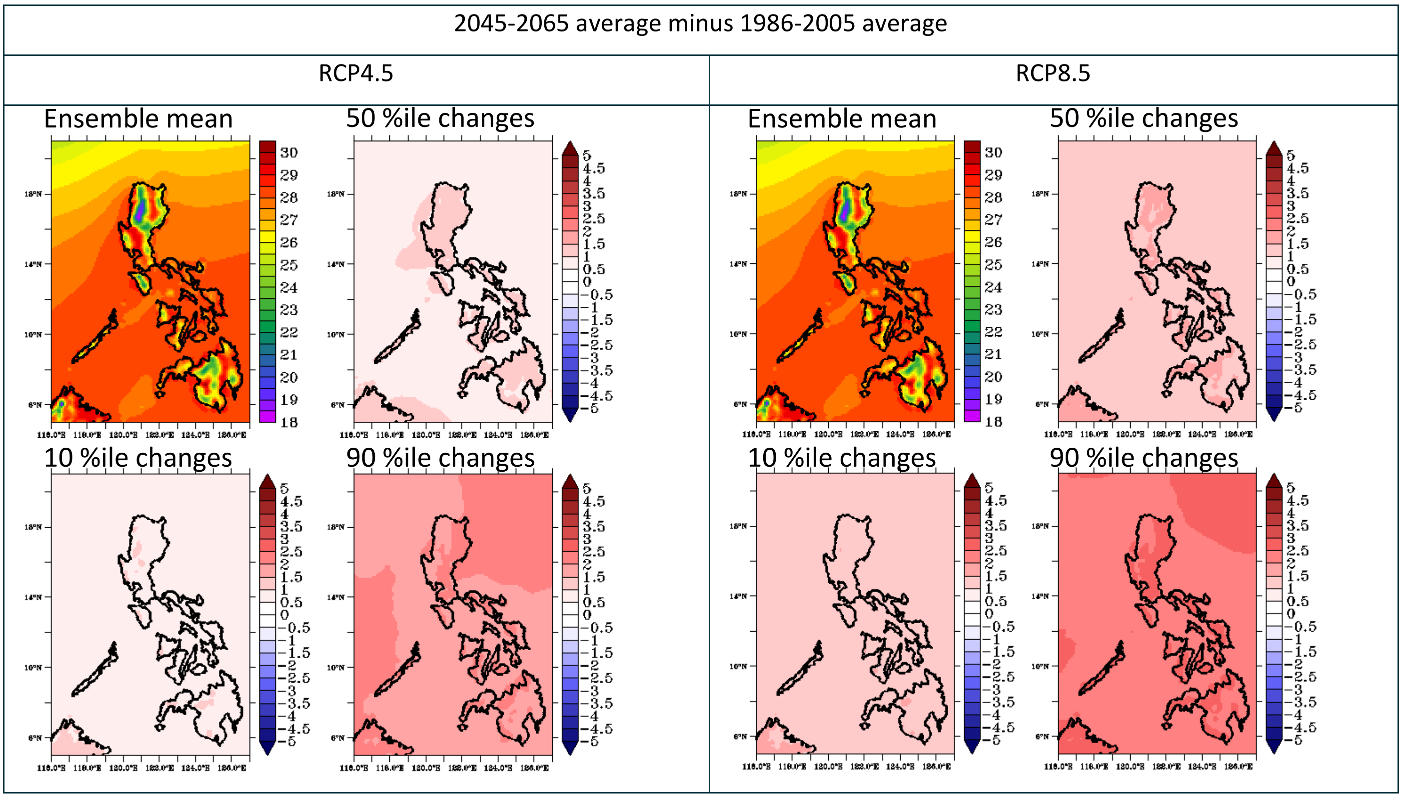
3-5: Average daily minimum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



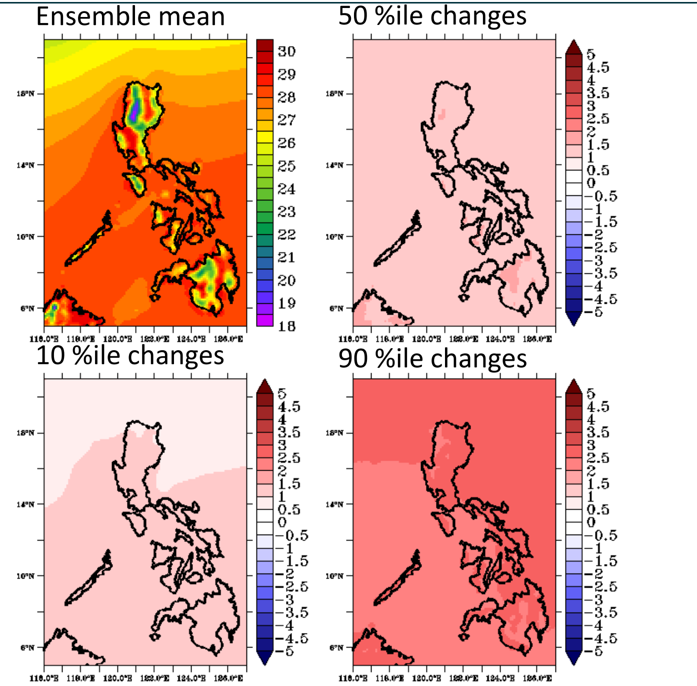
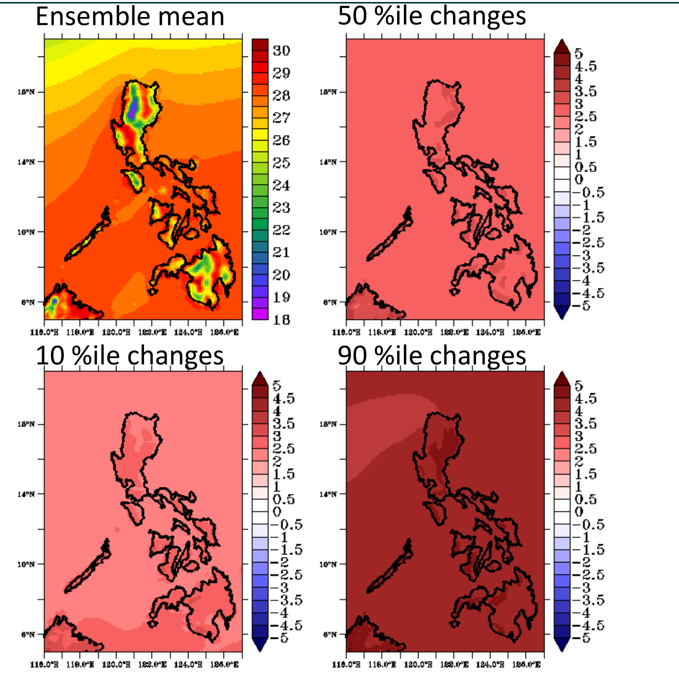
3-6: Time series plots of annual average daily minimum air temperatures (°C) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.4 Tmax: Average daily maximum air temperature

Similar to the average 2 metre air temperature, the daily maximum air temperature is projected to warm strongly by the end of the century for RCP8.5 (Figures 3-7, 3-8 and 3-9). Again this warming is similar to average air temperature and minimum temperatures. There is slightly greater warming (0.1°C) projected for maximum temperature relative to average and minimum temperatures, especially for northern and western Philippines.



3-7: Average daily maximum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5
	

3-8: Average daily maximum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP8. RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

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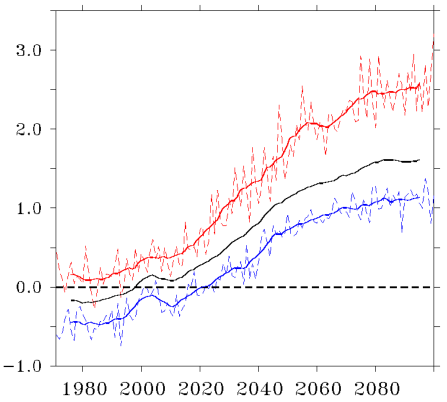
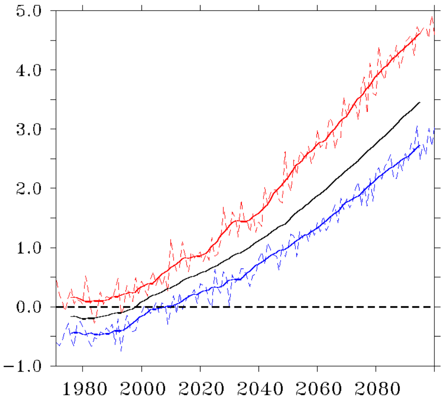
<tr><td>Philippines</td><td>
</td><td>
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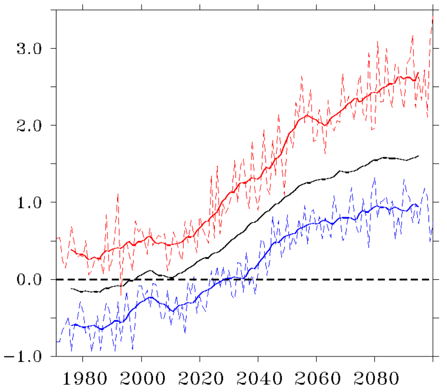
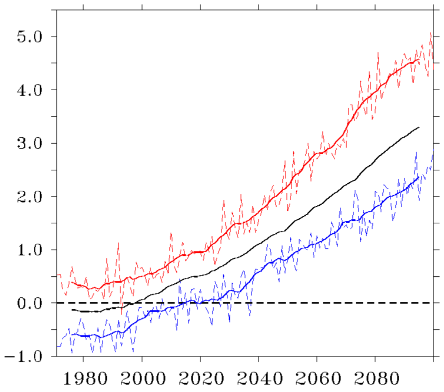
<tr><td>Cagayan Prov.</td><td>
</td><td>
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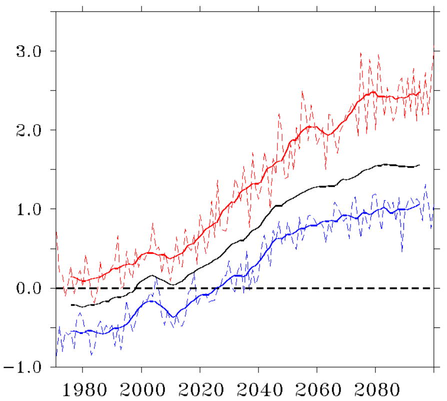
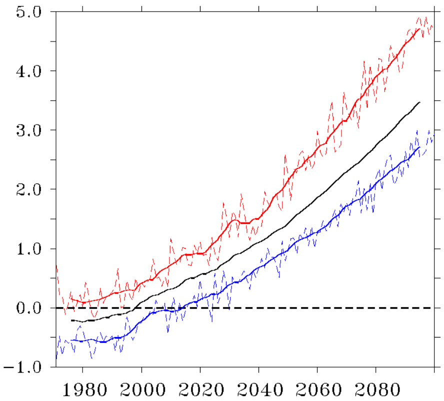
<tr><td>Jalaur</td><td>
</td><td>
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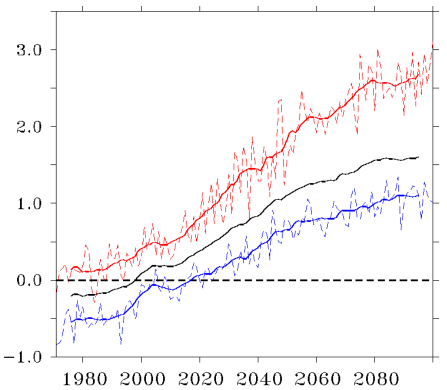
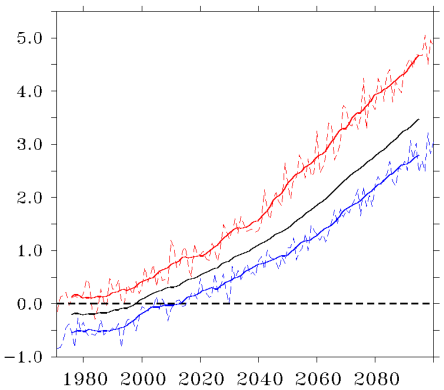
<tr><td>Surigao del Norte</td><td>
</td><td>
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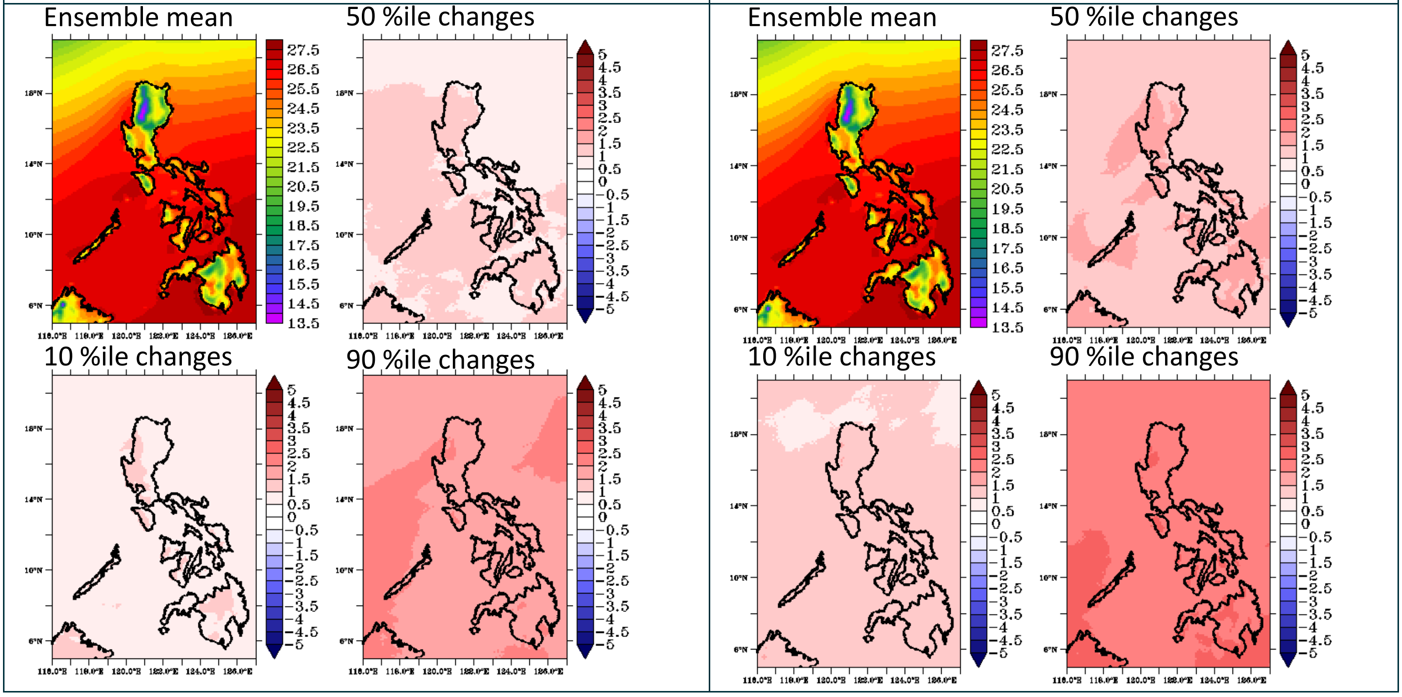
3-9: Time series plots of change in the annual average maximum air temperature (°C) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

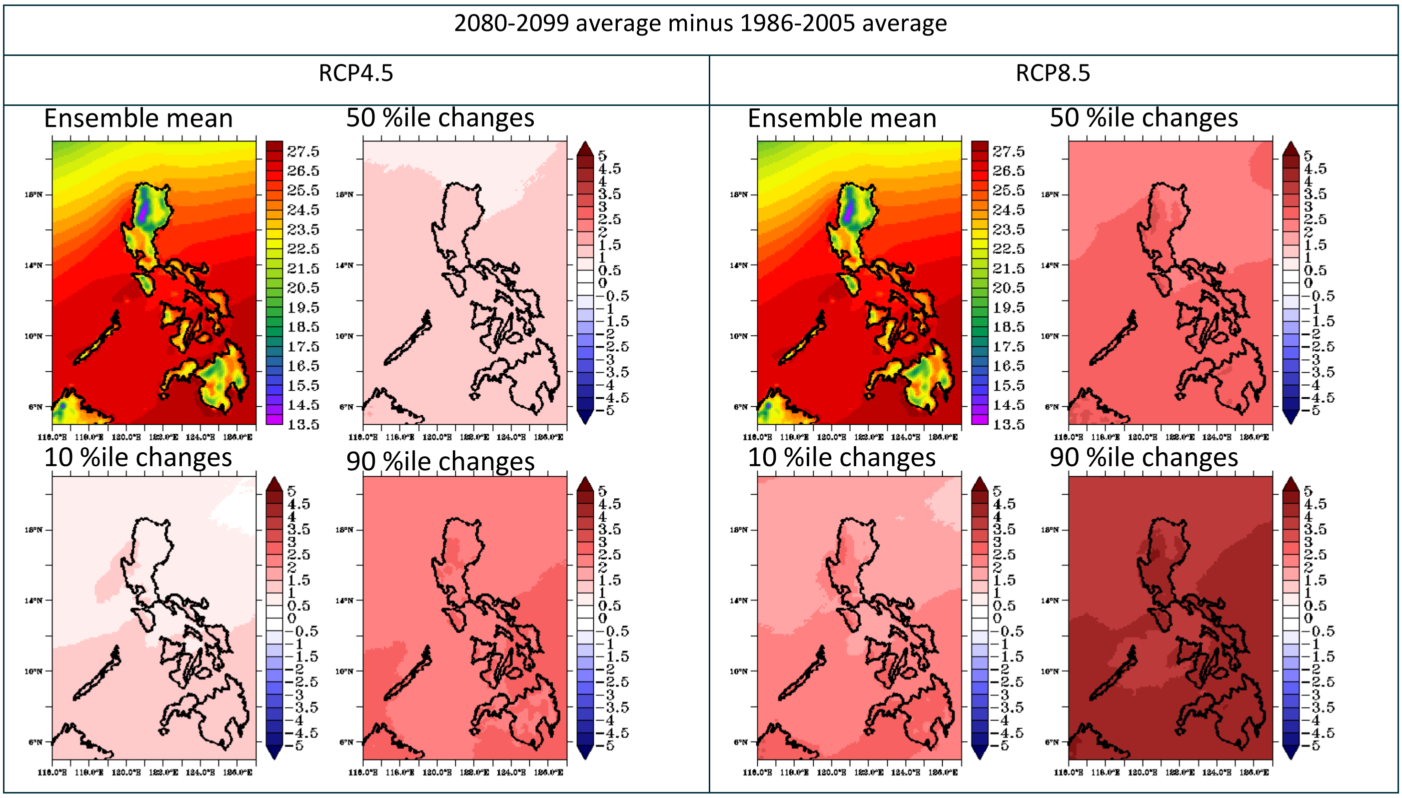
3.5 10th percentile of daily average air temperature (TA10p)

The 10th percentile of average air temperature is an indication of the temperature for cool days throughout the year. An increase in this index shows that the temperature of cool days is increasing. The plots below (see Figures 3-10, 3-11 and 3-12) show an increase of about 3°C in the temperature of a typical cool day by the end of the century with RCP8.5. The rate of increase under RCP4.5 decreases and temperature stops increasing for Cagayan Province by end of the century.

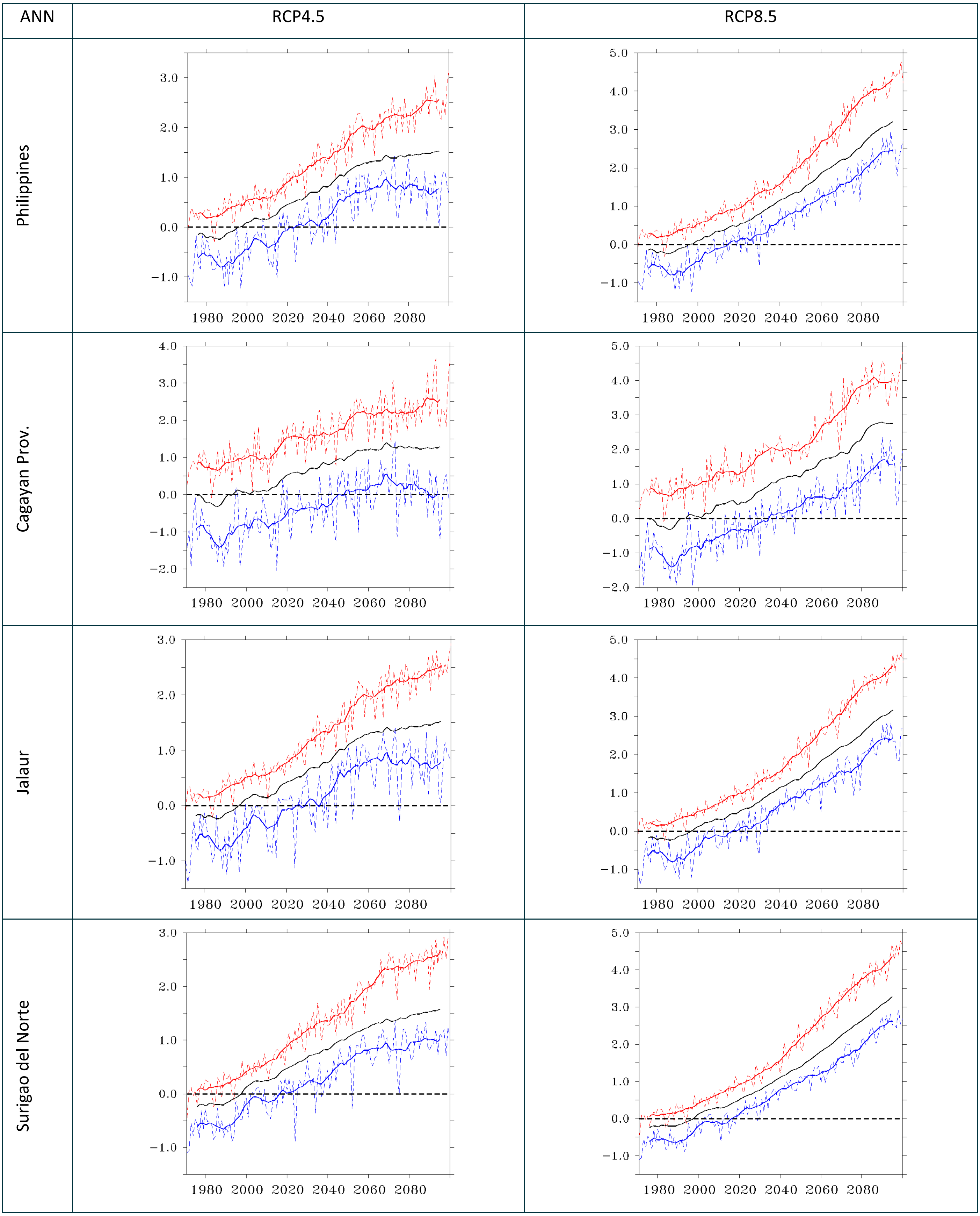
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-10: Average 10th percentile of average air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



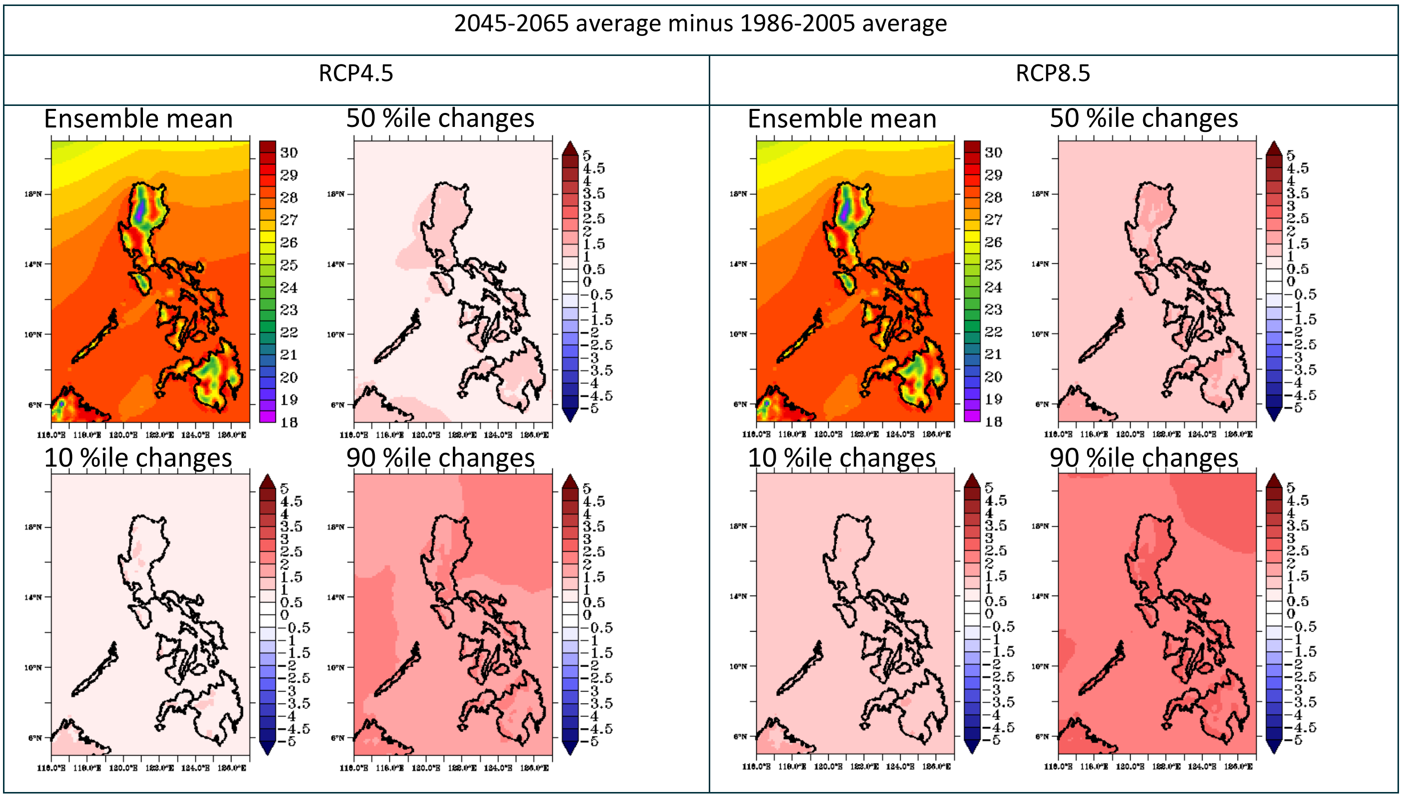
3-11: Average 10th percentile of average air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



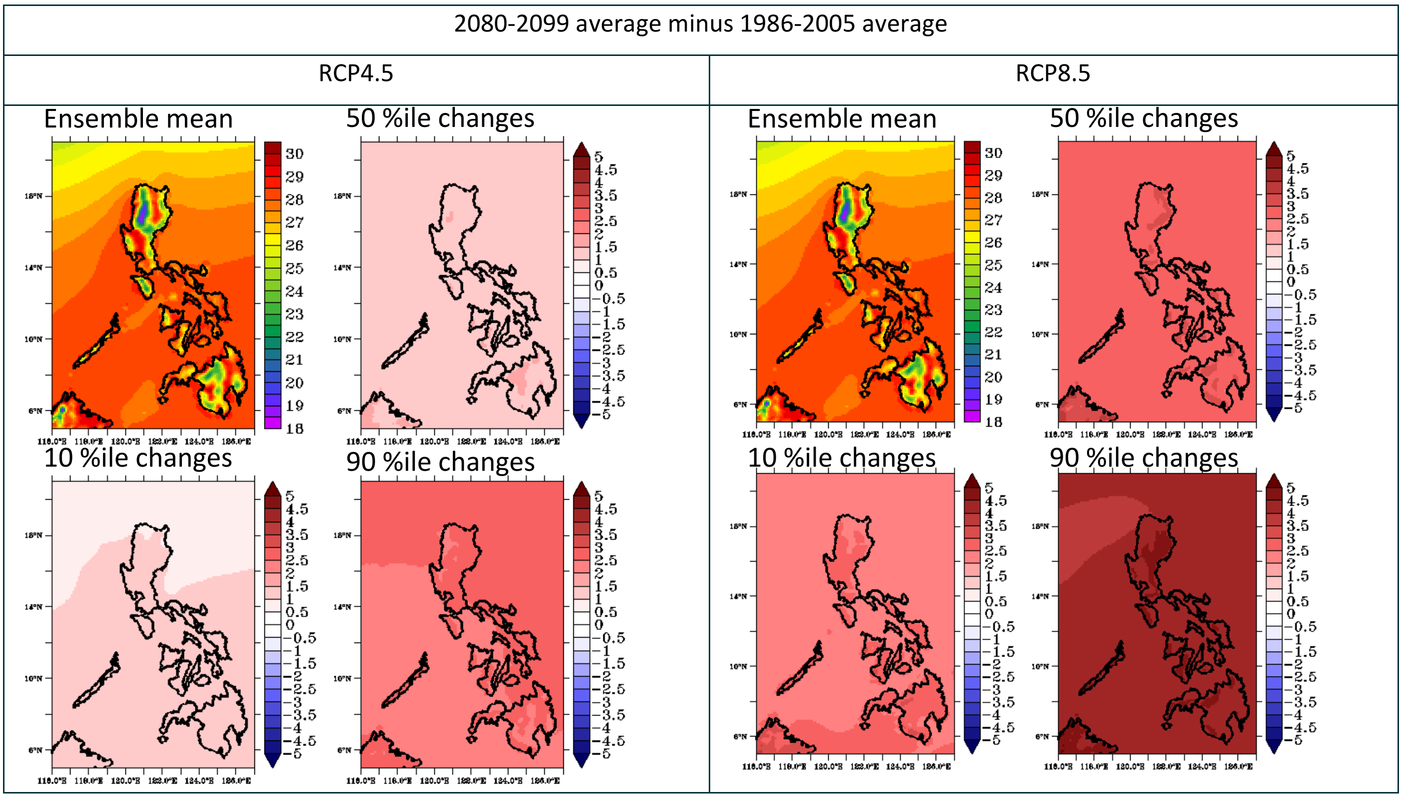
3-12: Time series plots of change in the 10th percentile of average air temperature for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.6 90th percentile of maximum air temperature (TX90p)

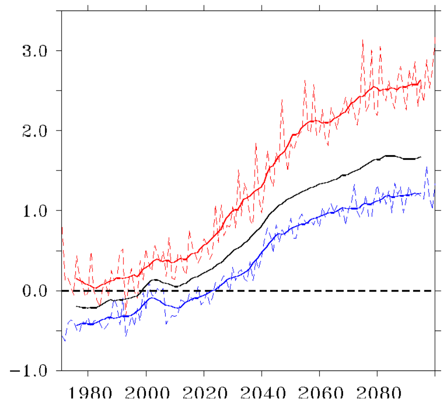
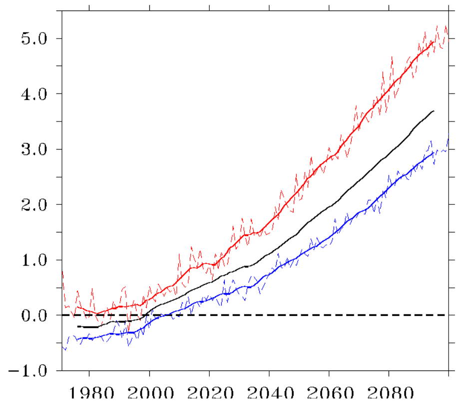
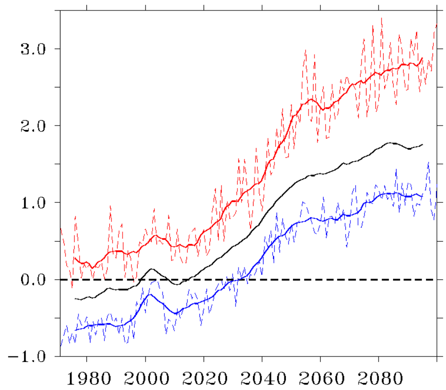
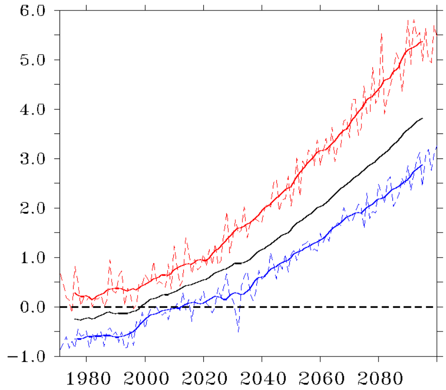
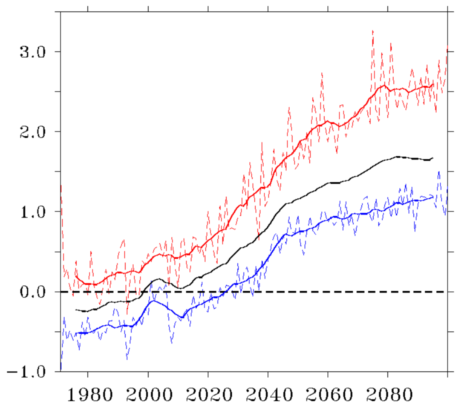
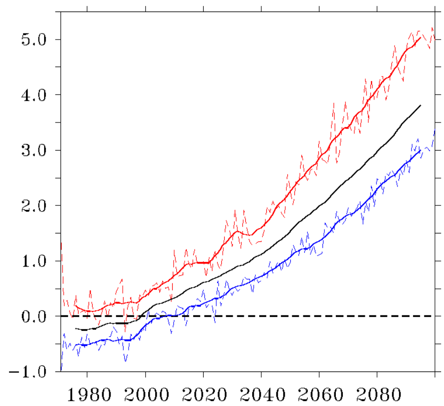
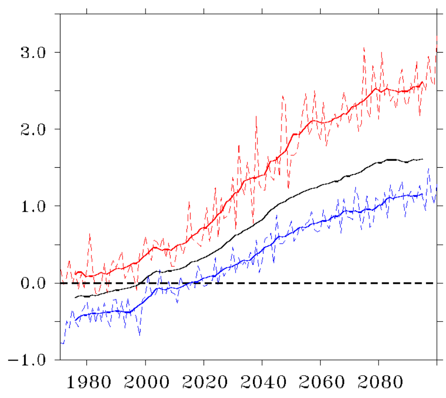
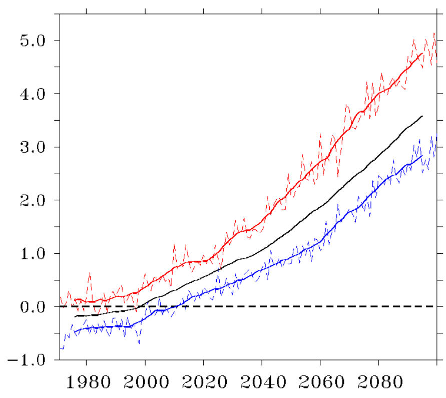
The 90th percentile of maximum temperature is the temperature for a typical warm day during the year. The projected changes in number of the 90th percentile of daily maximum temperature (TX90p) indicates significant increase throughout the century (Figure 3-13, 3-14 and 3-15). The amount and pattern of warming is similar to the maximum air temperature.



3-13: Average 90th percentile of maximum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



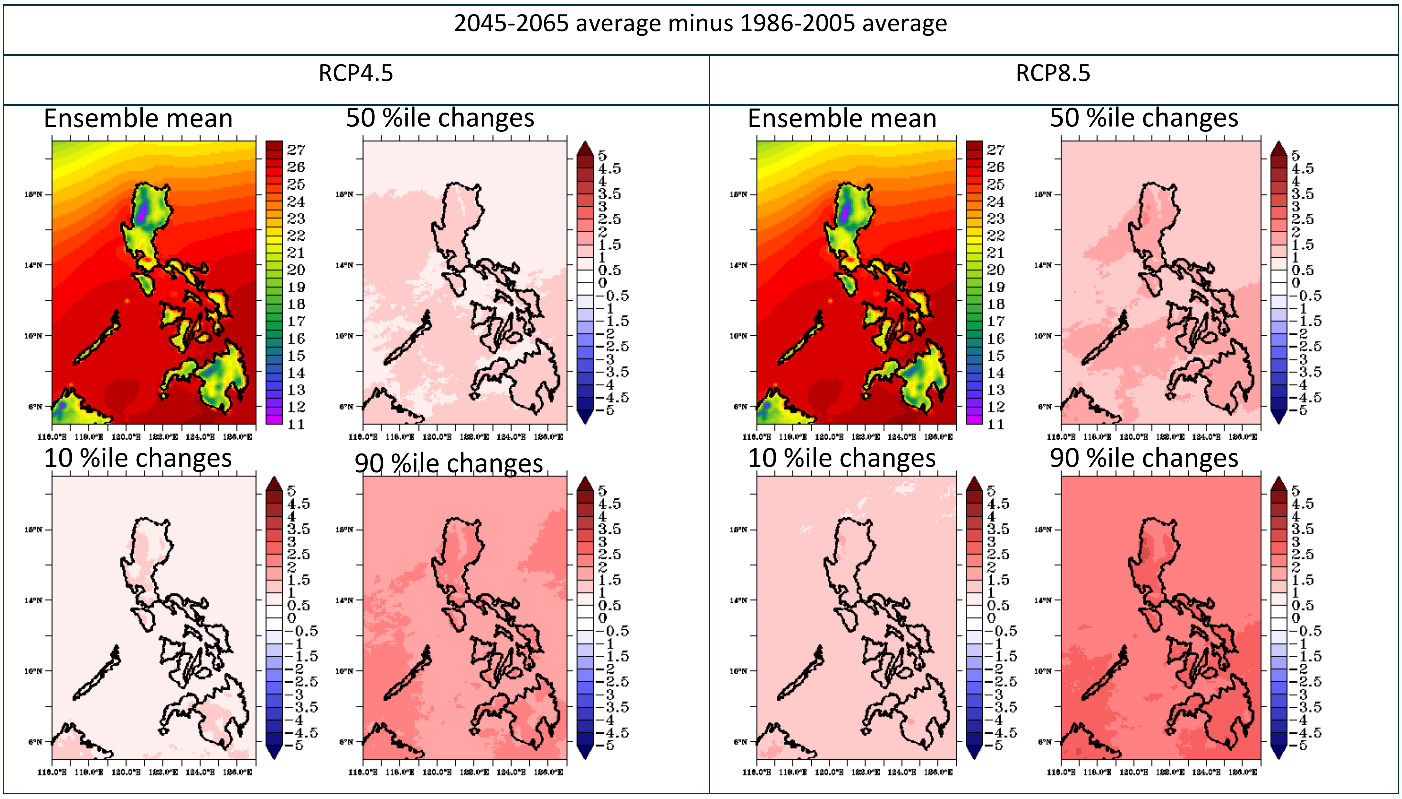
3-14: Average 90th percentile of maximum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

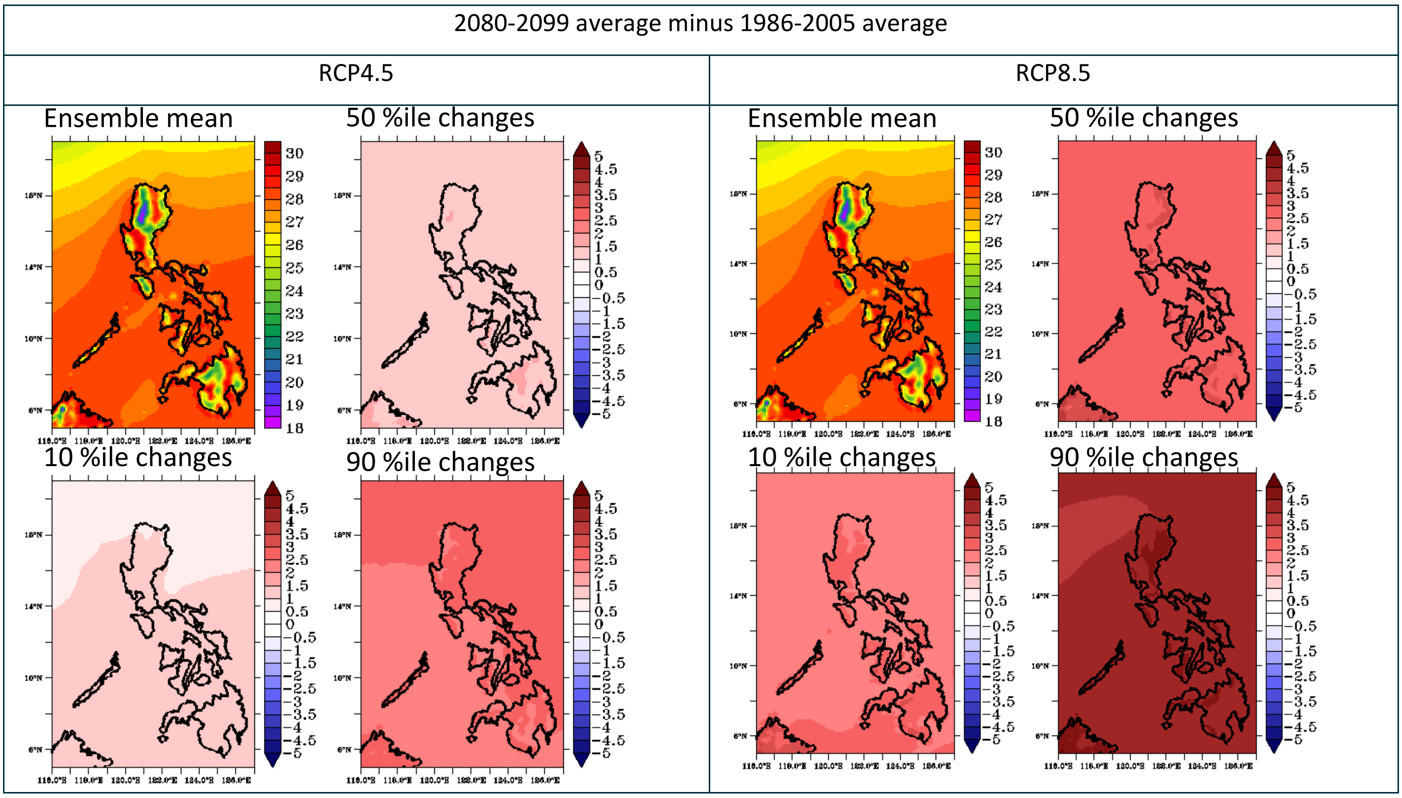
3-15: Time series plots of change in the annual 90th percentile of maximum air temperature (°C) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.7 10th percentile of daily minimum air temperature (TN10p)

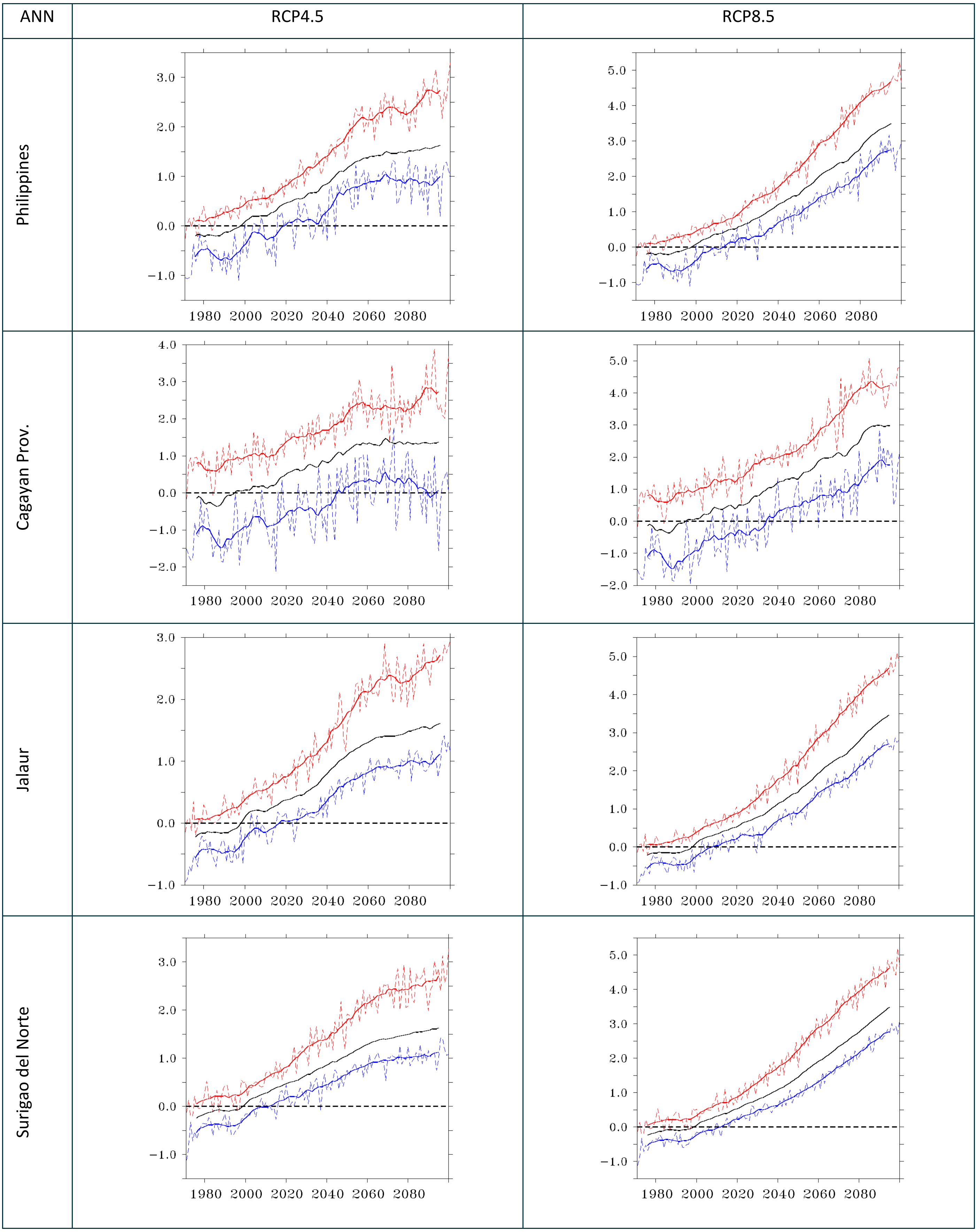
The 10th percentile of minimum air temperature (TN10p) is a measure of the temperature for cool nights over the year. Commensurate with the increase in the minimum air temperature, the 10th percentile of the minimum temperatures is projected to increase by the end of the century for RCP8.5 (Figure 3-16, 3-17 and 3-18).



3-16: Average annual 10th percentile of minimum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-17: Average annual 10th percentile of minimum air temperature (°C) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

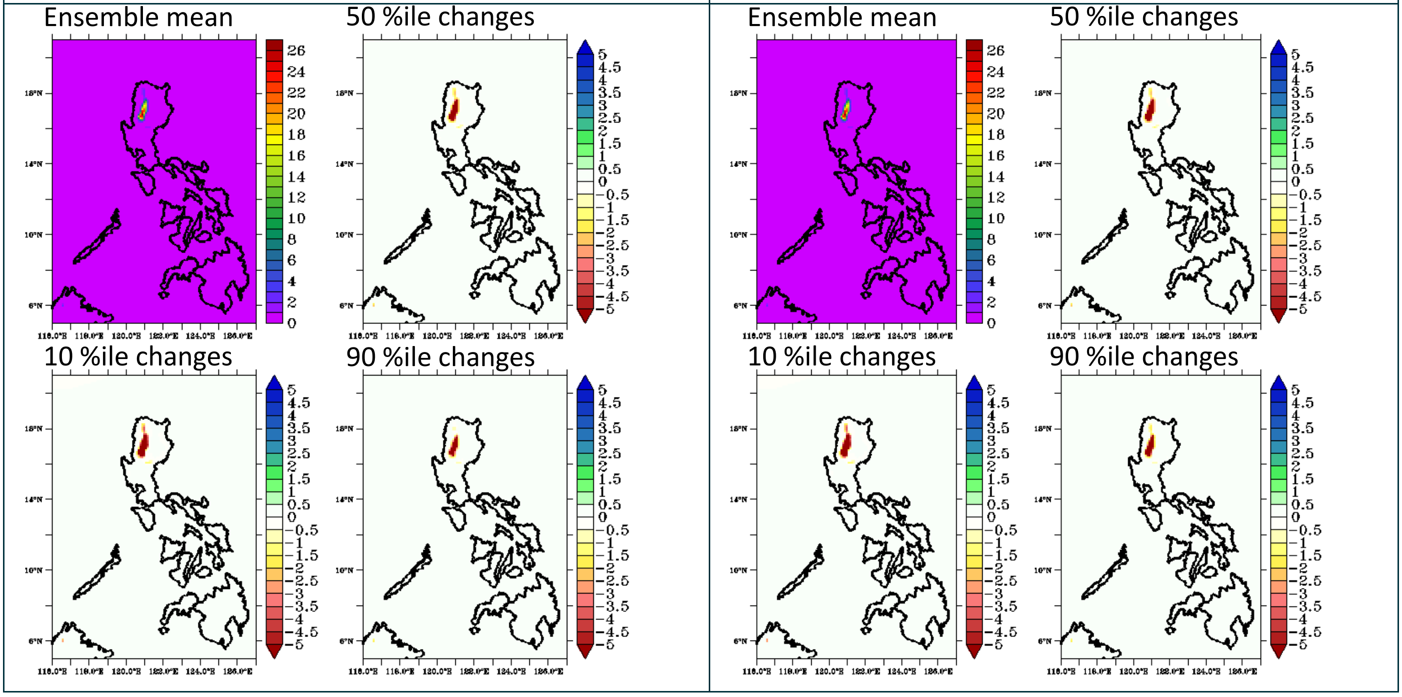


3-18: Time series plots of change in the annual 10th percentile of minimum air temperature (°C) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

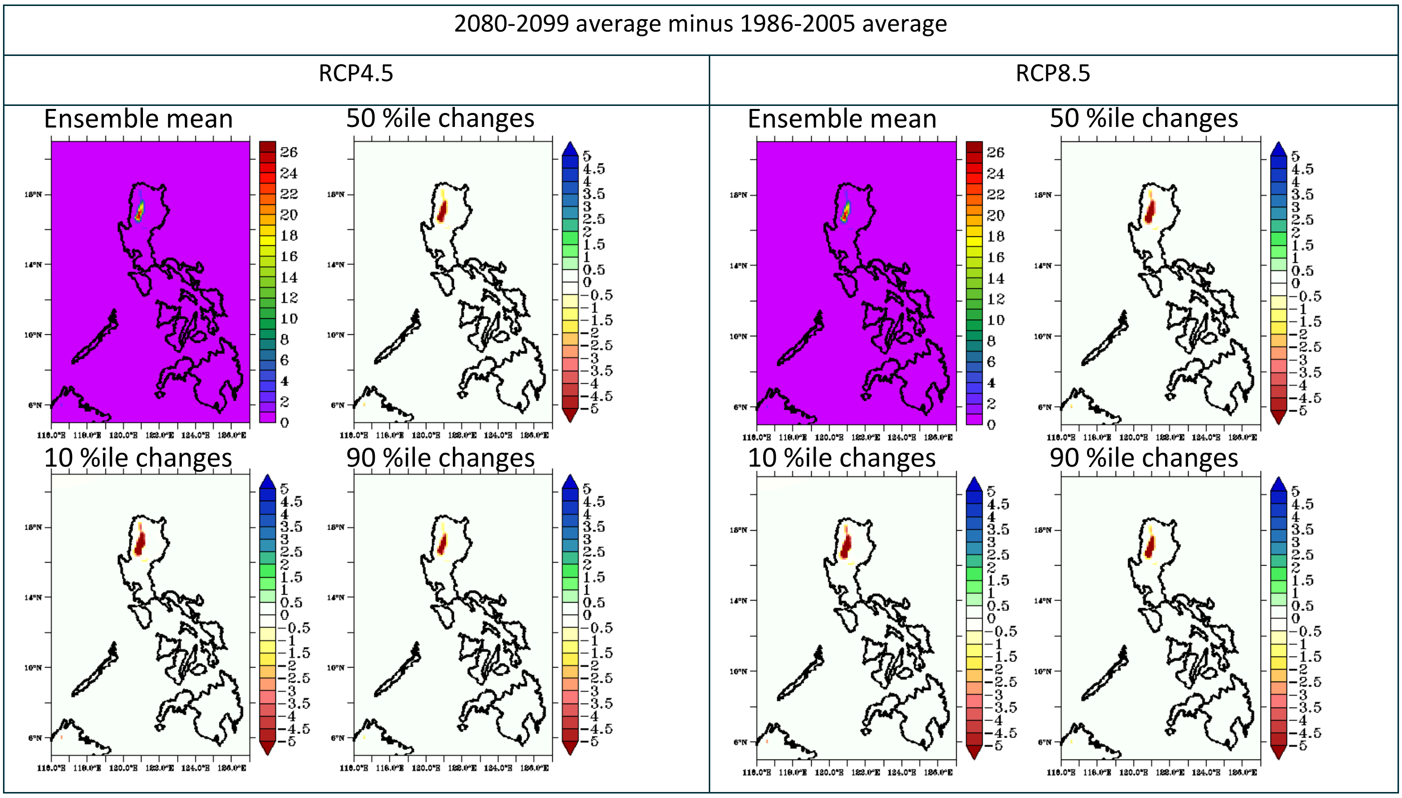
3.8 Number of days annually with average daily temperature below 13°C (T13)

Cold days (with average temperature less 13°C) do not occur in most of the Philippines, except in northern mountainous regions. In the region where it does occur currently, it is projected to decrease by the mid and end of the century for RCP4.5 and RCP8.5 (Figures 3-19, 3-20 and 3-21). The values decrease from just above 20 days to around 10 days by the end of the century for RCP8.5.

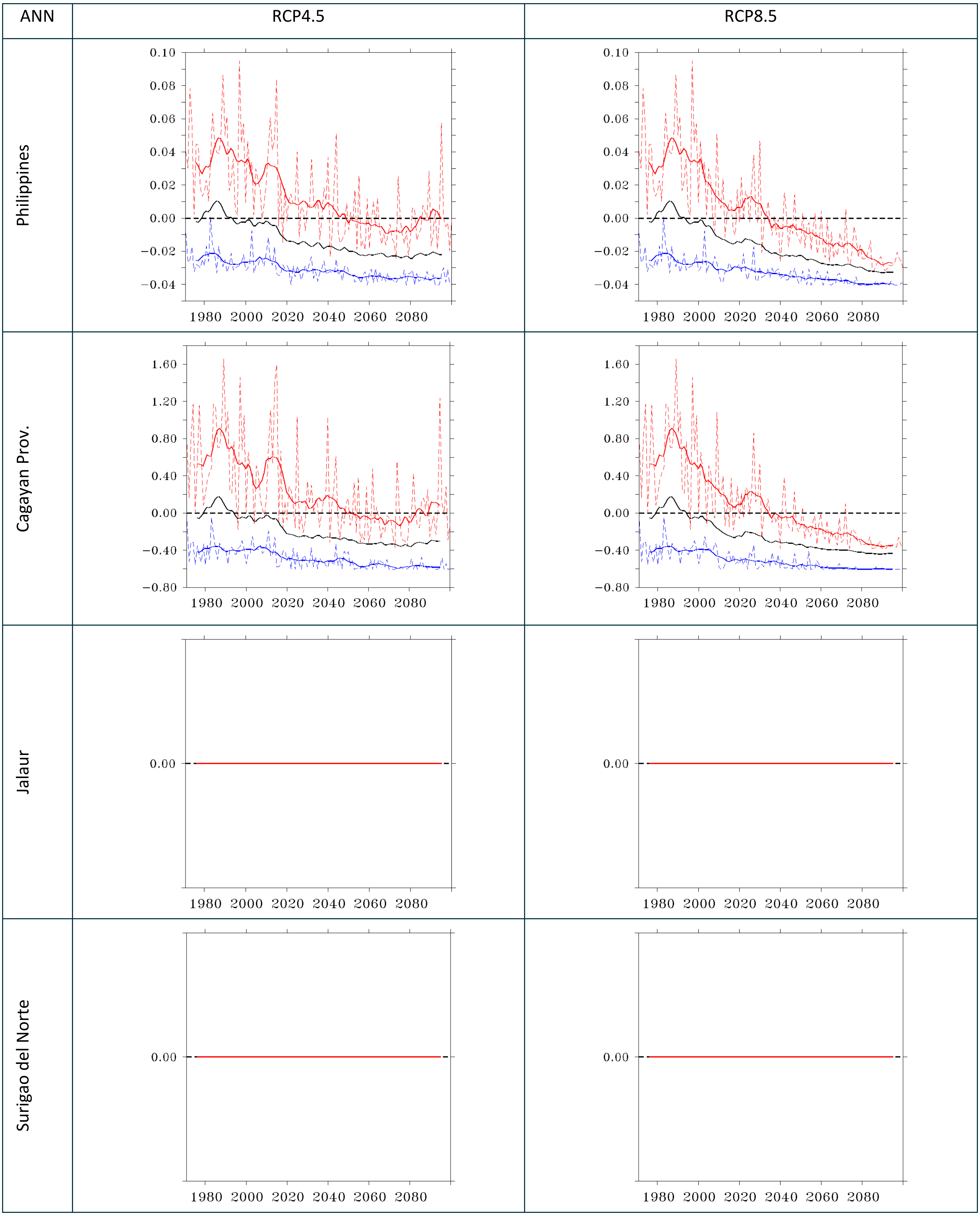
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-19: Average number of days annually with average temperature below 13°C for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-20: Average number of days annually with average temperature below 13°C for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

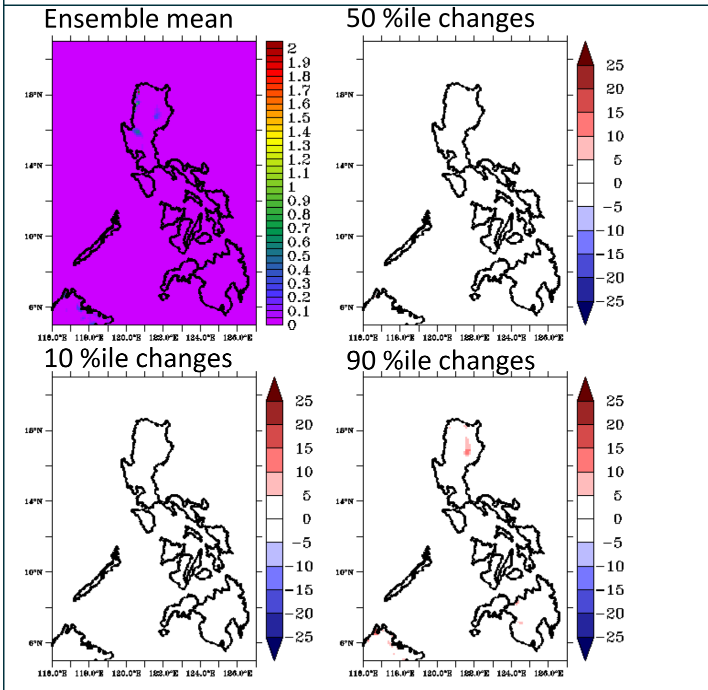


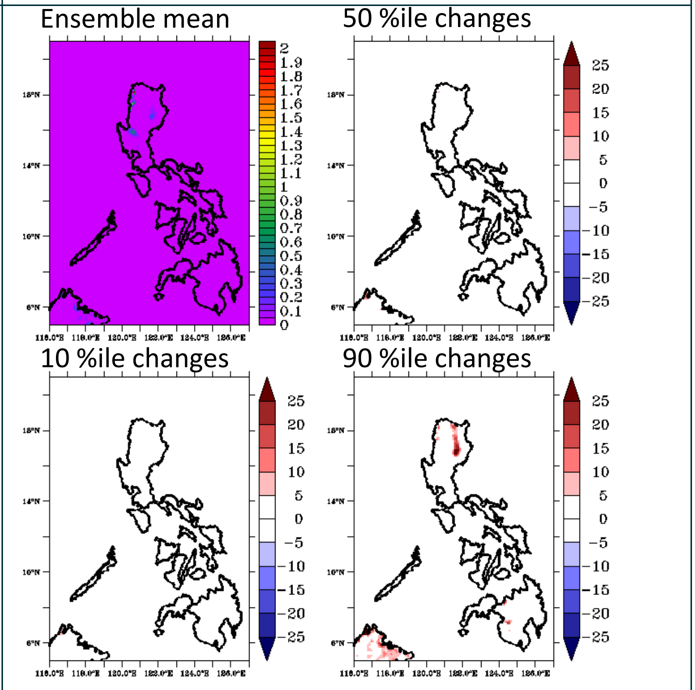
3-21: Time series plots of change in the annual number of days with the average daily air temperatures less than 13°C for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.9 Number of days annually with daily maximum temperature greater than 35°C (T35)

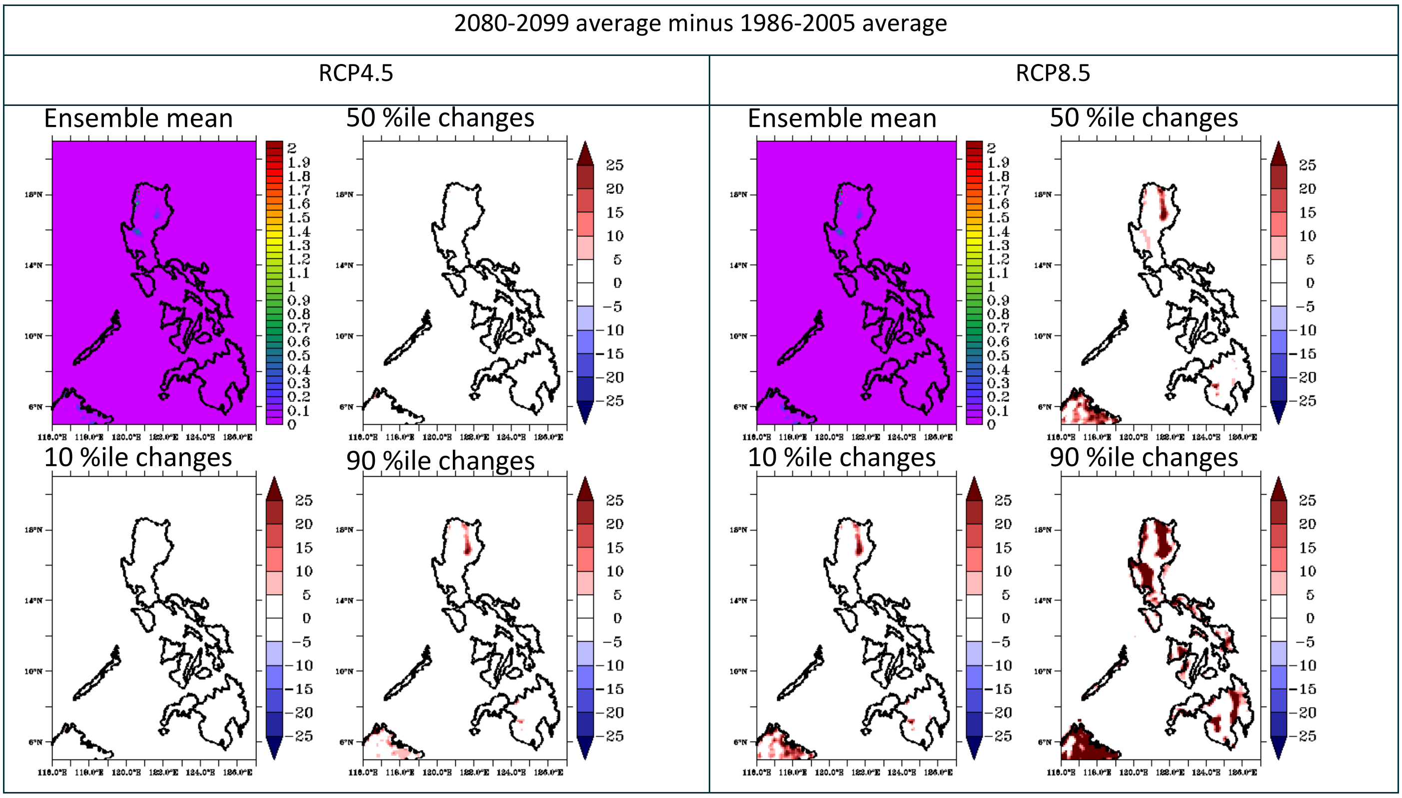
The number of days with maximum temperature greater than 35 °C depends critically upon the ability of the model to capture the maximum temperature distribution correctly. A small bias can affect the magnitude of the number of days significantly. Although there are few days with daily maximum temperatures above 35°C in these model simulations for the current climate, they are projected to increase near the end of the century for both RCP4.5 and RCP8.5 (Figure 3-22, 3-23 and 3-24). For example, in Cagayan Province, the number goes from 0 to more than 10 (for ensemble mean), with an increase to more than 40 days for the 90th percentile change.

2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5

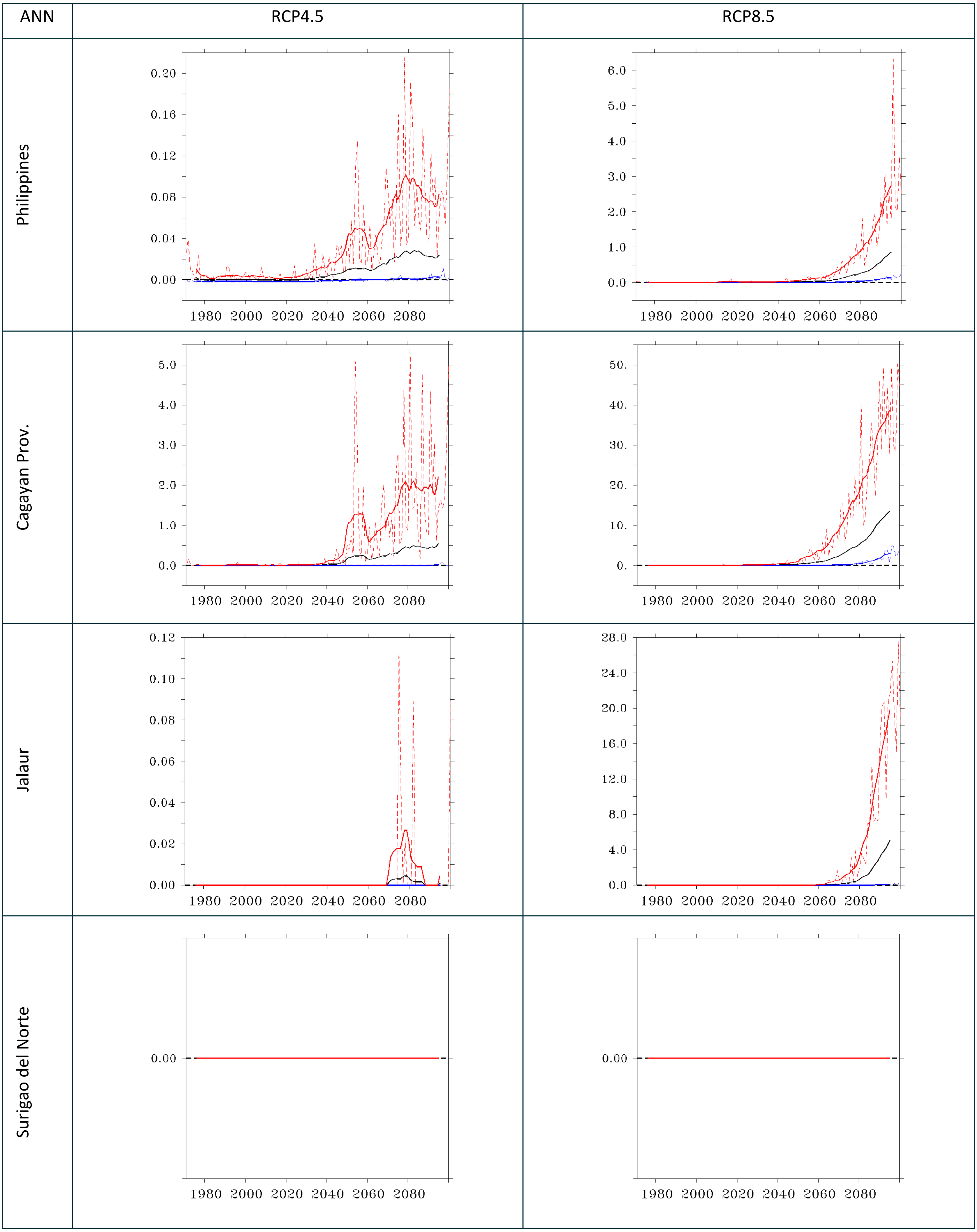




3-22: Average number of days annually with maximum temperature above 35°C for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-23: Average number of days annually with maximum temperature above 35°C for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

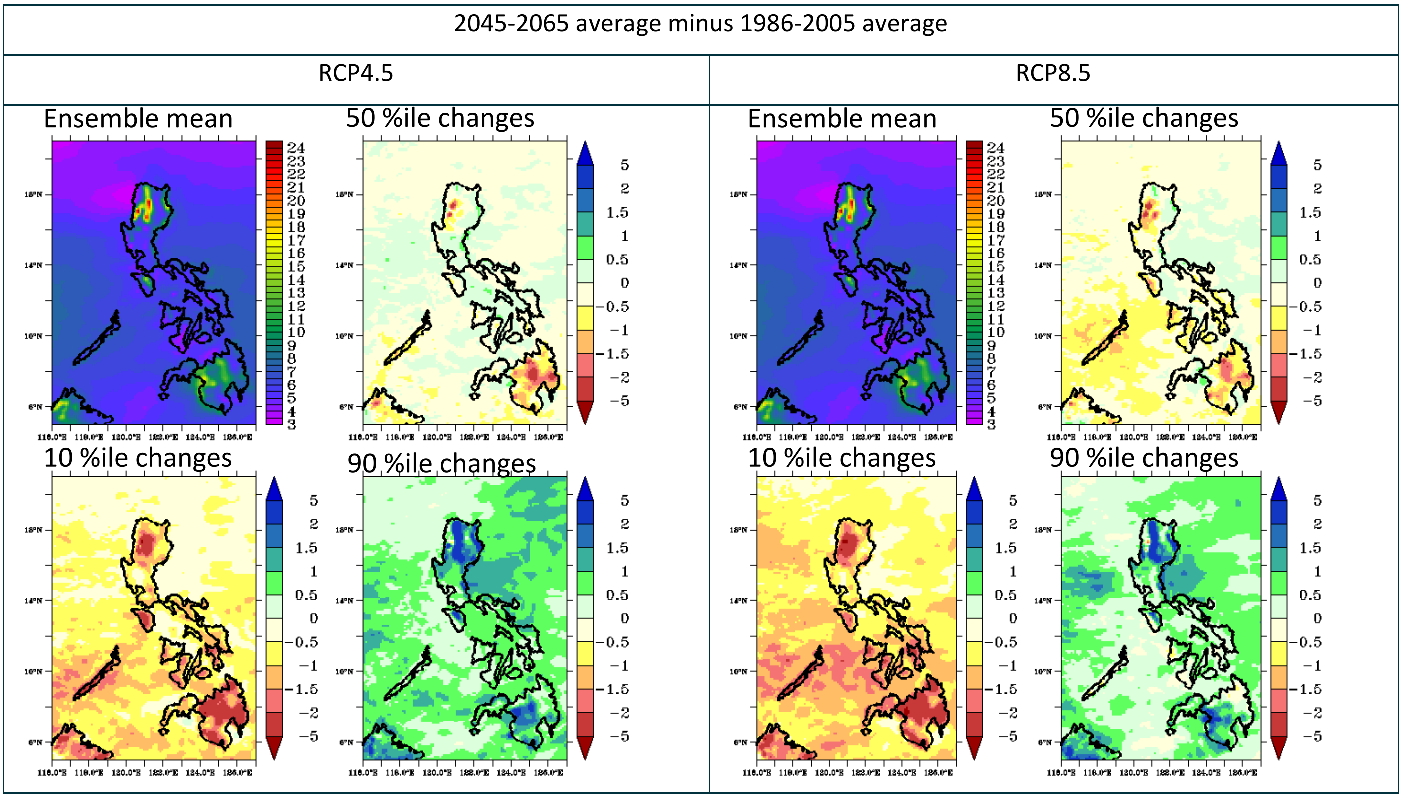


3-24: Time series plots of change in annual number of days with maximum air temperatures above 35°C for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

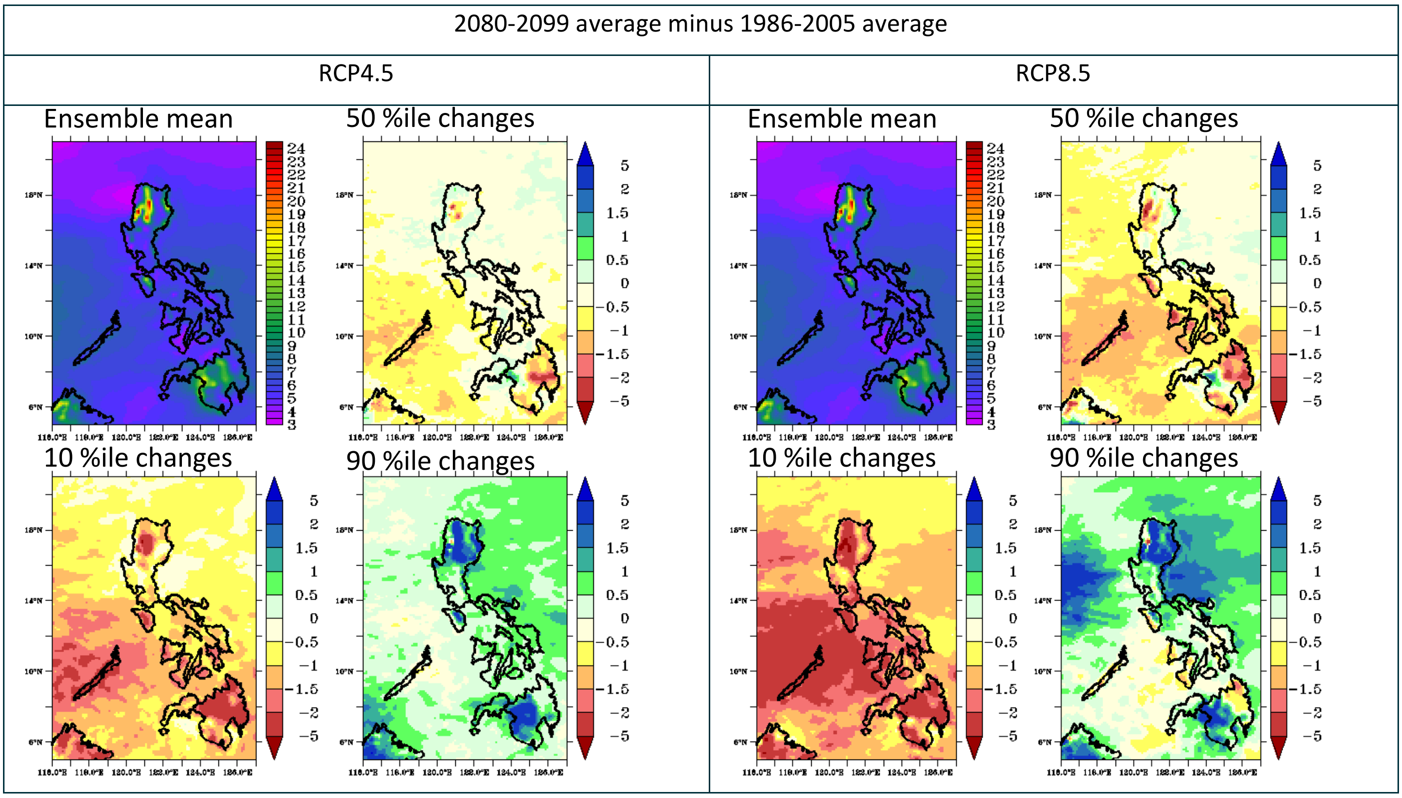
3.10Daily Rainfall

Unlike temperature, the projected changes in annual average daily rainfall show a larger range of responses, with both increases and decreases projected dependent upon which model simulation is used.   The median changes broadly show decreases over Philippine land areas, but with some models showing increases (as indicated by the 90th percentile changes) and some showing decreases (as indicated by the 10th percentile changes) (Figures 3-25, 3-26 and 3-27). However, some regions show only little change even for the 90th percentile (white areas in plots). The decreases are evident in most regions except Cagayan Province, where there are some projected increases along the east coast, which counteract the decreases in the western portions of the Province, leading to little change for a regional average.

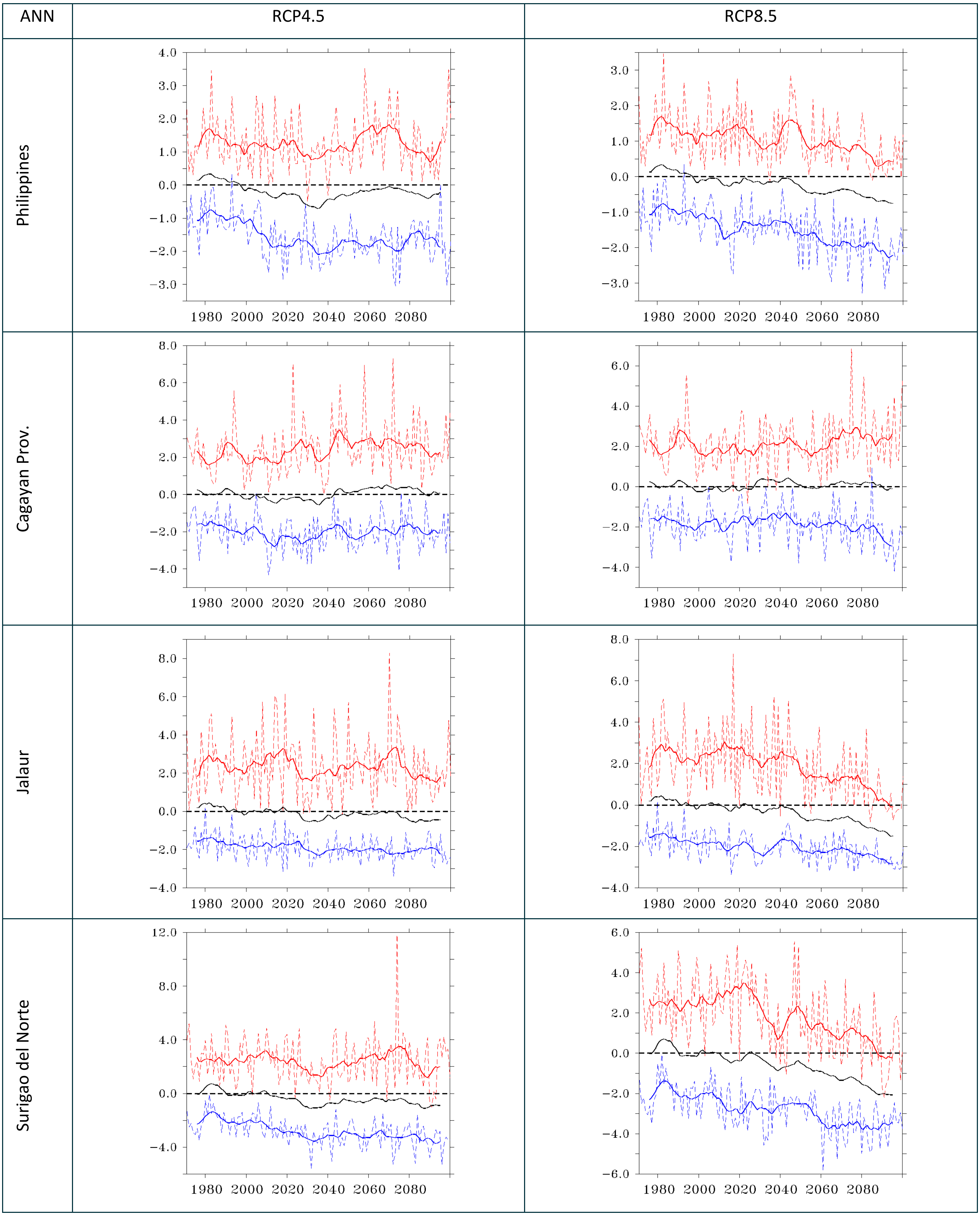
The differing responses for the four seasons for the whole of the Philippines is shown in Figure 3-28. The strongest response is for JJA (June to August) and SON (September to November) with RCP8.5 where decreases are evident. Only MAM (March to May) has increases across the Philippines projected for the ensemble mean with RCP8.5. The changes with RCP4.5 tend to be small.



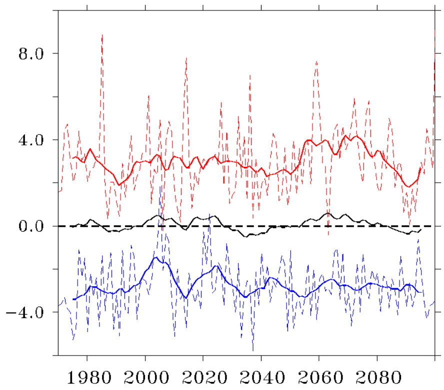
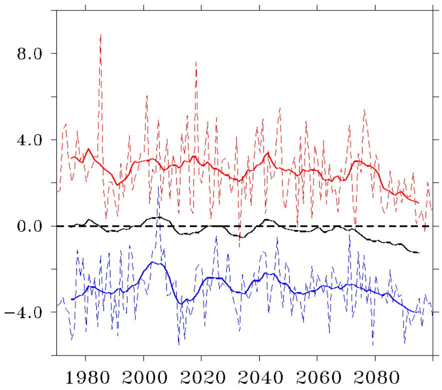
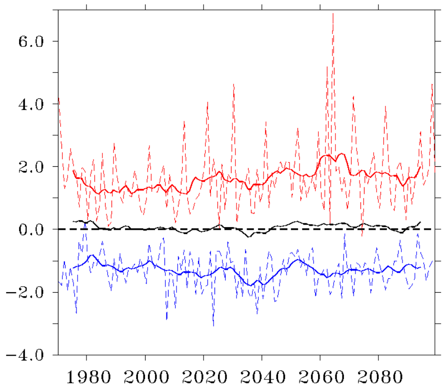
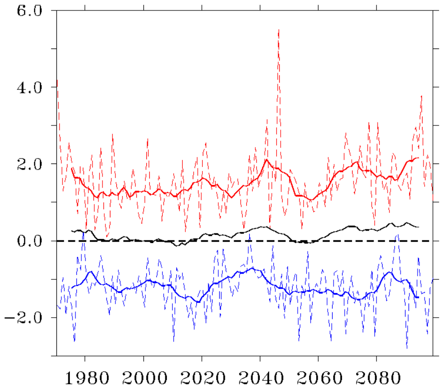
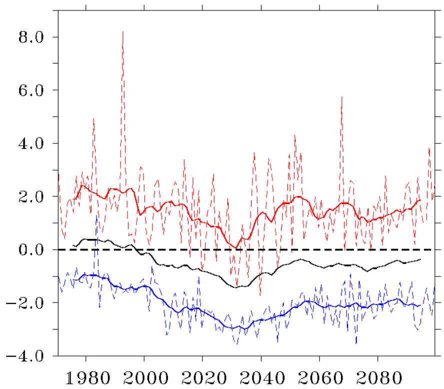
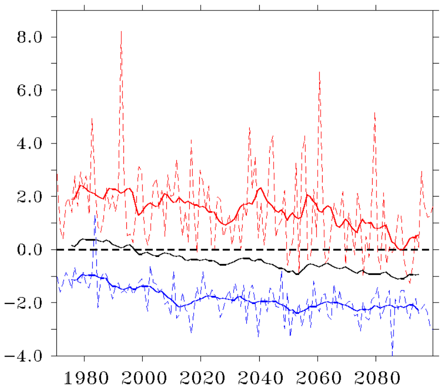
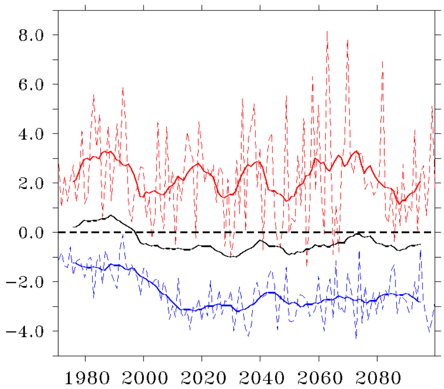
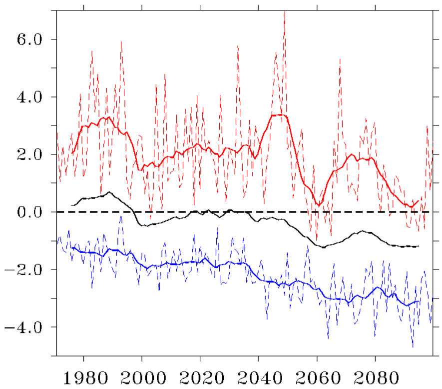
3-25: Average daily rainfall rate (mm/day) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-26: Average daily rainfall rate (mm/day) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



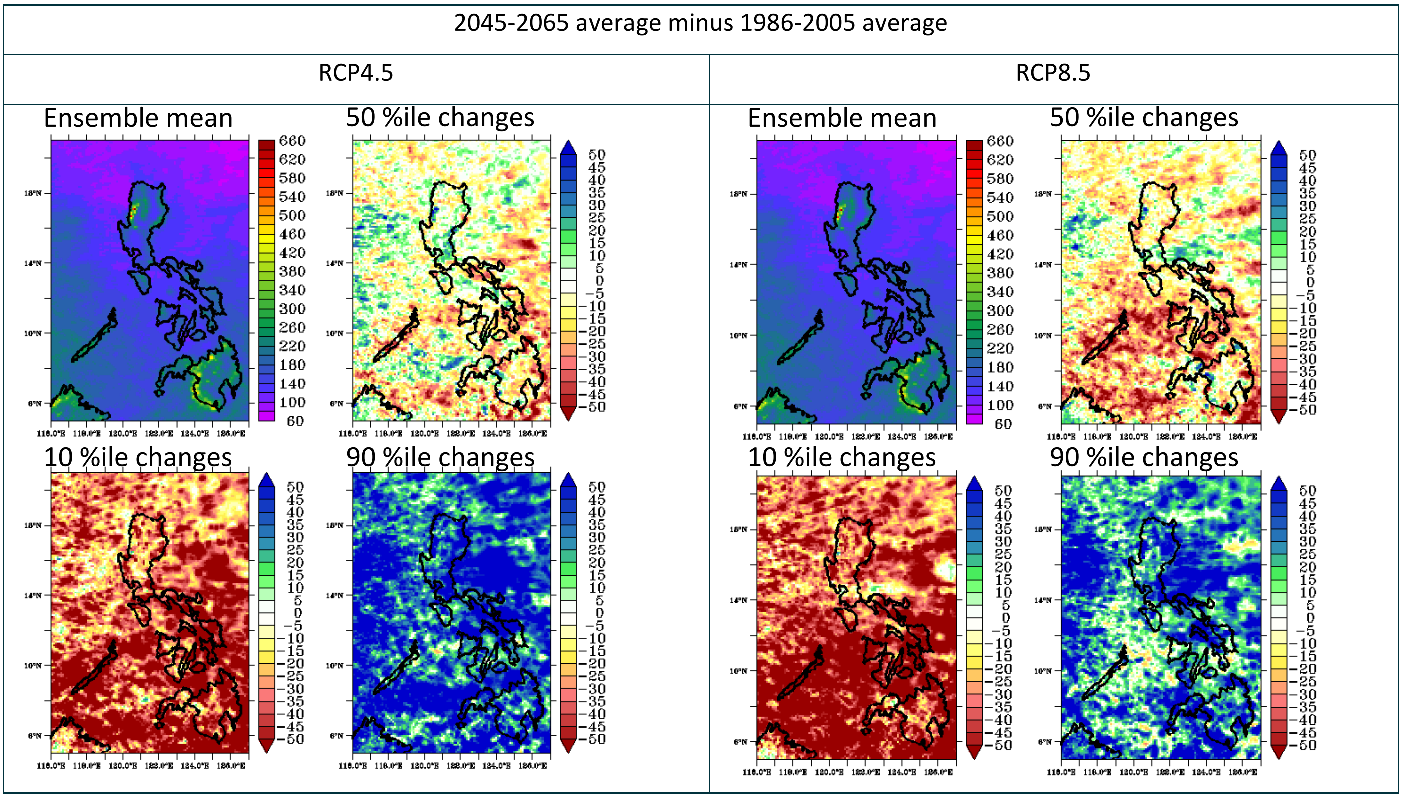
3-27: Time series plots of change in the annual average daily rainfall rate (mm/day) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

Philippines		
	RCP4.5	RCP8.5
DJF		
MAM		
JJA		
SON		

3-28: Time series plots of change in the seasonally averaged daily rainfall rate (mm/day) for the Philippines for RCP4.5 (left column) and RCP8.5 (right column). DJF is December to February, MAM is March to May, JJA is June to August and SON is September to November. Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

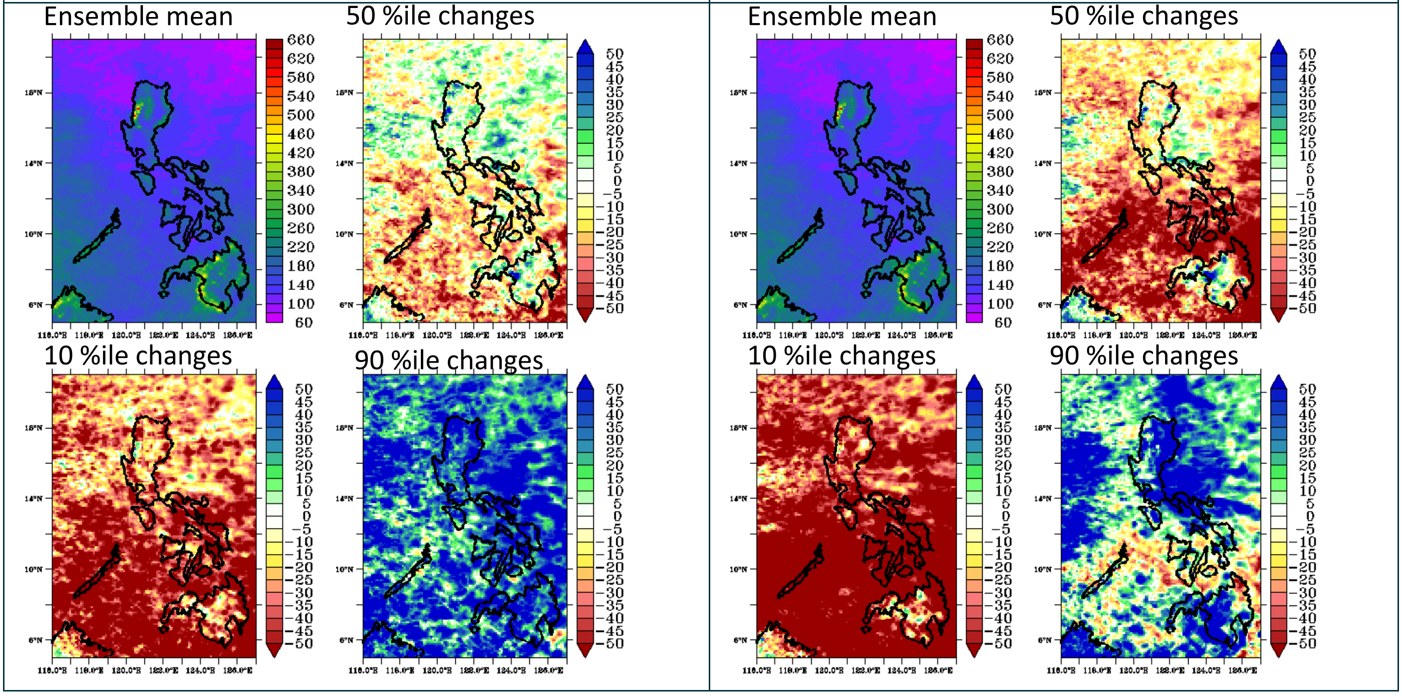
3.11 Maximum 1-day rainfall (RX1)

Maximum annual 1-day rainfall (RX1) is generally projected to show little change in most of the Philippines, though with slight (not significant) trend toward lower values, especially under RCP8.5 by the end of the century for RCP8.5 (Figures 3-29, 3-30, and 3-31). Note the large spread of the 10th and 90th percentile changes values (negative and positive respectively) indicating a large range of uncertainty in these projections for most of the Philippines. Inspecting the time series graphs for the three regions confirms the large spread of results, indicating a lack of confidence in any significant projected mean changes. However, there is a slight tendency to have greater decreases in southern Philippines towards the end of the century with RCP8.5, indicating a reduced risk of larger events over time. Due to the difficulties in projecting extreme rainfall and the large range of projected changes, there is low confidence in these changes.

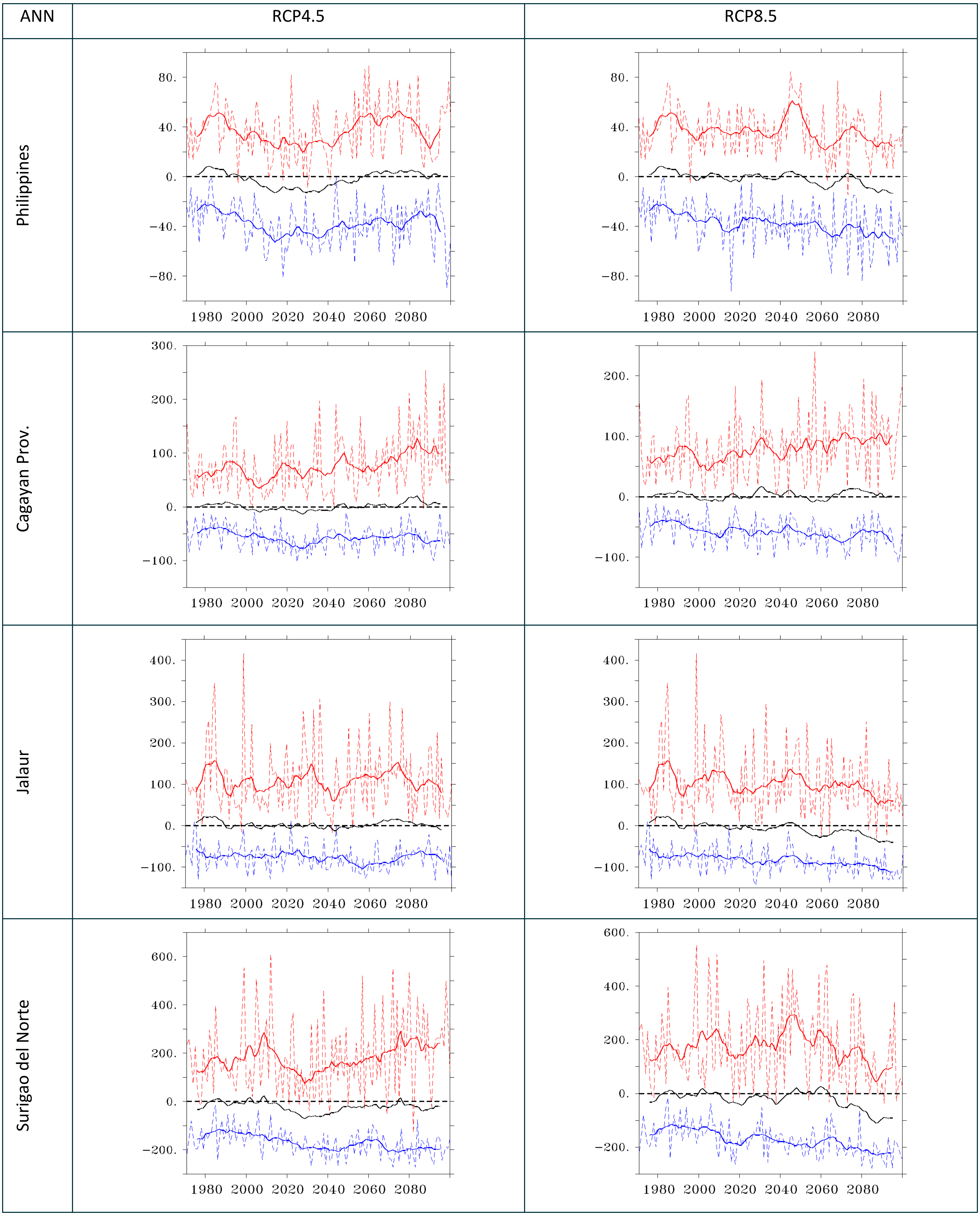


3-29: Annual 1-day maximum rainfall (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5



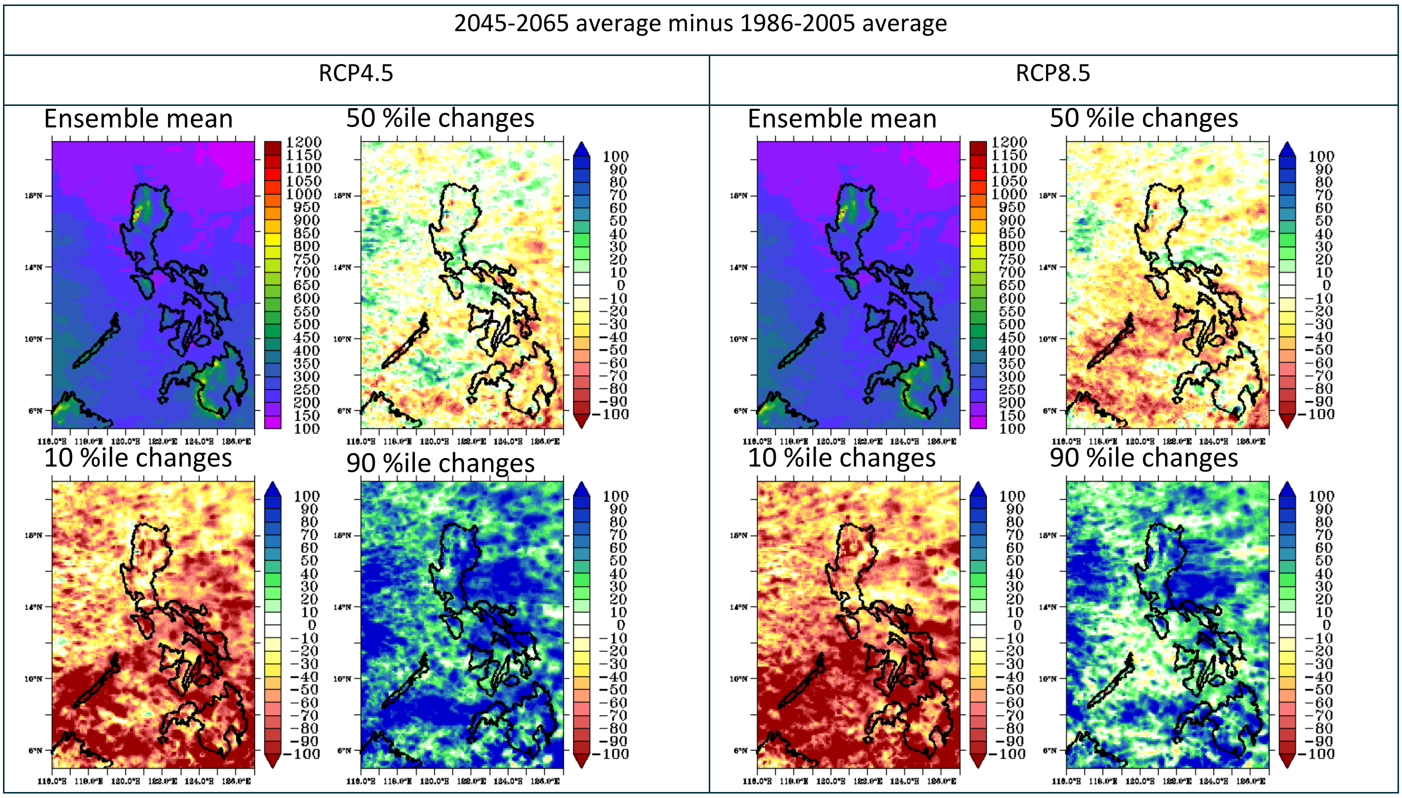
3-30: Annual 1-day maximum rainfall (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-31: Time series plots of change in the annual highest 1-day precipitation amount index (mm) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

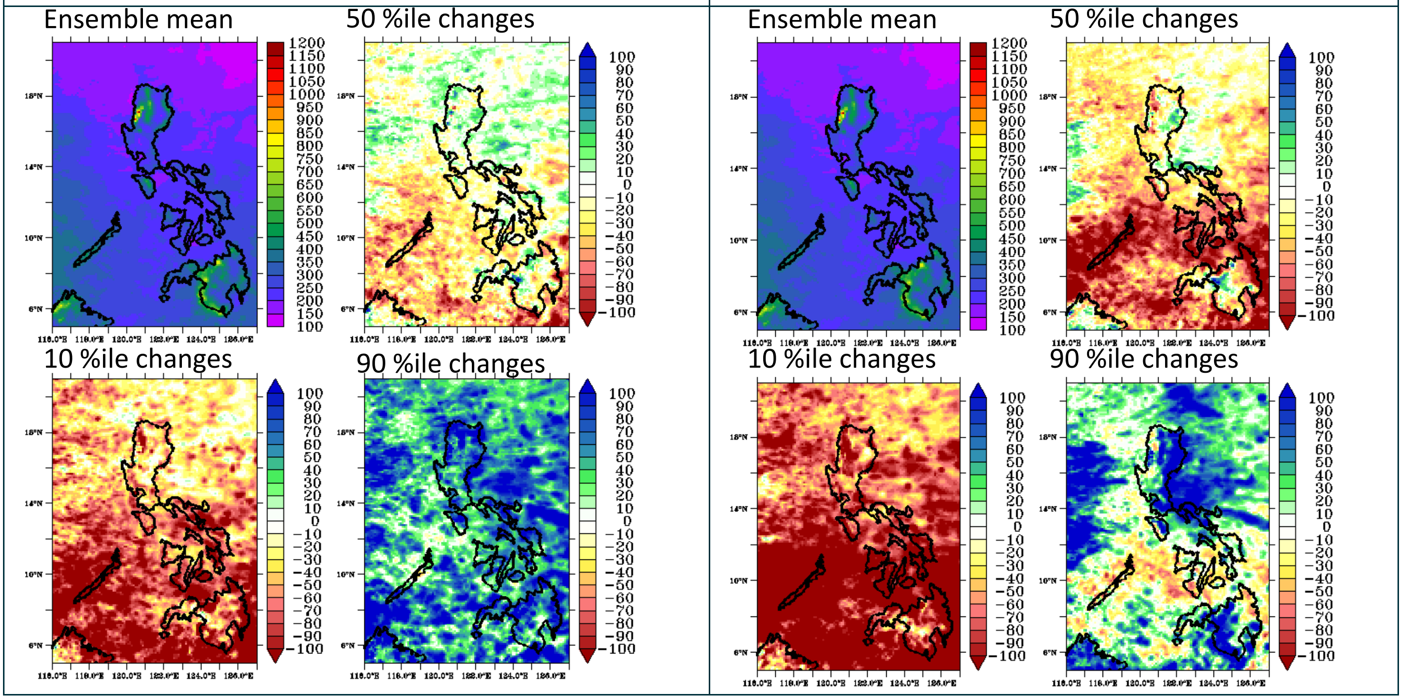
3.12 Maximum 5-day rainfall (RX5day)

Similar to RX1 above, the projected changes in maximum annual 5-day rainfall show a range of responses, both in amounts of rainfall and number of events with 5-day rainfall above 50 mm by the end of the century for RCP8.5 (Figures 3-32, 3-33 and 3-34). Similar to RX1day noted previously, due to the large spread of projected change values, there is a large uncertainty in the trend of this parameter. Also similar to RX1, there is some indication of decreases in southern Philippines. The frequency of 5-day rainfall periods with greater than 50 mm generally shows a more systematic decreases in both the maximum 5-day rainfall amounts, but more noticeably in the frequency of 5 day events with more than 50 mm rainfall. The time series show a large range projected changes, both increases and decreases for all regions except under RCP8.5 by end of the century, where decreases are evident for Jalaur and Surigao del Norte regions. However, that statistical significance of these changes has not been tested.

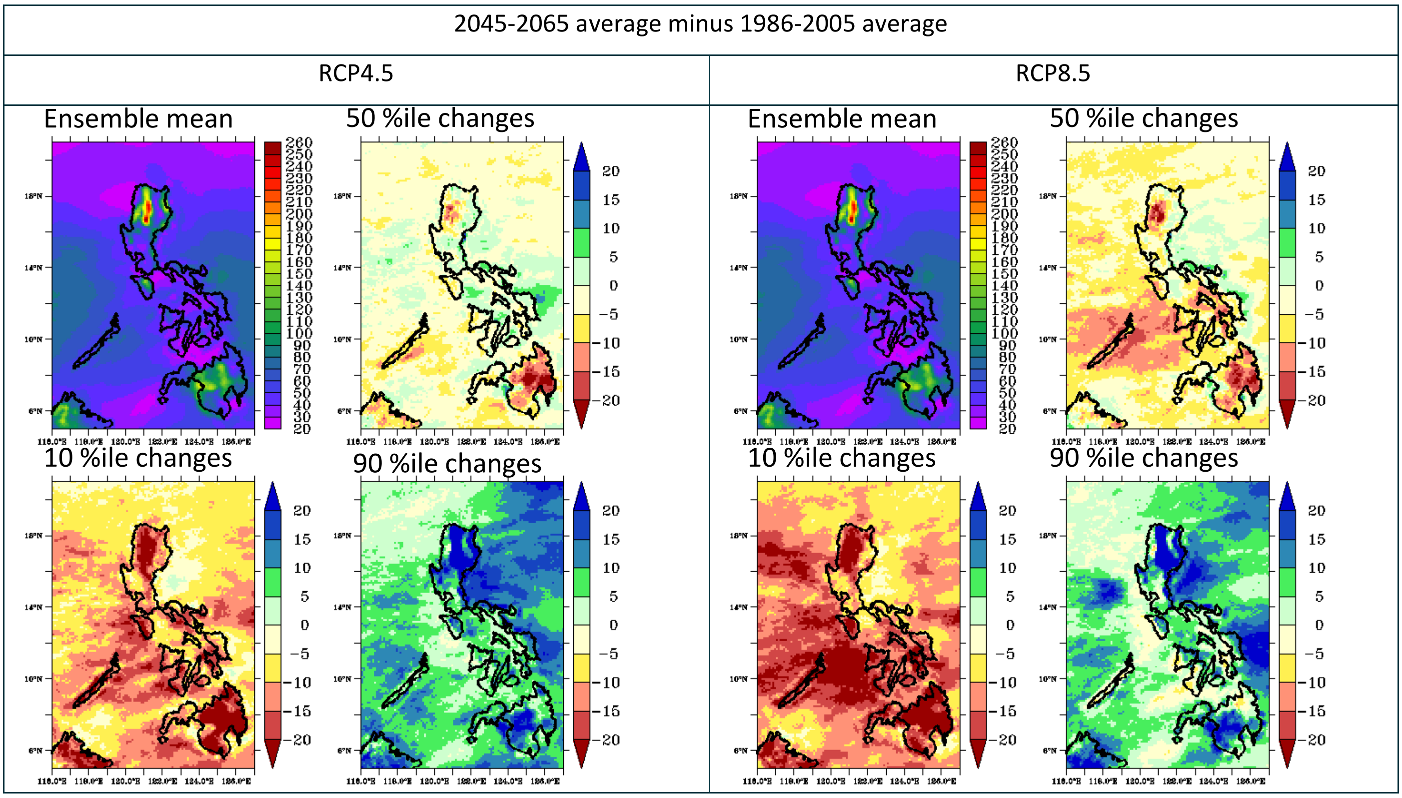


3-32: Annual 5-day maximum rainfall amounts (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

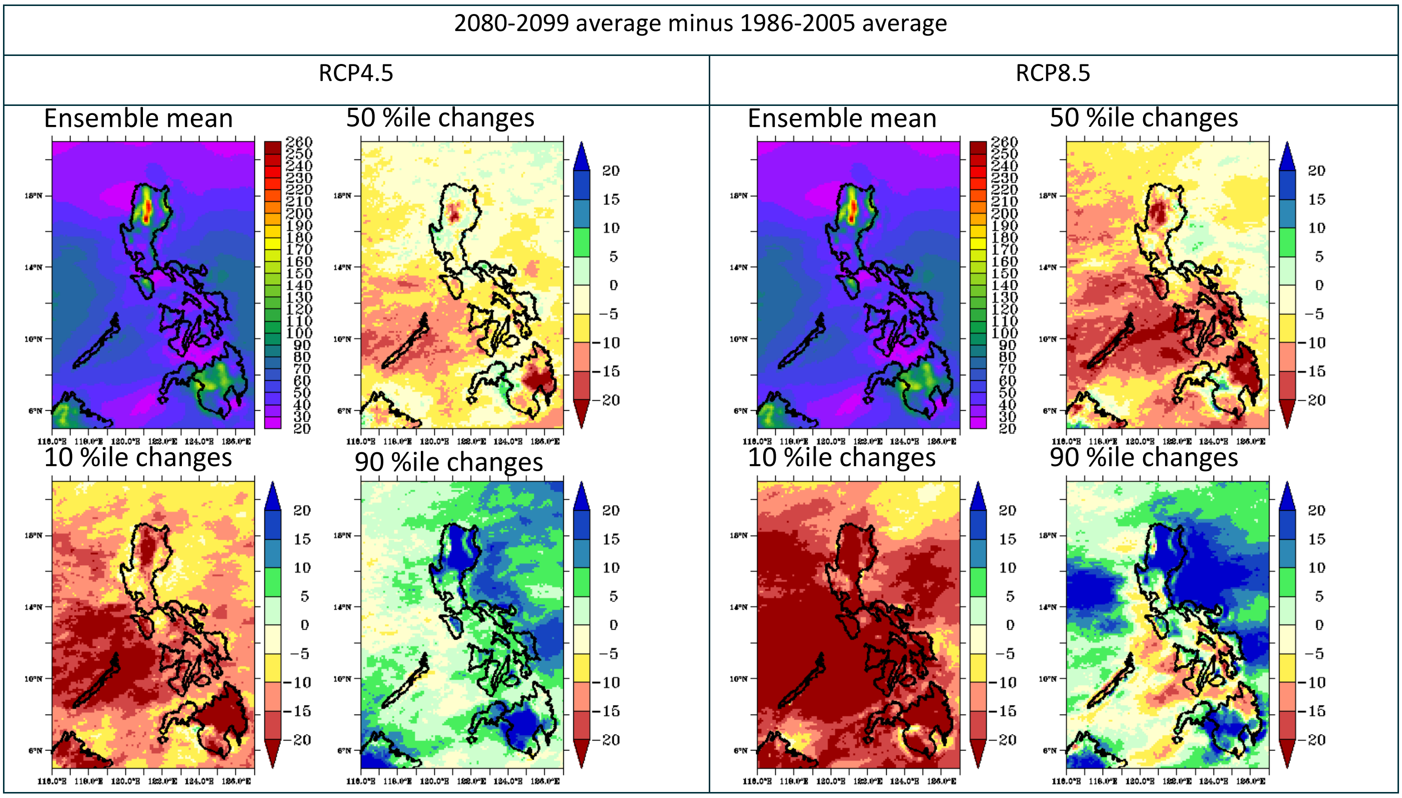
2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5



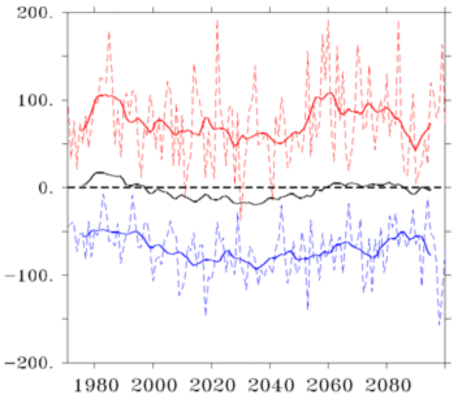
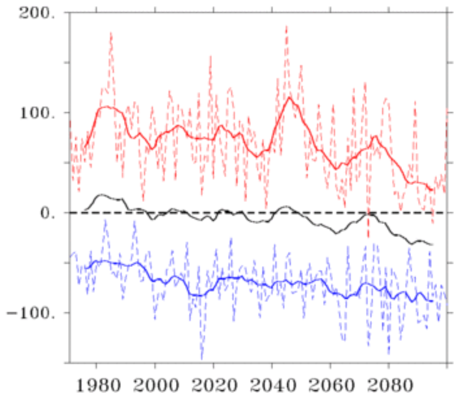
3-33: Annual 5-day maximum rainfall amounts (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-34: Number of days annually with 5-day rainfall amounts above 50 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-35: Number of days annually with 5-day rainfall amounts above 50 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

<table>
<tr><th>ANN</th><th>RCP4.5</th><th>RCP8.5</th></tr>
<tr><td>Philippines</td><td>
</td><td>
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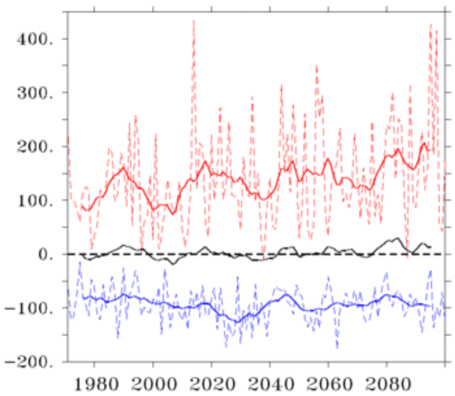
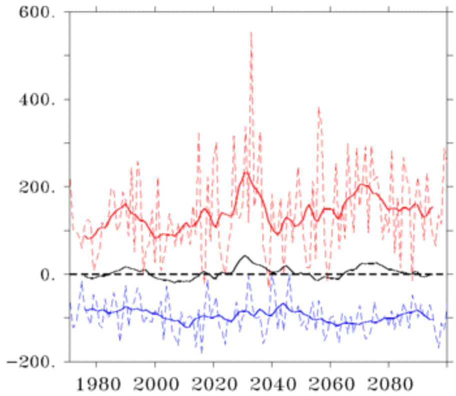
<tr><td>Cagayan Prov.</td><td>
</td><td>
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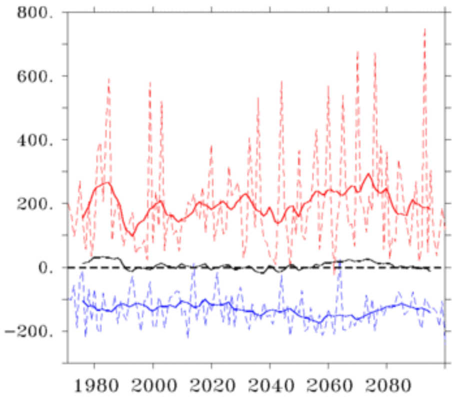
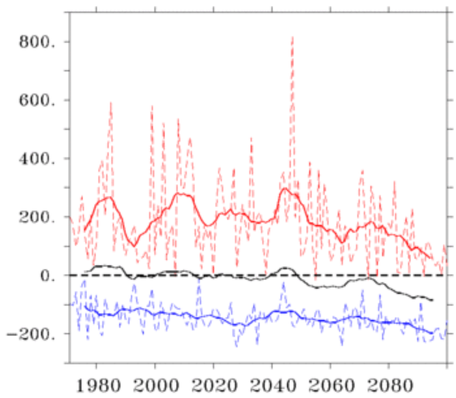
<tr><td>Jalaur</td><td>
</td><td>
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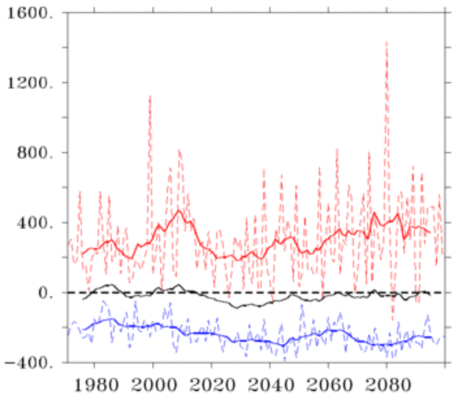
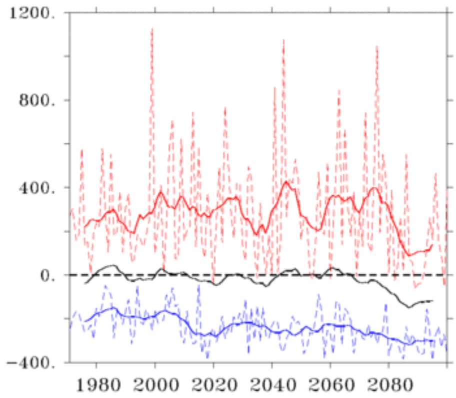
<tr><td>Surigao del Norte</td><td>
</td><td>
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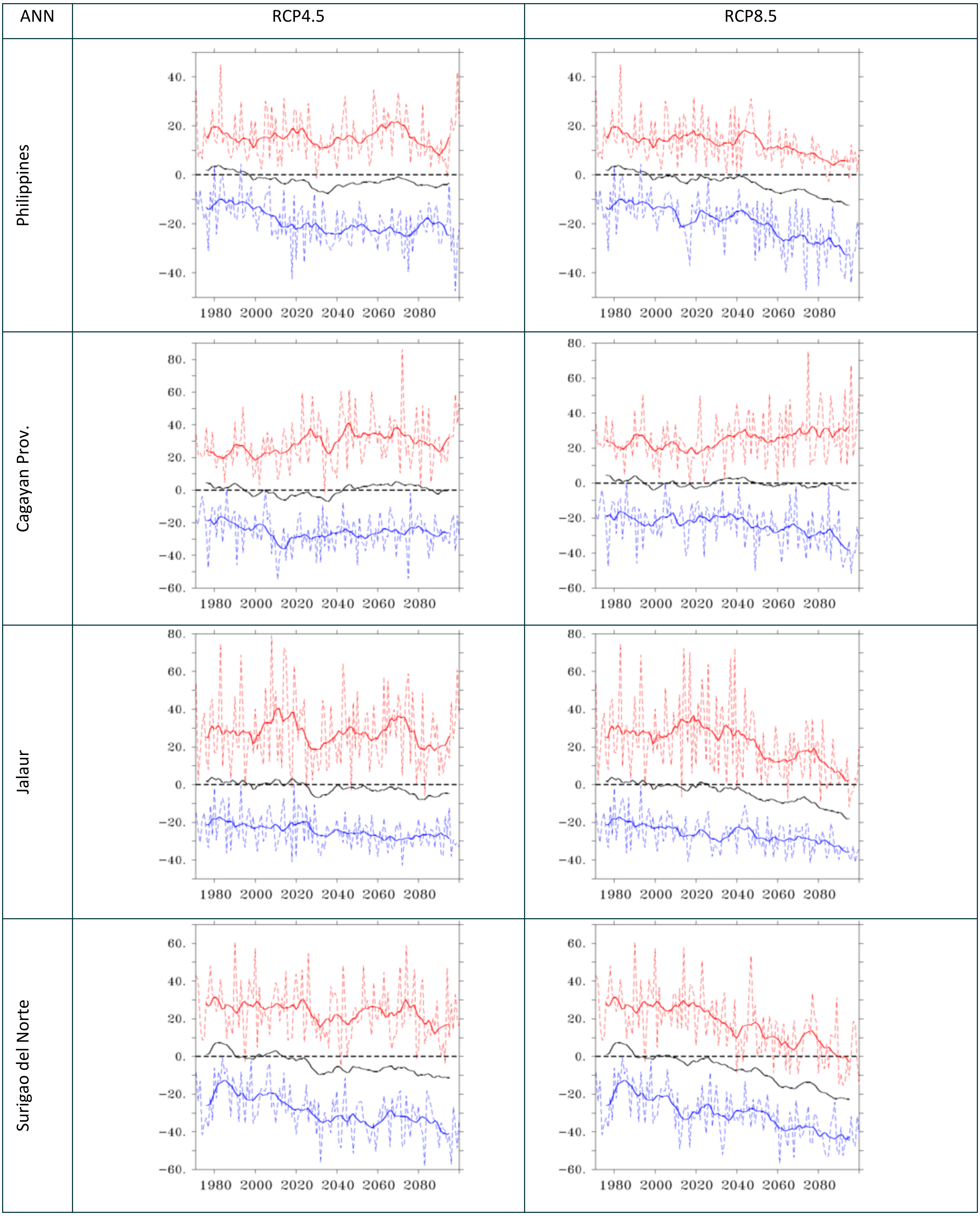
3-36: Time series plots of change in the annual highest 5-day precipitation amounts for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

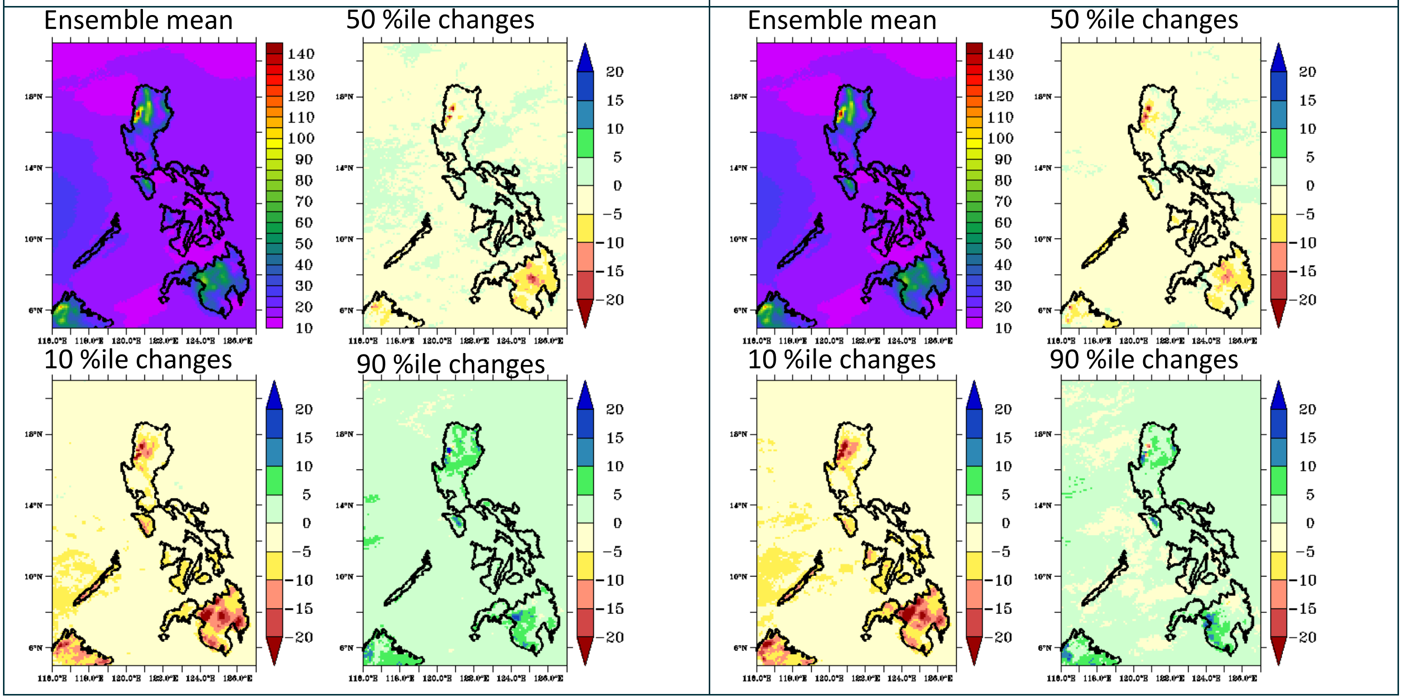


3-37: Time series plots of change in the annual number of 5-day heavy precipitation (greater than 50 mm) periods for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

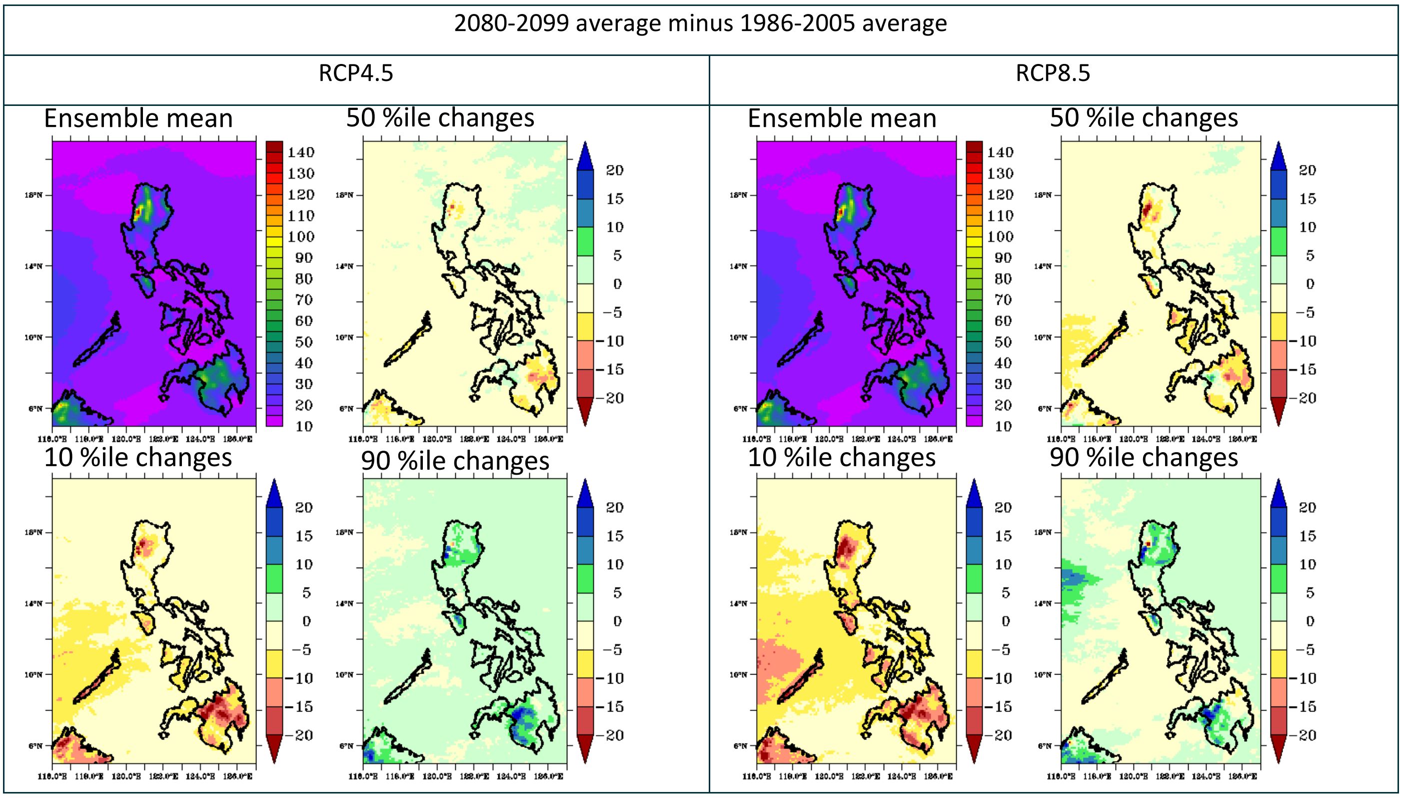
3.13 Heavy rainfall amount: R95pamt

The projected changes in heavy rainfall amounts, as indicated by the 95th percentile of annual daily rainfall (R95pamt) (Figures 3-38, 3-39 and 3-39), generally shows mean decreases among the CCAM simulations by end of the century for RCP8.5, though some models (as indicated by the 90th percentile change) show possible increases. As can be seen in the time series plots, the decreases are most evident for Jalaur and Surigao del Norte regions, though even there are decreases within the Cagayan Province region, which are counteracted by increases within the region as well.

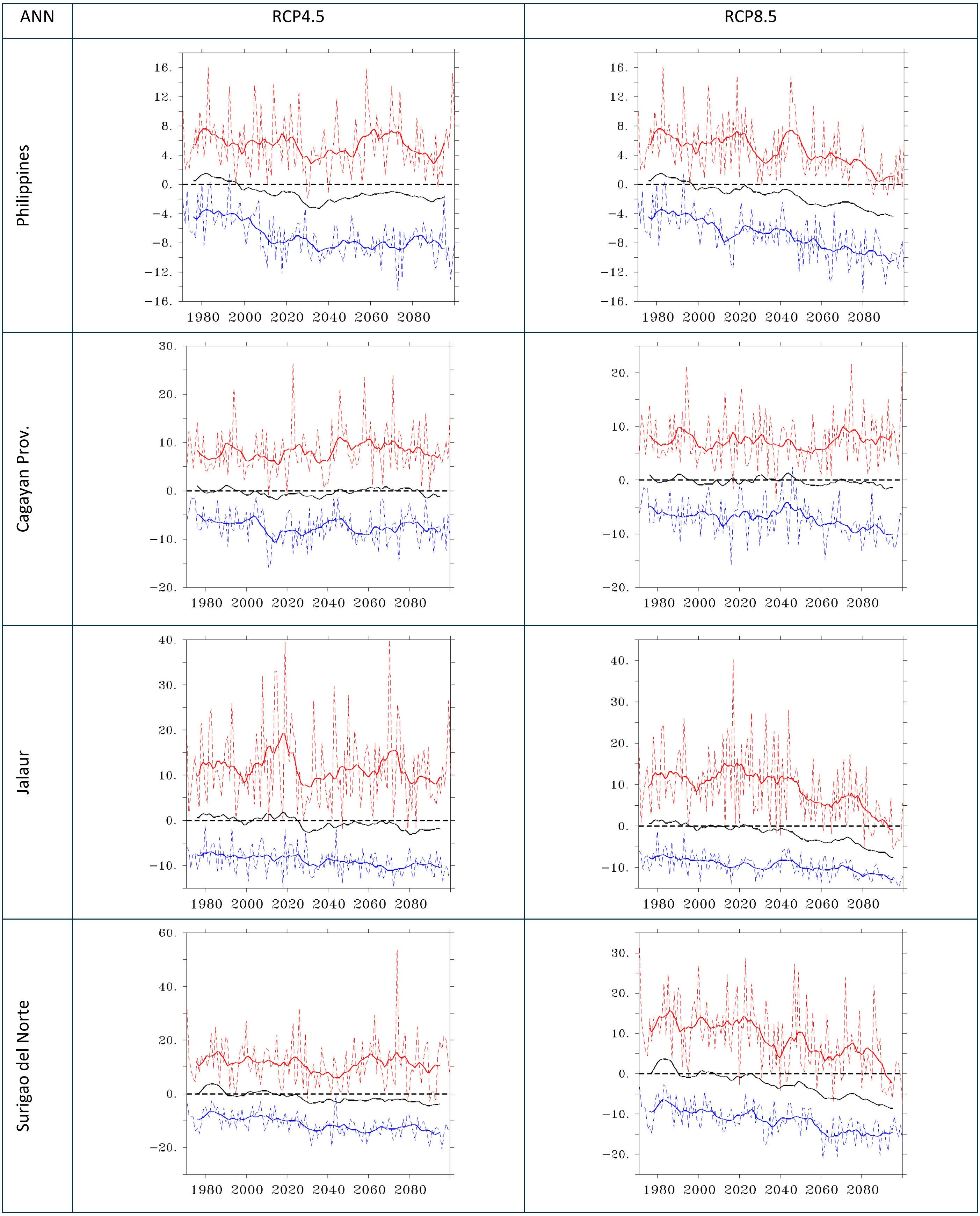
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-38: The amount of daily rainfall at the 95th percentile annually, R95pamt, (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-39: The amount of daily rainfall at the 95th percentile annually, R95pamt, (mm) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

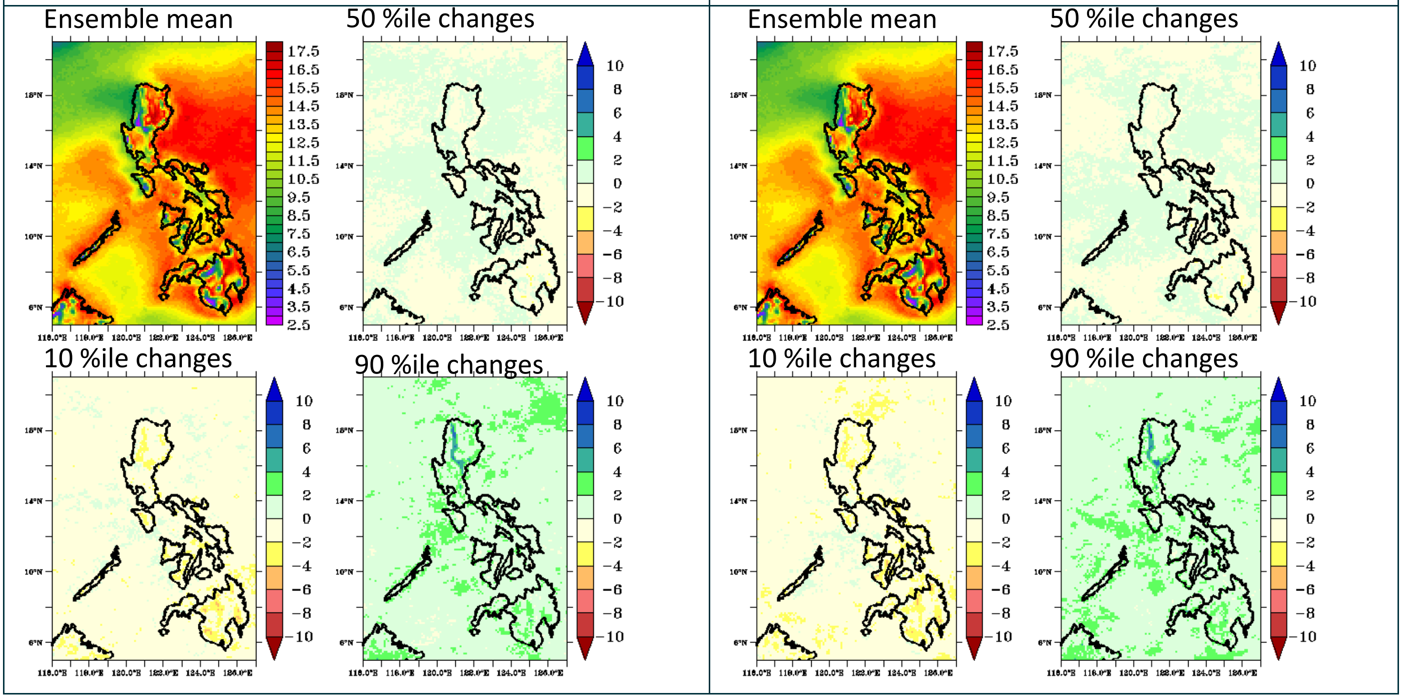


3-40: Time series plots of change in the amount of daily rainfall at the 95th percentile annually, R95pamt, (mm) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

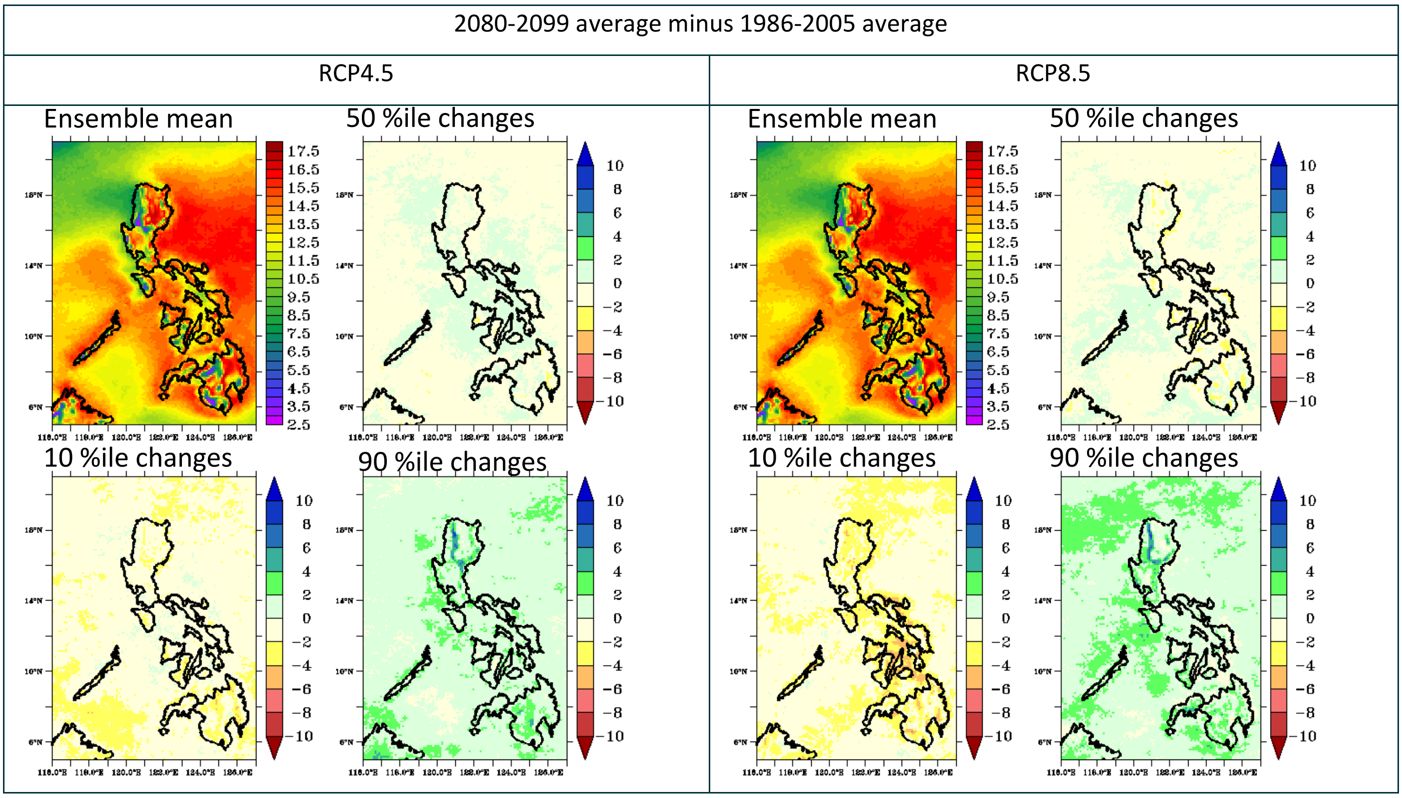
3.14CWD: Consecutive wet days

The number of consecutive wet day periods (Figures 3-41, 3-42 and 3-45) generally shows little change across the Philippines. The 50th percentile shows small changes in the maximum length of consecutive wet days (CWD; periods more than 5 days long with rainfall greater than or equal to 1 mm/day) by end of the century with RCP8.5 (Figures 3-43, 3-44 and 3-46). Note the time series plots indicate that there is a spread of projected changes, with some models showing increases and others decreases in the number of events.

2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5

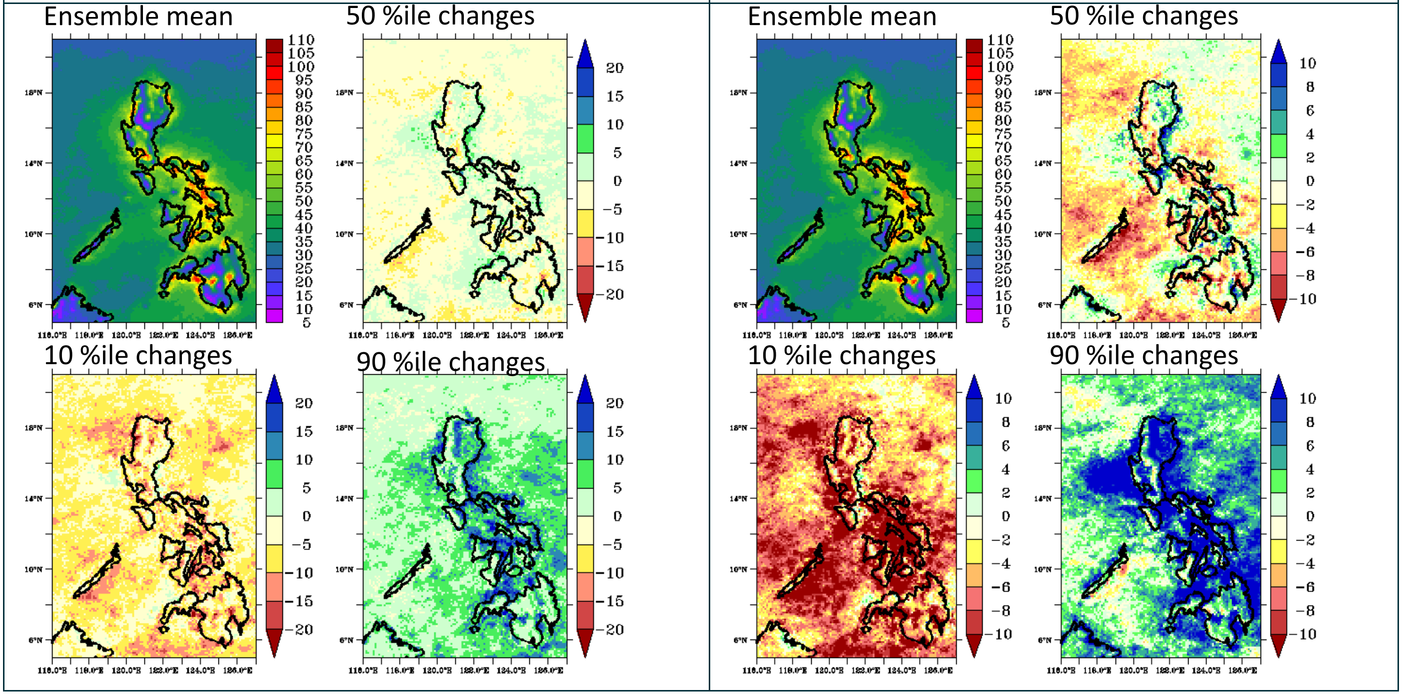


3-41: Average annual number of consecutive wet days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

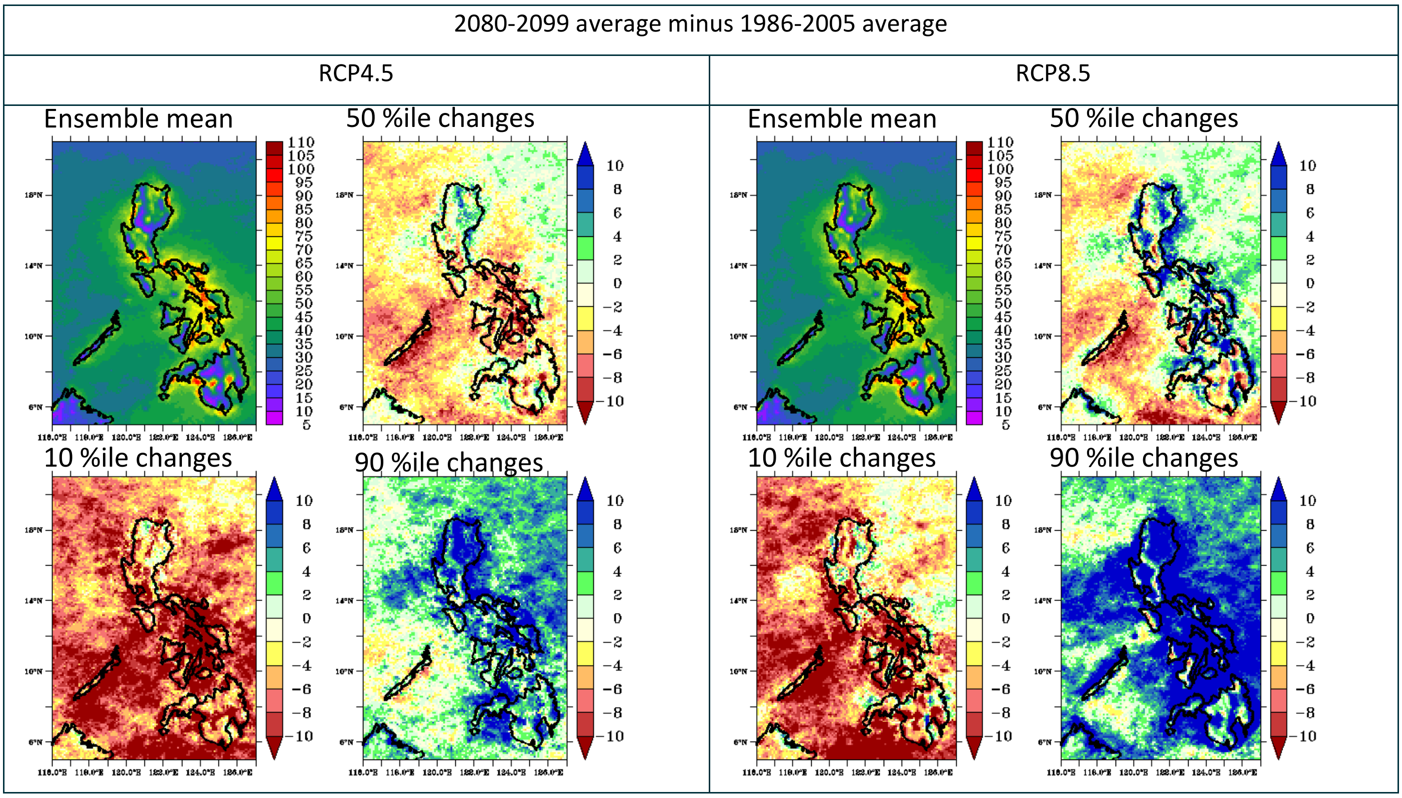


3-42: Average annual number of consecutive wet days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

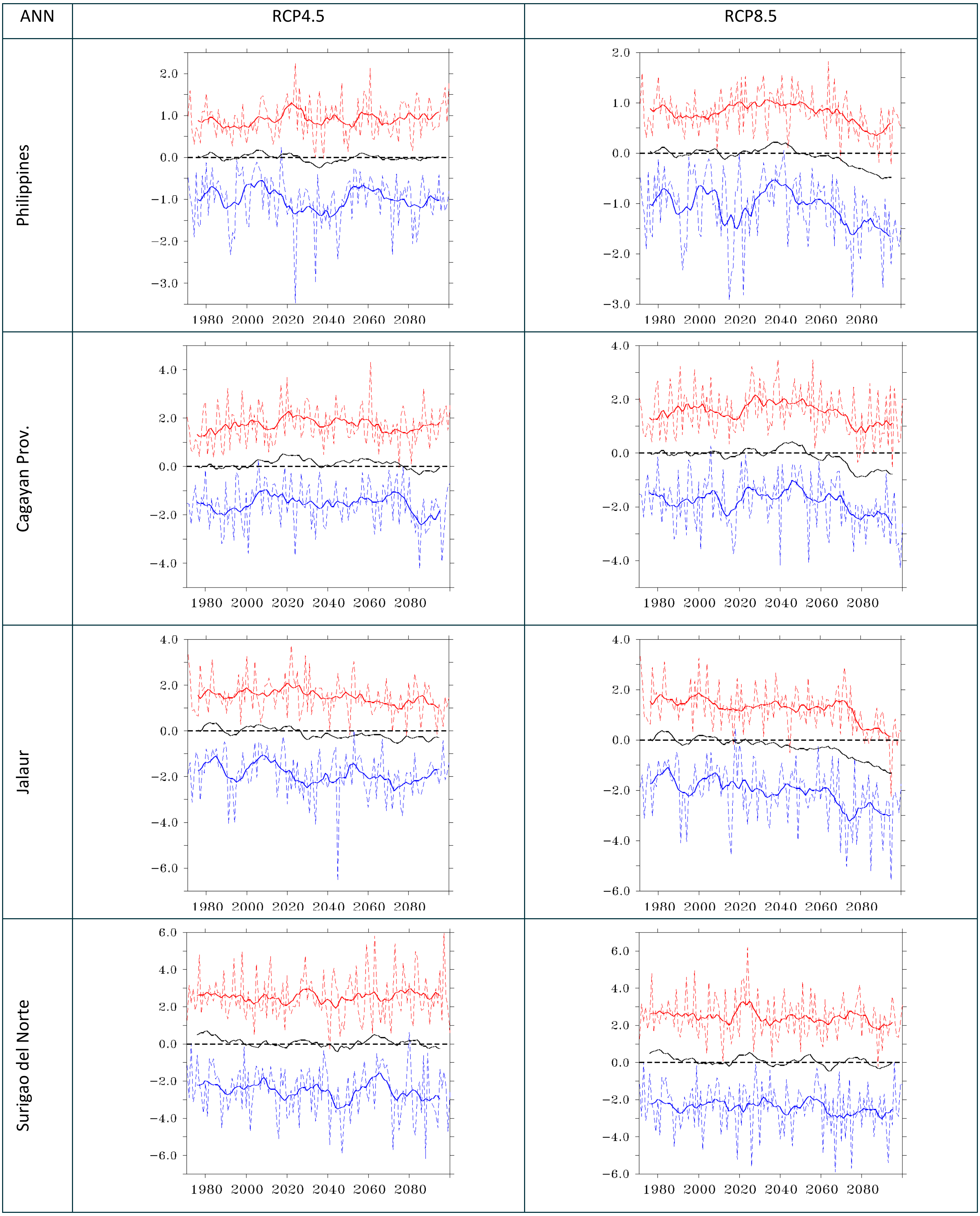
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



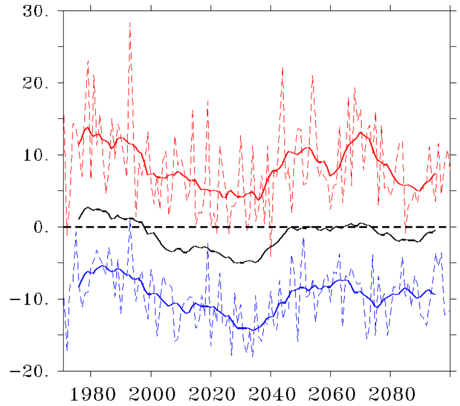
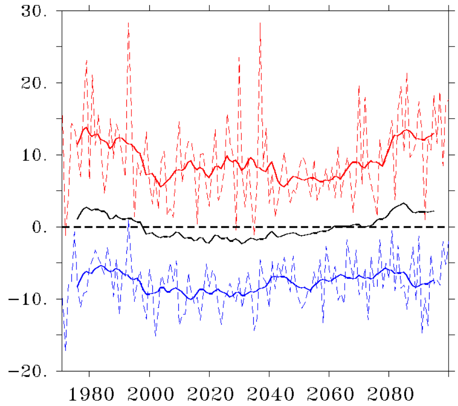
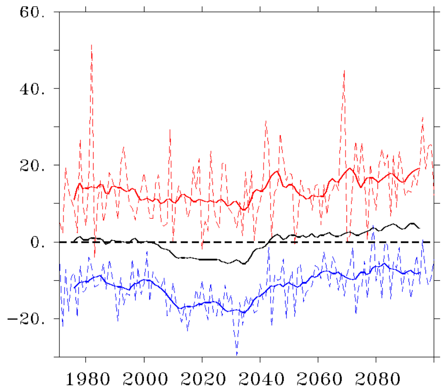
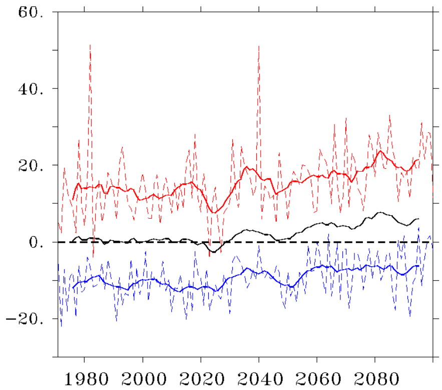
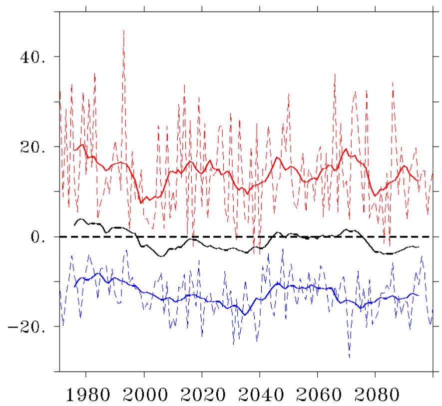
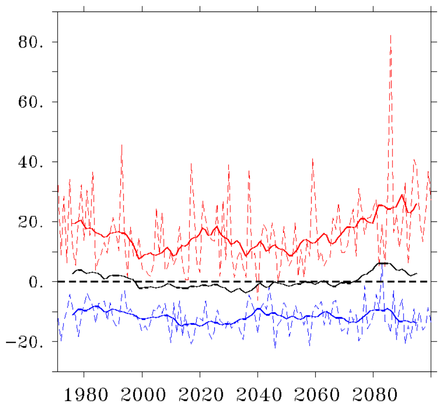
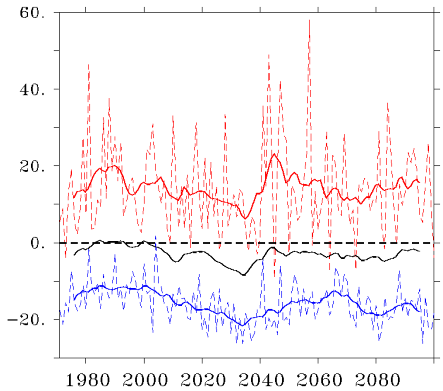
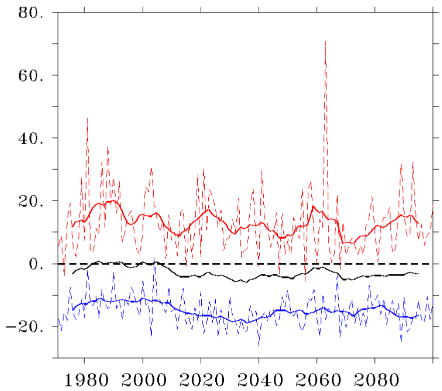
3-43: Average maximum length of annual consecutive wet days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-44: Average maximum length of annual consecutive wet days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-45: Time series plots of change in the annual number of consecutive wet days periods of more than 5 days for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

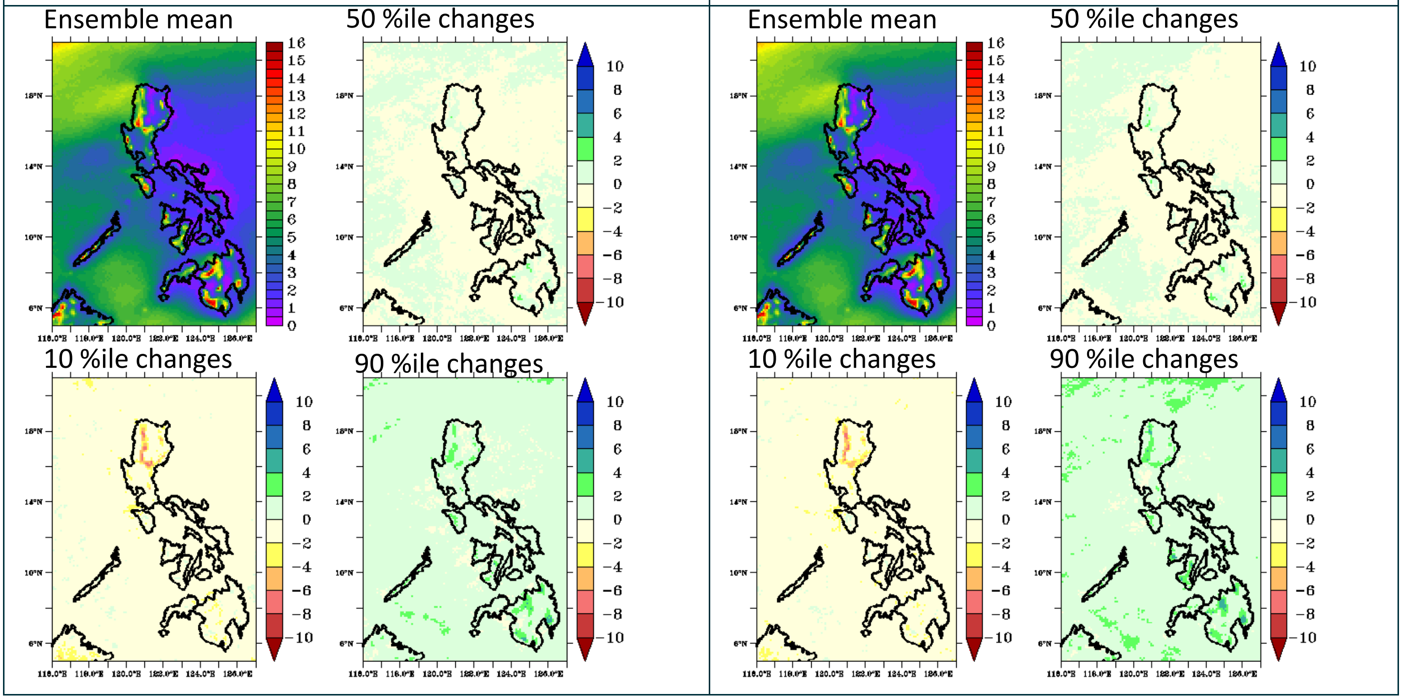
3-46: Time series plots of change in annual maximum length of annual consecutive wet days for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.15CDD: Number and length of consecutive dry days

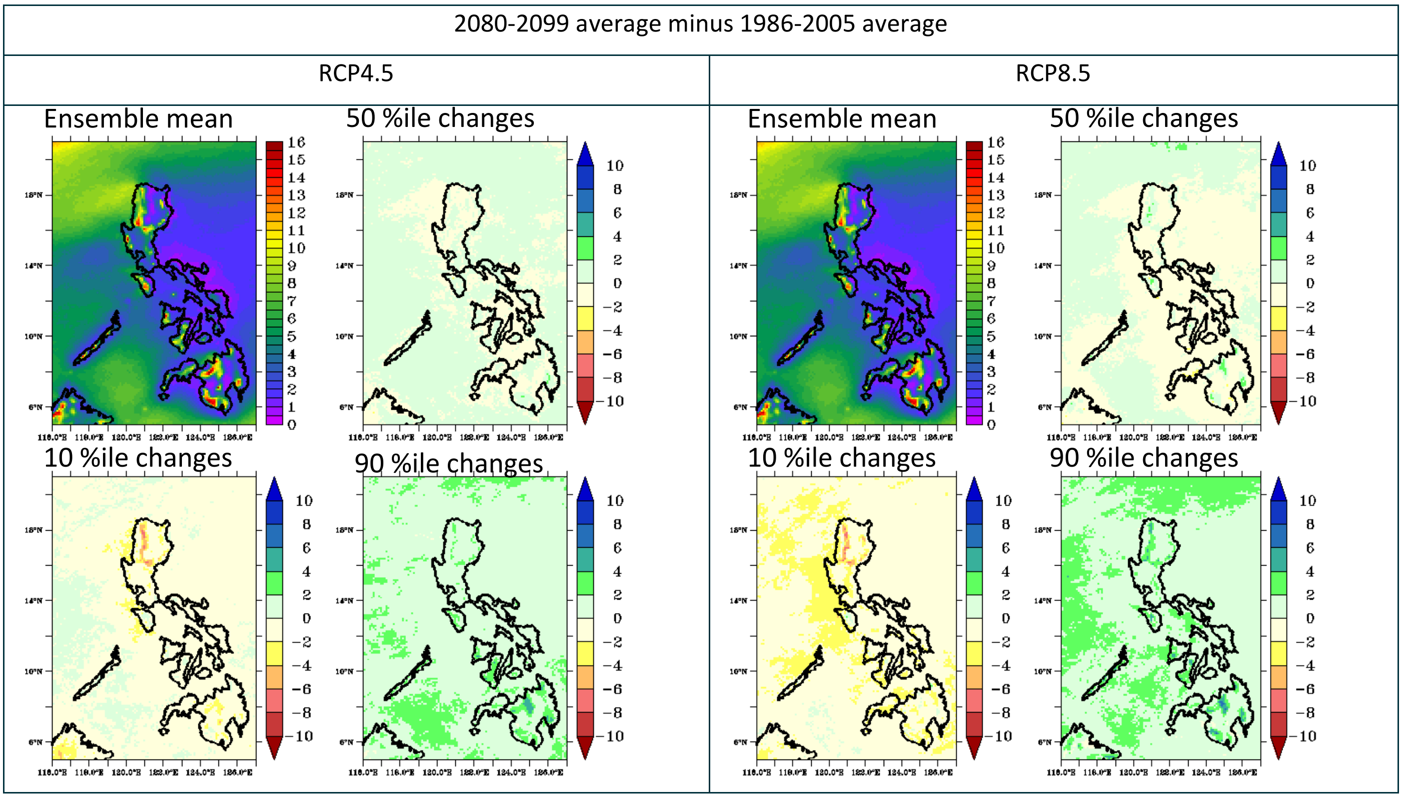
The multi-model mean projected changes in the number and maximum length of consecutive dry days (CDD; periods more than 5 days long with rainfall less than 1 mm/day) by end of the century for RCP8.5 (Figures 3-47, 3-48, 3-49, 3-50, 3-51 and 3-52) indicate only small changes in both indices.

2045-2065 average minus 1986-2005 average

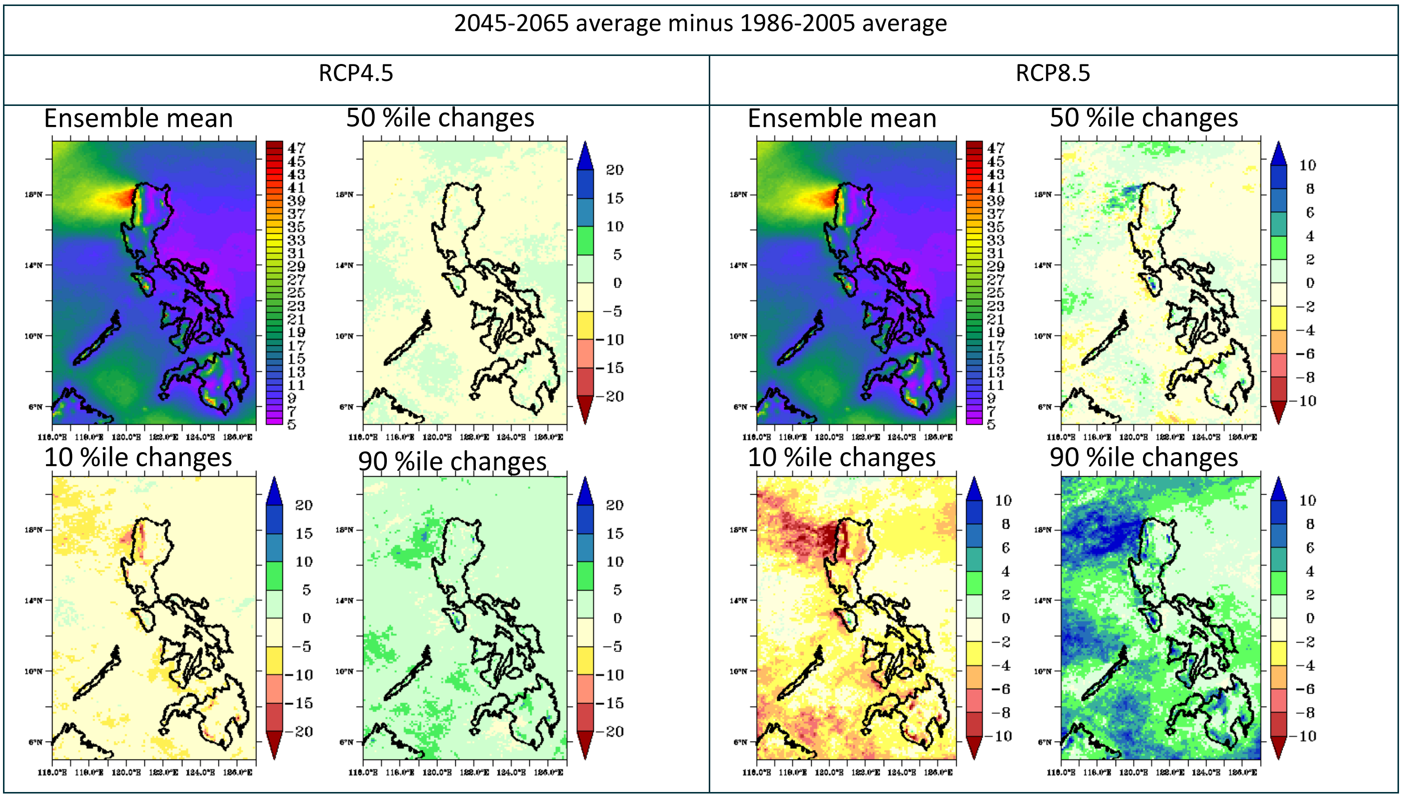
RCP4.5	RCP8.5



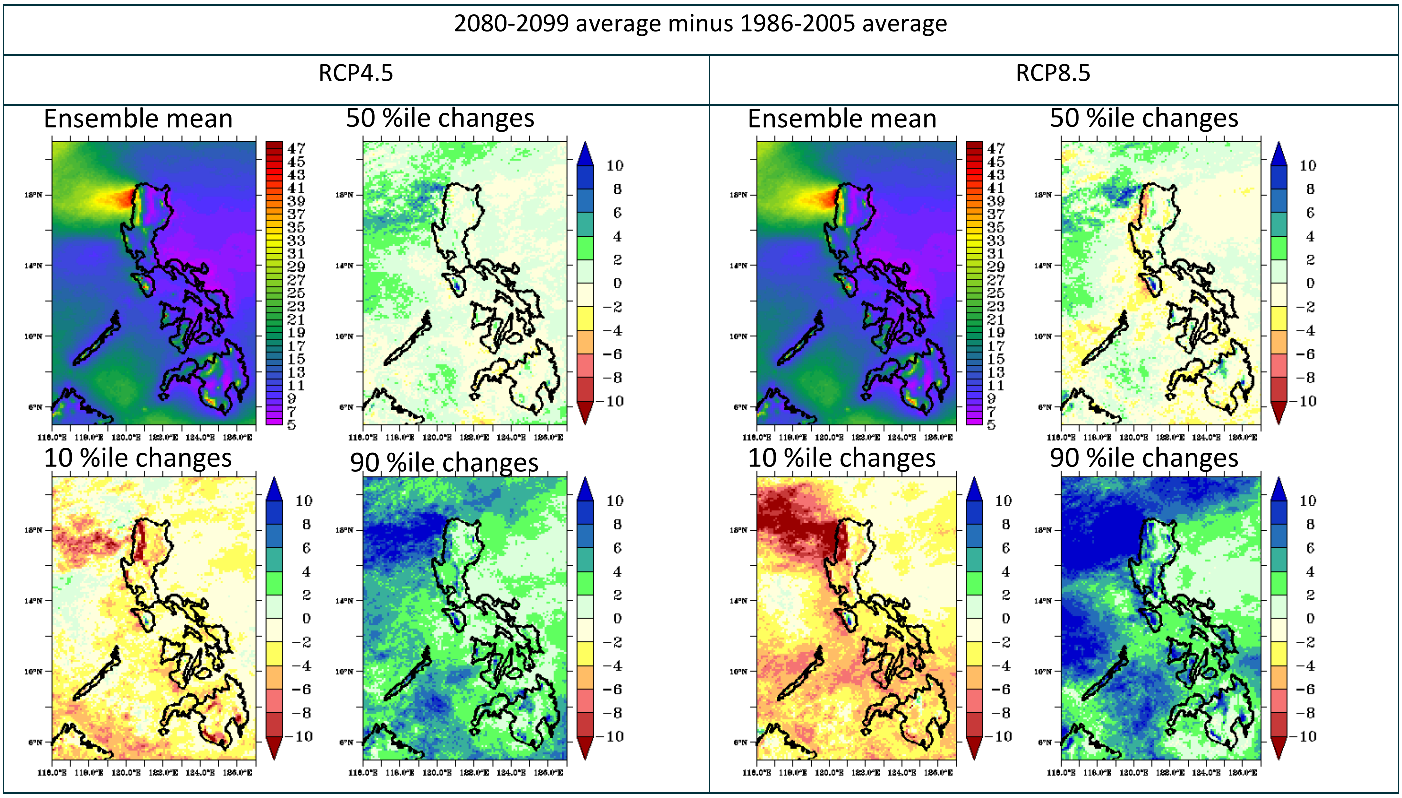
3-47: Average annual number of consecutive dry days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



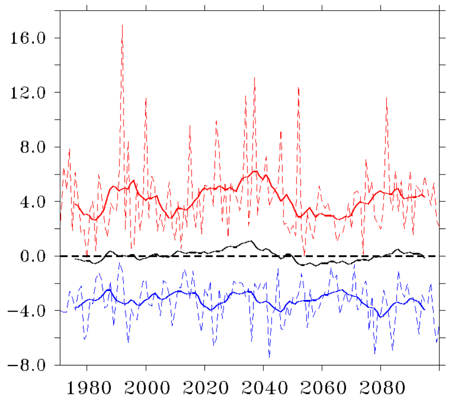
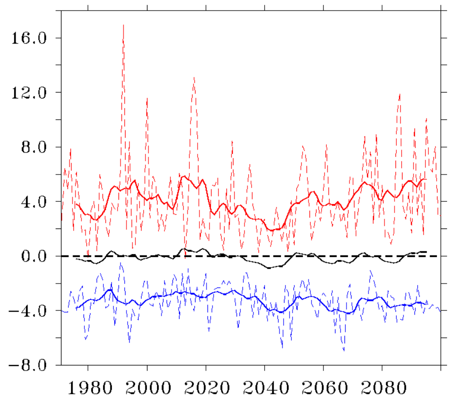
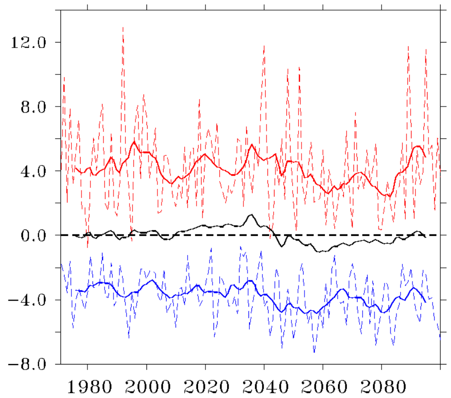
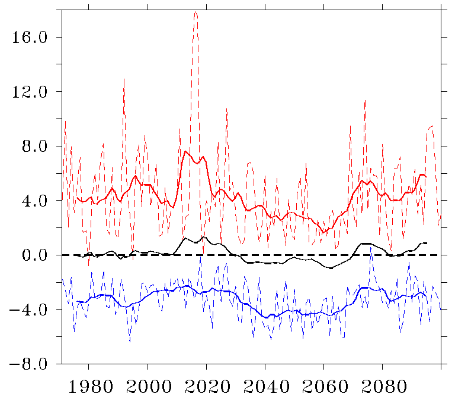
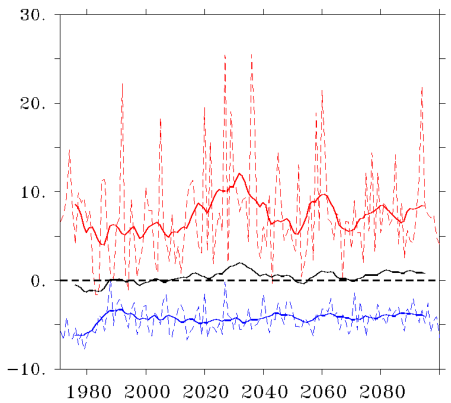
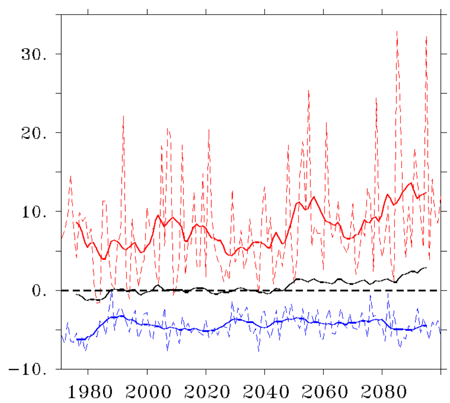
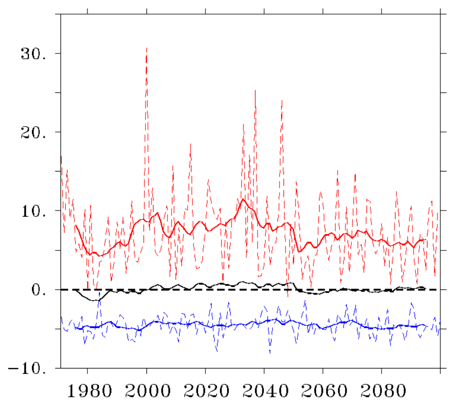
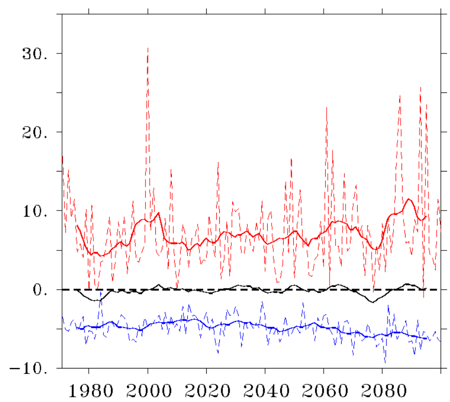
3-48: Average annual number of consecutive dry days for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



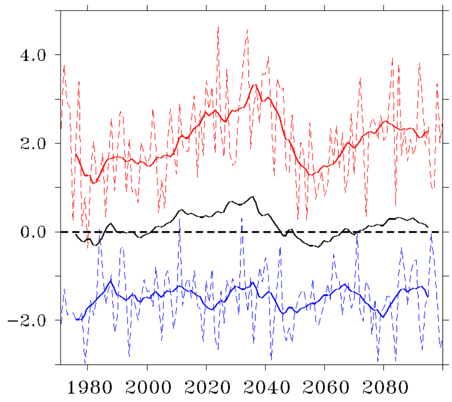
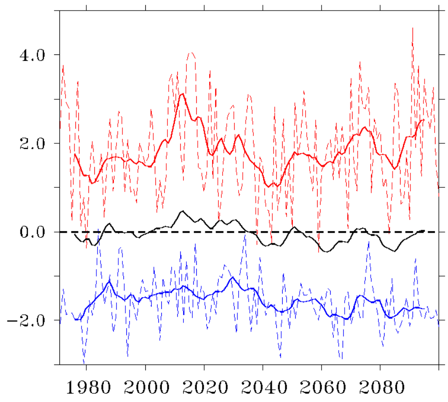
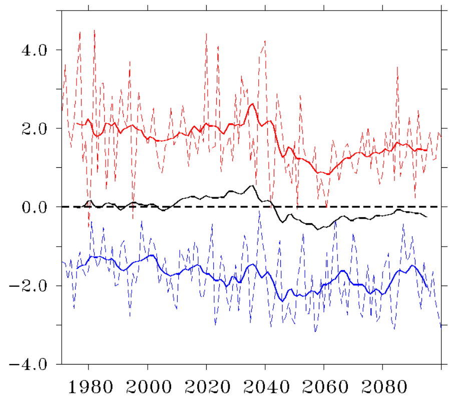
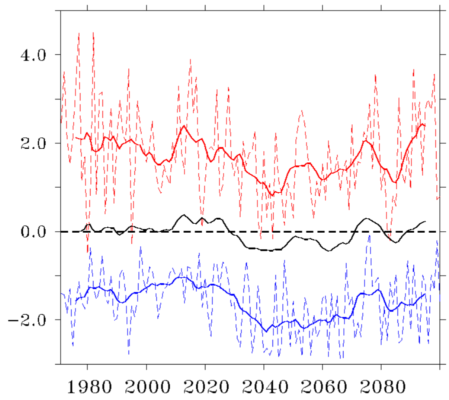
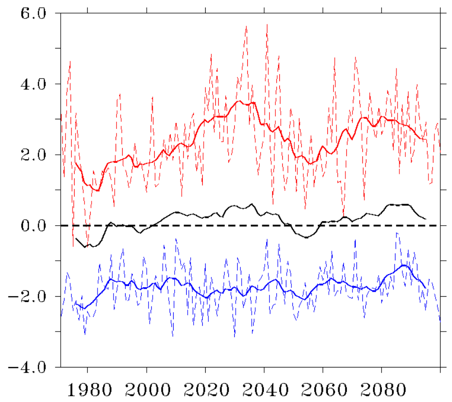
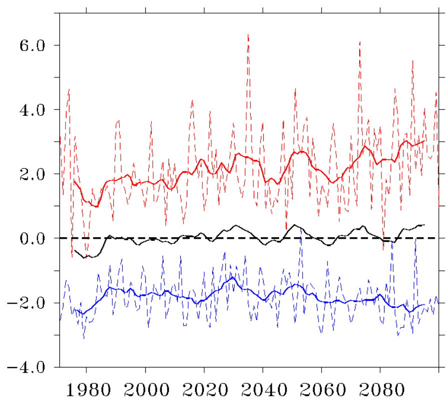
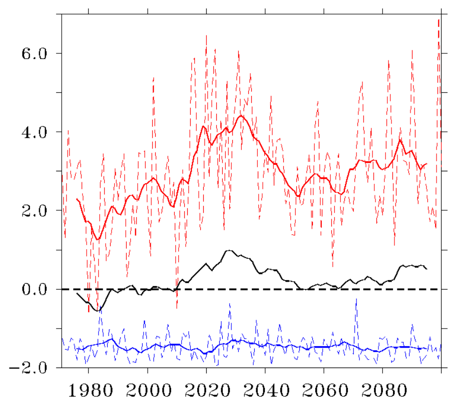
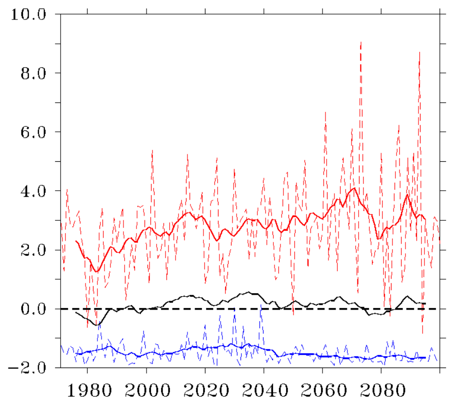
3-49: Average maximum length of consecutive dry days (days) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-50: Average maximum length of consecutive dry days (days) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

3-51: Time series plots of change in annual maximum length of consecutive dry days for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

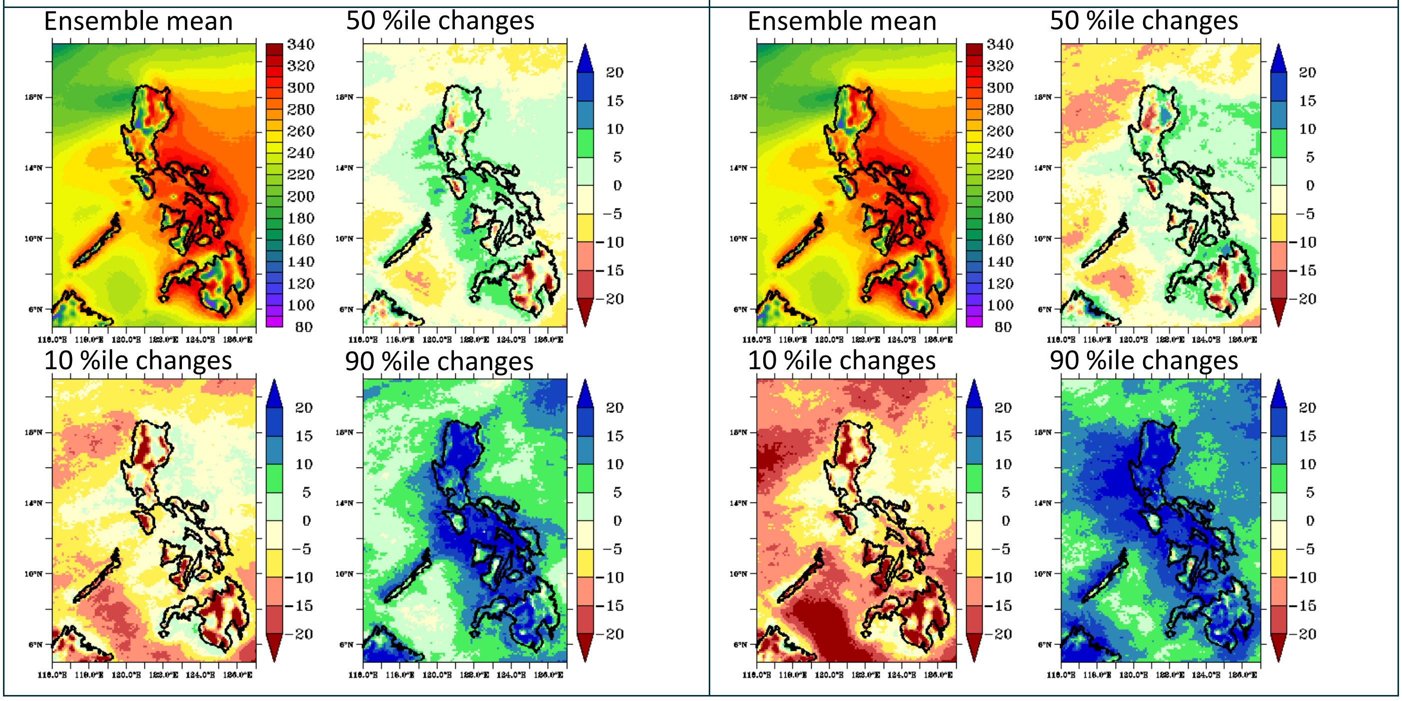
ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

3-52: Time series plots of change in the annual number of consecutive dry days periods of more than 5 days for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

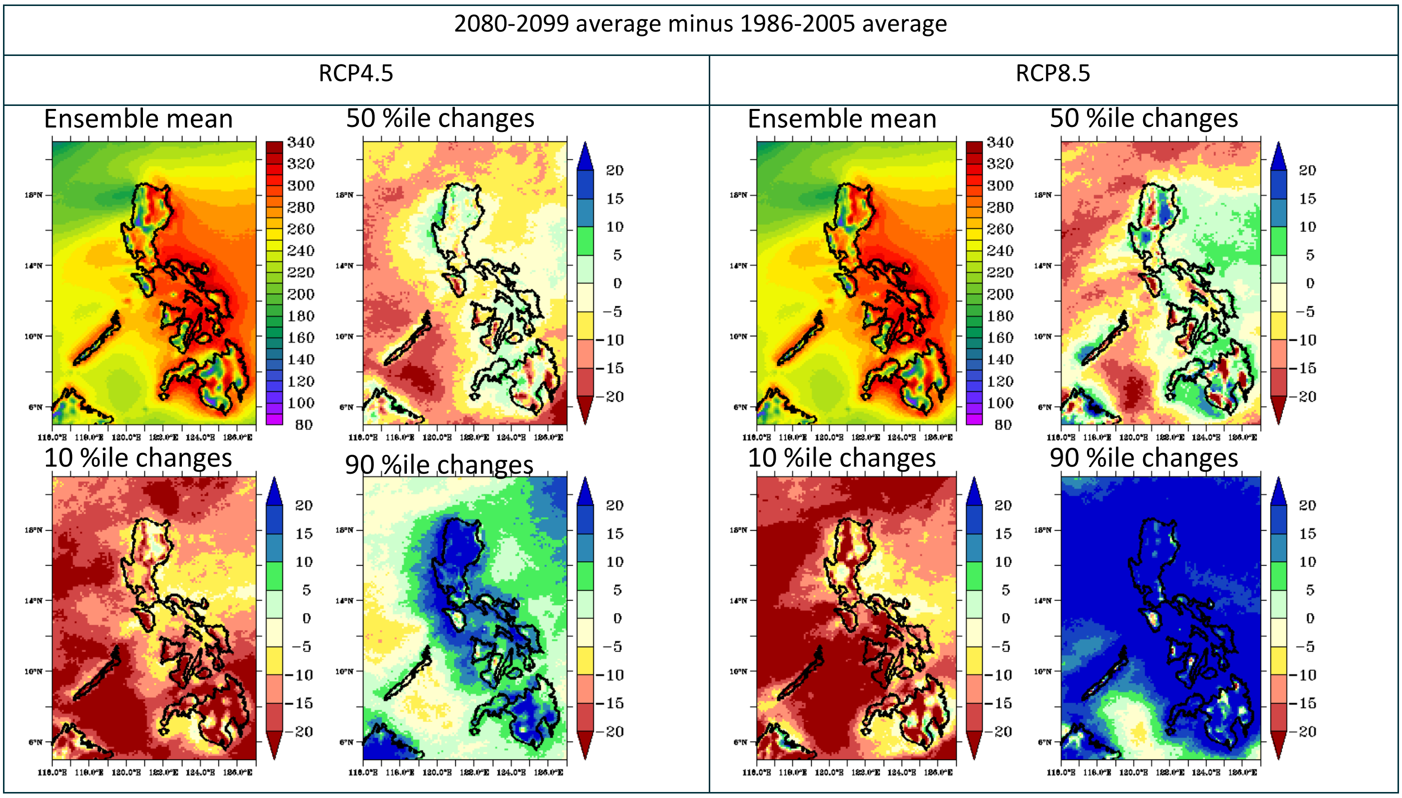
3.16Number of days with more than 1 mm (PD1)

The number of rain days is defined as days with greater than or equal to 1 mm rainfall. The median (50th percentile) result shows regions of both increase and decrease in number of rain days (see Figures 3-53 to 3-55).

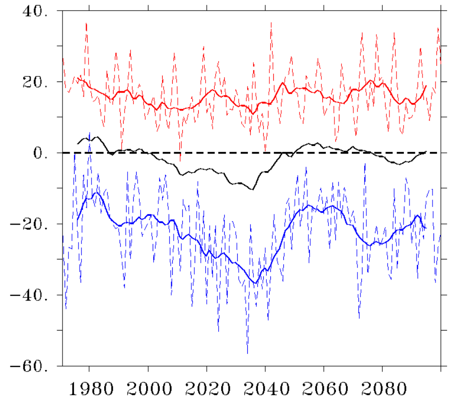
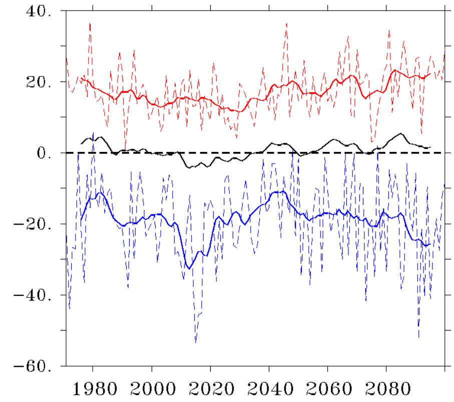
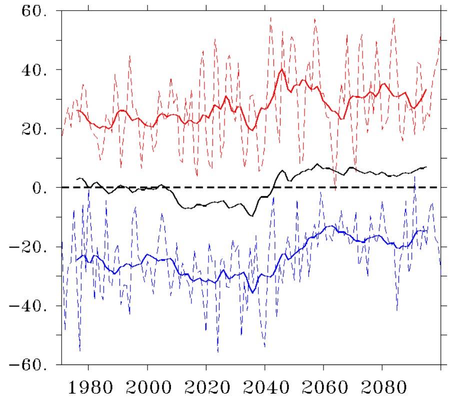
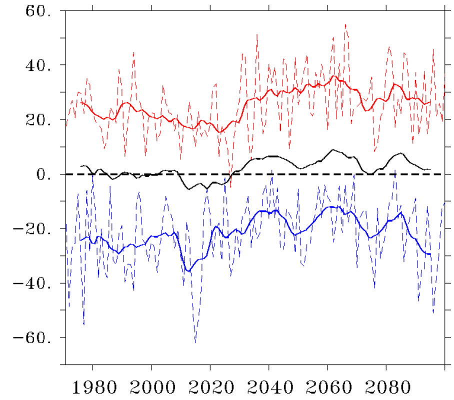
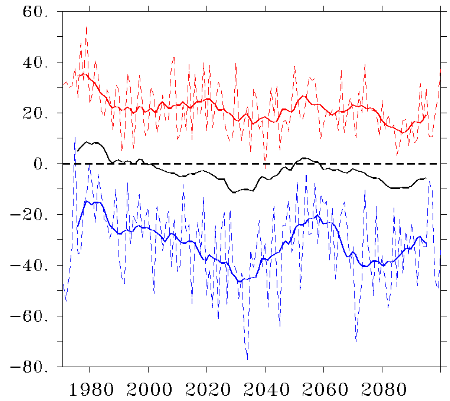
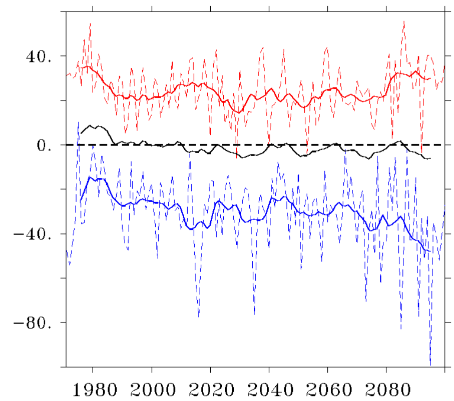
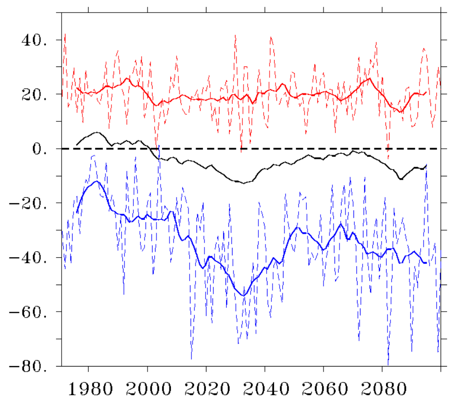
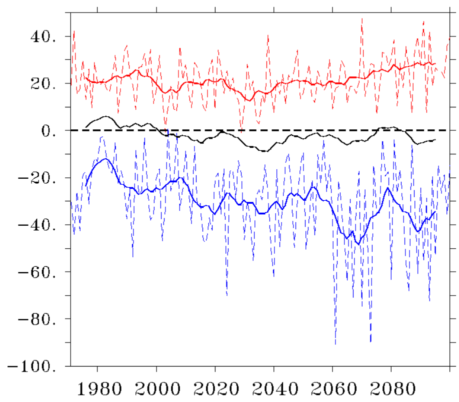
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-53: Average number of days with greater than 1 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-54: Average number of days with greater than 1 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

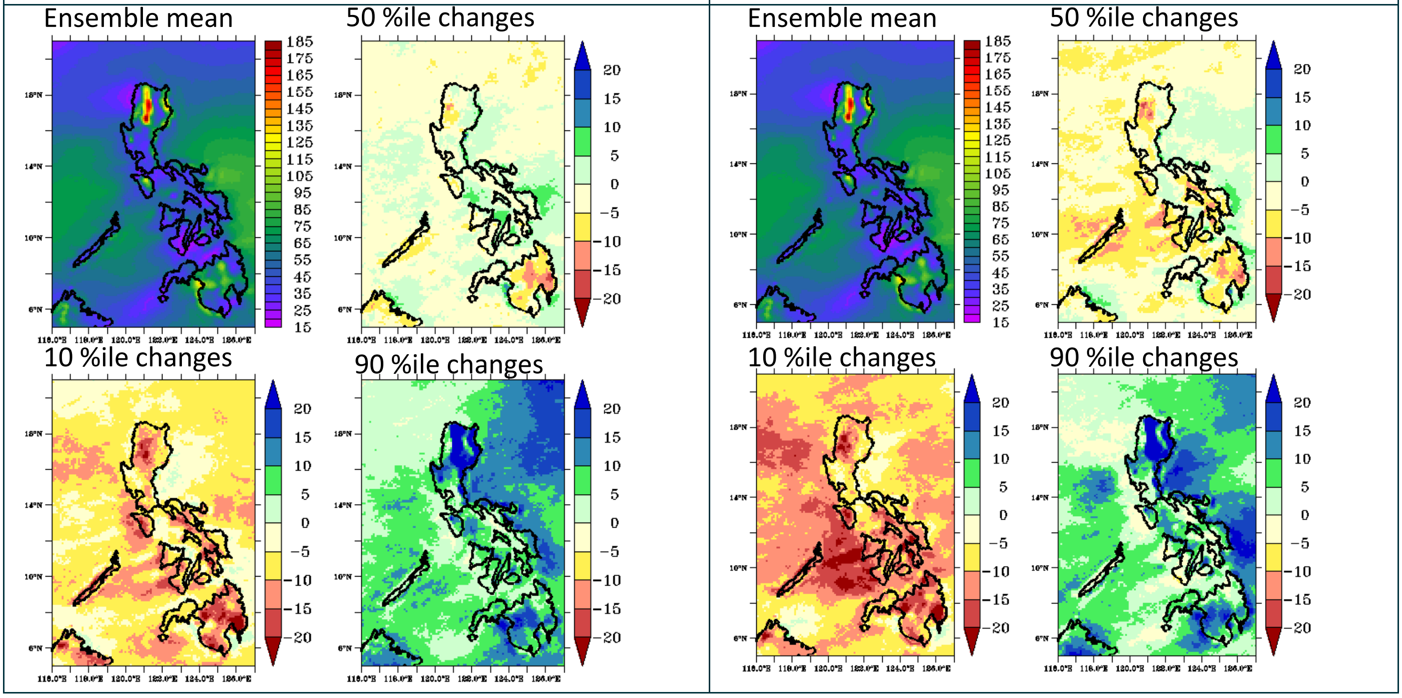
ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

3-55: Time series plots of change in the annual number of wet days index for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.17 Number of days with more than 10 mm (R10mm)

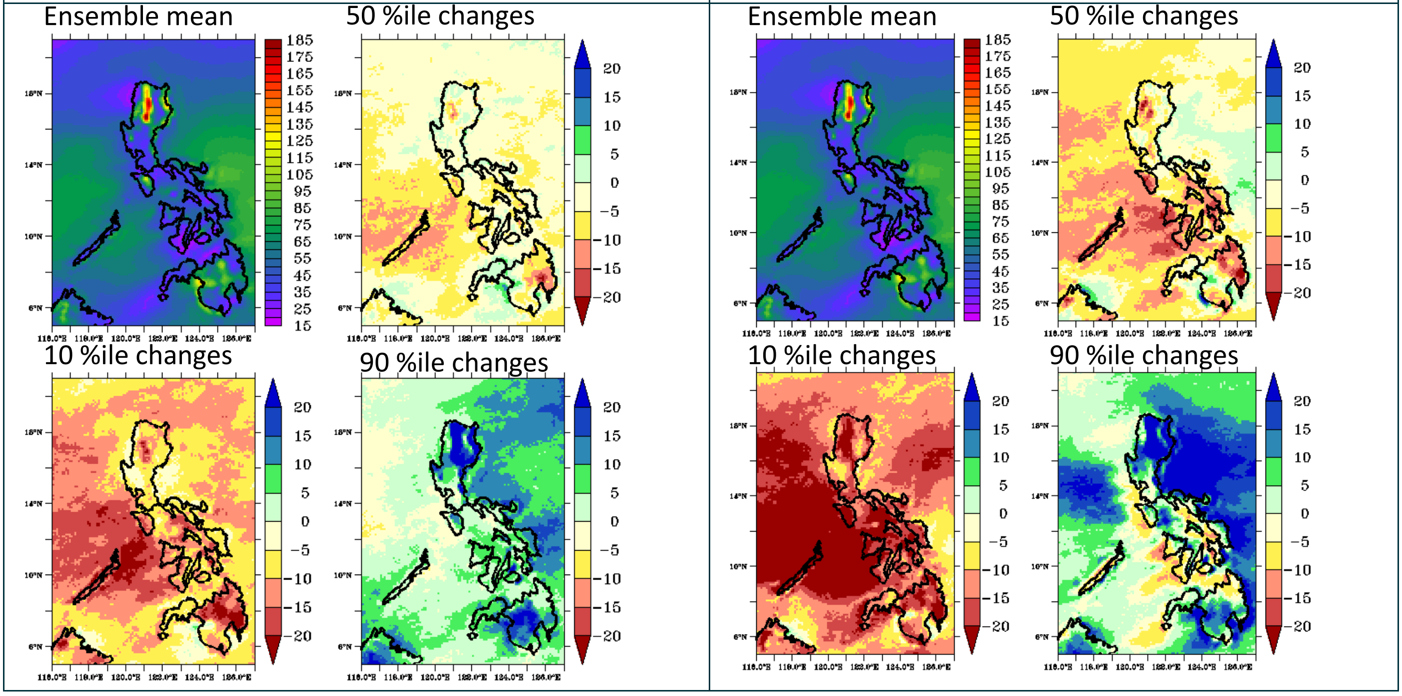
R10mm is defined as the number of days with 10 mm or more of precipitation. The projections show a slight decrease in rain days with more than 10 mm, becoming more pronounced by end of the century with RCP8.5 (see figures 3-56 to 3-58).

2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5

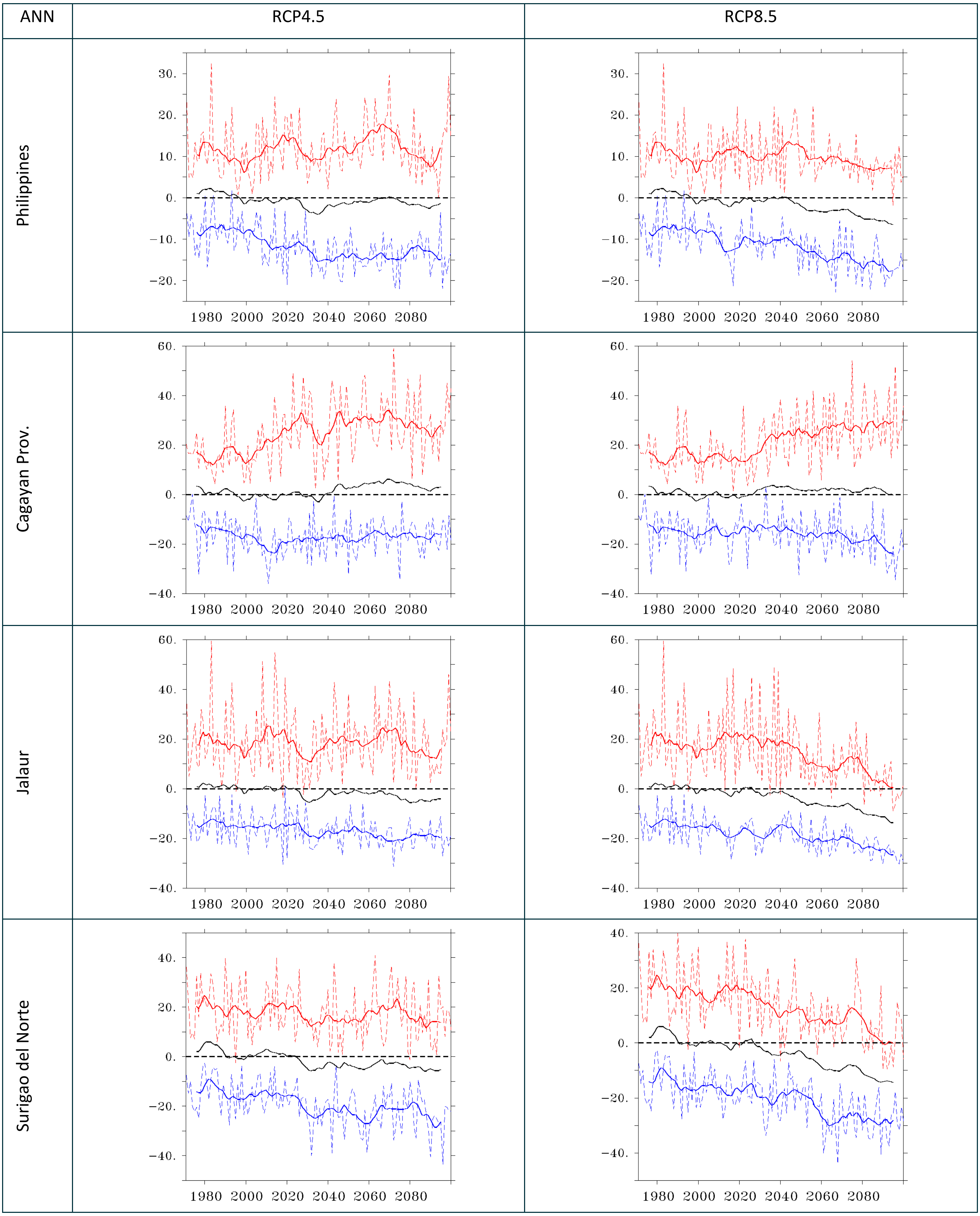


3-56: Average number of days with greater than 10 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5



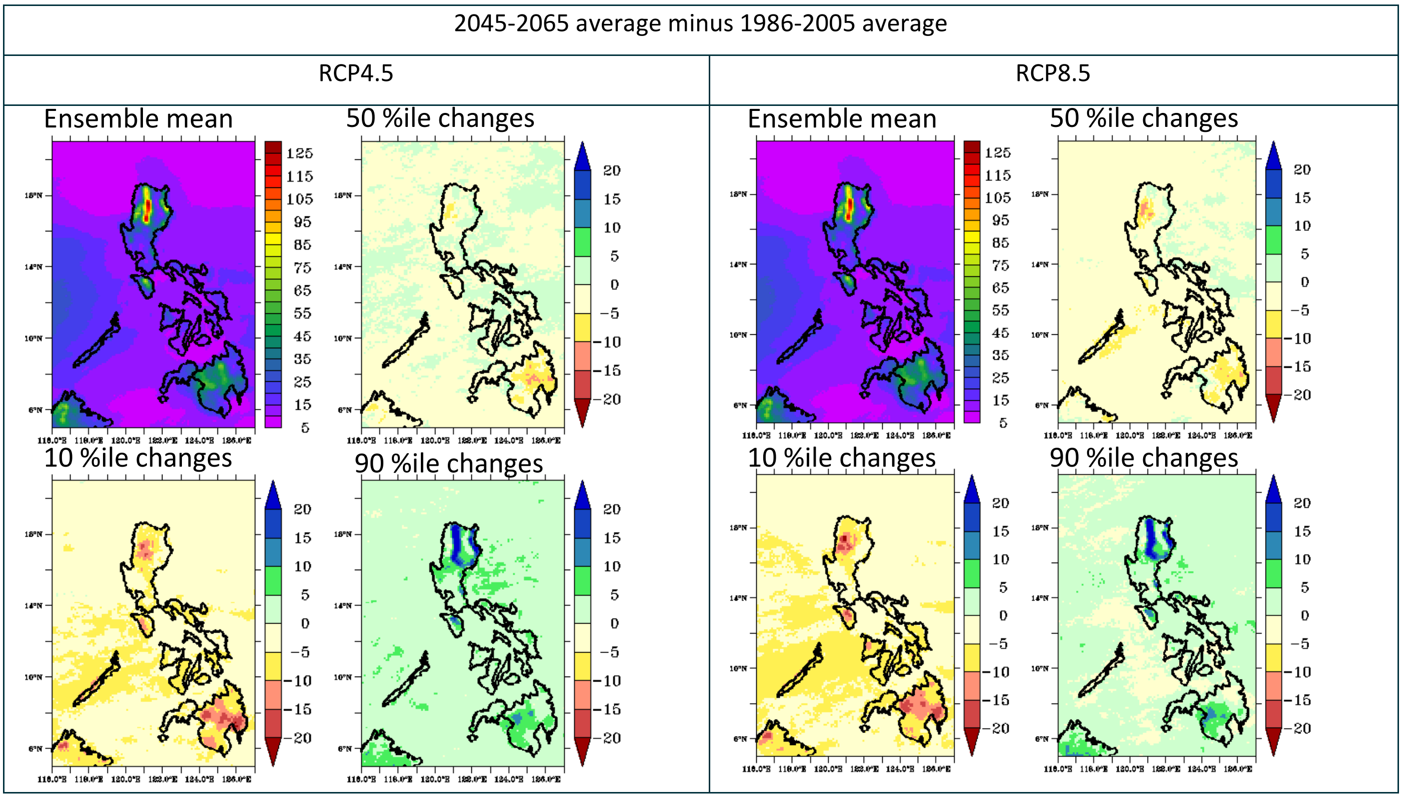
3-57: Average number of days with greater than 10 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-58: Time series plots of change in the annual heavy precipitation days index (r10mm) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

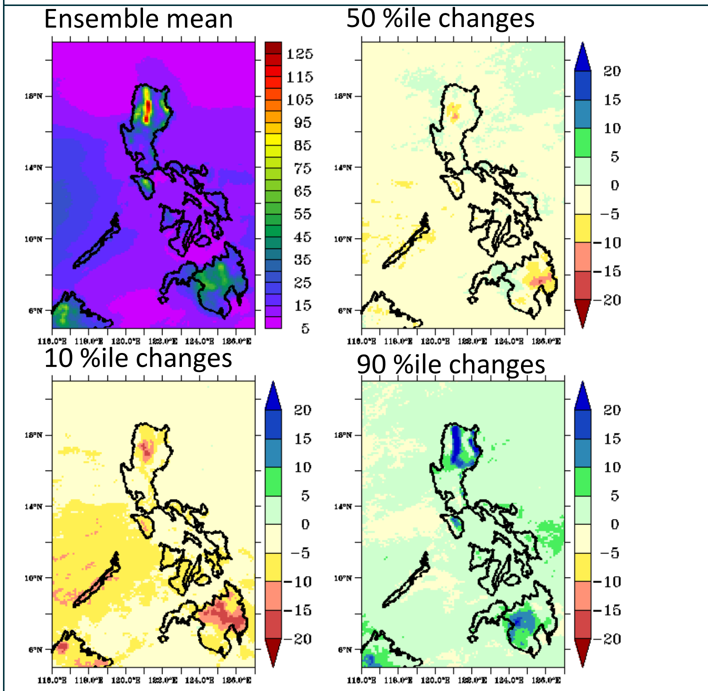
3.18Number of days with more than 20 mm (R20mm)

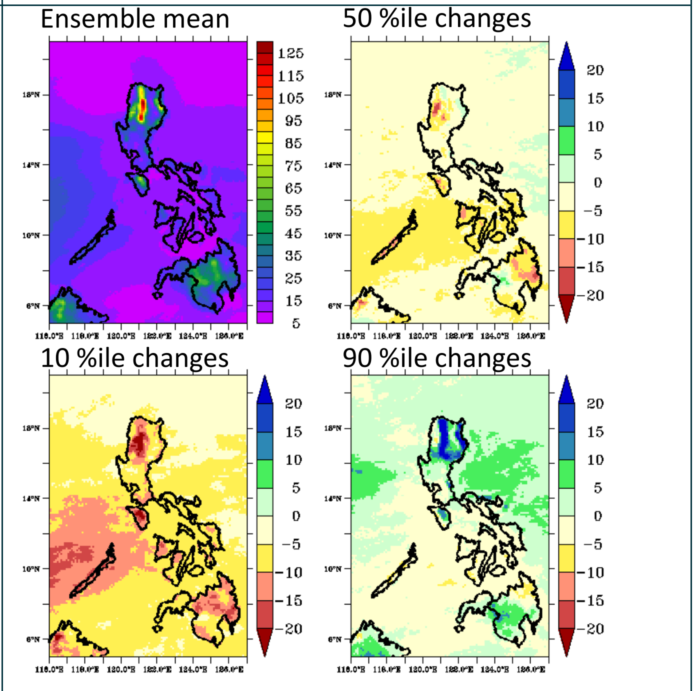
R20mm is defined as the number of days annually with greater than 20 mm of precipitation. The projected changes in aresmall for RCP4.5, but there are more decreases with RCP8.5 (Figure 3-59 and 3-60). Examination of the time series (Figure 3-61) confirms this picture, but with regional differences.



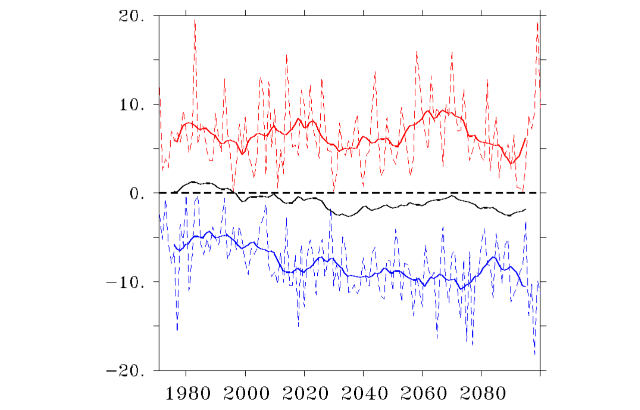
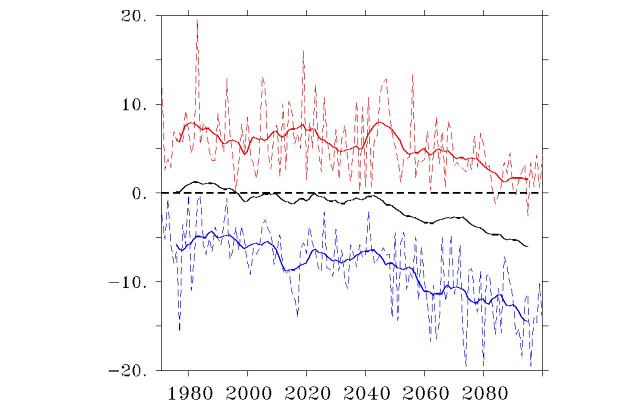
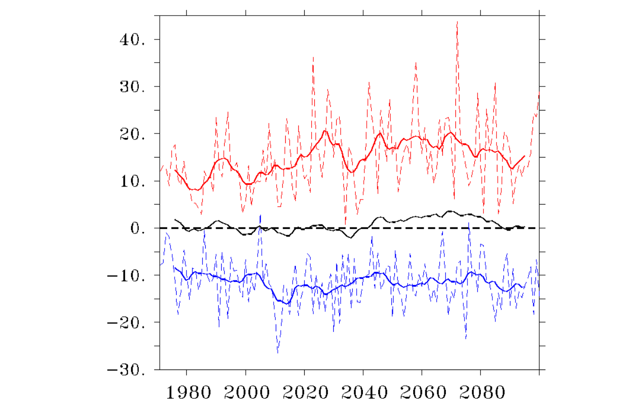
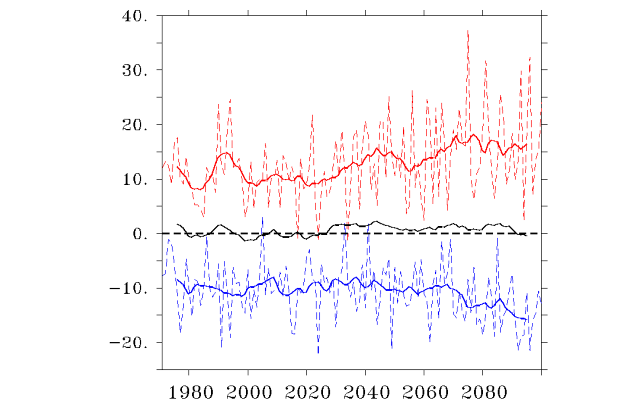
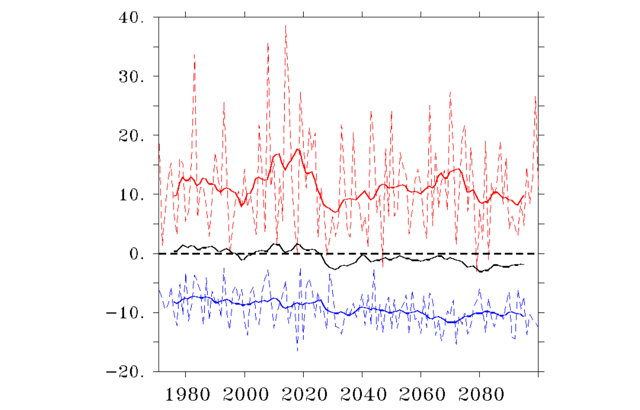
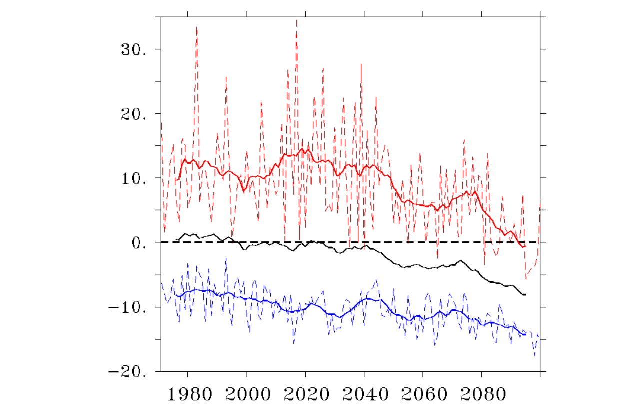
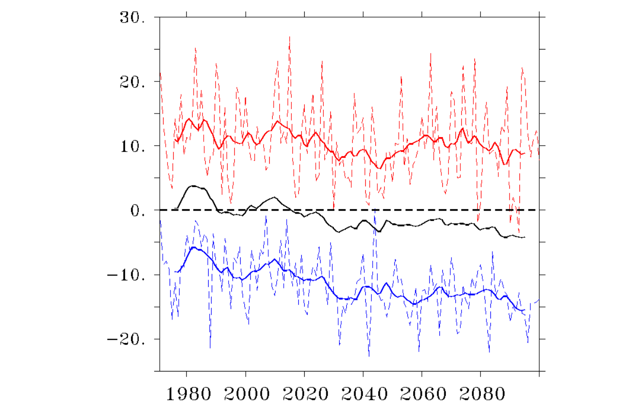
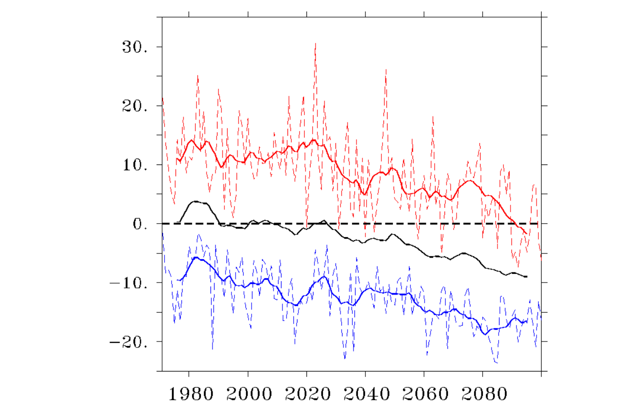
3-59: Average number of days with greater than 20 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

2080-2099 average minus 1986-2005 average	
RCP4.5	RCP8.5





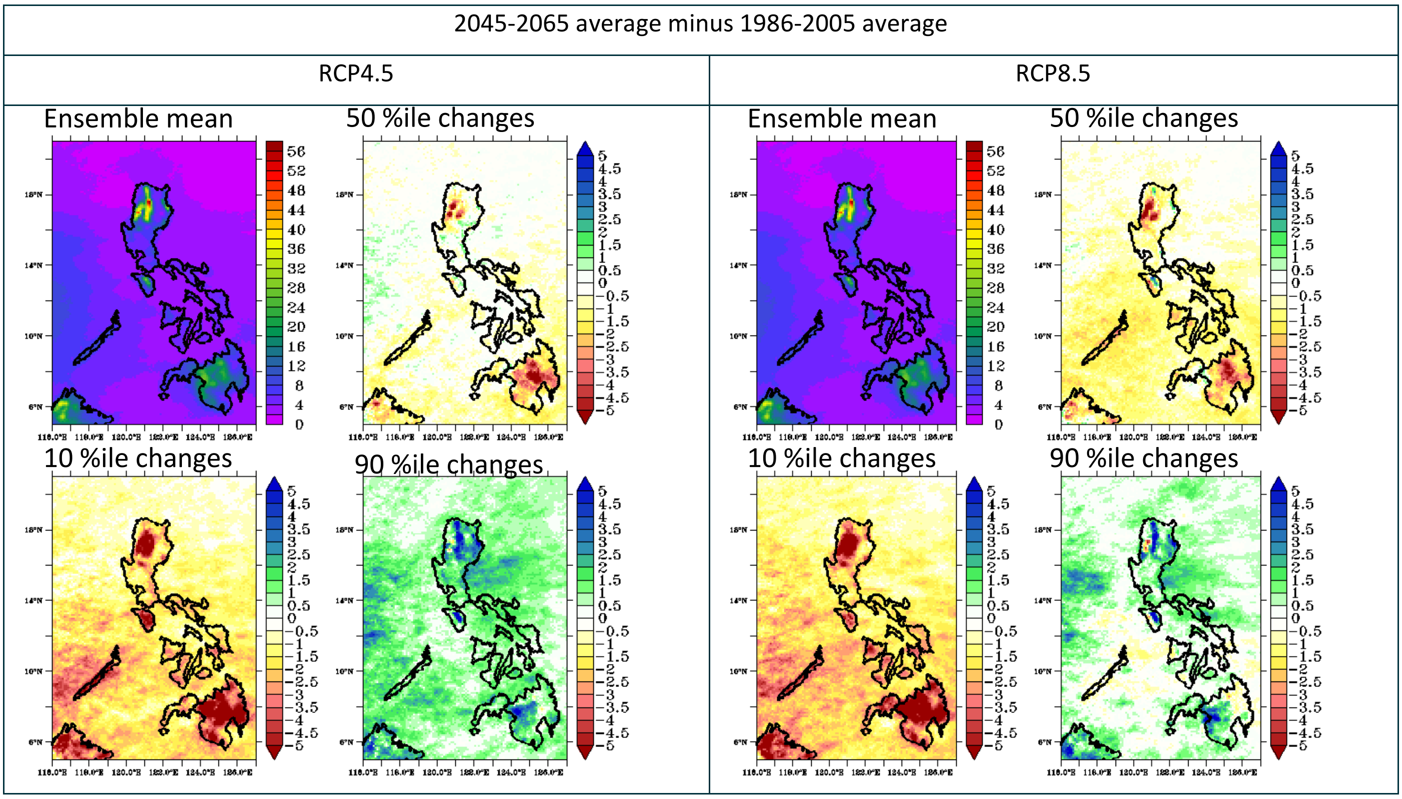
3-60: Average number of days with greater than 20 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

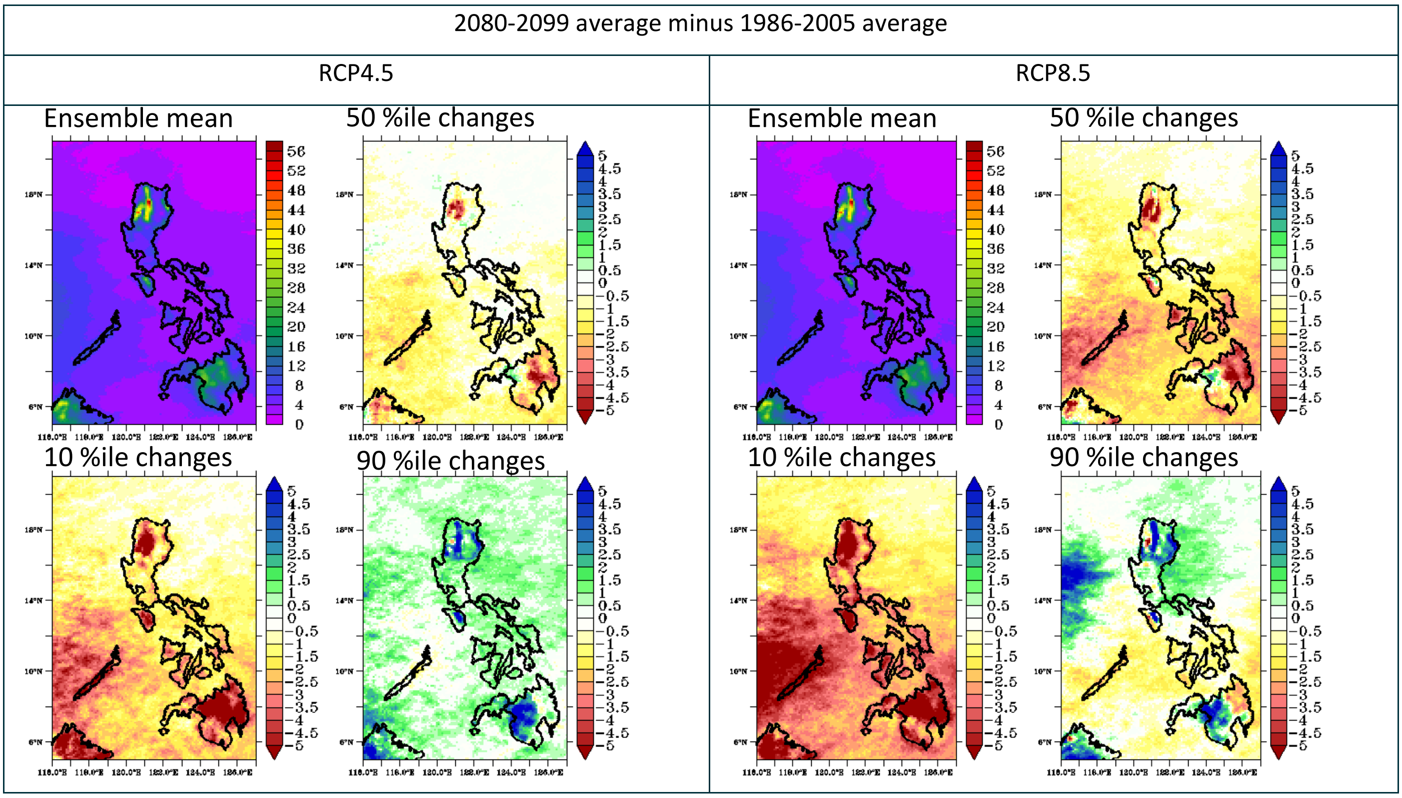
3-61: Time series plots of change in the annual number of days with more than 20 mm rainfall (r20mm) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.19 Number of days with more than 50 mm (PD50)

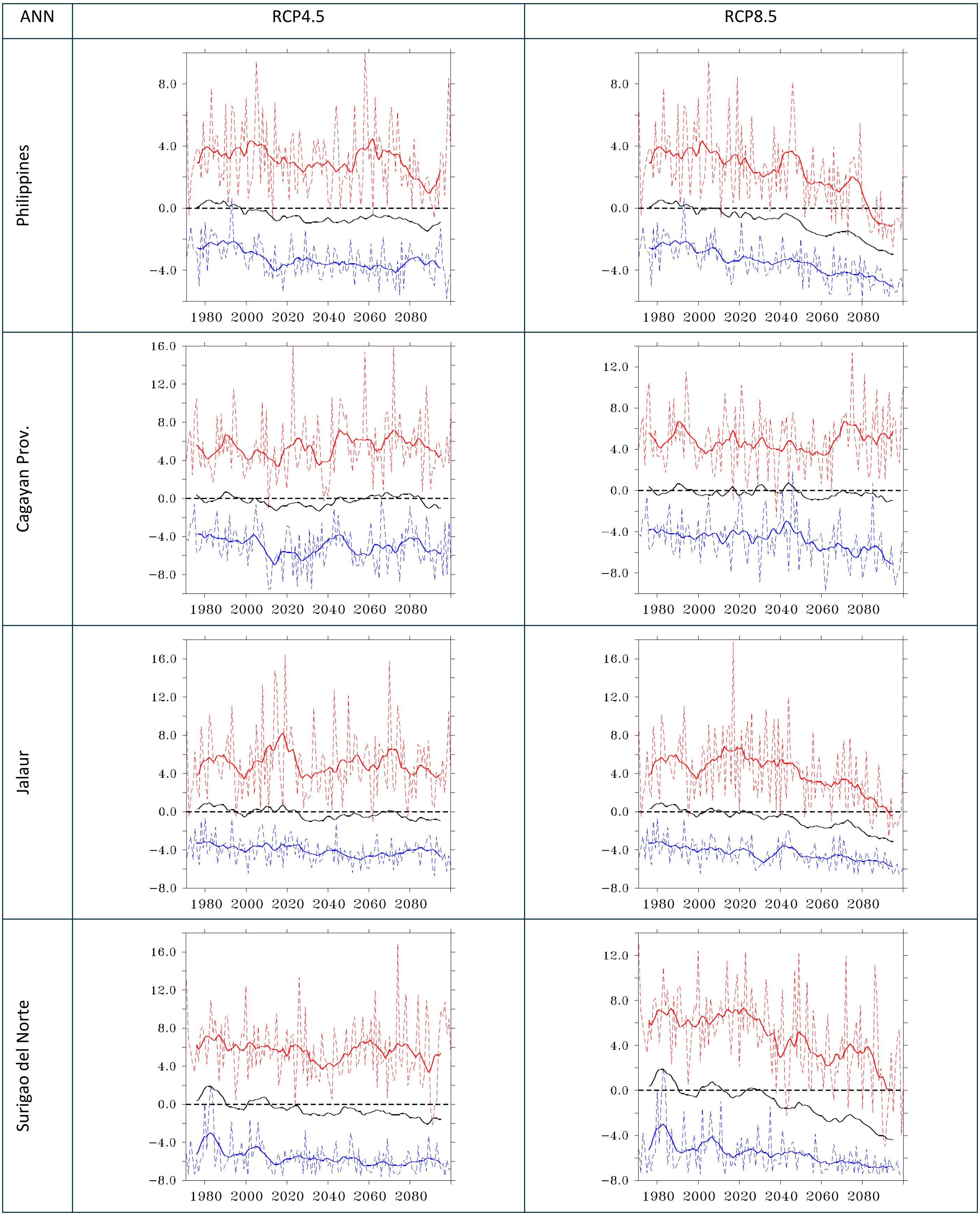
PD50 is the number of days with precipitation of 50 mm or more. The projections indicate decreases in the number of days with greater than 50 mm rain, especially for northern and southern Philippines with RCP8.5 (Figures 3-62 to 3-64).



3-62: Average number of days with greater than 50 mm for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



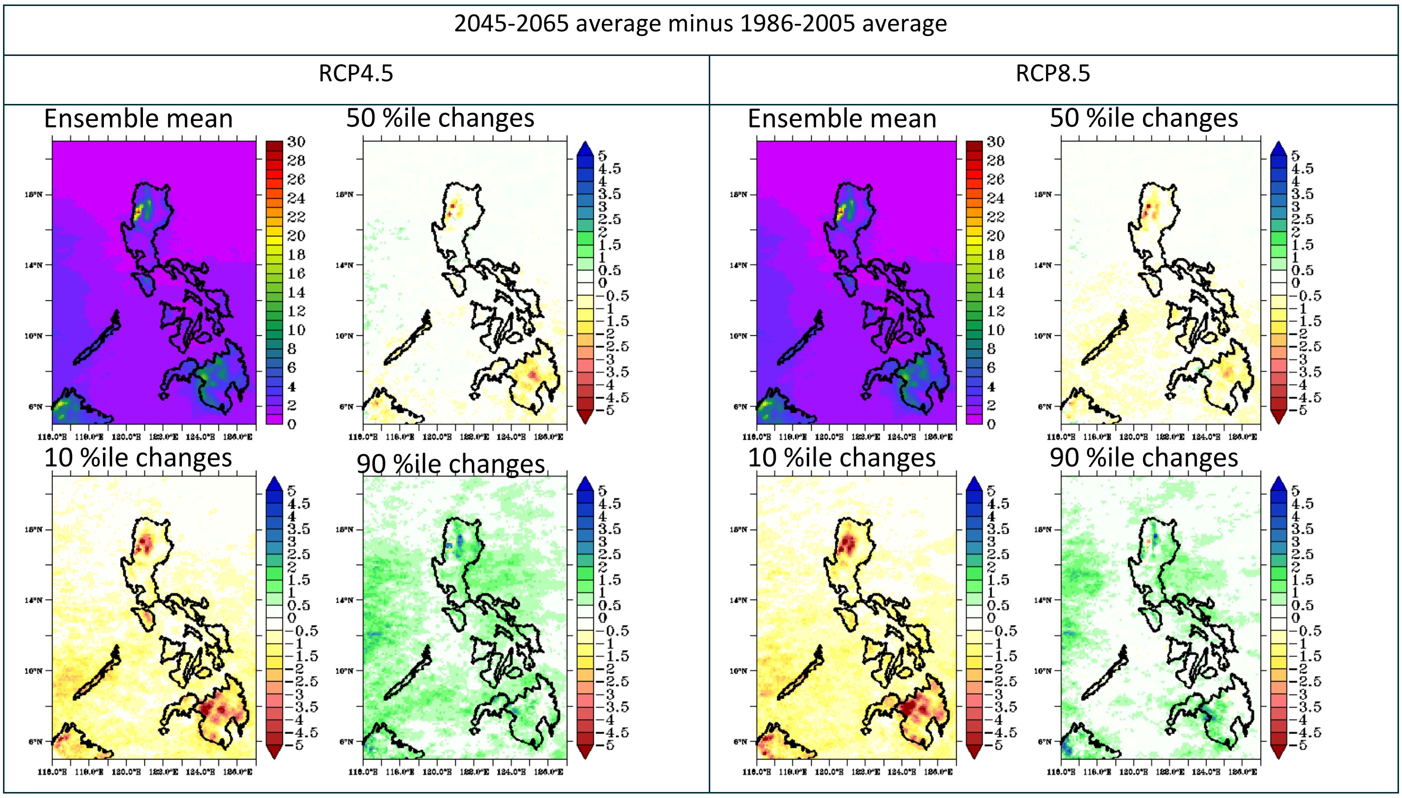
3-63: Average number of days with greater than 50 mm of rain for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



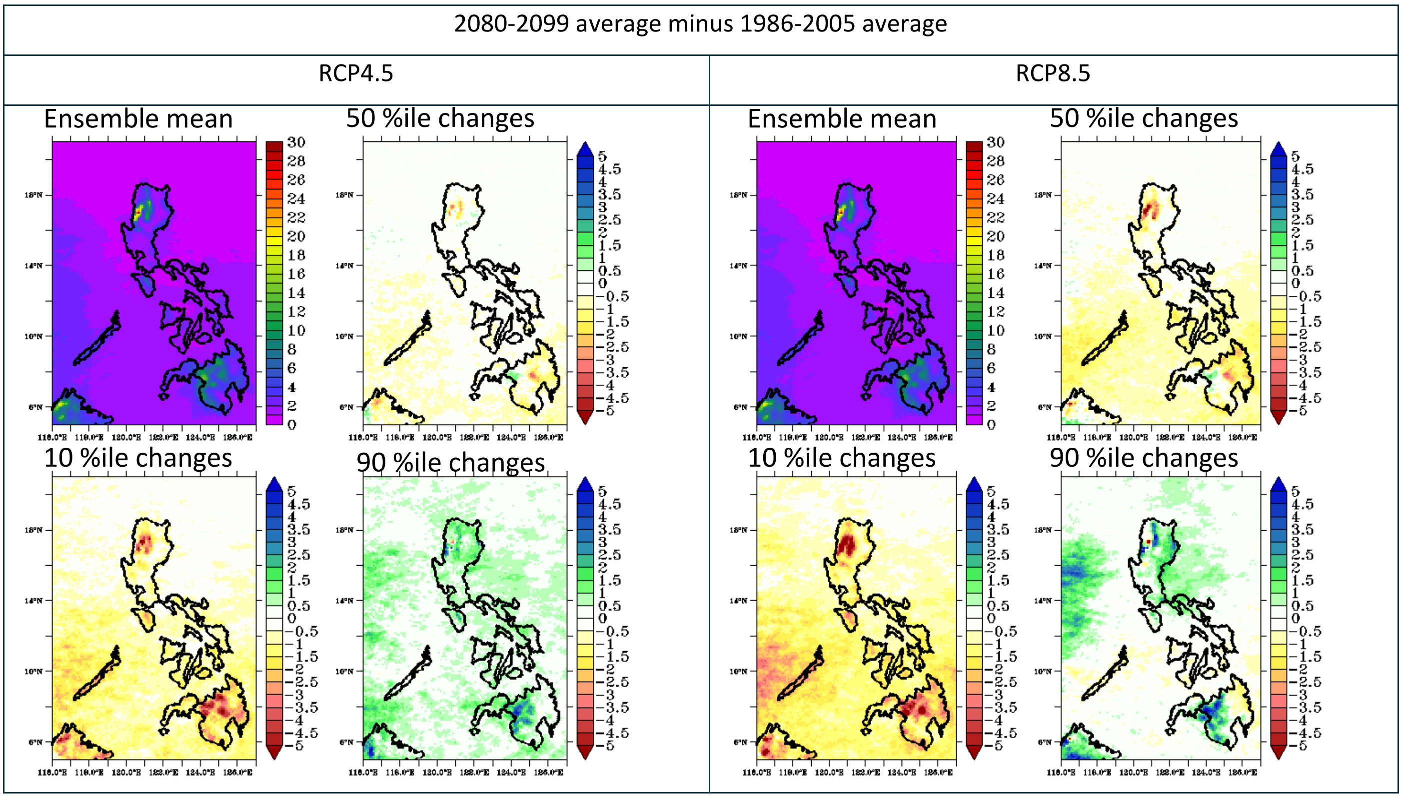
3-64: Time series plots of change in the annual number of days with greater than 50 mm of rain for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.20Number of days with more than 100 mm (PD100)

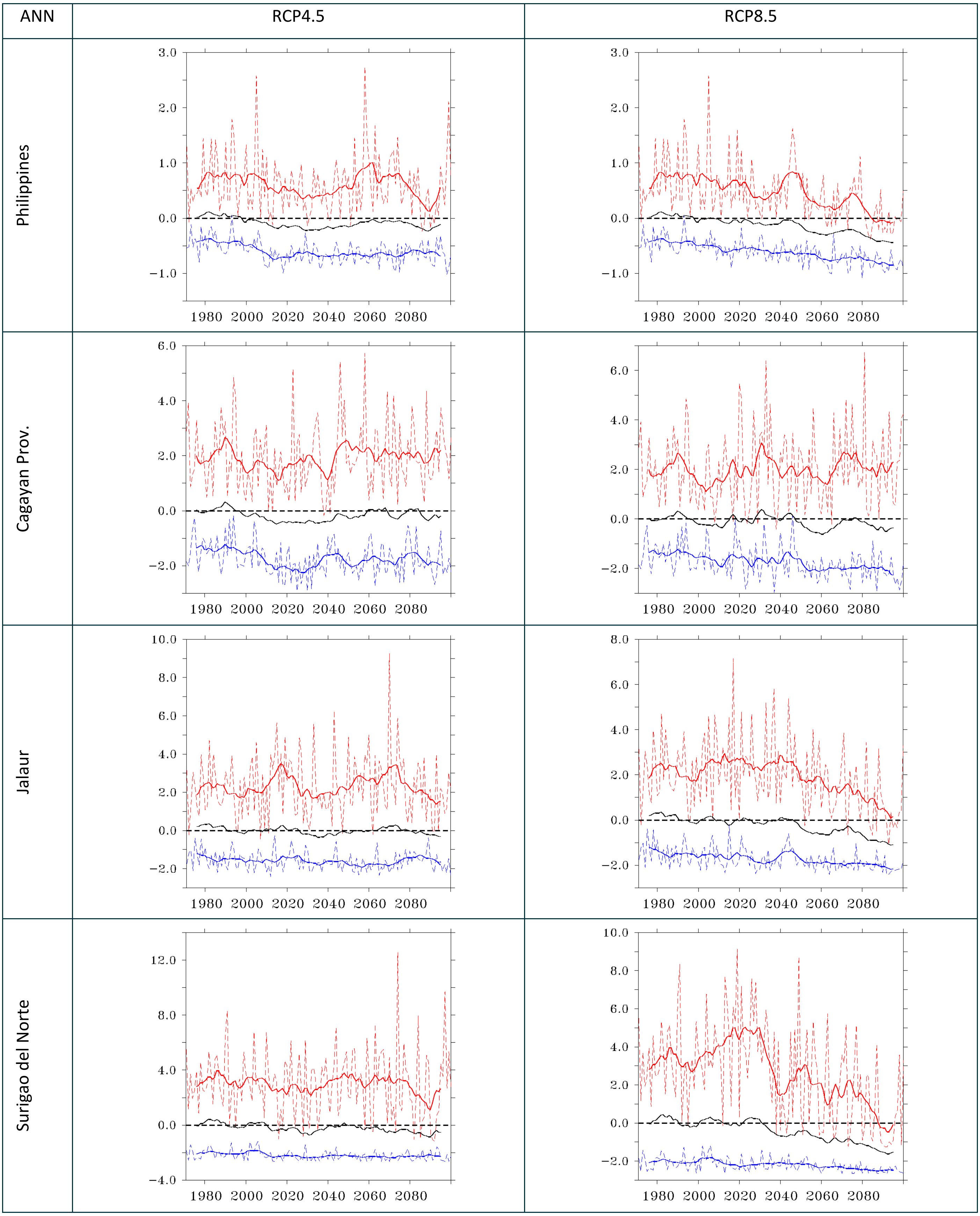
PD100 is the number of days with precipitation of 100 mm or more. Decreases are evident especially with RCP8.5 (Figure 3-65 to 3-67).



3-65: Average number of days with greater than 100 mm of rain for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-66: Average number of days with greater than 100 mm of rain for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

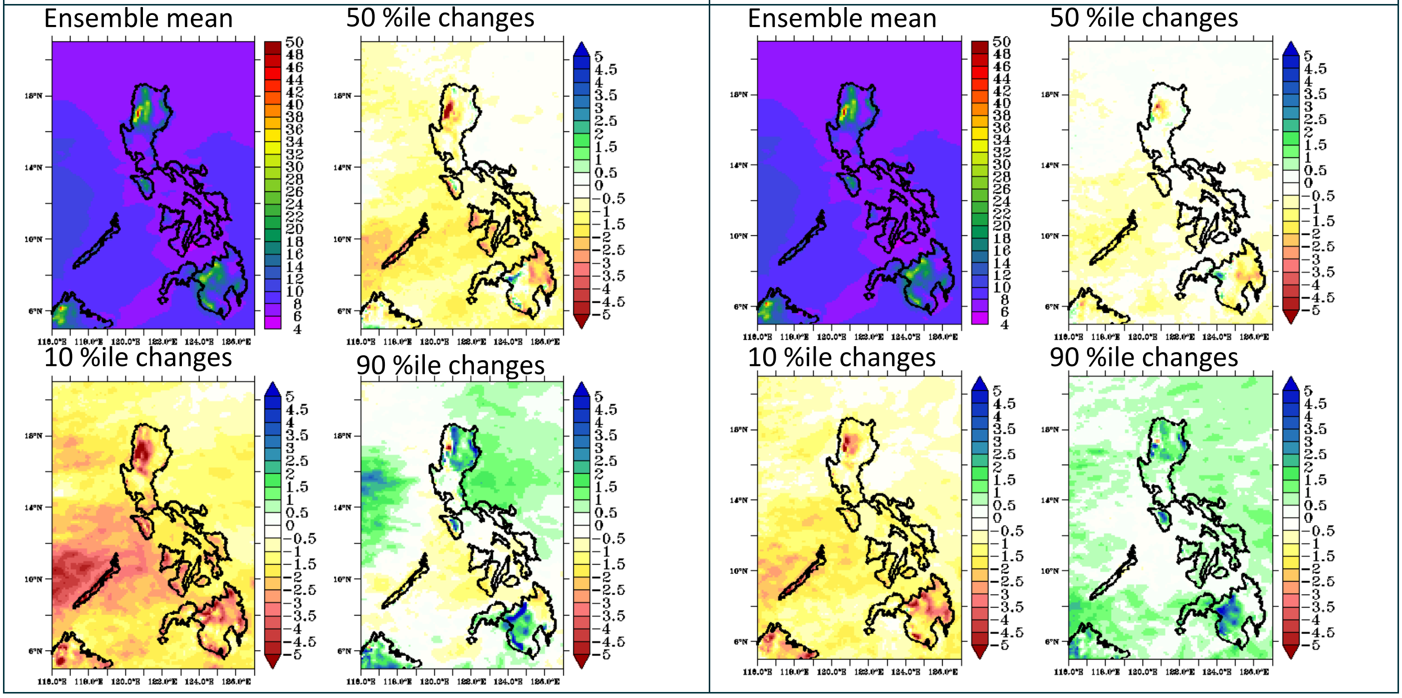


3-67: Time series plots of change in the annual number of days with greater than 100 mm of rain for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

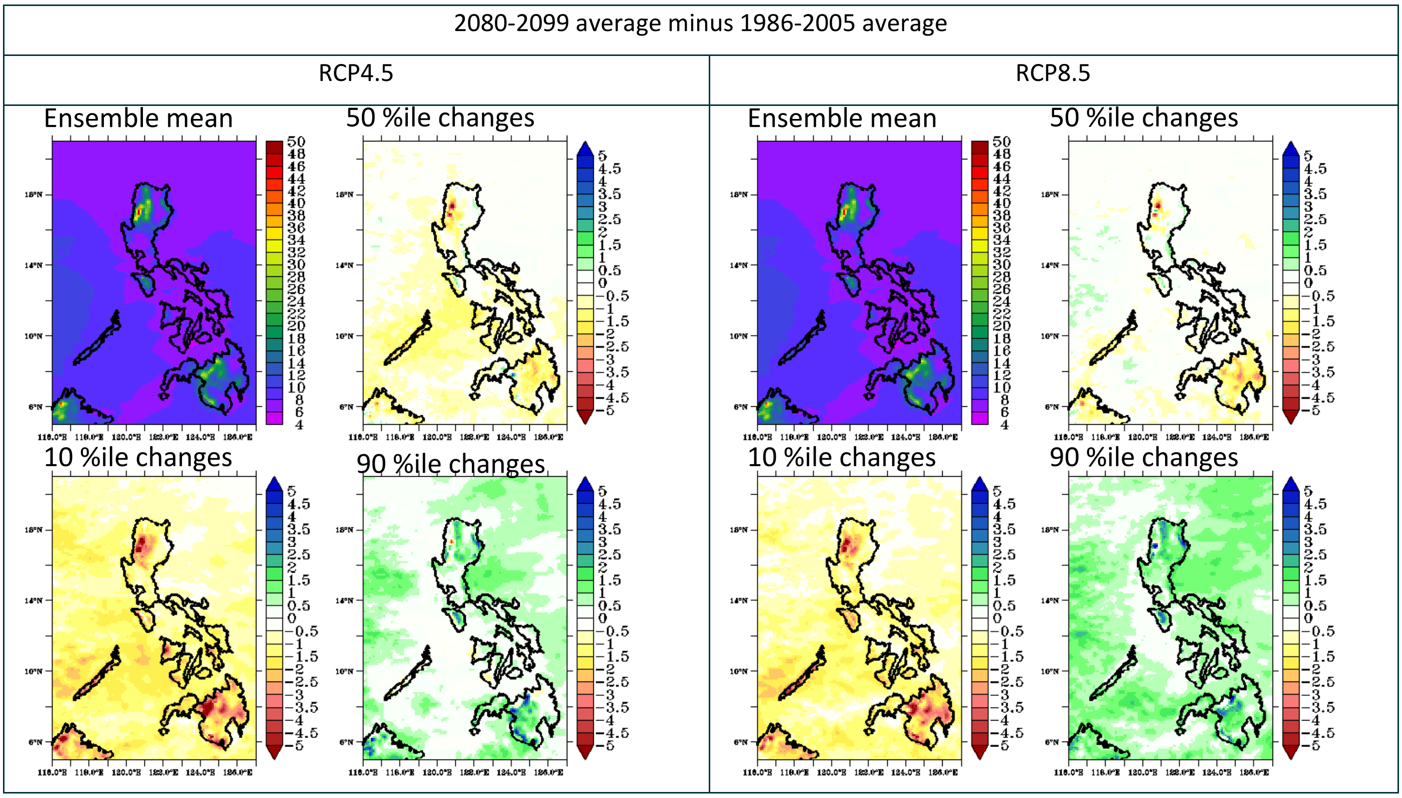
3.21 Daily rainfall intensity index (SDII)

SDII is defined to be the average amount of rainfall for all days with 1 mm or more of precipitation. The average amount of rain to fall during rainy days is projected to decrease slightly (Figure 3-68 to 3-70).

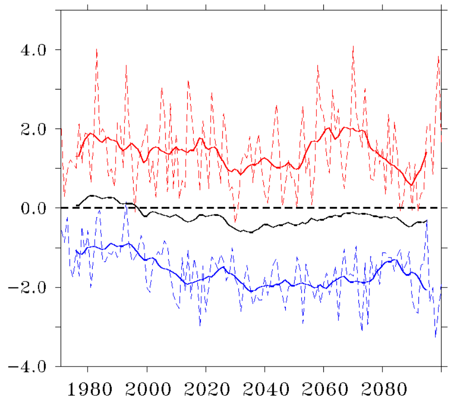
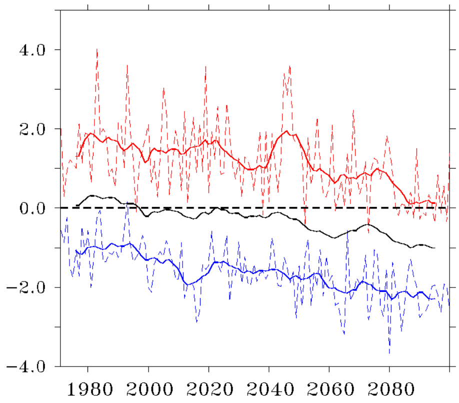
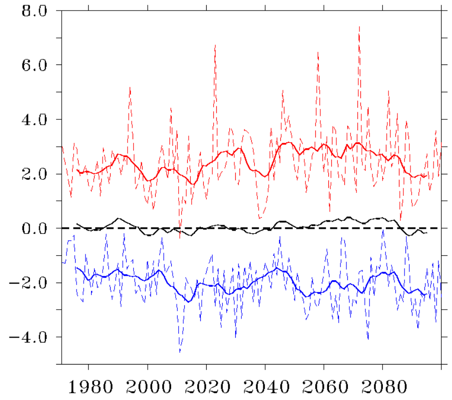
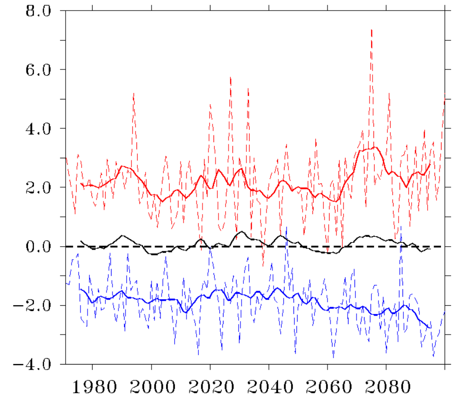
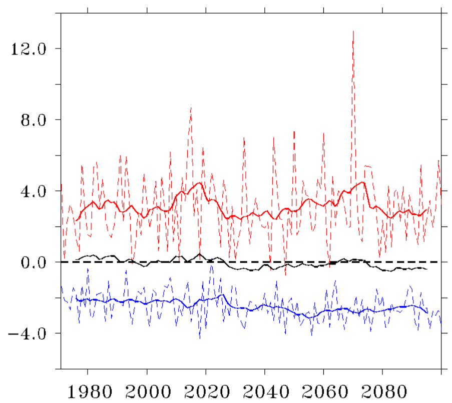
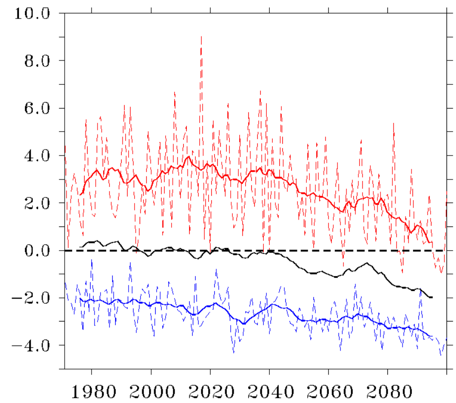
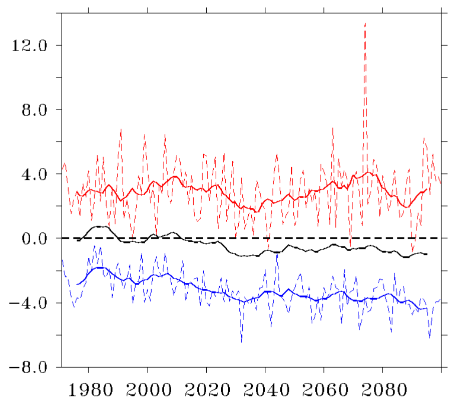
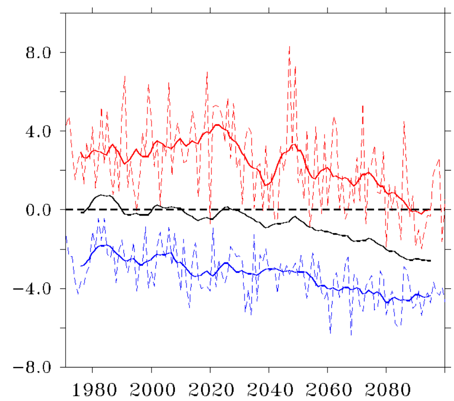
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-68: Average daily rainfall intensity index (mm/day) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



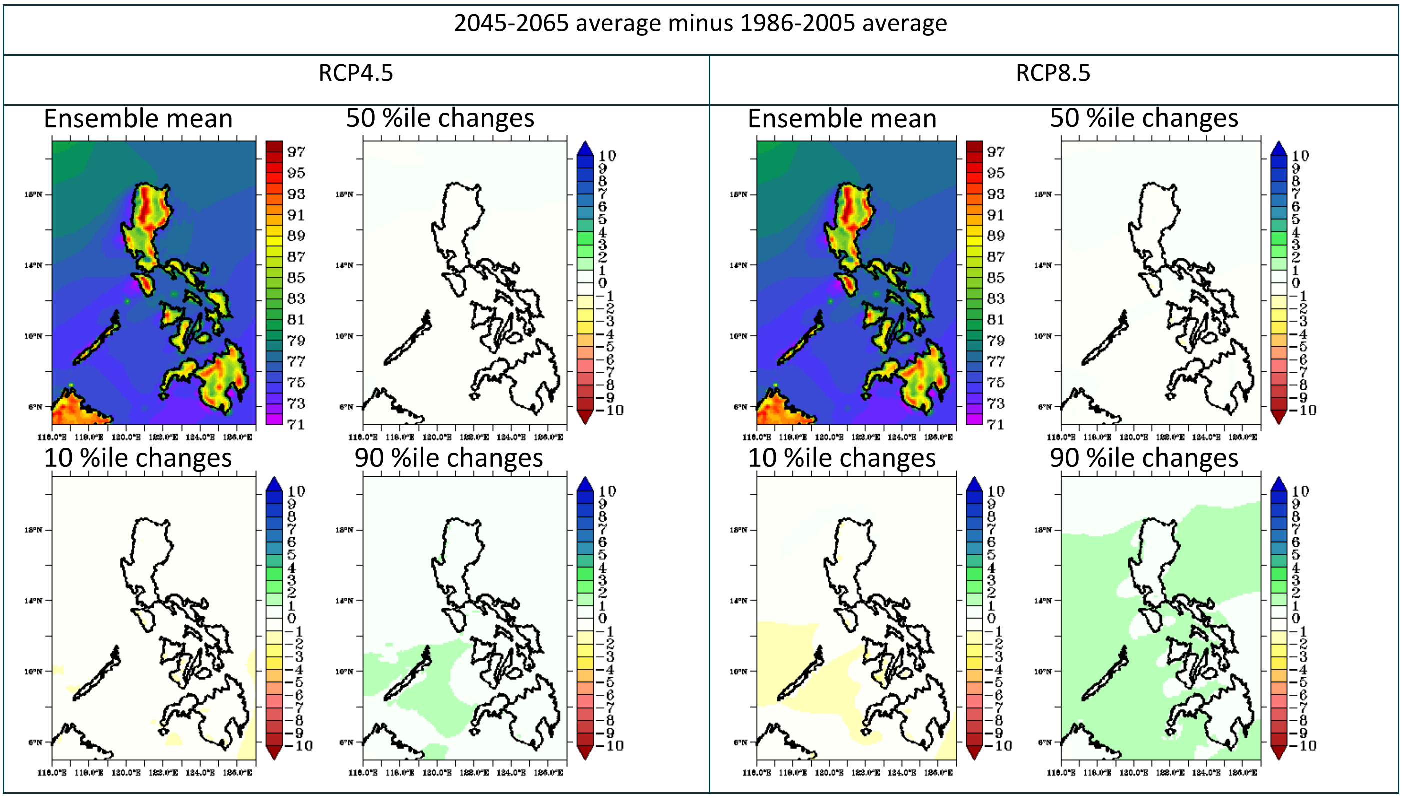
3-69: Average daily rainfall intensity index (mm/day) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

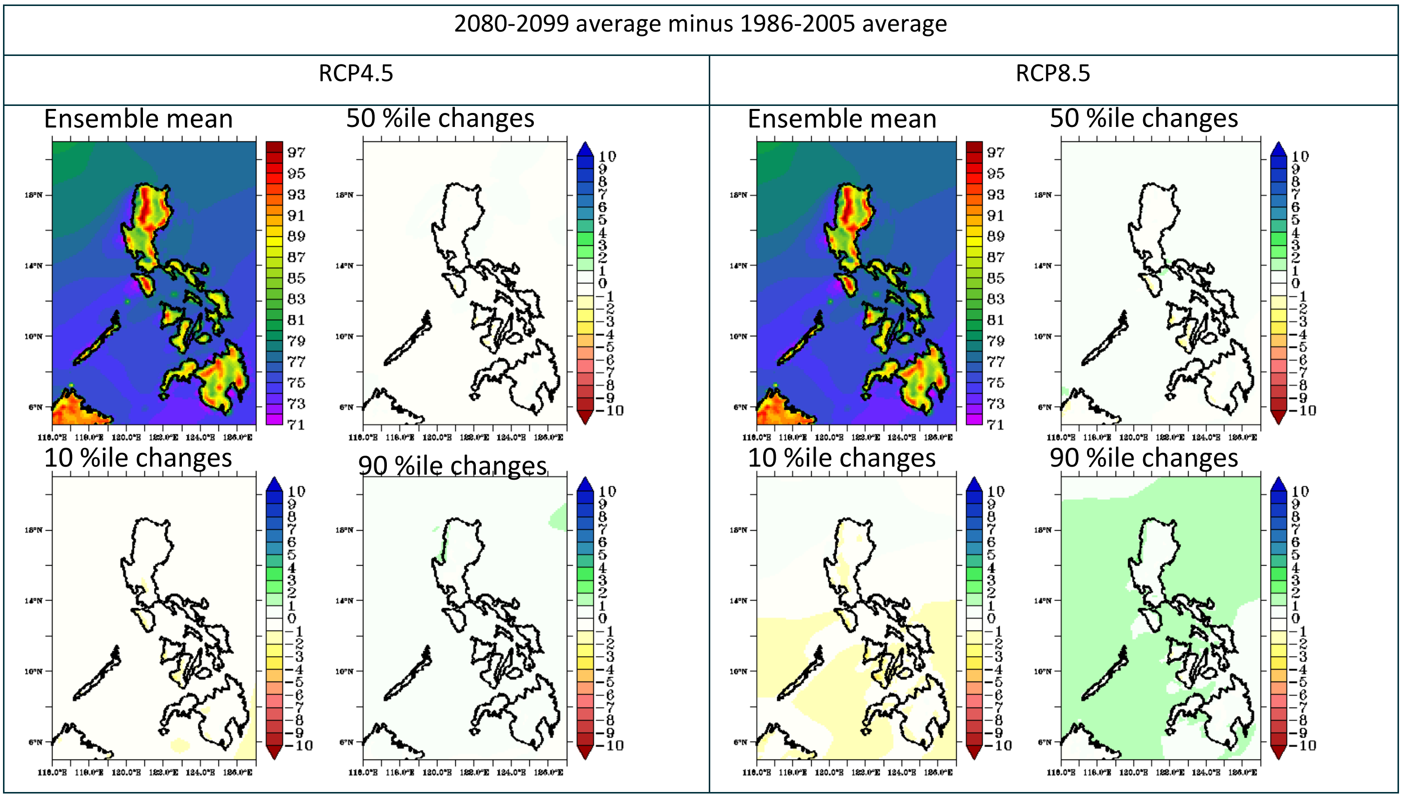
3-70: Time series plots of change in the annual daily intensity index (mm) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.22 Surface relative humidity

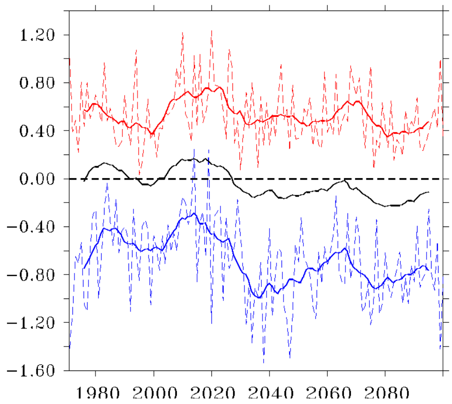
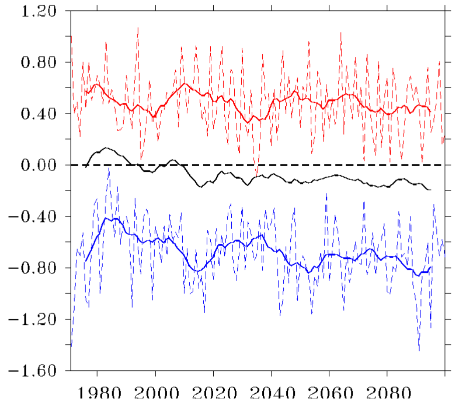
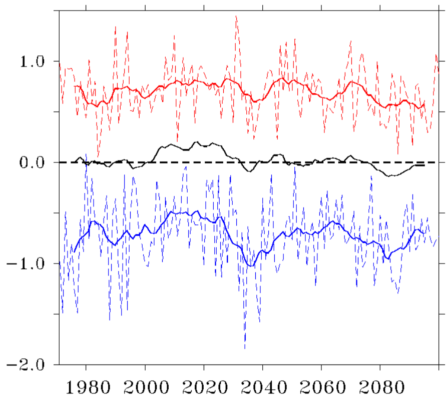
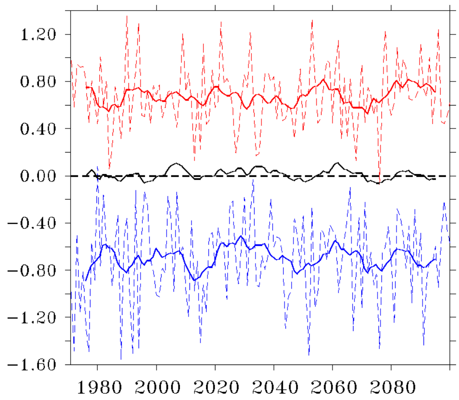
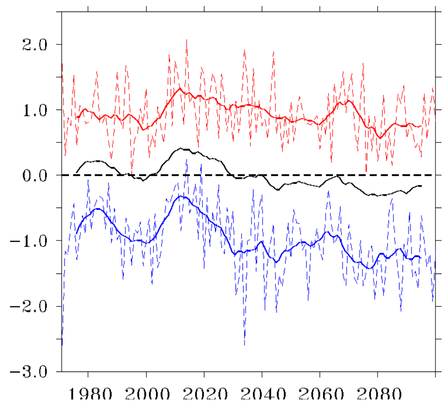
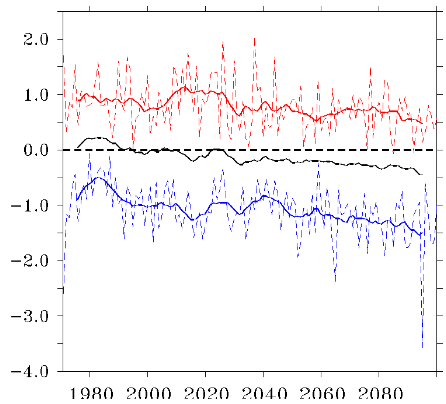
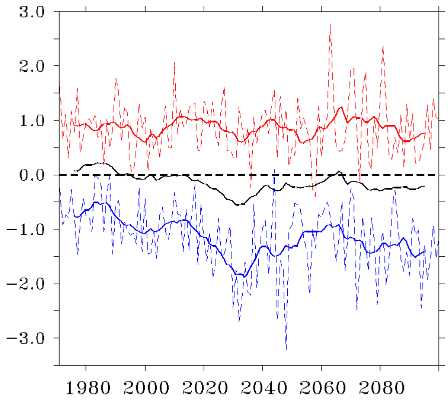
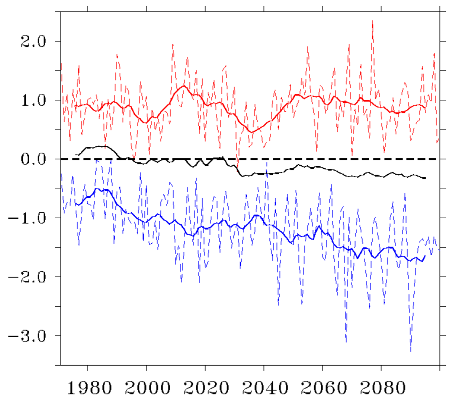
The multi-model mean projected changes in surface relative humidity show little change (Figures 3-71, 3-72 and 3-73: Time series plots of change in the annual surface relative humidity (%) for the Philippines and the three subregions shown in Figure), with a slight tendency to increases than decreases (the 90th percentile increases are larger than the 10th percentile decreases). The time series indicate a slight decrease under RCP8.5.



3-71: Average surface relative humidity (%) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-72: Average surface relative humidity (%) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

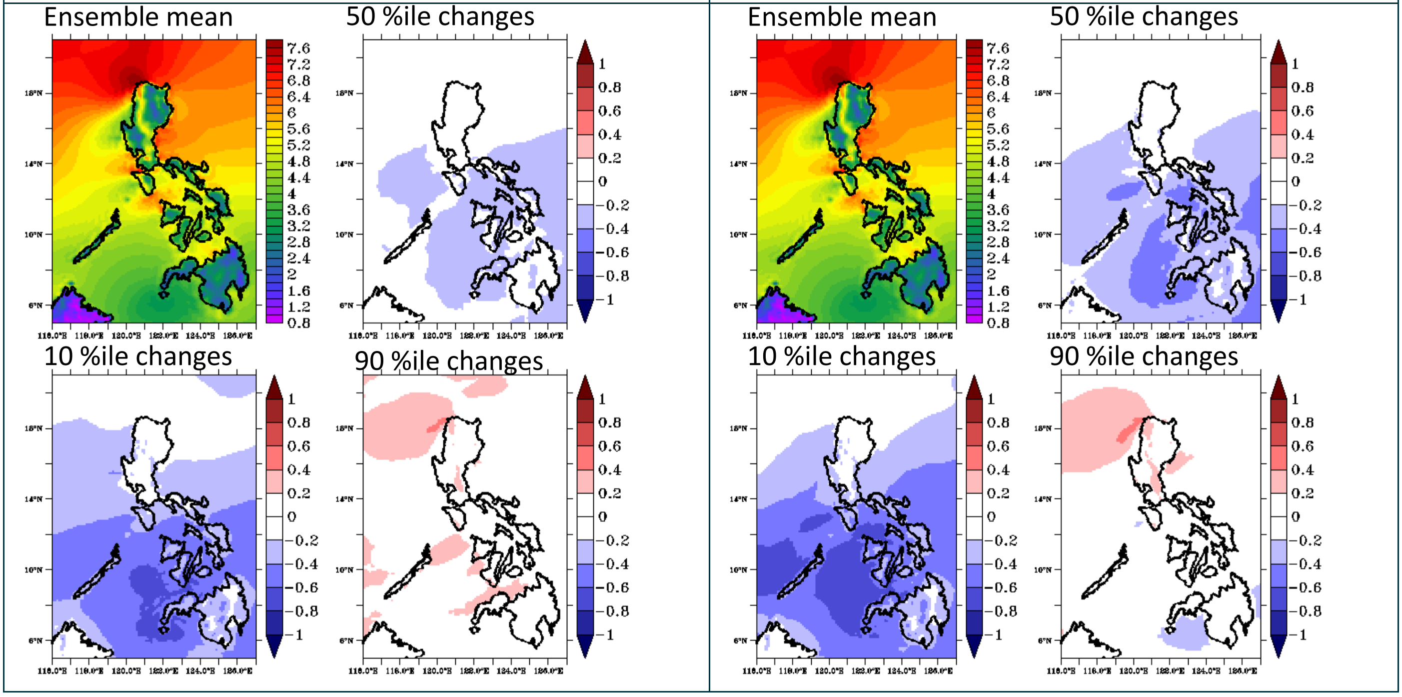
ANN	RCP4.5	RCP8.5
Philippines		
Cagayan Prov.		
Jalaur		
Surigao del Norte		

3-73: Time series plots of change in the annual surface relative humidity (%) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

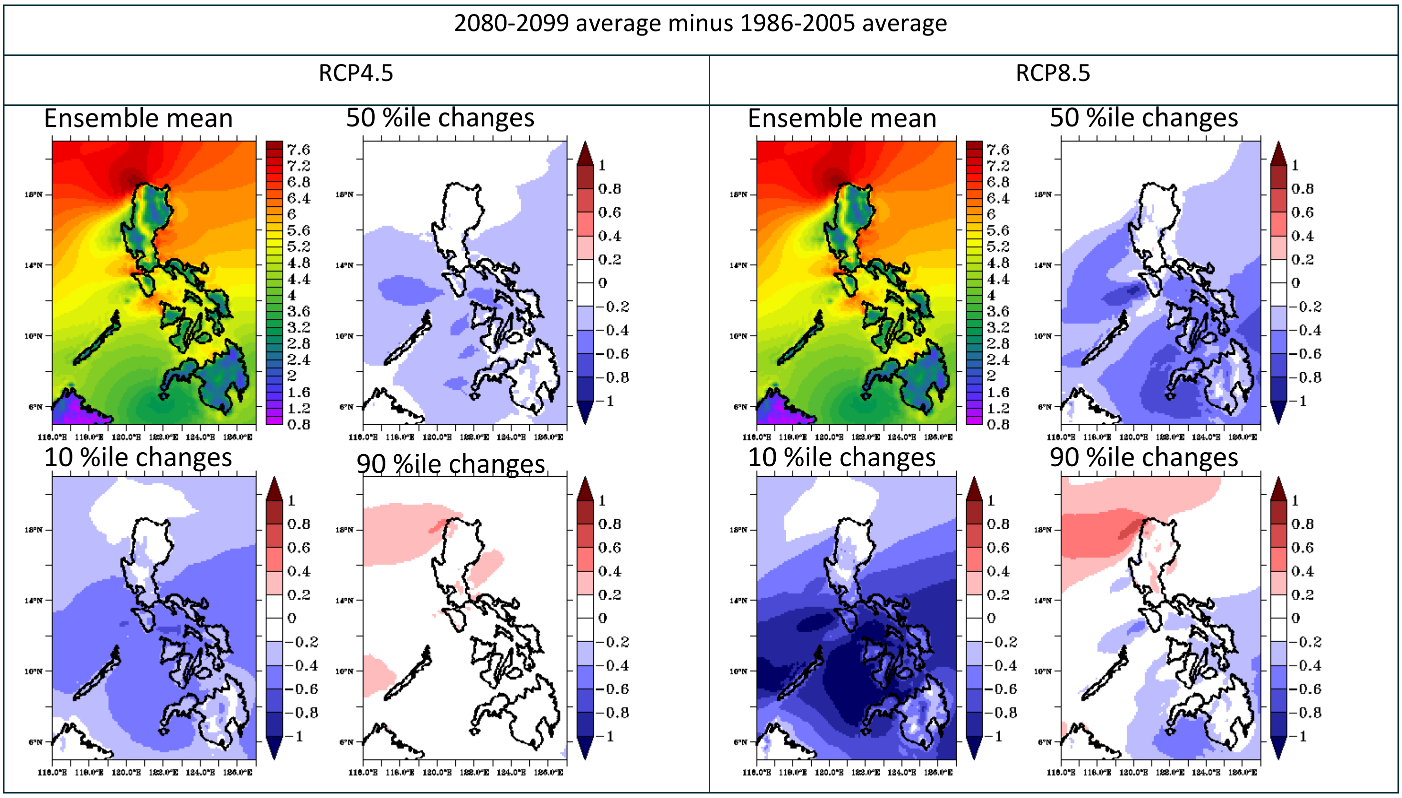
3.23 Wind speed 10 metres above the surface

Projected wind speed 10 metres above the surface generally decreases, but changes are small (generally less than 0.4 m/sec in magnitude), see Figures 3-74, 3-75 and 3-76: Time series plots of change in the annual average wind speed at 10 m (m/sec) for the Philippines and the three subregions shown in Figure. The decreases in wind speed are slightly greater over southern Philippines.

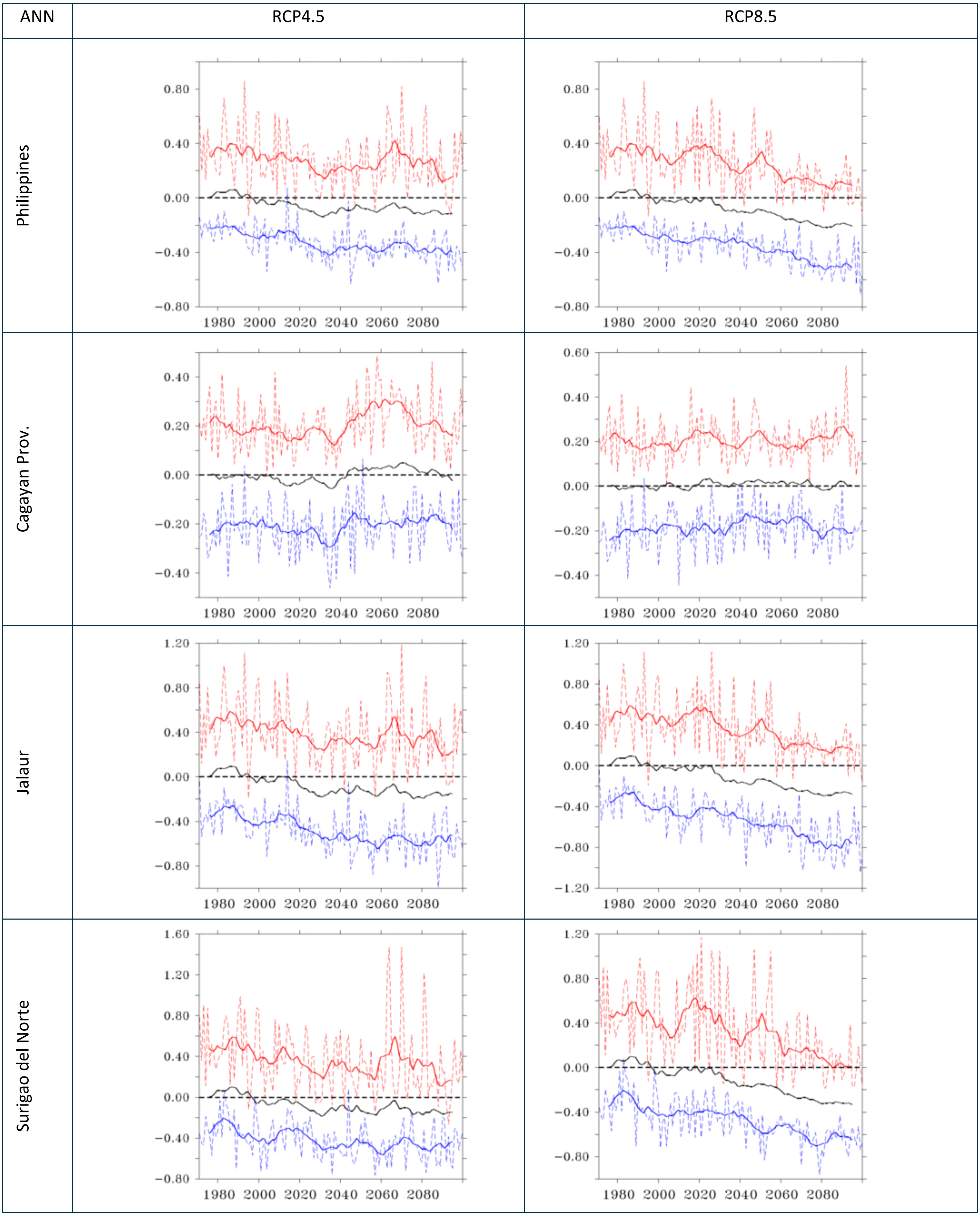
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-74: Average wind speed 10 metres above surface (m/sec) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



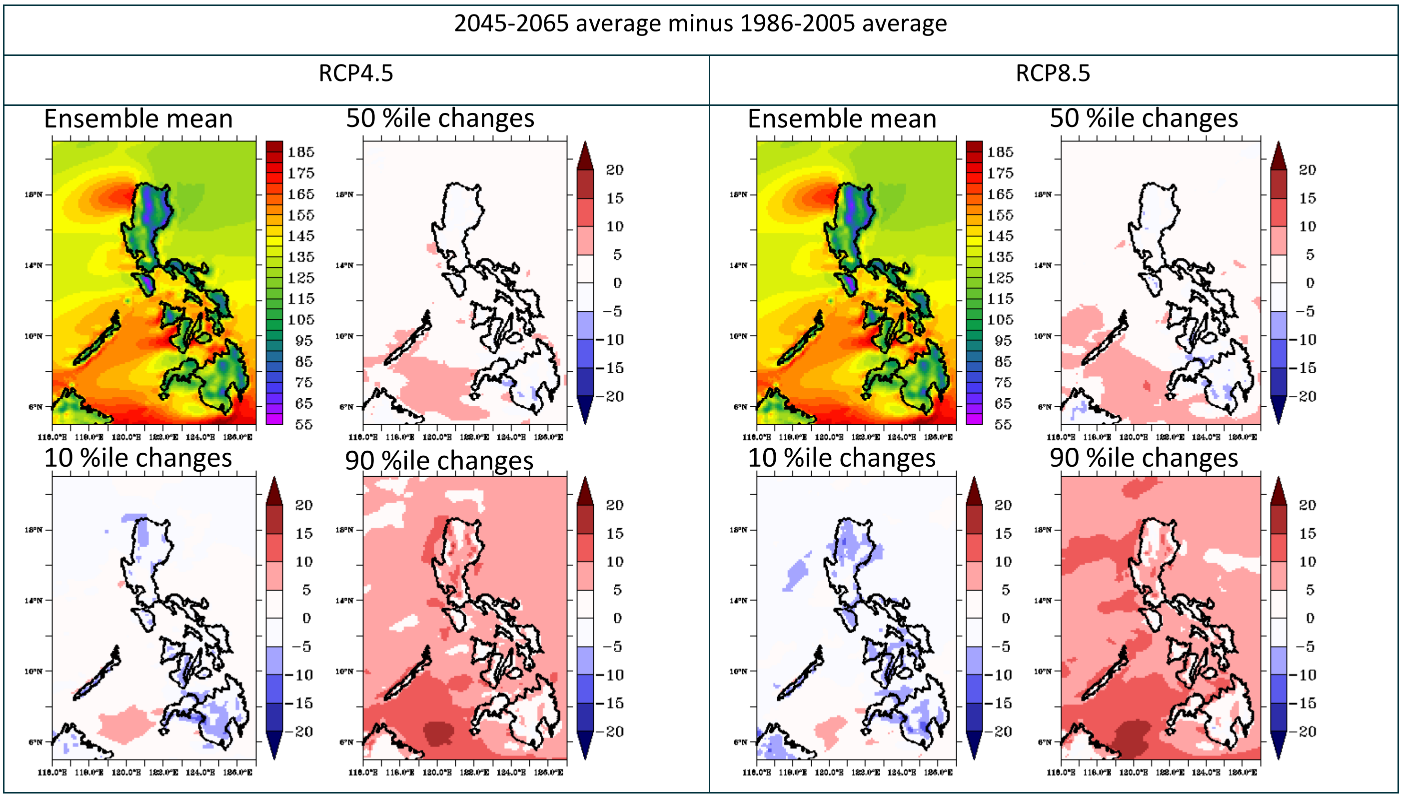
3-75: Average wind speed 10 metres above surface (m/sec) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



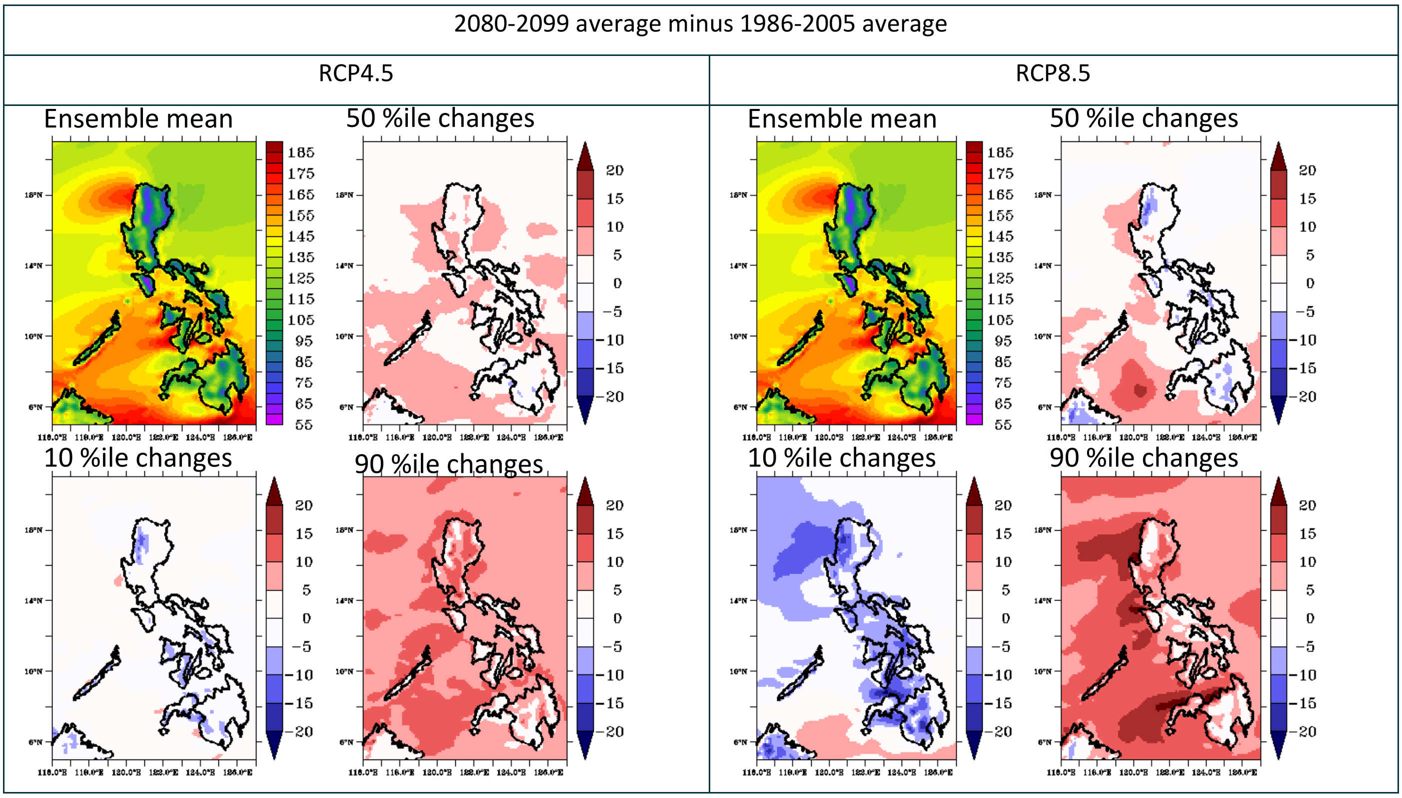
3-76: Time series plots of change in the annual average wind speed at 10 m (m/sec) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

3.24 Downward solar radiation

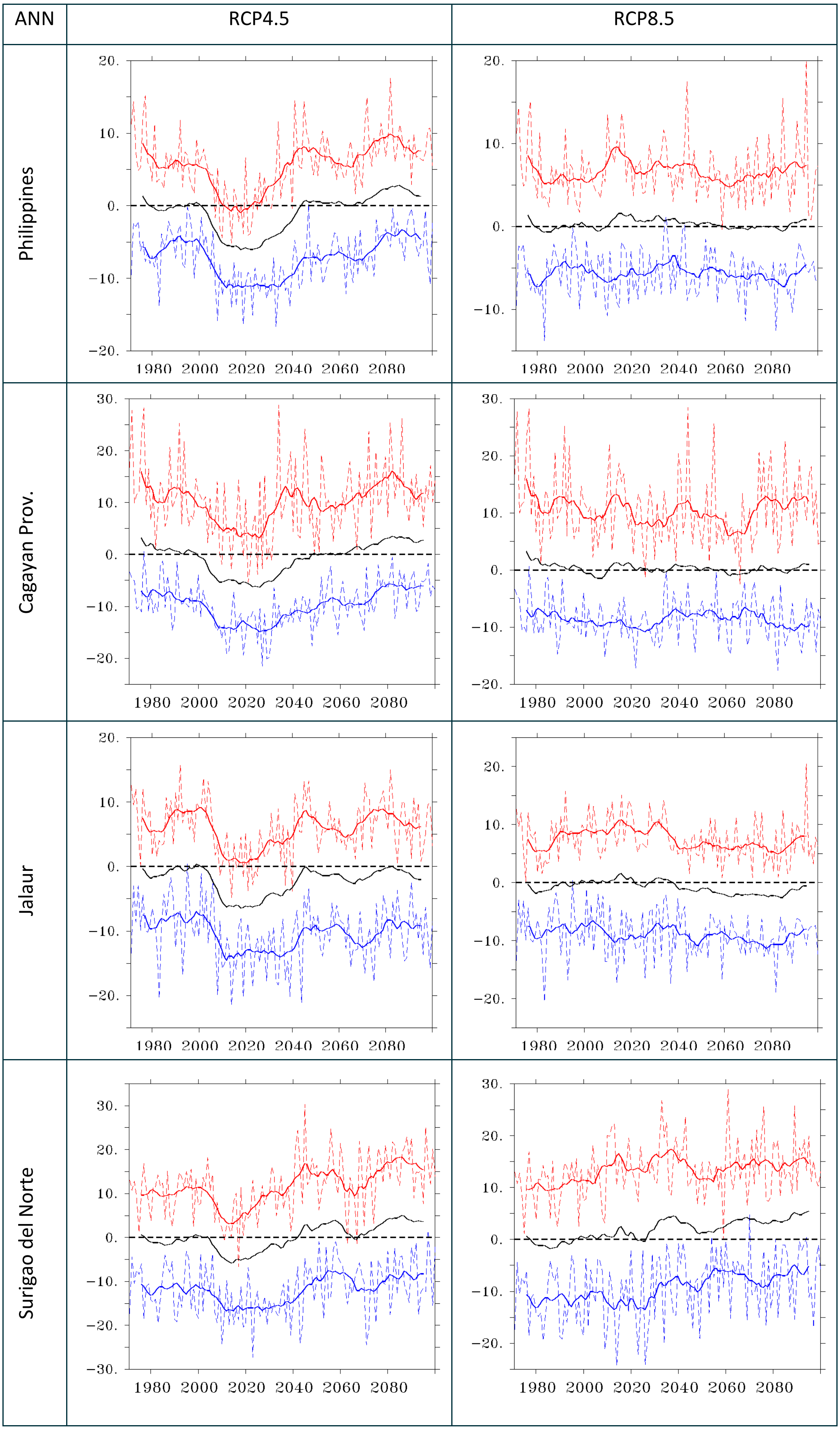
Projected changes in downward solar radiation (Figures 3-77, 3-78 and 3-79: Time series plots of change in the annual average downward solar radiation (W/m^2) for the Philippines and the three subregions shown in Figure) indicate increases in most of the Philippines. The time series plots show interesting multi-decadal oscillations, the cause of which is unknown at this time.



3-77: Average downward solar radiation (W/m^2) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-78: Average downward solar radiation (W/m^2) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.

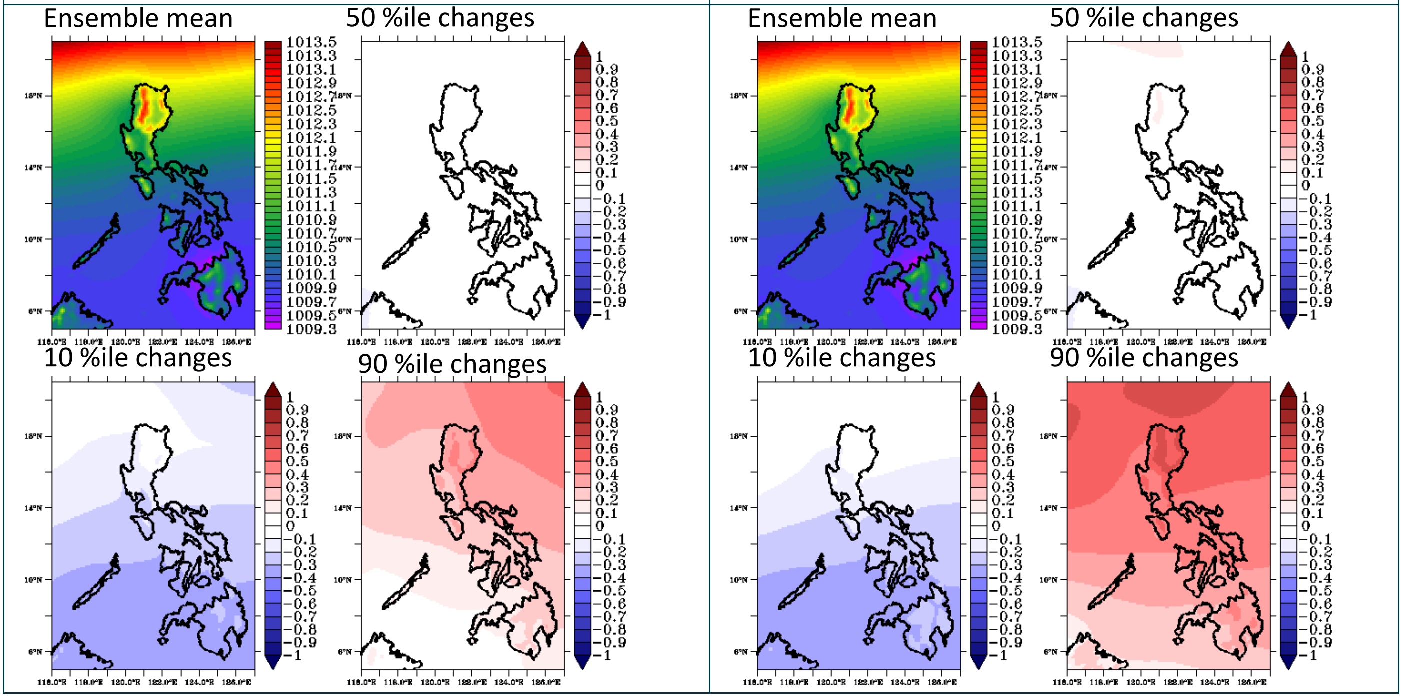


3-79: Time series plots of change in the annual average downward solar radiation (W/m^2) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

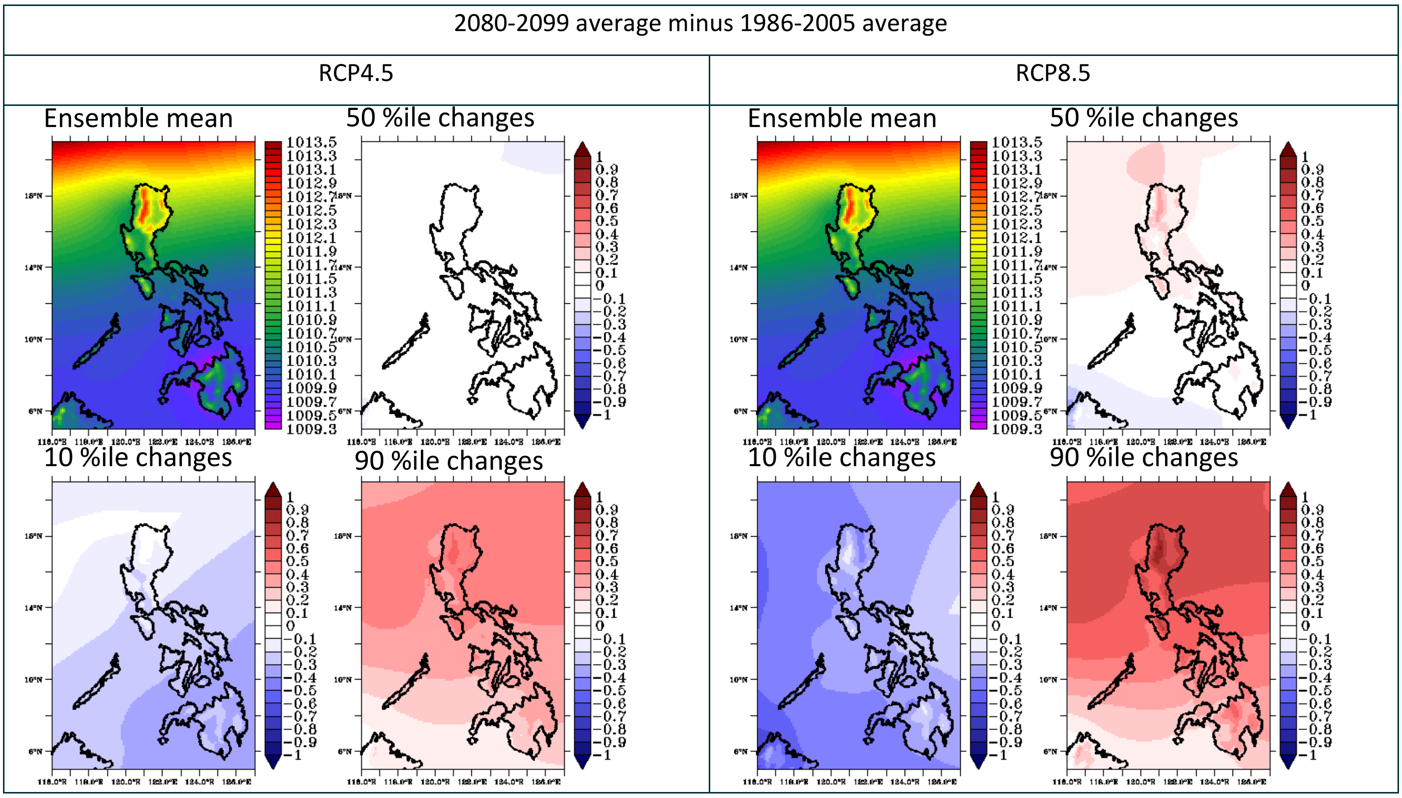
3.25 Mean sea-level pressure

Mean sea level pressure can provide some information about possible circulation changes around the Philippines. The changes are relatively small (Figures 3-80, 3-81 and 3-82), though in general there is a weakening of the meridional gradient (annual mean for current climate has higher pressure to the north), while the projected change values indicate strengthening. This contrasts with the decrease in mean wind speed (which indicates weakening).

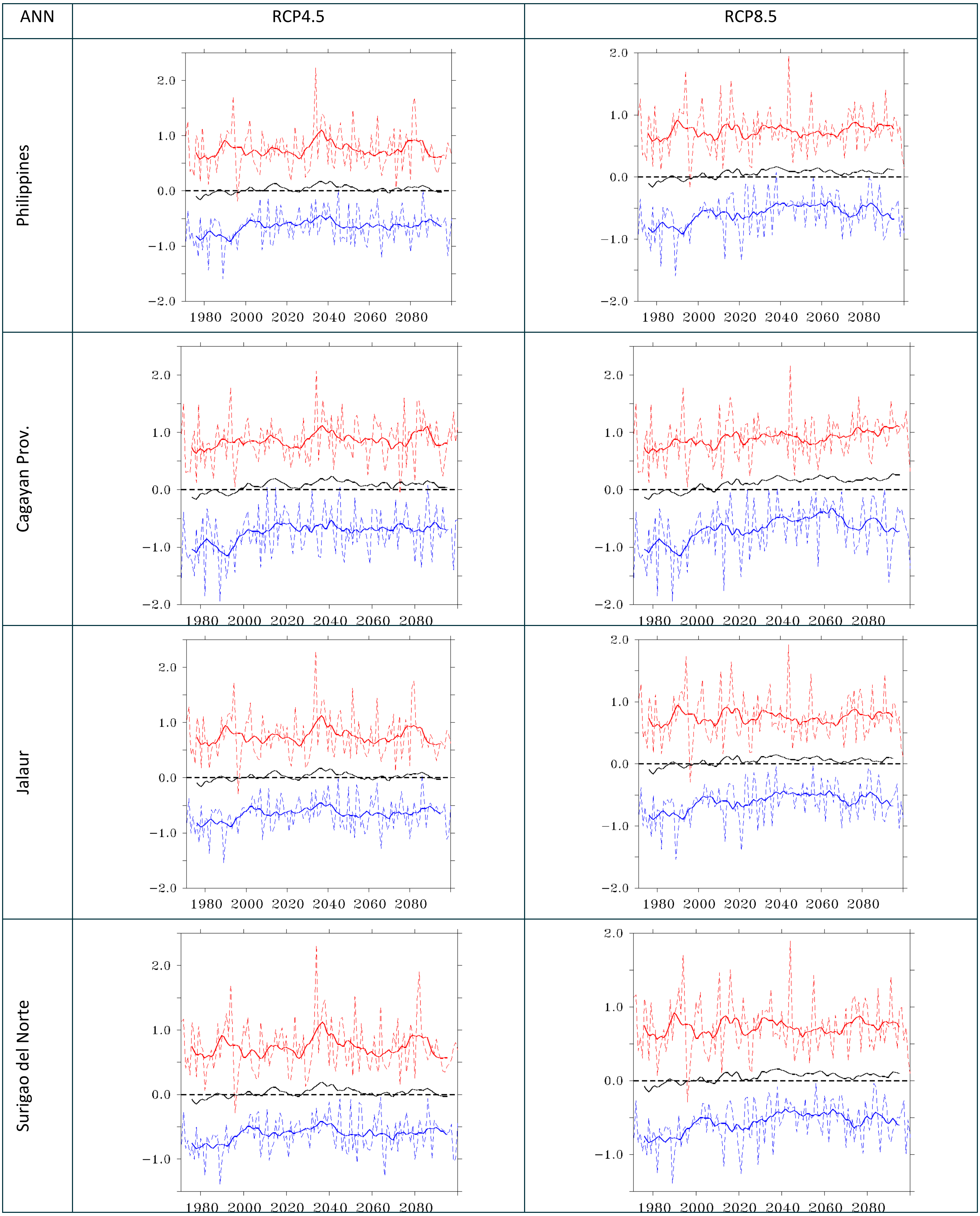
2045-2065 average minus 1986-2005 average	
RCP4.5	RCP8.5



3-80: Average mean sea level pressure (hPa) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2046-2065 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-81: Average mean sea level pressure (hPa) for 1986-2005 (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP4.5 (left) and RCP8.5 (right) based upon the six CCAM simulations.



3-82: Time series plots of change in the annual sea level pressure(hPa) for the Philippines and the three subregions shown in Figure 1-2 for RCP4.5 (left column) and RCP8.5 (right column). Black line is mean, red line is 90th percentile, and blue line is 10th percentile. Solid lines show the 10-year running mean. Dashed black line is zero mark.

4 Tropical Cyclone statistics

4.1 Procedure

We used six criteria for detecting tropical cyclones from the model simulations, as follows:

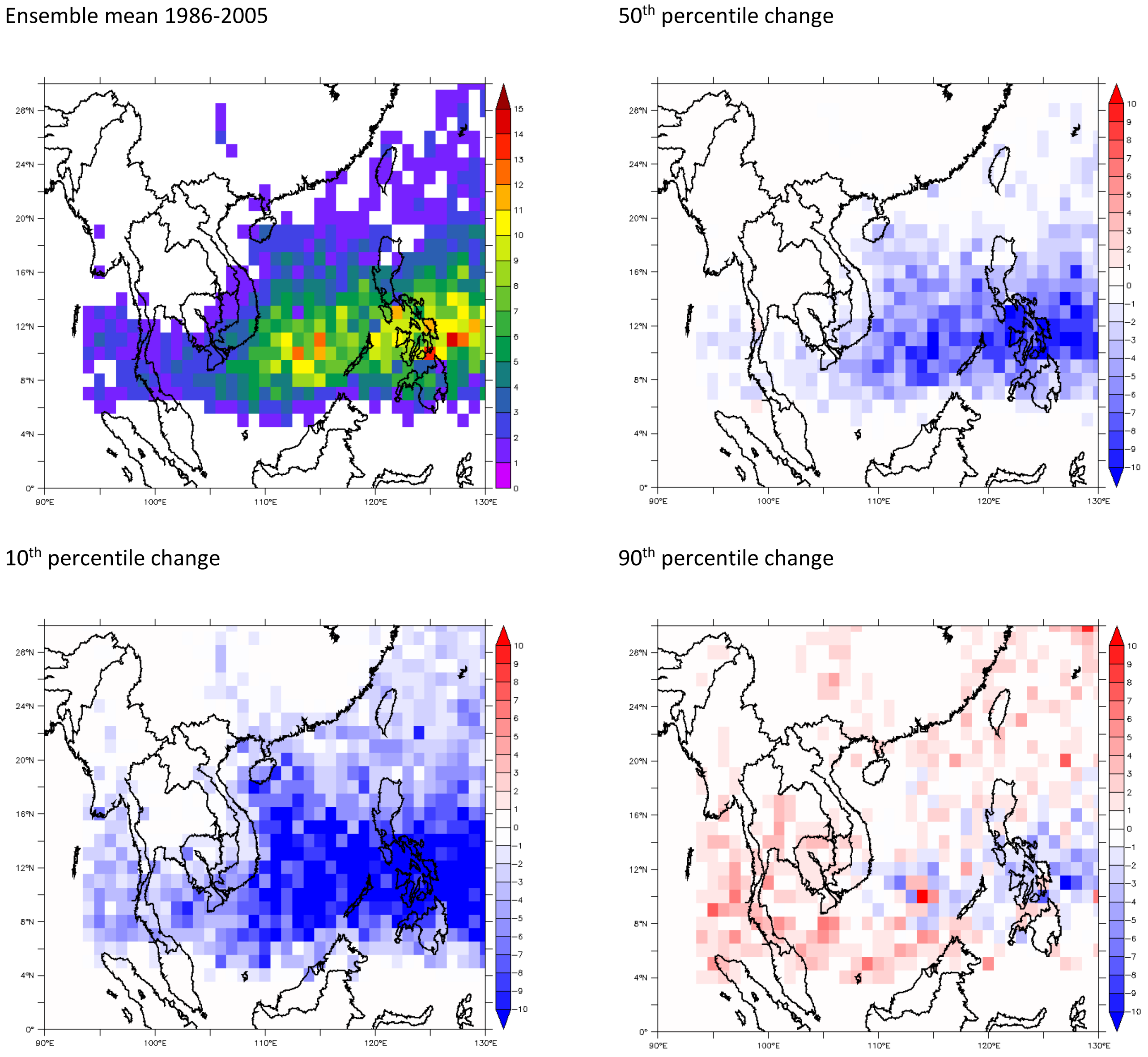
1. Surface vorticity must be greater than 10^{-6}/sec;
2. There is a closed pressure pattern with minimum pressure anomalies of -0.5 hPa within a radius of 300 km from a point satisfying (1); this is defined as the minimum pressure of the storm;
3. The total tropospheric temperature anomalies, calculated by summing up temperature anomalies at 700, 500 and 300 hPa must be greater than +0.5°C;
4. The temperature anomaly at the centre of the storm at 300 hPa (upper atmosphere) must be greater than the temperature anomaly at 850 hPa (lower atmosphere);
5. The geopotential height anomaly at 500 hPa is less than -10 m;
6. Outer-core wind strength at 850 hPa is at least 2 m/sec. The outer core wind is defined as the mean tangential wind speed between a radius of 1 degree and 2.5 degree from the centre of the storm

Note that all anomalies are relative to the mean over a 2.5 degree radius circle centred on the low.

In order to capture tropical cyclones forming over the central and western Pacific and entering the region, the tropical cyclone detection used in this report was based upon the 50 km CCAM simulations. Results are presented for a larger area in order to present the larger scale changes in tropical cyclones in these simulations.

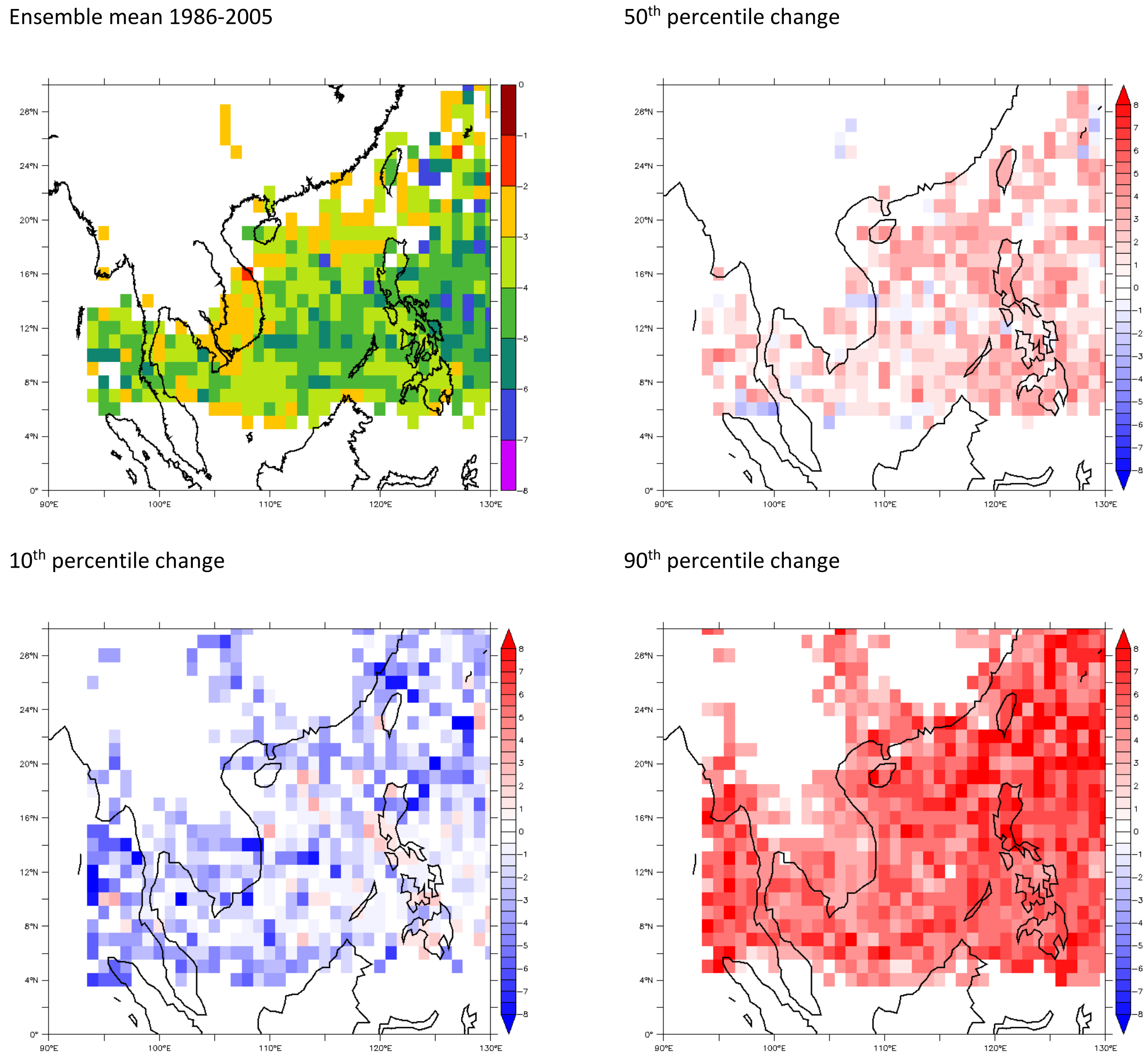
4.2 Results

Validation of the tropical cyclone density in the simulations was presented in the Technical Report for the High-resolution Climate Projections for Vietnam project (Katzfey et al., 2014) and is not discussed here. The number of tropical cyclones (density per 1° x 1° grid box) is projected to decrease by the end of the century for RCP8.5, with only a few models projecting a slight increase (Figure 4-1). This could partly explains the projected decrease in rainfall and wind speed, and the increase in solar radiation.



4-1: Average tropical cyclone density (number per degree box) for Southeast Asia for the 1986-2005 period (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP8.5 based upon the six CCAM simulations.

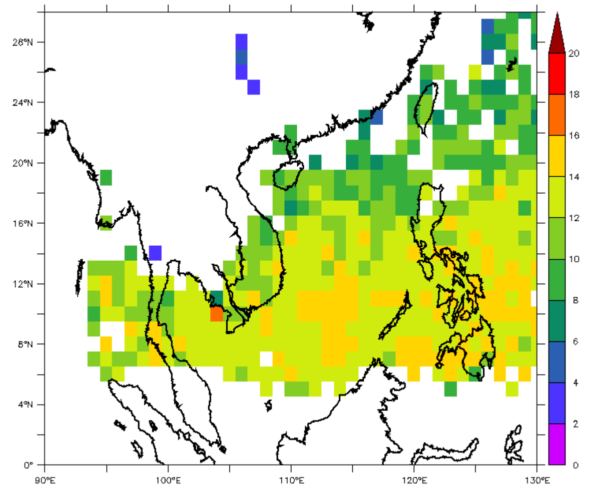
One measure to detect the projected changes in tropical cyclone intensity is the pressure anomaly of the minimum sea level pressure relative to the surroundings (here assumed to be for a circle of about 2.5° radius around the low). Most models project an increase in this pressure anomaly (i.e., the value becomes less negative), indicating less intense tropical cyclones by the end of the century for RCP8.5 (Figure 4-2). Only a few models project a slightly deeper low (decreases in the pressure anomaly).



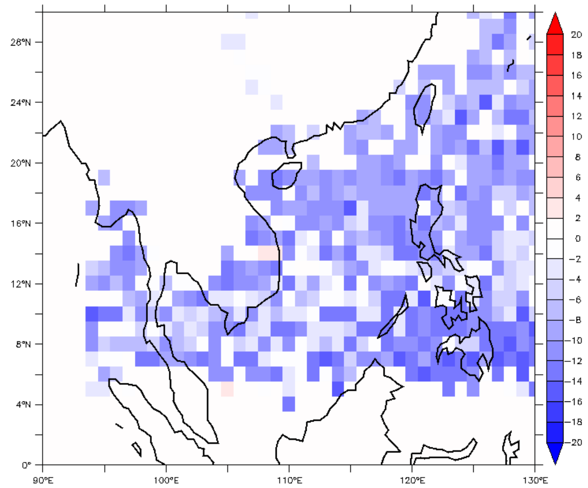
4-2: Average tropical cyclone minimum sea level pressure anomaly for the 1986-2005 period (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP8.5 based upon the six CCAM simulations.

The strength of the winds around the cyclone is another measure of the intensity, here indicted by the strength of the mean 850 hPa tangential winds (Figure 4-3), called the outer core strength wind speed. Most models project decreases in the outer core wind strength by the end of the century for RCP8.5.

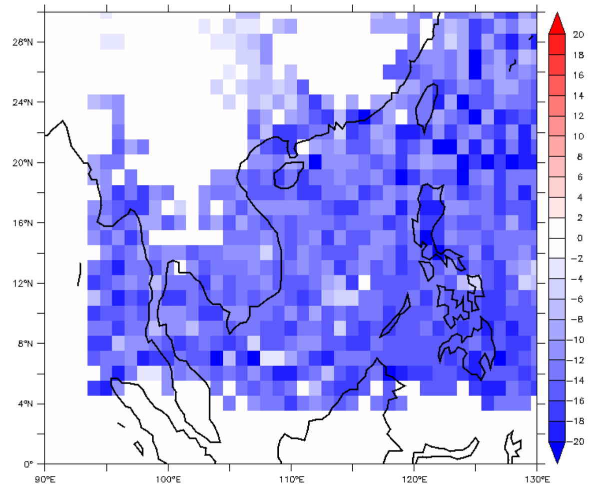
Ensemble mean 1986-2005



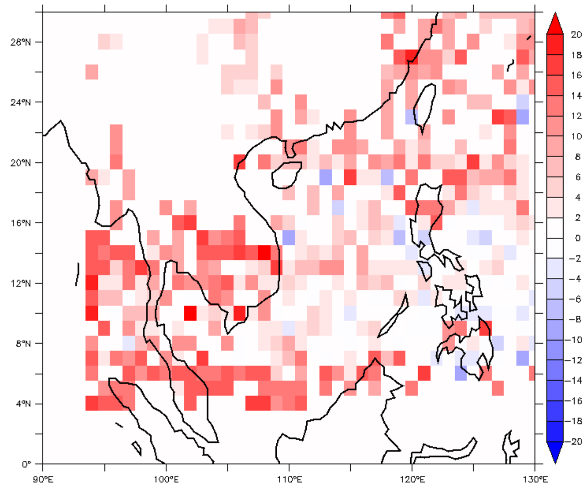
50th percentile change



10th percentile change



90th percentile change



4-3: Average tropical cyclone outer core wind strength (m/sec) for the 1986-2005 period (top left), and 50th (top right), 10th (bottom left) and 90th (bottom right) percentile changes for 2080-2099 relative to 1986-2005 for RCP8.5 based upon the six CCAM simulations.

5 Summary

This report summarises the results from the CCAM downscaling of six GCMs for two RCPs (RCP 4.5 and RCP 8.5). Maps of the change signal for the range of indices calculated can be used to determine the change in risk associated with each index. In addition to median changes (50th percentile), the 10th and 90th values show the range of possible changes, and a measure of uncertainty.

Some key results are:

- Increase in temperature by 1.5-3°C for RCP 4.5 and 2.5-5°C for RCP 8.5, though with decreased warming later in the century with RCP4.5 related to the CO_2 concentrations not increasing. The temperature continues to increase (and even at a faster rate) with the increasing CO2 concentrations with RCP8.5. Similar changes are seen with maximum and minimum temperatures.
- Changes in temperature extremes are similar to the mean temperature, with an increase in the number of hot days. As indicated by the number of days with maximum temperatures greater than 35°C, the simulations project that, even though there are only a very few cases in the current climate, there is a significant increase late in the century with RCP 8.5 in northern Philippines (up to nearly 40 days per year in Cagayan Province).
- Changes in mean annual rainfall are general small, but with a non-significant, drying trend except in the northern Philippines. The decreases are evident in all seasons except MAM when little change is projected.
- Trends for the extreme rainfall statistics are broadly similar to the projected mean rainfall changes with little significant changes projected. This is interesting as with warmer temperatures, the holding capacity of the air is larger potentially allowing for greater rainfalls. Possibly, the decrease in the number of tropical cyclones (noted later) is related to these changes. The number of rain days (days with greater than 1 mm) show large spatial variability, with both increases and decrease in the change signals. While the number and length of consecutive dry days do not change much, the number of consecutive wet days does decrease in southern Philippines.
- Little change is projected for surface relative humidity. Wind speed is projected to decreases slightly across the Philippines. Solar radiation is projected to change little, but with slight increase in southern Philippines. The surface pressure changes indicate a slight strengthening of the mean meridional pressure gradient across the Philippines.
- The number of tropical cyclone numbers is projected to decrease across the region. The various measures of intensity for the average tropical cyclone is projected to decrease as well. No analysis was completed for changes in the more intense cyclones.

The results provide some measure of the projected changes to risks associated with climate change across the Philippines. However, due to the limited number of downscaled GCMS and the use of only one downscaling model, the results need to be used with caution. The much larger range of GCMs should be investigated, as well as the use of other downscaling methods and models.

Future research should focus on the physical understanding of the projected changes in order to gain confidence in the changes. Other lines of evidence should be used, such as current trends, changes in vertical structure of the atmosphere and how this might related to the changes indicated here. Other line of evidence are discussed in the latest IPCC report (IPCC, 2014). In addition, consultation with climate experts in PAGASA before using this and any projections for impact assessments is strongly encouraged.

Note all data used to generate these plots were provided to PAGASA. In addition, at the final workshop, the scripts used to generate the various indices, as well as plots, were provided. Training on the use of the scripts was provided and tested while in Manila.

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