TCC Training Seminar on Global Warming Projection Information

9 – 15 November 2022

Tokyo, Japan (Online)

Tokyo Climate Center

Japan Meteorological Agency

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Global Warming Projection Information

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Contents

Schedule

and

List of Participants

TCC Training Seminar
on Global Warming Projection Information
Online, 9 - 15 November 2022

Bangladesh	-3.00 hrs. (Start at 11:00 am)	Nepal	-3.15 hrs. (Start at 10:45 am)
Bhutan	-3.00 hrs. (Start at 11:00 am)	Philippines	-1.00 hrs. (Start at 01:00 pm)
Indonesia	-2.00 hrs. (Start at noon)	Thailand	-2.00 hrs. (Start at noon)
Malaysia	-1.00 hrs. (Start at 01:00 pm)	Viet Nam	-2.00 hrs. (Start at noon)
Mongolia	-1.00 hrs. (Start at 01:00 pm)	Hong Kong, China	-1.00 hrs. (Start at 01:00 pm)

Day 1 - Wednesday, 9 November	
14:00-14:05 (UTC+9)	1. Opening - Welcome Address - Group photo shooting
14:05-14:10 (UTC+9)	2. Introduction: Outline and scope of the Training Seminar
14:10-15:10 (UTC+9)	3. Lecture: "Introduction to Global Warming Projection" for experts on basis of global warming analysis information
15:10-16:10 (UTC+9)	Break
16:10-16:15 (UTC+9)	Introduction of JMA
16:15-17:15 (UTC+9)	4. Lecture: Outline of IPCC AR6

Day 2 - Thursday, 10 November	
14:00-15:00 (UTC+9)	5. Lecture: Guidance to Global Warming Projection data
15:00-16:00 (UTC+9)	Break
16:00-17:10 (UTC+9)	6. Lecture: Production of Global Warming Projection Information - Introduction of the global warming projection data - Explanation of the exercise - Example of detecting warming signals

Day 3 - Friday, 11 November	
Taking questions from trainees through Email	8. Exercise: Generating global warming projection information for your country - Preparation for presentation (self-study format)

Day 4 - Monday, 14 November	
Taking questions from trainees through Email	8. Exercise: Generating global warming projection information for your country (cont.) - Preparation for presentation (self-study format)

Day 5 - Tuesday, 15 November	
14:00-15:00 (UTC+9)	8. Presentation by participants (5 participants) - Presentation (6 min.) followed by Q&A (3 min.)
15:00-16:00 (UTC+9)	
16:00-17:00 (UTC+9)	8. Presentation by participants (cont.) (5 participants) - Presentation (6 min.) followed by Q&A (3 min.)
17:00-17:10 (UTC+9)	9. Wrap up and closing

List of participants

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Introduction to Global Warming Projection

Basics of Global Warming

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1. Climate, Climate System and Global Warming

WMO shows:

- Weather describes short term natural events - such as fog, rain, snow, blizzards, wind and thunder storms, tropical cyclones, etc. - in a specific place and time.
- Climate, sometimes understood as the average weather, is defined as the measurement of the mean and variability of relevant quantities of certain variables (such as temperature, precipitation or wind) over a period of time, ranging from months to thousands or millions of years. Climate in a wider sense is the state, including a statistical description, of the climate system.
- The climate system consists of five major components: the atmosphere, the hydrosphere, the cryosphere, land surface, and the biosphere (Fig.1). The climate system is continually changing due to the interactions between the components as well as external factors such as volcanic eruptions or solar variations and human-induced factors such as changes to the atmosphere and changes in land use.

Figure 2 shows past changes in global mean surface temperature. In particular, it can be seen that there has been a significant increase since around 1980. Figure 3 shows atmospheric CO_2 concentrations observed in the past. Since the atmosphere is well-mixed, it is affected locally by human activities and forests, but on average over a relatively large area, it is almost uniform over the entire globe. It can be seen that this has increased little by little since industrialization. Figure 4 shows the results of past surface temperature changes calculated using a climate model, distinguishing between natural and anthropogenic factors. We can see that anthropogenic factors have contributed to the increase in global mean surface temperature.

Triggered by anthropogenic (human-induced) factors such as CO_2 emissions, the surface temperature is gradually rising. The climate system is a complex system, and various changes are occurring in the climate system, NOT limited to the increase in surface temperature. This is the "Global Warming".

2. Greenhouse Effect and Greenhouse Gases

The earth receives about 400 W/m^2 of solar radiation on average on the whole earth, and about 30% of it is reflected or scattered. The Earth emits 240 W/m^2 of terrestrial radiation, which roughly balances the amount absorbed. Assuming a uniform temperature of the earth, the temperature corresponding to this radiant energy is about 255K. This is much lower than the actual surface temperature. Assuming that the Earth's atmosphere does not absorb solar and terrestrial radiation, the average surface temperature is also about 255K.

The Earth's atmosphere is approximately 99% composed of approximately 78% N2, approximately 20% O2, and approximately 1% Ar. These homonuclear diatomic and monatomic molecules absorb little solar and terrestrial radiation. On the other hand, molecules of the earth's atmosphere, such as CO2 and H2O, which have more complex structures, absorb electromagnetic waves of specific wavelengths specific to each molecule, and simultaneously undergo a transition to a higher energy level. Solar radiation and terrestrial radiation are in different wavelength bands, and these <u>gas molecules absorb more light with terrestrial wavelengths</u>.

Assuming a system of a single parallel-plate atmosphere that is transparent to solar radiation and completely absorbing terrestrial radiation, calculations yield a surface temperature of 288 K for the Earth. This is pretty close to the real world average surface temperature.

In this way, <u>the difference in absorption characteristics of solar radiation and terrestrial radiation by the earth's atmosphere affects the temperature of the earth, and this effect is called the greenhouse effect</u>. The gas molecules that cause the difference in absorption characteristics are called greenhouse gases. In addition to H2O and CO2, O3 and NH3 etc. are known as greenhouse gases.

<u>As the greenhouse effect increases and the greenhouse effect intensifies,</u> the surface temperature of the earth becomes higher. This is clearly shown in the vertical one-dimensional radiative and radiative-convective equilibrium models. Therefore, <u>the increase in greenhouse gases is considered to be the trigger and essence of global warming</u>.

3. Projection of global warming and elucidation of its mechanism using climate models

In order to predict the future of the climate system, which is a complex system, numerical simulations have been performed using the coupled atmosphere-ocean model, which has been developed and used for research since around 1970. Since the IPCC (Intergovernmental Panel on Climate Change) was launched (1988), it has become active little by little, and the future projections of the climate system are now being made using climate models developed by many institutions/groups. Originally, it was based on an ideal experimental setup with simple models, such as atmospheric models coupled with simple ocean models (e.g., slab ocean models), given the greenhouse gases concentrations. Since then, the models have been improved by introducing ocean models, various processes of aerosols, and material cycle processes such as carbon, etc. In addition, numerical calculations are now being performed in a variety of experimental designs, enabling a variety of investigations that contribute to mitigation measures. One example of this is the utilization of factor analysis shown in Figure 4.

The climate models have been developed and improved by reflecting not only meteorology but also various knowledge related to atmospheric, oceanic, and land surface processes. Although the climate models still have many shortcomings and uncertainties, its ability to reproduce past climates has improved through observational verification.

Using the climate models, we can not only predict the future, but also obtain various scientific knowledge related to global warming. In the following sections, we will introduce some of the knowledge about global warming obtained from the physical processes incorporated into the climate models and the behavior of the climate models.

4. Various processes in the climate system and their effects on global warming

As already mentioned, the climate system has many components. Its state changes due to external forcing and variability within the climate system (variation within each component, interaction between components). The change in surface temperature due to the strengthening of the greenhouse effect can also be considered as the response of the atmosphere and ground surface to the input of CO2 etc. from the outside.

Changes in the climate system are not limited to changes in surface temperature. Various subsequent physical processes change the state of the climate system. Below are some of the main physical processes. Some physical processes have feedback effects. Also, the response time (time to reach equilibrium) varies.

[1] Planck response: When the amount of greenhouse gases in the atmosphere increases, the atmosphere and ground surface heat up in a short period of time, and then terrestrial radiation increases and almost reaches an equilibrium state

(Planck response, negative feedback). [2] Ice-Albedo feedback: Due to the increase in surface temperature, the area of sea ice and snow cover will decrease. This lowers the surface albedo (reflectance of solar radiation), causing further warming and ice melting (positive feedback). This also decreases the global reflectance of solar radiation, increasing the net shortwave incidence. This leads to an increase in the surface temperature of the earth. In addition, the melting of ice sheets causes sea level rise. [3] Water vapor feedback: As the atmosphere warms, the amount of saturated water vapor in the atmosphere increases by about 7%/K. Assuming that the relative humidity does not change, the amount of water vapor, which is a greenhouse gas, increases and the greenhouse effect is strengthened (positive feedback). The increase in water vapor content in the atmosphere causes an increase in precipitation intensity, or extreme precipitation. This also intensifies the precipitation pattern observed under the current climate to increase water vapor transport and enhance water vapor convergence (wet-get-wetter/dry-get-drier). [4] Cloud feedback: Clouds have a high reflectance, which reduces the amount of solar radiation that enters them, thus reducing global warming. On the other hand, it also works to increase warming due to the greenhouse effect, which absorbs terrestrial radiation. There are still many uncertainties about the effect of clouds on global warming, but it is believed that low-level clouds play the former role, and high-level clouds play the latter role. [5] Lapse rate feedback: There is a difference between the amount of warming in the lower atmosphere and that in the upper atmosphere due to global warming. It is thought that the amount of warming is greater in the upper atmosphere at low latitudes and in the lower atmosphere at high latitudes. Under the condition that the terrestrial radiation emitted into space is equal, when the amount of warming in the upper atmosphere is large (small), the amount of warming near the surface of the earth is small (large). This is called lapse rate feedback. In addition, since the amount of warming in the upper atmosphere is greater in low-latitude regions, it is thought that the atmosphere is becoming more stable with global warming, and that convection occurs less frequently. [6] Absorption by the sea: CO2 and heat enter the upper ocean from the lower atmosphere, which further warms the deep ocean and increases carbonation (ocean acidification and its impact on marine ecosystems). This time scale is thousands of years. Also, even if CO2 emissions decrease in the future, it will be emitted from the ocean instead, which will delay the decrease in atmospheric CO2 concentration over a long period of time. Ocean warming causes sea level rise through the expansion of seawater. The warming is also feared to have serious impacts on marine ecosystems.

5. Important concepts related to global warming

Radiative forcing and climate sensitivity are known as important concepts.

Radiative forcing is the amount of change in the radiation balance at the top of the troposphere caused by a factor when the climate system changes. Higher radiative forcing means that the factor has a greater impact on global warming. Future projections using climate models require future scenarios for greenhouse gas concentrations, emissions, etc., and the total radiative forcing is taken into account in creating future scenarios.

Climate sensitivity is a quantity that quantitatively indicates how much the climate system is affected by a certain external factor. Global warming usually uses changes in global average surface temperature as the impact on the climate system. In particular, it is generally evaluated in the form of changes in surface temperature (effects on the climate system) against changes in radiative forcing (external factors) when the atmospheric CO_2 concentration is doubled.

6. Summary and Comments

The basics of global warming were lectured. Global warming is caused by intensifications of the greenhouse effect due to increases in anthropogenic greenhouse gases. The climate system is extremely complex, and there are many physical and other processes that cause various changes.

As per the IPCC report, if society continues to rely on fossil fuels as before, radiative forcing will reach 8.5W/m2 at the end of this century, and it is estimated that the temperature will rise by about 4K compared to pre-industrial times. Since this has a great impact on human life, international cooperation is required to reduce CO_2 emissions under policies such as moving away from fossil fuels.

Figures:

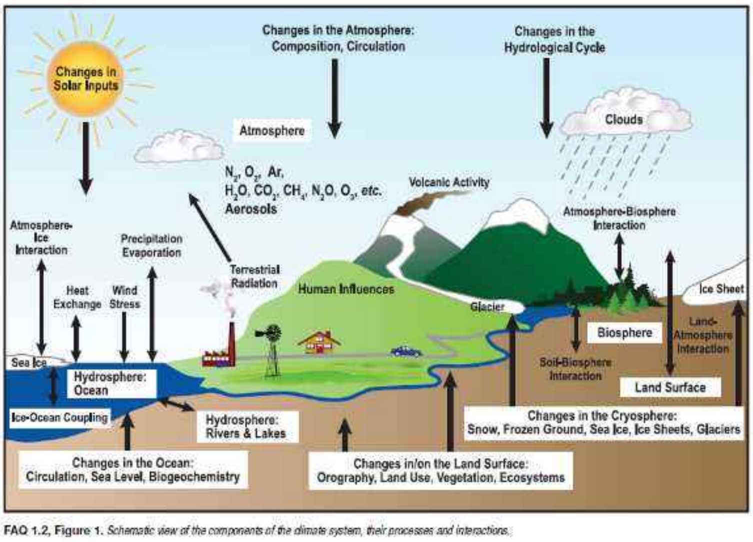


Figure 1: Schematic diagram of the climate system. (AR5)

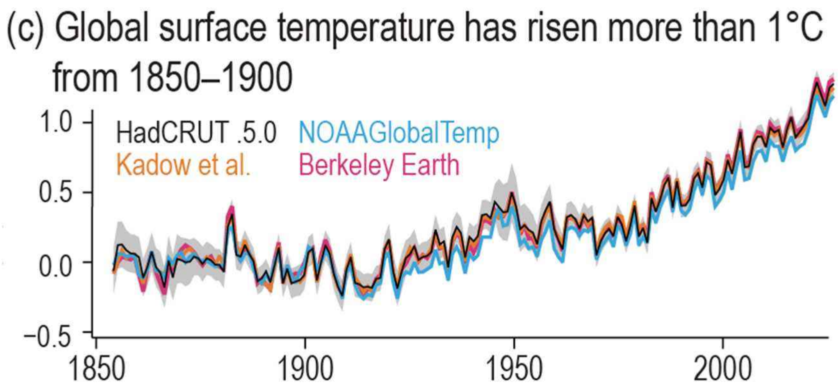


Figure 2: past changes in global mean surface temperature. (AR6)

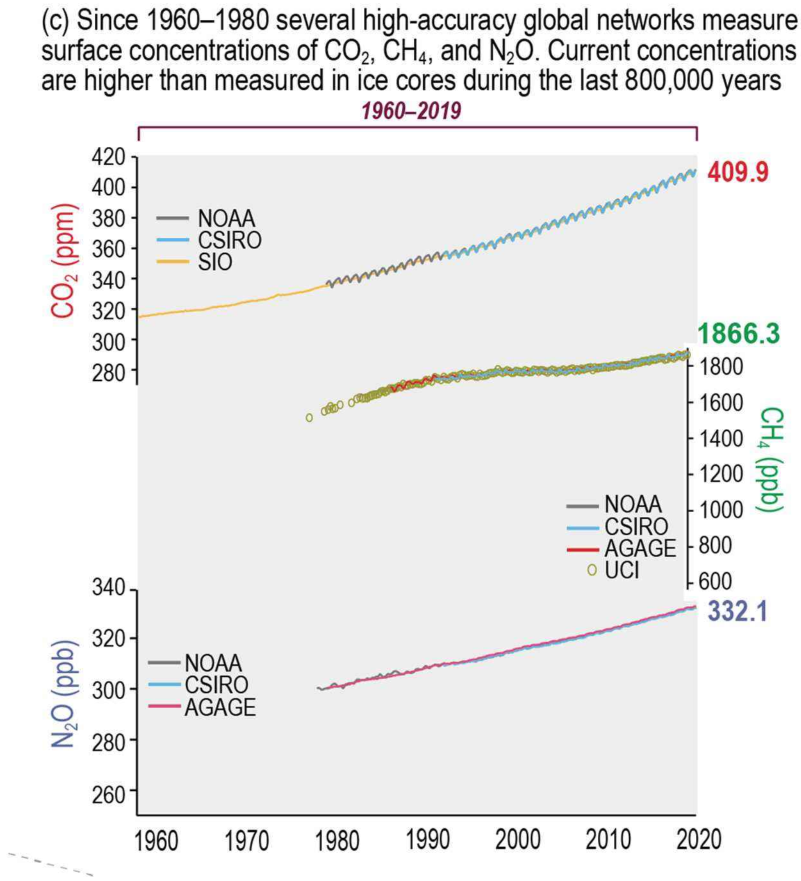


Figure 3: Atmospheric <u>CO_2 concentrations</u> observed in the past. (AR6)

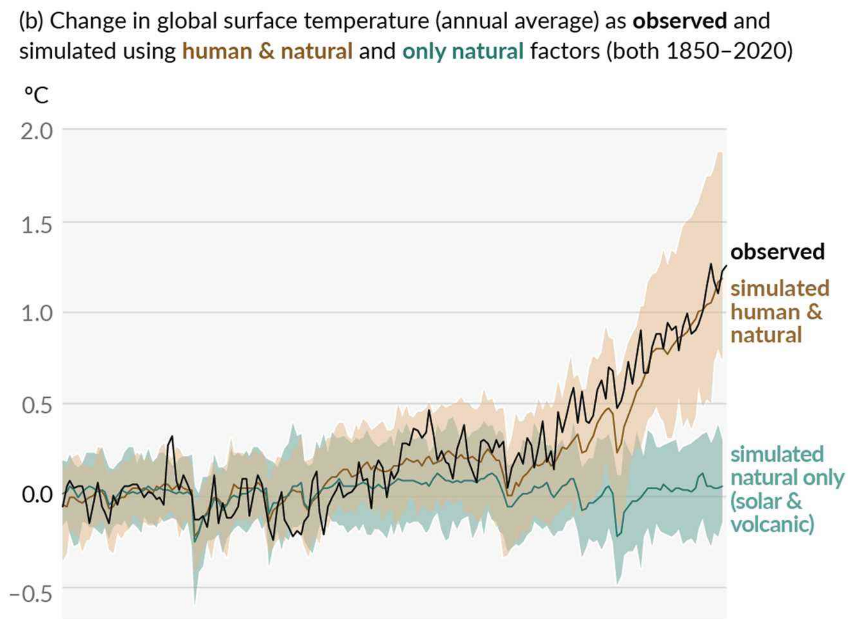


Figure 4: Change in global surface temperature as observed and simulated using human & natural and only natural factors. (AR6)

Outline of IPCC AR6

TCC Training Seminar on Global Warming Projection Information
16:15 – 17:15 (UTC+9) on 9 November 2022 (Day 1)

Outline of IPCC AR6

Introduction to IPCC AR6

WAKAMATSU Shunya

Schedule of this seminar

1st Day (9 November 2022)
- Lecture on climate change
- Lecture on IPCC AR6 <- We are here

2nd Day (10 November 2022)
- Lecture on Climate Change Monitoring and Future Projections
- Lecture on assessment of future climate change and introduction to your exercise

3rd Day – 4th Day (11 and 14 November)
- (self-study format) Exercise on Observed Trends and Global Warming Projection for your country

5th Day (15 November)
- Your presentation (6 minutes per person)

PART 1: INTRODUCTION TO IPCC AR6

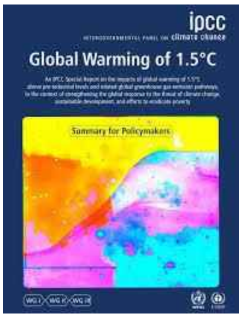
PART 2: DISCUSSION ABOUT STATEMENTS ABOUT YOUR COUNTRY/REGION

The Intergovernmental Panel on Climate Change (IPCC)

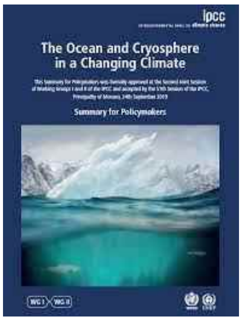
- IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988.
- The IPCC currently has 195 members.
- The objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies.
  - The IPCC does not conduct its own research. Experts volunteer their time as IPCC authors to assess the thousands of scientific papers published to provide a comprehensive summary on assessment reports.
  - The assessment reports are a key input into the international negotiations (e.g., UNFCCC) to tackle climate change. The reports also provide fundamental information to the member governments.
- IPCC reports are neutral, policy-relevant but not policy-prescriptive.

https://www.ipcc.ch/
https://archive.ipcc.ch/organization/bureaumembers.shtml

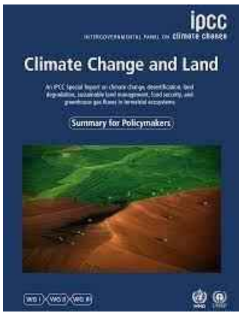
Sixth Assessment Cycle



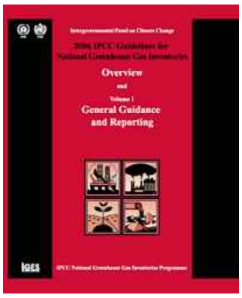
Global Warming of 1.5° C
(October 2018)



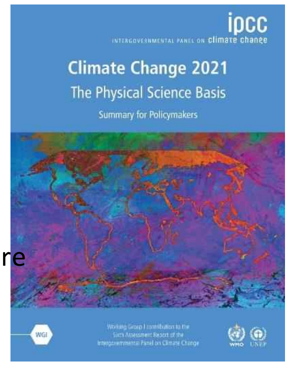
The Ocean and Cryosphere in a Changing Climate
(September 2019)

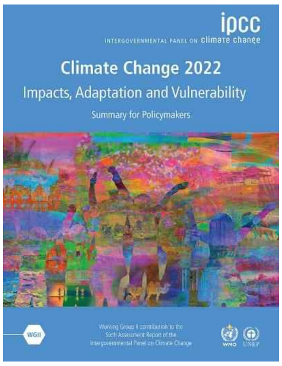


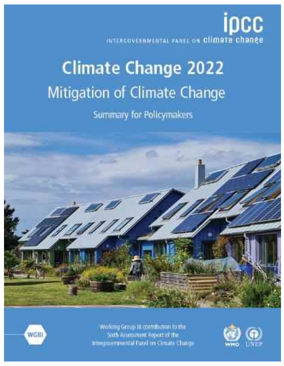
Climate Change and Land
(August 2019)



2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
(May 2019)







Sixth Assessment Reports

AR6 WG1: The Physical Science Basis (August 2021)	AR6 WG2: Impacts, Adaptation and Vulnerability (February 2022)	AR6 WG3: Mitigation of Climate Change (April 2022)

AR6 Synthesis Report: Climate Change 2022
(not yet published)

Innovations and changes in AR6 WG1

WG1

- The new structure of the Working Group I report shows there will be more **integrated knowledge** and understanding compared to the previous report.
  - In the Fifth Assessment Report (AR5) there were separate chapters on the assessment of models, observational evidence, paleo-climate records etc, but now these topics are integrated together across multiple chapters.
- There is a far greater emphasis on **regional climate change** in the Working Group I report; the final third of the chapters all have a regional focus.
  - These chapters will cover the large advances in scientific knowledge on changes in extreme events and attributing these events to man-made climate change, notably in Chapter 11 (Weather and climate extreme events in a changing climate), a new dedicated chapter on this topic.
- Interactive online regional atlas featuring data underpinning the Working Group I assessment, including observed and projected climate change information.
  - Users can perform spatial and temporal analyses using many datasets used in the assessment, access synthesized regional information for climatic impact drivers and download data.
- There's a greater focus on how the **Earth responds to climate change** in the Working Group I report, looking for example at how the oceans and atmosphere respond when greenhouse gas emissions are reduced or if carbon removal techniques are used, and the timelines associated with these actions.
  - There will also be an updated assessment of our understanding of how sensitive the Earth's temperature is to carbon dioxide emissions.
- In the Fifth Assessment Report, four Representative Concentration Pathways (RCPs) were used to simulate future climate change. This time the IPCC uses **Shared Socio-Economic Pathways** (SSPs) that look at a far great range of options / scenarios. There's a greater focus on lower degrees of warming because of these scenarios.
  - Levels of warming like 1.5° C and 2° C can be assessed more rigorously than in AR5. The assessment can also look at the timing of when we could see a global mean temperature of these global warming levels.
- Others are shown in AR6 Fact Sheet (https://www.ipcc.ch/site/assets/uploads/2021/06/Fact_sheet_AR6.pdf).

Improved understanding of human influence

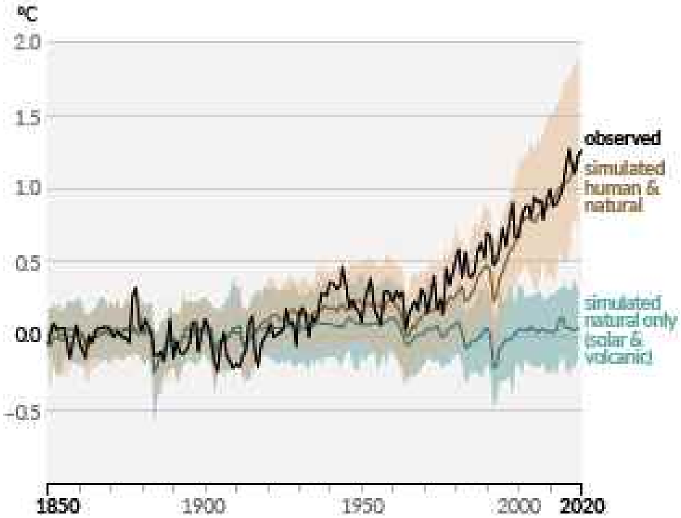
WG1

It is unequivocal that human influence has warmed the atmosphere, ocean and land.

- AR5 Climate Change 2013:
  - Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.
  - It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.
- AR4 Climate Change 2007:
  - Warming of the climate system is unequivocal
  - Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.
- TAR Climate Change 2001:
  - most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations
- SAR Climate Change 1995:
  - a discernible human influence on global climate
- FAR Climate Change (1990):
  - There is concern that human activities may be inadvertently changing the climate of the globe through the enhanced greenhouse effect

Changes in global surface temperature relative to 1850–1900

Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)

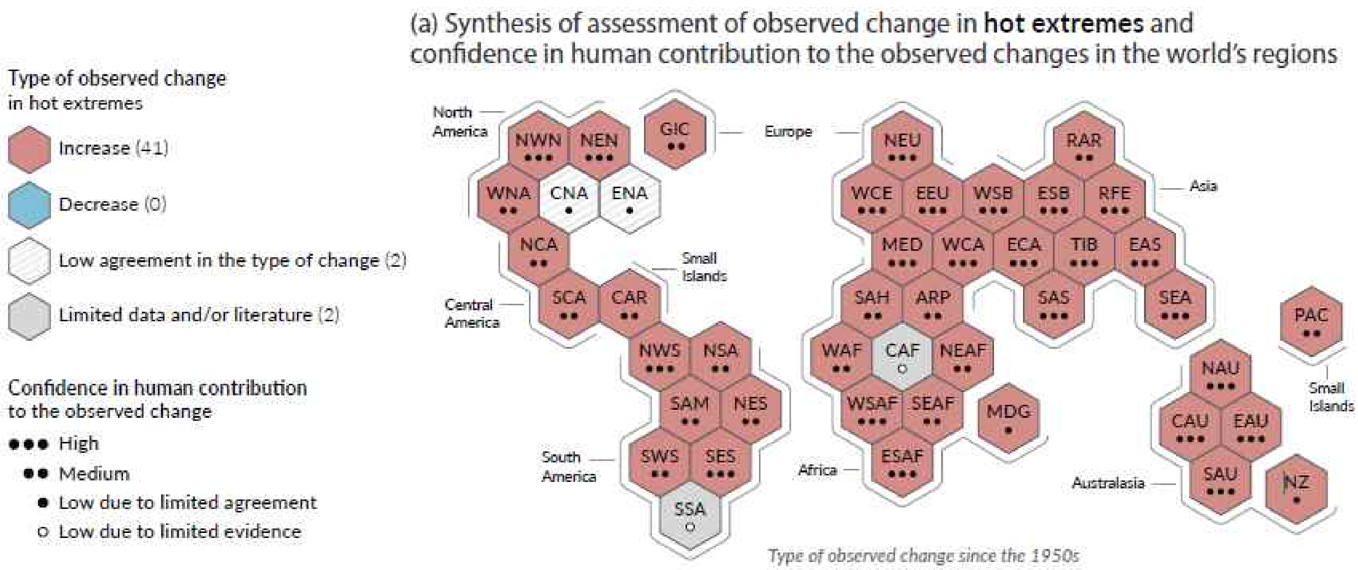


IPCC AR6 WG1 SPM Figure SPM.1

Evidence of observed changes in extremes has strengthened

WG1

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes



IPCC AR6 WG1 SPM Figure SPM.3

Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.

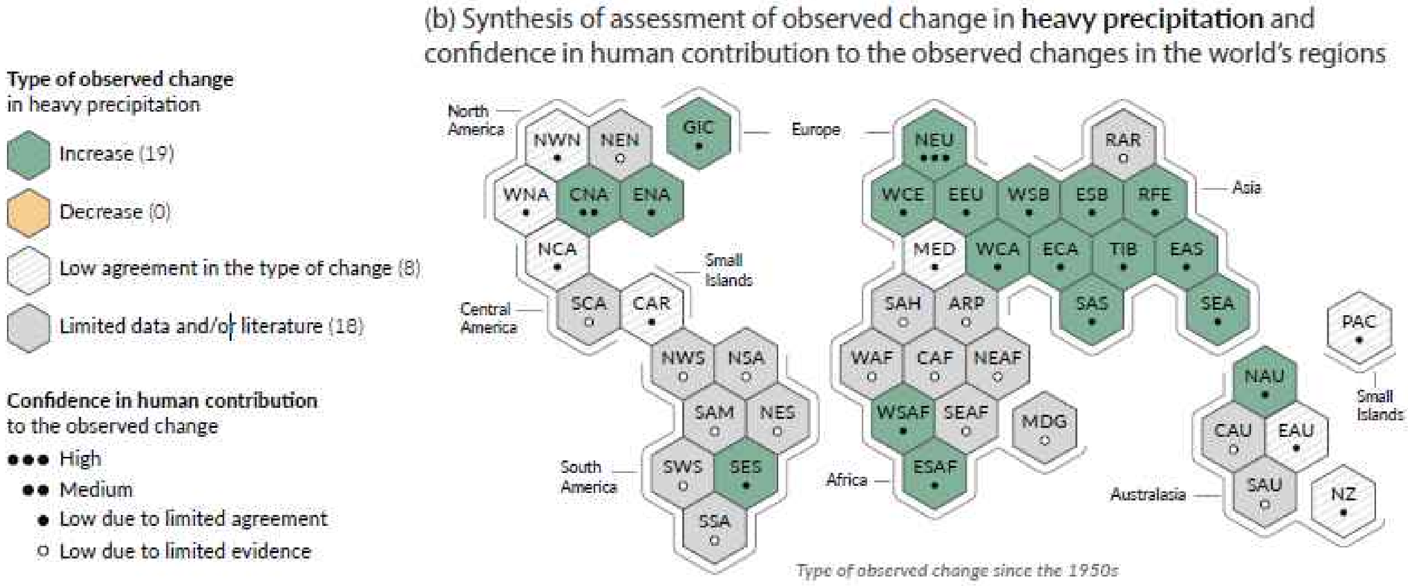
The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution* literature

** the relatively new science of event attribution is able to quantify the role of climate change in altering the probability and magnitude of some types of weather and climate extremes. (FAQ 11.3)*

Updated Assessments of observed changes in extremes

WG1

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes



IPCC AR6 WG1 SPM Figure SPM.3

Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.

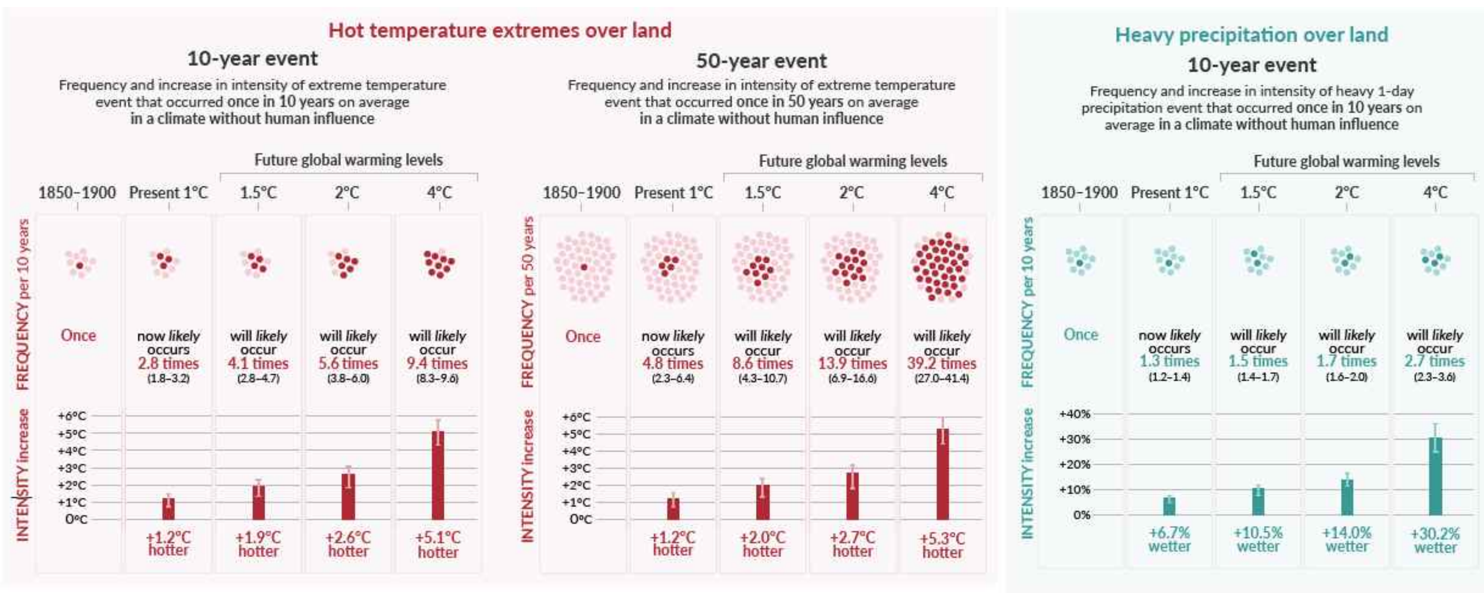
The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution* literature

** the relatively new science of event attribution is able to quantify the role of climate change in altering the probability and magnitude of some types of weather and climate extremes. (FAQ 11.3)*

Updated Assessments of projected changes in extremes

WG1

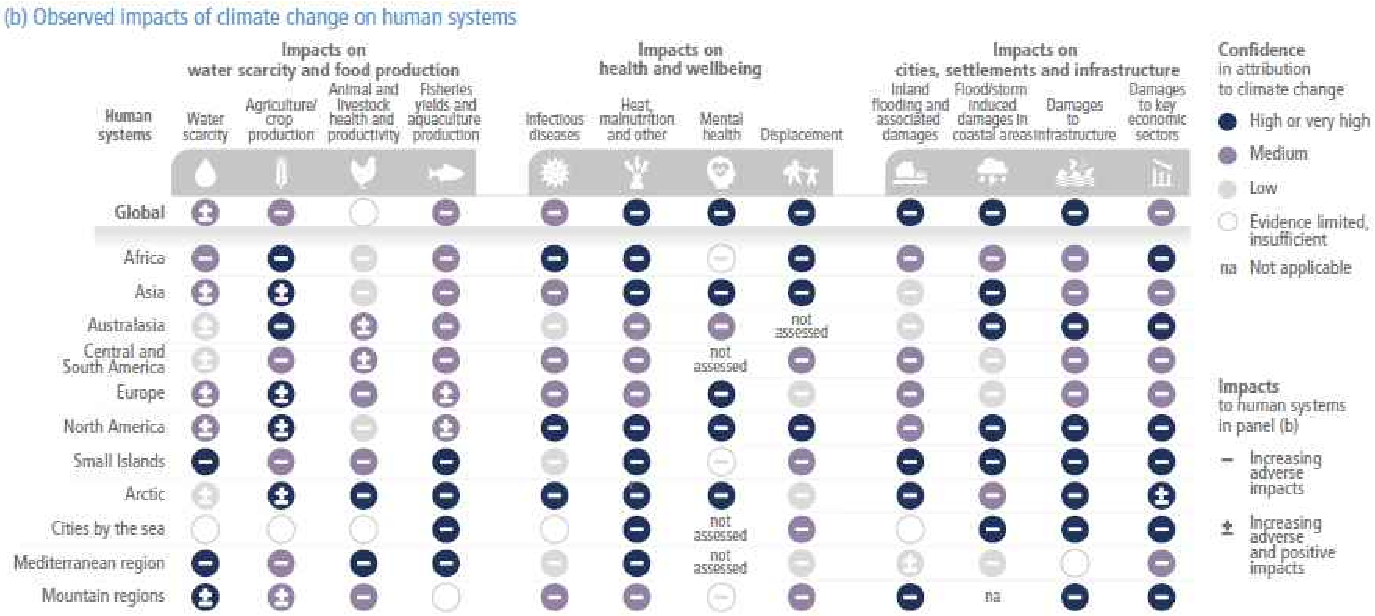
Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming



IPCC AR6 WG1 SPM Figure SPM.6

Impacts of extreme events

- Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability.
- The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt.



IPCC AR6 WG2 SPM Figure SPM.2

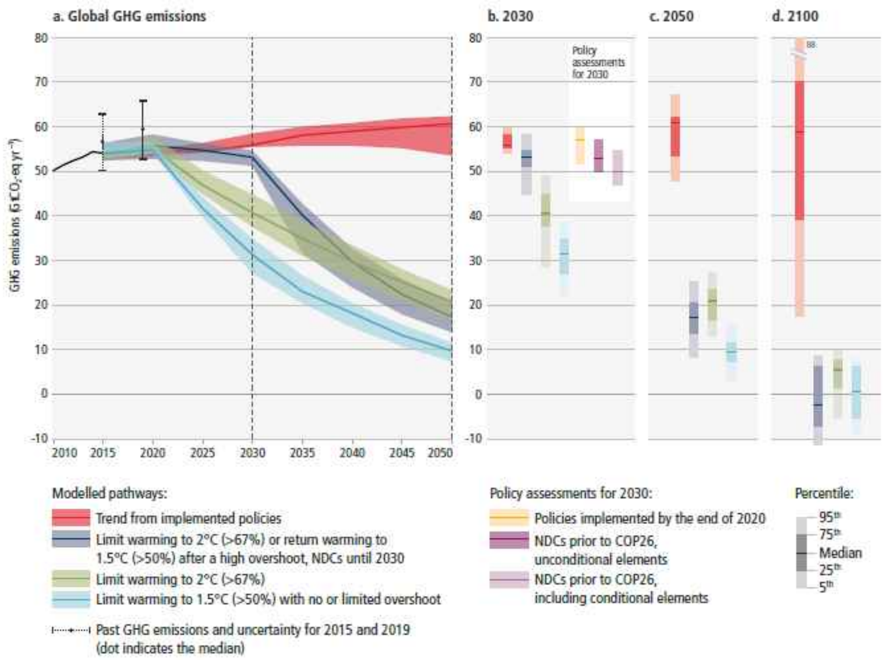
Early warning systems as adaptation

- Adaptation to water-related risks and impacts make up the majority of all documented adaptation (high confidence).
- For inland flooding, combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives *(medium confidence)*
- There are a range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined *(high confidence)*.

Without a strengthening of policies, it leads to a warming of 3.2

WG3

- Without a strengthening of policies beyond those that are implemented by the end of 2020, GHG emissions are projected to rise beyond 2025, leading to a median global warming of 3.2 [2.2 to 3.5] ° C by 2100
- Global GHG emissions in 2030 associated with the implementation of Nationally Determined Contributions (NDCs) announced prior to COP26 would make it likely that warming will exceed 1.5° C during the 21st century.24 Likely limiting warming to below 2° C would then rely on a rapid acceleration of mitigation efforts after 2030.



Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming (WG1)

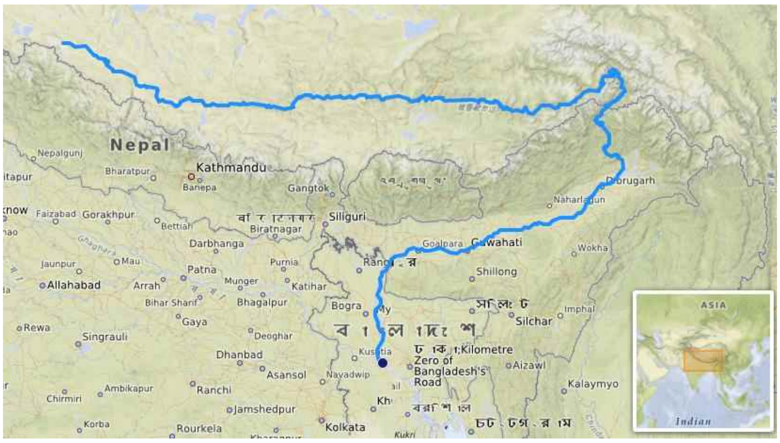
The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming (WG2)

PART 1: INTRODUCTION TO IPCC AR6

PART 2: DISCUSSION ON IPCC SENTENCES ABOUT YOUR COUNTRY/REGION

Sentences in Chapter 11

- Bangladesh
  - …… event attribution focused on runoff using hydrological models, and examples include …… the Brahmaputra River in Bangladesh (Philip et al., 2019).
  - In Bangladesh, the annual number of propagating mesoscale convective systems (MCSs) decreased significantly during 1998–2015 based on TRMM precipitation data (Habib et al., 2019).
- Indonesia
  - In 2015 (when Extreme El Niño happened), Indonesia experienced a severe drought and forest fire, causing pronounced impact on economy, ecology and human health due to haze crisis (Field et al., 2016; Huijnen et al., 2016; Patra et al., 2017; Hartmann et al., 2018).

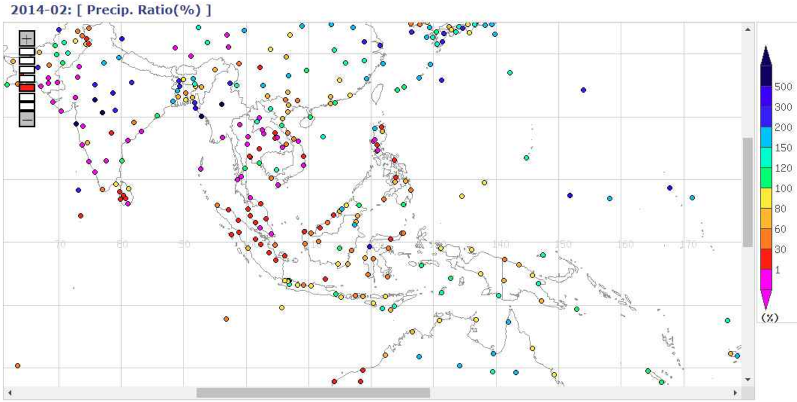


Path of the Brahmaputra River (Wikipedia)

2015 Southeast Asian haze (Wikipedia)

Sentences in Chapter 11

- Malaysia
  - there are studies in regions of almost all continents that generally indicate intensification of sub-daily extreme precipitation, although there remains low confidence in an overall increase at the global scale. …… Studies include an increase in extreme sub-daily rainfall …… in Peninsular Malaysia (Syafrina et al., 2015),
  - In Asia, no climate change signal was found in the record dry spell over Singapore and Malaysia in 2014 (Mcbride et al., 2015) …… Nevertheless, the South East Asia drought of 2015 has been attributed to anthropogenic warming effects (Shiogama et al., 2020).
- Mongolia
  - Increases in the frequency and duration of heatwaves are also observed in Mongolia (Erdenebat and Sato, 2016) and India (Ratnam et al., 2016; Rohini et al., 2016).



(ClimatView)

dry spell over Singapore and Malaysia in 2014

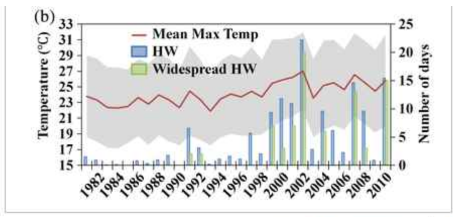


Figure 1 Open in figure viewer PowerPoint

(a) Climatology of HW frequency determined from reanalysis data. White and black circles indicate the 70 surface meteorological stations. Black circles indicate 21 stations used for soil moisture. Red line shows the area used for Figure 4. (b) Interannual variation of JJA-mean maximum air temperature and its standard deviation (gray shading) averaged over the 70 stations in Mongolia. Bars represent the annual number of HW and widespread HW (when more than half of the 70 stations simultaneously observed HW) days, respectively.

(Erdenebat and Sato, 2016)

Sentences in Chapter 11

- Pakistan
  - More intense heatwaves of longer durations and occurring at a higher frequency are projected over India (Murari et al., 2015; Mishra et al., 2017) and Pakistan (Nasim et al., 2018).
- Philippines
  - In Super Typhoon Haiyan, which struck the Philippines on 8 November 2013, Takayabu et al. (2015) took an event attribution approach with cloud system-resolving (around 1 km) downscaling ensemble experiments to evaluate the anthropogenic effect on typhoons, and showed that the intensity of the simulated worst-case storm in the actual conditions was stronger than that in a hypothetical condition without historical anthropogenic forcing in the model. However, in a similar approach with two coarser parametrized convection models, Wehner et al. (2019) found conflicting human influences on Haiyan's intensity.

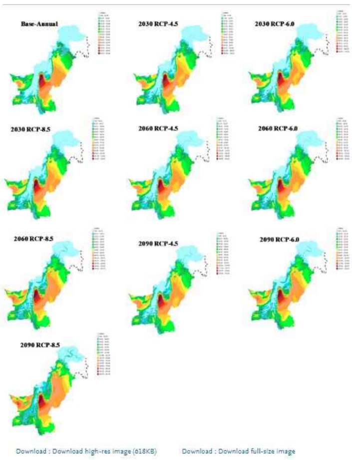


Fig. 8. Projections of Annual heat accumulation by spatial degree day model for 2030, 2060, and 2090 with Representative concentration pathways.

(Nasim et al., 2018)

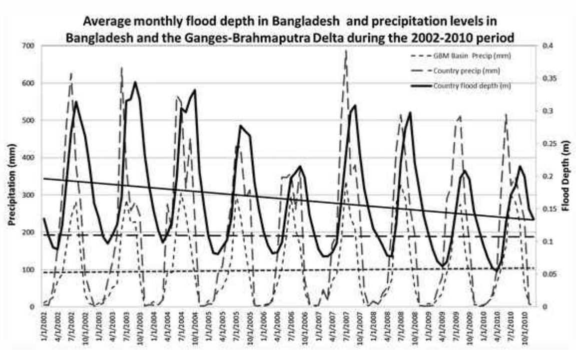
(Wikipedia)

Map plotting the storm Haiyan's track and intensity, according to the Saffir–Simpson scale

Sentences in Chapter 12

- Bangladesh
  - In South Asia (SAS), the numbers of flood events and human fatalities have increased in India during 1978–2006 (Singh and Kumar, 2013), whereas the average country-wide inundation depth has been decreasing during 2002–2010 in Bangladesh, attributed to improved flood management (low confidence) (Sciance and Nooner, 2018).
- Indonesia
  - High confidence of decrease (Mean precipitation projected change) in Indonesia (Atlas.5.4.5).

Fig. 6



Average country flood depth (m) plotted against the average country and basin wide precipitation (mm) between January 1, 2002 and December 27, 2010). Each datasets trend line is also displayed with matching line styles. Flood depth slope was −0.00601 m/year, country level precipitation slope was 0.12 mm/year, and GBM basin level precipitation slope was 0.15 mm/year

(Sciance and Nooner, 2018)

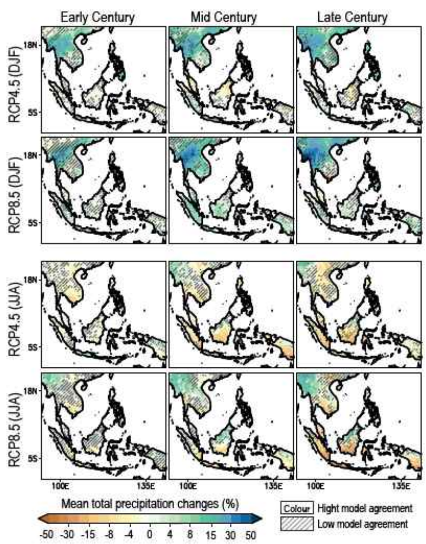
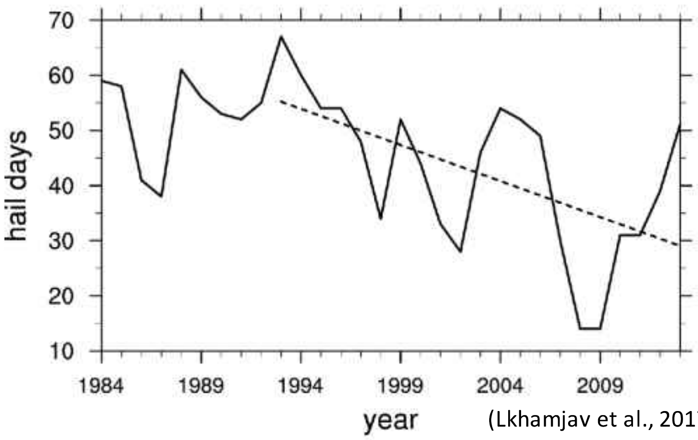


Figure Atlas.19 | The RCM-projected changes in mean precipitation between the early (2011–2040), mid- (2041–2070) and late (2071–2099) 21st century and the historical period 1976–2005. Data are obtained from the CORDEX-SEA downscaling simulations. Diagonal lines indicate areas with low model agreement (less than 80%). Figure adapted from Tangang et al. (2020).

(IPCC AR6 WG1 Atlas)

Sentences in Chapter 12

- Mongolia
  - A rate of decrease of 0.214 hail days per decade has also been reported for Mongolia between 1984–2013, where the annual number of hail days averaged is 0.74 (Lkhamjav et al., 2017).
- Nepal
  - Intense monsoon rainfall in northern India and western Nepal in 2013, which led to landslides and one of the worst floods in history, has been linked to increased loading of GHG and aerosols (Cho et al., 2016).



(Lkhamjav et al., 2017)

Fig. 2. Annual variation of the number of hail days. The dashed line indicates the linear trend since 1993.

(Wikipedia)

Effect of flood in Darchula district of Nepal.

Sentences in Chapter 12

- Pakistan
  - Aridity in West Central Asia and parts of South Asia increased in recent decades (medium confidence), as documented in Afghanistan (Qutbudin et al., 2019), Iran (Zarei et al., 2016; Zolfaghari et al., 2016; Pour et al., 2020), most parts of Pakistan (K. Ahmed et al., 2018, 2019), and many parts of India (Roxy et al., 2015; Mallya et al., 2016; Matin and Behera, 2017; Ramarao et al., 2019).
- Papua New Guinea
  - a swell event due to distant extratropical cyclones in December 2008 raised extreme water levels leading to flooding affecting five Pacific island nations: Marshall Islands, Micronesia, Papua New Guinea, Kiribati and Solomon Islands (Hoeke et al., 2013; Merrifield et al., 2014).

Up to 1,408 houses were damaged or destroyed as a direct result of the sea swells and subsequent floods in New Ireland province. PNGRCS.

(The International Federation's Disaster Relief Emergency Fund (DREF) operation final report)

Sentences in Chapter 12

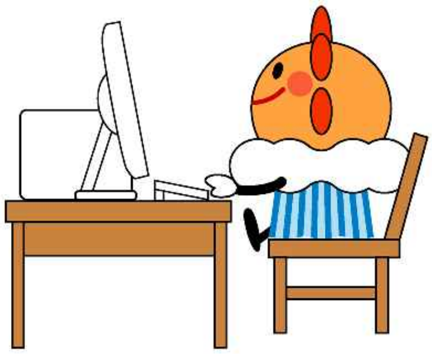
- **Philippines and Vietnam**
  - There was a drying tendency in the dry season and significant wetting in the wet season in the Philippines during 1951–2010 (Villafuerte et al., 2014), and slight wetting in Vietnam during 1980–2017 (Stojanovic et al., 2020) (low confidence).
  - the frequency of TCs affecting the Philippine region and Vietnam is projected to decrease (Kieu-Thi et al., 2016; C. Wang et al., 2017; Gallo et al., 2019) (medium confidence).
- **Philippines**
  - decreasing exposure in the region of South Asia (SAS) and southern China (Cinco et al., 2016; Kossin et al., 2016; see Chapter 11). However, while the analysis shows fewer typhoons, more extreme TCs have affected the Philippines (low confidence) (Takagi and Esteban, 2016).

e.g., 2013 Typhoon Haiyan

- **Vietnam**
  - Relative sea level (RSL) change in many coastal areas in Asia, especially in EAS, is affected by land subsidence due to sediment compaction under building mass and groundwater extraction (high confidence) (Erban et al., 2014; Nicholls, 2015; Minderhoud et al., 2019; Qu et al., 2019). During 1991–2016, the Mekong Delta in Vietnam sank on average about 18 cm as a consequence of groundwater withdrawal, and the subsidence related to groundwater extraction has gradually increased with highest sinking rates estimated to be 11 mm yr^{-1} in 2015 (Minderhoud et al., 2017).
  - Compound impacts of precipitation change, land subsidence, sea level rise, upstream hydropower development, and local water infrastructure development may lead to larger flood extent and prolonged inundation in the Vietnamese Mekong Delta (Triet et al., 2020).

Mekong Delta (Wikipedia)

Thank you for your attention!



Guidance to Global Warming Projection data

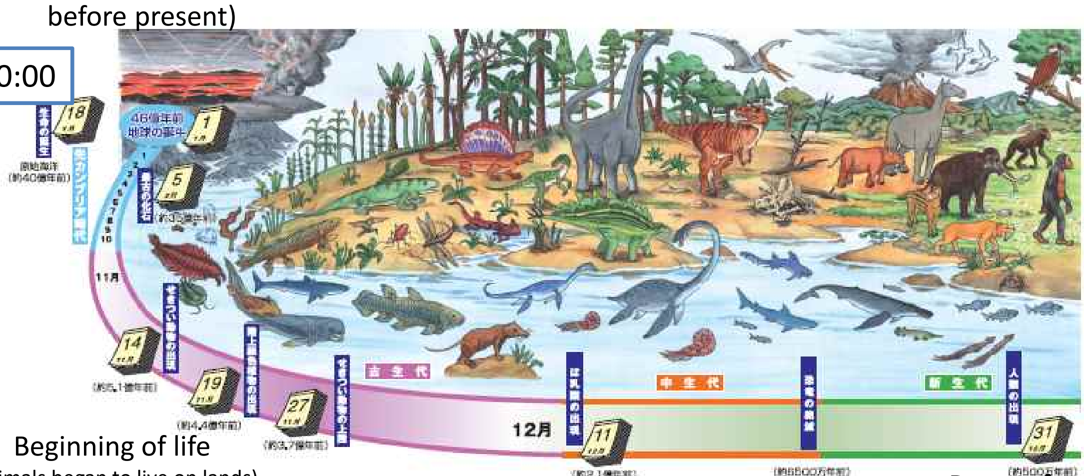
Importance of Climate Change Monitoring and Future Projections

WAKAMATSU Shunya

History of the Earth

Earth's formation
(4.6 billion years before present)

January 1st 00:00



Beginning of life
(Animals began to live on lands)
(3.7 billion years before present)

November 27th

Disappearance of the dinosaurs
(65 million years before present)

December 26th

Dawn of humanity
(5 million years before present)

December 31th

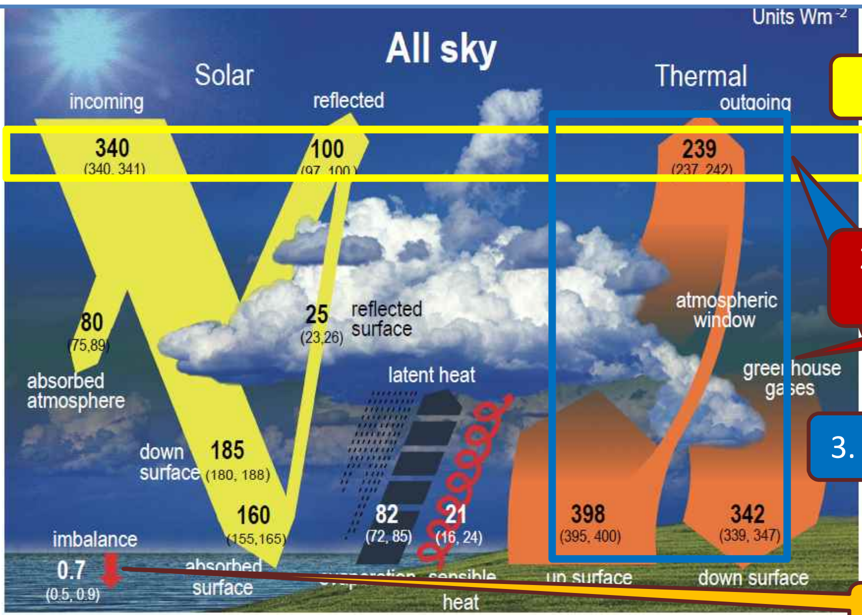
Source: 環境省リーフレット「いのちはつながっている」

Energy Budget & Global Warming

Japan Meteorological Agency

- Increasing concentrations of greenhouse gases due to human activities have led to an greater trapping of the Sun's heat and in turn a warming of the earth's atmosphere and surface known as global warming.

Global mean energy budget of the Earth for the early 21st century



1. Radiative balance at the TOA

Incoming: 340W/m^2,
Outgoing: (100+239)W/m^2

2. Absorption and re-emission of infrared radiation by GHG

3. Reduction of outgoing radiation

Net "accumulating" energy

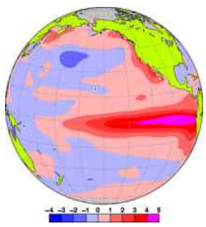
IPCC AR6 WG1 Figure 7.2

Factors of Climate Change

Japan Meteorological Agency

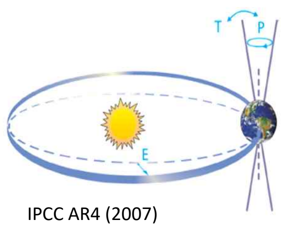
Natural Internal Variability

- El Niño phenomenon



Natural External Factor

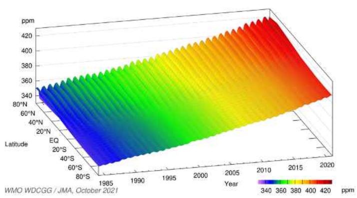
- Eruption of volcanos
- Fluctuation of Sun's activity

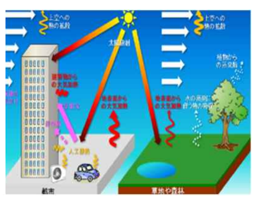


IPCC AR4 (2007)

Anthropogenic Factor

- Change of land use
- Emission of greenhouse gases



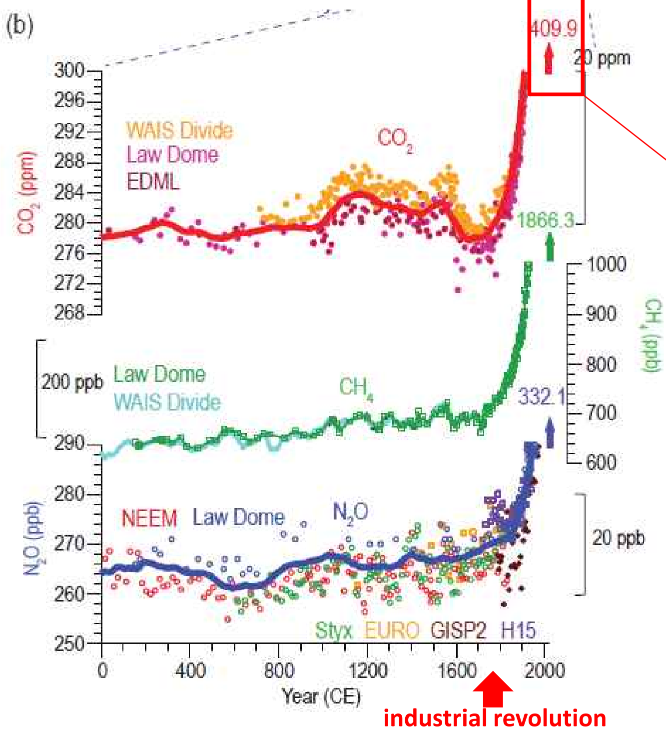


https://www.data.jma.go.jp/ghg/kanshi/ghgp/co2_e.html

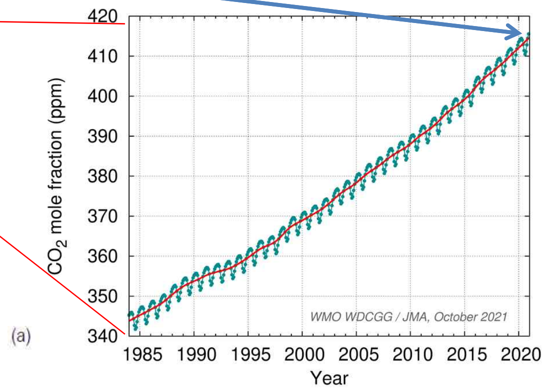
Long-term change of CO2 concentration

Japan Meteorological Agency

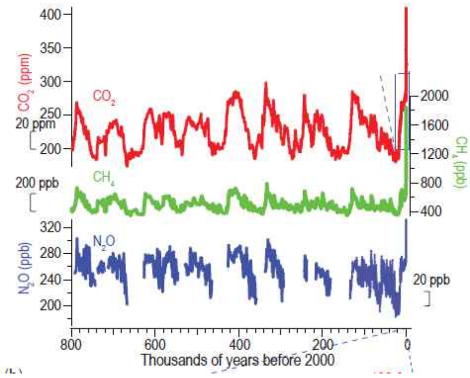
the amount of CO2 in the atmosphere reached 413.2 parts per million (ppm) in 2020.



IPCC AR6 WG1 Figure 2.4

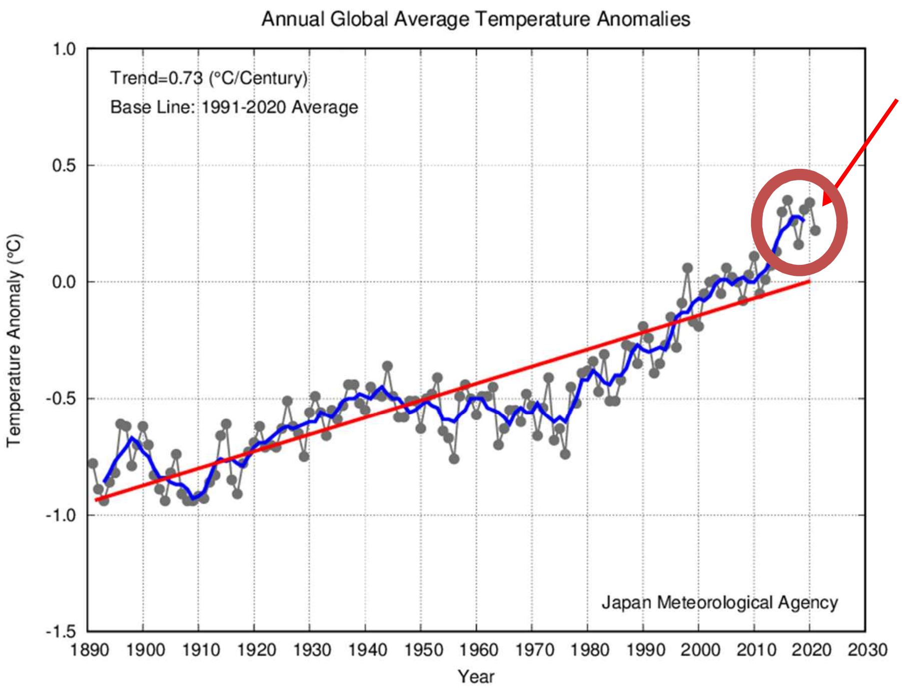


https://www.data.jma.go.jp/ghg/kanshi/ghgp/co2_e.html



Long-term change of global temperature

Japan Meteorological Agency



Anomalies are deviation from baseline (1991-2020 Average).
The black thin line indicates surface temperature anomaly of each year.
The blue line indicates their 5-year running mean.
The red line indicates the long-term linear trend.

2014-2021: top eight warmest

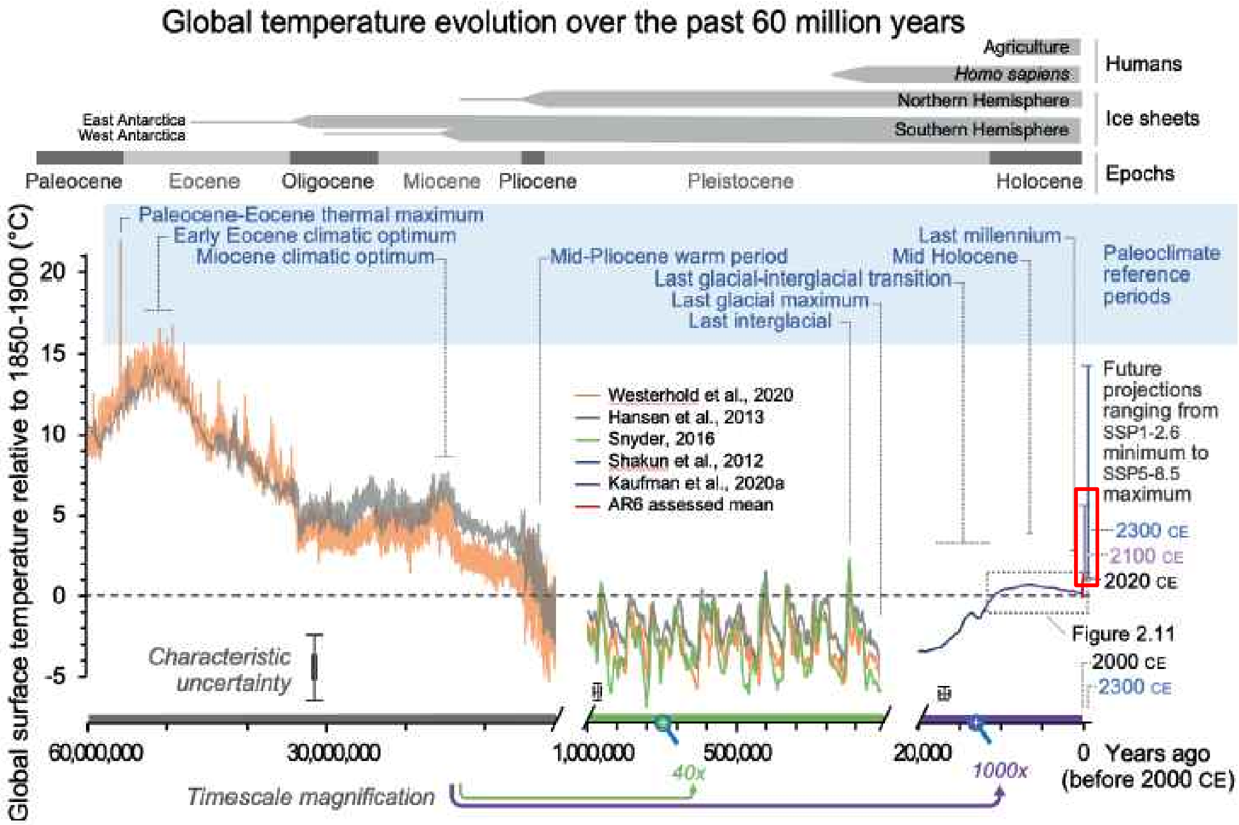
Annual global average temperature for 2021 was the 6th warmest since 1891.

Annual global average temperature increases at a rate of about 0.73°C per century.

The past eight years (2014 to 2021) were the eight warmest years for the 131-year period since 1981.

https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/ann_wld.html

Long-term change of global temperature



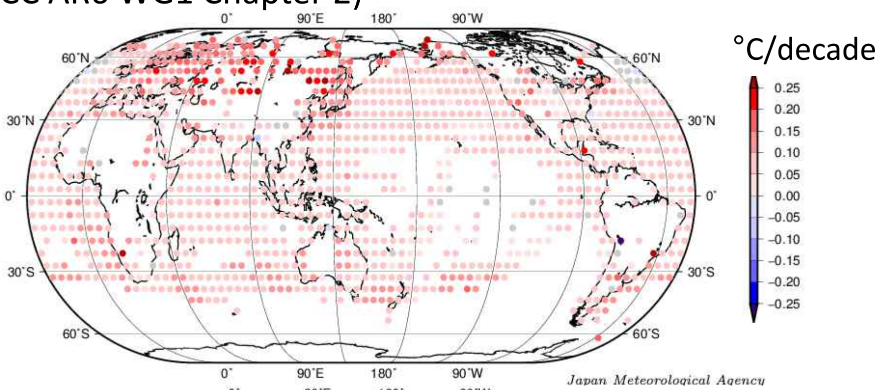
IPCC Fifth Assessment Report (WG1 Figure 5.7)

Long-term trend of annual temperature

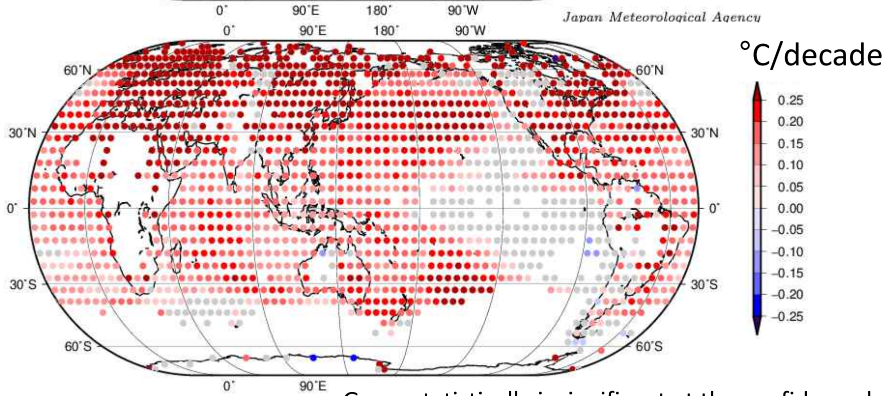
気象庁 Japan Meteorological Agency

- "Warming accelerated after the 1970s, but not all regions are warming equally" (IPCC AR6 WG1 Chapter 2)

1891-2021



1979-2021

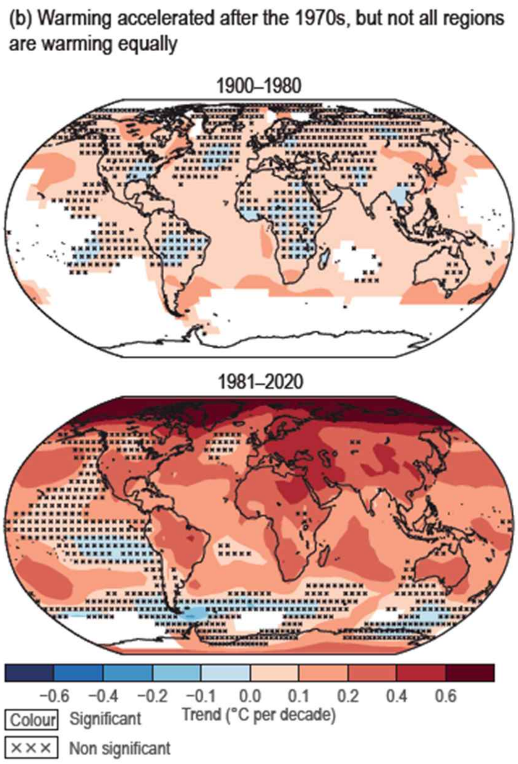


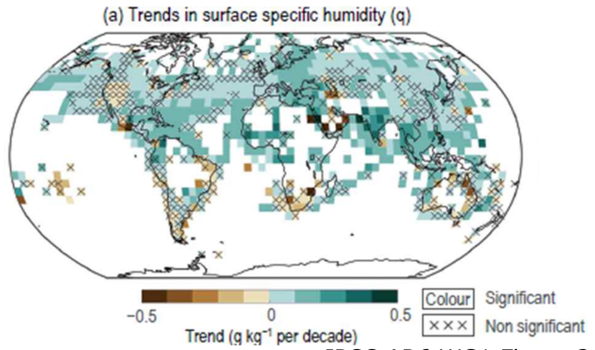
https://www.data.jma.go.jp/cpdinfo/temp/an_wld.html

Grey : statistically insignificant at the confidence level of 90%

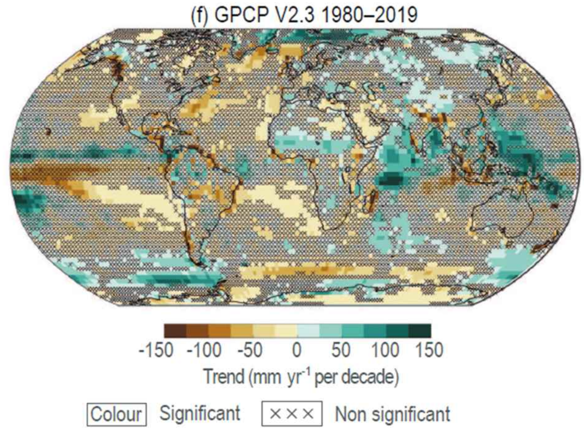
Observed Climate Change

Japan Meteorological Agency





IPCC AR6 WG1 Figure 2.13

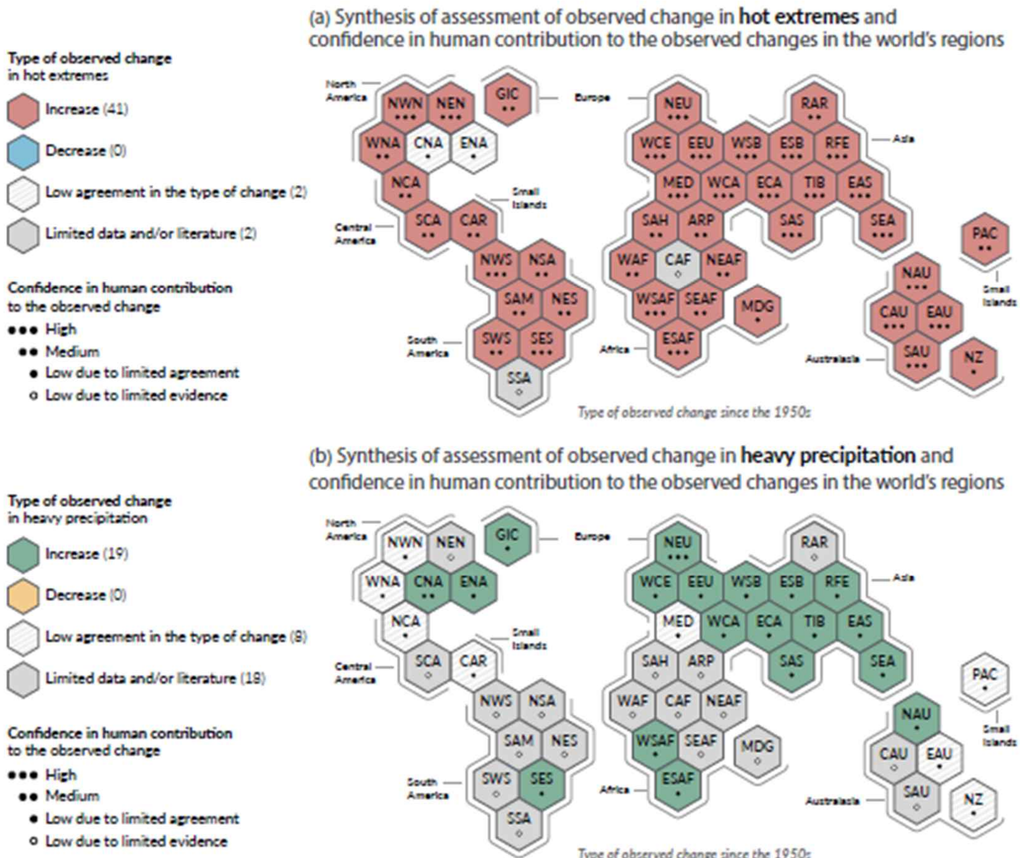


IPCC AR6 WG1 Figure 2.11

IPCC AR6 WG1 Figure 2.15

Observed Climate Change since 1950s

Japan Meteorological Agency



IPCC AR6 WG1 Figure SPM.3

Key Regional Risks in Asia

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

Subject to copy edits

INTERGOVERNMENTAL PANEL ON climate change — ipcc — WMO UNEP

Regional fact sheet - Asia

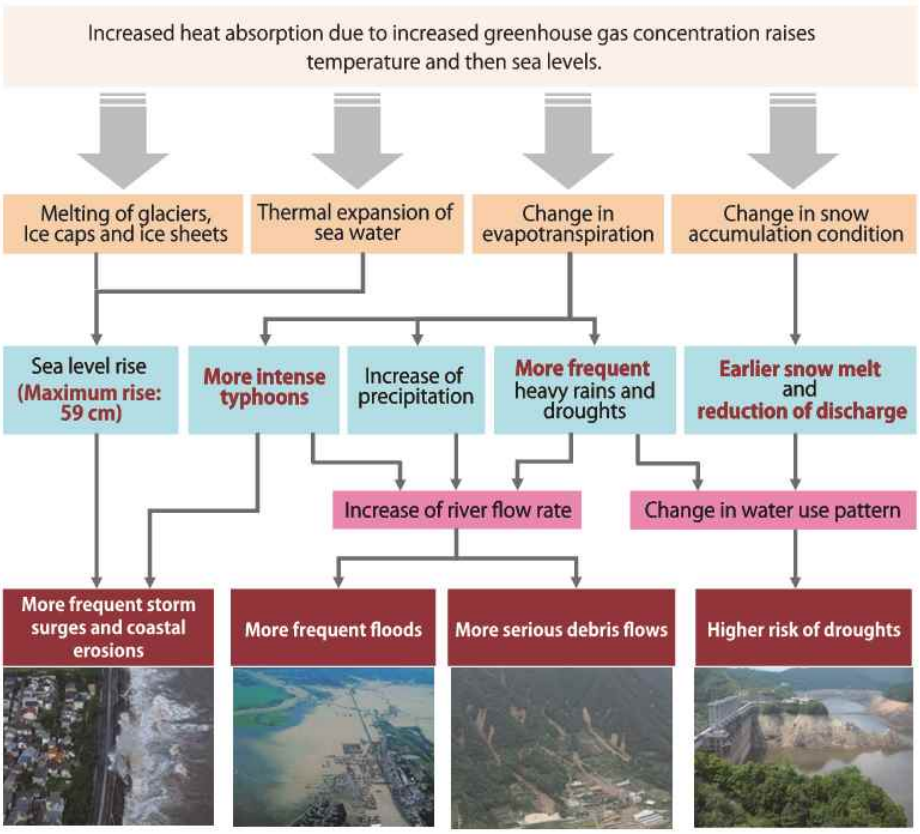
Common regional changes

- The observed mean surface temperature increase has clearly emerged out of the range of internal variability compared to 1850-1900. Heat extremes have increased while cold extremes have decreased, and these trends will continue over the coming decades (*high confidence*).
- Marine heatwaves will continue to increase (*high confidence*).
- Fire weather seasons will lengthen and intensify, particularly in North Asia regions (*medium confidence*).
- Average and heavy precipitation will increase over much of Asia (*high to medium confidence*).
- Mean surface wind speeds have decreased (*high confidence*) and will continue to decrease in central and northern parts of Asia (*medium confidence*).
- Glaciers are declining and permafrost is thawing. Seasonal snow duration, glacial mass, and permafrost area will decline further by the mid-21st century (*high confidence*).
- Glacier runoff in the Asian high mountains will increase up to mid-21st century (*medium confidence*), and subsequently runoff may decrease due to the loss of glacier storage.
- Relative sea level around Asia has increased faster than global average, with coastal area loss and shoreline retreat. Regional-mean sea level will continue to rise (*high confidence*).

IPCC AR6 WG1 Regional fact sheet - Asia

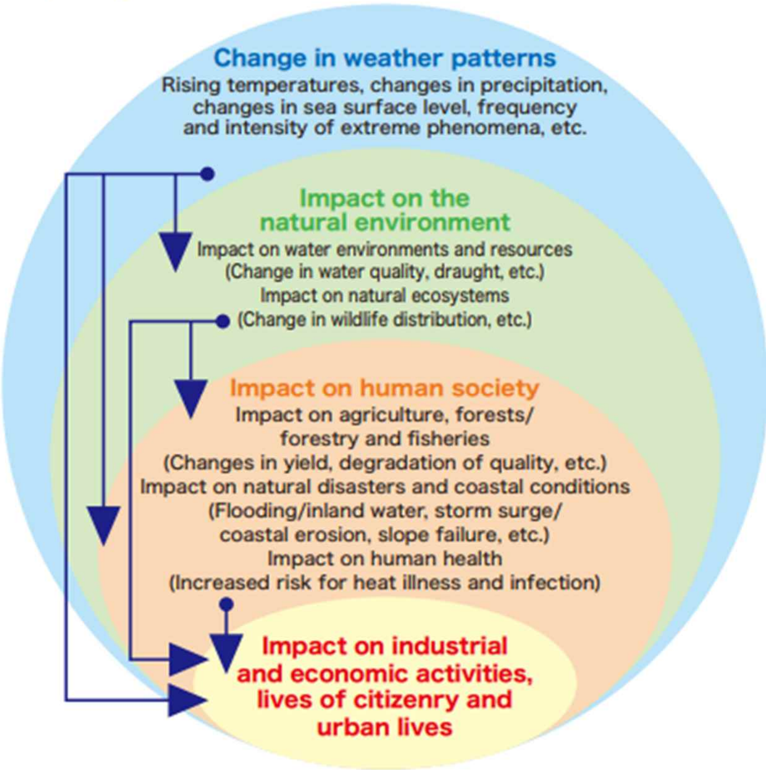
Global warming threats the water sector

気象庁 Japan Meteorological Agency



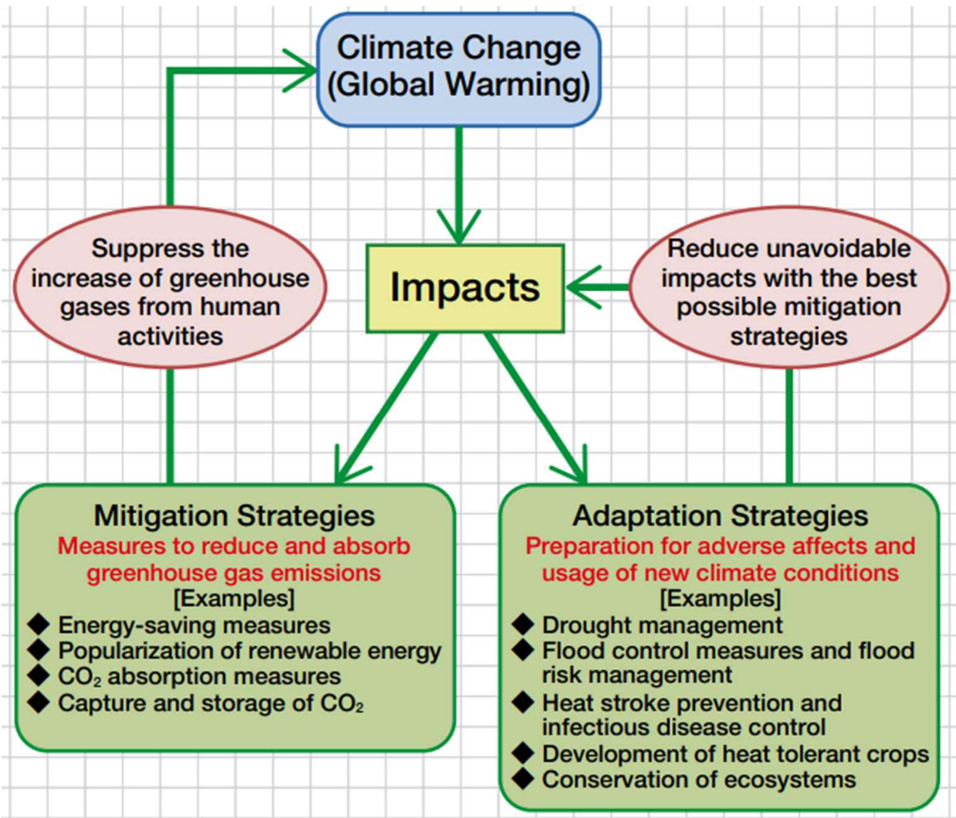
Ministry of Land, Infrastructure, Transport and Tourism, Japan. *Practical Guidelines* on. Strategic Climate Change. Adaptation Planning. -*Flood Disasters*- https://www.mlit.go.jp/river/basic_info/english/climate.html

Further impacts of climate change



Ministry of the Environment Ministry of Education, Culture, Sports, Science and Technology Ministry of Agriculture, Forestry and Fisheries Ministry of Land, Infrastructure, Transport and Tourism Japan Meteorological Agency “Climate Change in Japan and Its Impacts” https://www.env.go.jp/earth/tekiou/pamph2018_full_Eng.pdf

Adaptation and Mitigation



Ministry of Education, Culture, Sports, Science and Technology, Japan Meteorological Agency, Ministry of the Environment “Climate Change and Its Impacts in Japan” https://www.env.go.jp/en/earth/cc/impacts_FY2012.pdf

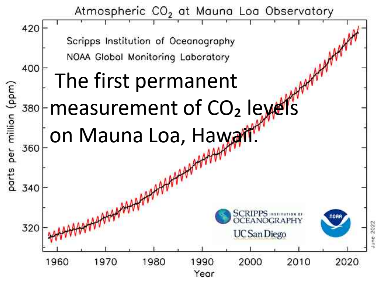
History of Climate Change Science

1824 Joseph Fourier indicated the existence of greenhouse effect.

1859 John Tyndall verified the existence of greenhouse effect.

1896 Svante Arrhenius estimated the future temperature change due to global warming.

1975 MANABE Syukuro (awarded Nobel Prize in Physics) and Wetherald made the first GCM which can deal with $2xCO_2$.
Their first estimate of global climate sensitivity was 2.93°C



The first permanent measurement of CO_2 levels on Mauna Loa, Hawaii.

https://gml.noaa.gov/ccgg/trends/

1957～58 International Geophysical Year

CO2, aurora, cosmic rays, geomagnetism, gravity, solar activity and so on.

1980s Improvement of simulation technique for global warming projection

1988 IPCC (Intergovernmental Panel on Climate Change)

Scientific intergovernmental body under the auspices of the United Nations, and established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). IPCC reports cover "the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation." The 2007 Nobel Peace Prize was shared between the IPCC and Al Gore.

1992 UNFCCC (United Nations Framework Convention on Climate Change)

International environmental treaty negotiated at the "Earth Summit" held in Rio de Janeiro in June 1992. The objective is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (Article 2)".

https://unfccc.int/

IPCC Sixth Assessment Report (AR6)

- Global Warming of 1.5℃, an IPCC special report on the impacts of global warming of 1.5 degrees Celsius above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty was launched in October 2018..
- Climate Change and Land, an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems was launched in August 2019.
- Special Report on the Ocean and Cryosphere in a Changing Climate was released in September 2019.
- 2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories was released in May 2019.

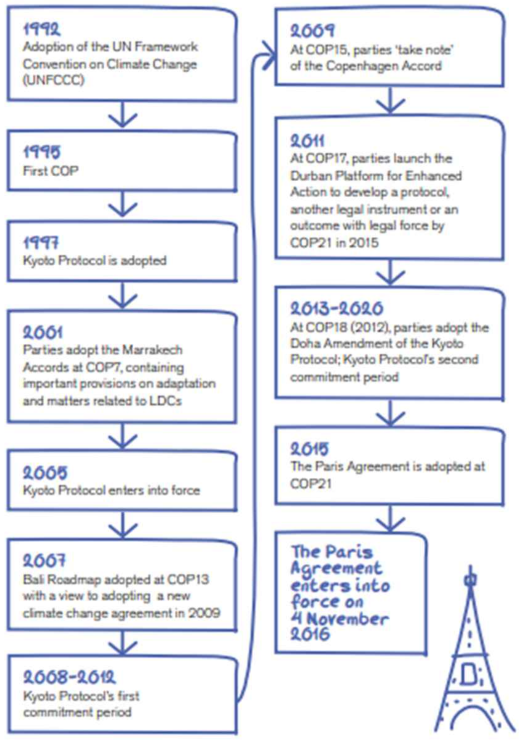
- Climate Change 2021: The Physical Science Basis, by IPCC Working Group I in August 2021
- Climate Change 2022: Impacts, Adaptation and Vulnerability, by Working Group II in March 2022
- Climate Change 2022: Mitigation of Climate Change, by Working Group III in April 2022.

- The concluding Synthesis Report is due in 2022 or 2023.

http://www.ipcc.ch/

Key Agreements in International Negotiations

Japan Meteorological Agency



Kyoto Protocol (COP3, 1997)

Legally binding treaty applies to only developed country parties.
Reduce their emissions during 2008-2012 and 2013-2020.

Durban Platform (COP17, 2011)

Set a deadline to agree on new and universal greenhouse gas reduction protocol with legal force by 2015 for the period beyond 2020 .

Paris Agreement (COP21, 2015)

PARIS2015 COP21·CMP11

A universal, legally binding international agreement
Reduce their emissions beyond 2020 to limit global warming to well below 2℃, preferably to 1.5℃.

Becoming a UNFCCC Delegate: What You Need to Know
https://www.uncclearn.org/resources/library/becoming-a-unfccc-delegate-what-you-need-to-know/

Role of JMA

Japan Meteorological Agency

Cooperation with related ministries and agencies

MOFA Japan

METI

文部科学省

etc…

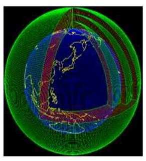
To deal with international and local affairs

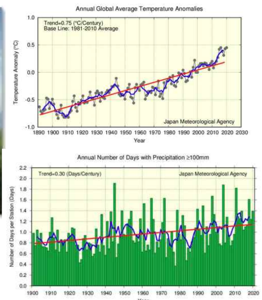
ipcc

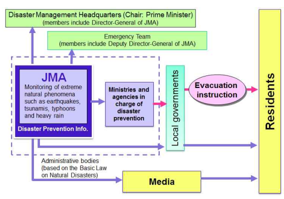
cCcA Center for Climate Change Adaptation
国立研究開発法人 国立環境研究所
気候変動適応センター

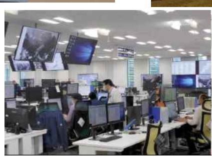
Observation, Monitoring and Issuing Disaster Prevention Information

Data Production on climate change









To provide scientific knowledge

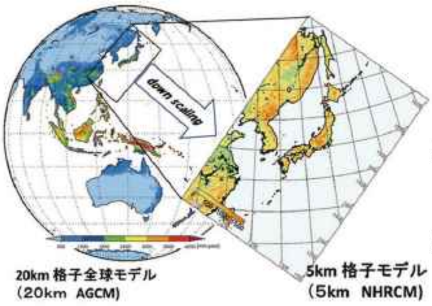
To prevent disaster

including provision of training as RCC

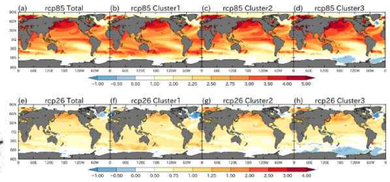
JMA's latest Global Warming Projection

Japan Meteorological Agency

Climate Change in Japan 2020
(MEXT and JMA, 2020)

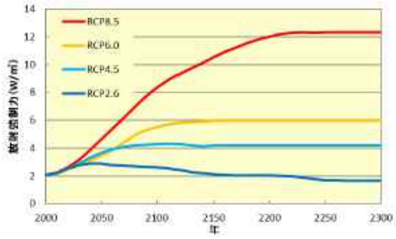


AGCM run with
four SST clusters

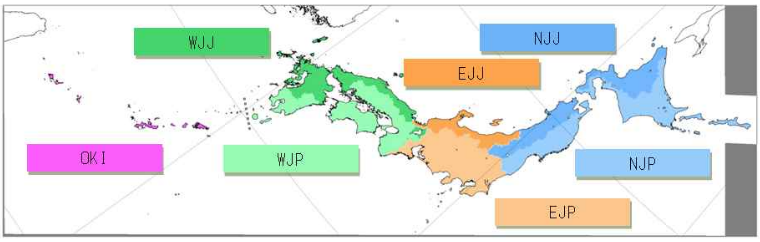


Greenhouse gas emission scenario :
RCP2.6 & RCP8.5

PRE: 1980-1999
FUT: 2076-2095



This report provides essential information for planning and decision-making in climate –change mitigation/adaptation for impact assessment by national and local government bodies.



https://www.data.jma.go.jp/cpdinfo/ccj/index.html
https://www.data.jma.go.jp/cpdinfo/ccj/2020/pdf/cc2020_gaiyo_en.pdf

Future changes in surface temperature

Japan Meteorological Agency

Surface Temperature

Observed changes

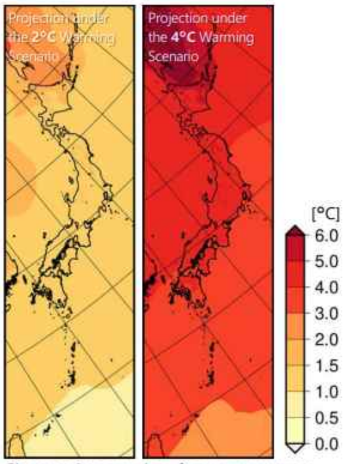
- The annual surface temperature over Japan (based on data from 15 observation stations considered to be relatively uninfluenced by urbanization) increased at a rate of 1.24°C per century between 1898 and 2019.
- Between 1910 and 2019, the annual numbers of days with maximum temperatures of ≥ 30 and ≥ 35°C and minimum temperatures of ≥ 25°C (referred to here as T_{max} ≥ 30°C, T_{max} ≥ 35°C and T_{min} ≥ 25°C days, respectively) have increased, while those of days with minimum temperatures of < 0°C (referred to here as T_{min} < 0°C days) have decreased. In particular, the number of T_{max} ≥ 35°C days has increased significantly since the mid-1990s.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	4°C Warming Scenario Potential conditions with no future additional mitigation measures
Annual surface temperature over Japan	Approx. 1.4°C increase	Approx. 4.5°C increase
Annual global average surface temperature	Approx. 1.0°C increase	Approx. 3.7°C increase
T_{max} ≥ 35°C days per year	Approx. 2.8-day increase	Approx. 19.1-day increase
T_{min} ≥ 25°C days per year	Approx. 9.0-day increase	Approx. 40.6-day increase
T_{min} < 0°C days per year	Approx. 16.7-day decrease	Approx. 46.8-day decrease

- Under both scenarios, the annual surface temperature over Japan for the end of the 21st century is expected to increase, with more T_{max} ≥ 35°C / T_{min} ≥ 25°C days and fewer T_{min} < 0°C days in many regions.
- The temperature increase over Japan is greater under the 4°C Warming Scenario than under the 2°C Warming Scenario.
- Under the same scenario, higher latitudes correspond to greater increases in temperature. Values are also higher in winter than in summer.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless otherwise stated.



Changes in annual surface temperature for the end of the 21st century (2076 – 2095 average) relative to the end of the 20th century (1980 – 1999 average)

5

https://www.data.jma.go.jp/cpdinfo/ccj/2020/pdf/cc2020_gaiyo_en.pdf

Future changes in precipitation

Japan Meteorological Agency

Precipitation

Observed changes

- While the frequency of daily and hourly extreme precipitation has increased in Japan, that of wet days has decreased (both statistically significant).
- No statistically significant long-term trend is observed in annual or seasonal precipitation over Japan.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	4°C Warming Scenario Potential conditions with no future additional mitigation measures
Annual number of days with precipitation ≥ 200 mm	Approx. x 1.5 increase	Approx. x 2.3 increase
Annual number of events with precipitation ≥ 50 mm/h	Approx. x 1.6 increase	Approx. x 2.3 increase
Annual maximum daily precipitation	Approx. 12% (15 mm) increase	Approx. 27% (33 mm) increase
Annual number of days with precipitation < 1.0 mm	No statistically significant change	Approx. 8.2-day increase

Precipitation ≥ 50 mm/h is torrential rainfall rendering umbrellas useless and creating spray that impairs visibility.

- The frequency and intensity of daily and hourly extreme precipitation over Japan are expected to increase, while those of wet days are expected to decrease.
- No statistically significant change in annual precipitation over Japan is projected.
  There is significant uncertainty in projections on regional and prefectural scales.
- The precipitation system associated with the *Baiu* (seasonal rain) front in June is expected to intensify and be south of its normal location.
  The projection for July is characterized by significant uncertainty.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless stated otherwise.

Future changes in snow

Japan Meteorological Agency

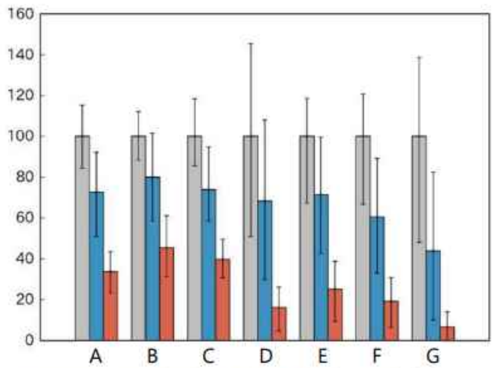
Snowfall and Snow Depth

Observed changes

- Data collected at observation stations on the Sea of Japan side of the country indicate that:
  - the annual maximum snow depth in winter has decreased; and
  - the annual number of days with snowfall ≥ 20 cm has decreased.

Projections

	2°C Warming Scenario Potential conditions with achievement of the Paris Agreement's 2°C target	4°C Warming Scenario Potential conditions with no future additional mitigation measures
Annual maximum snow depth and snowfall	Approx. 30% decrease (except Hokkaido and certain other areas)	Approx. 70% decrease (except some areas of Hokkaido)
Snowfall period	/	Shorter (delayed start, early end)
Heavy snowfall (decadal max. in the present climate)	/	Potential increase in Honshu mountainous areas and Hokkaido inland areas



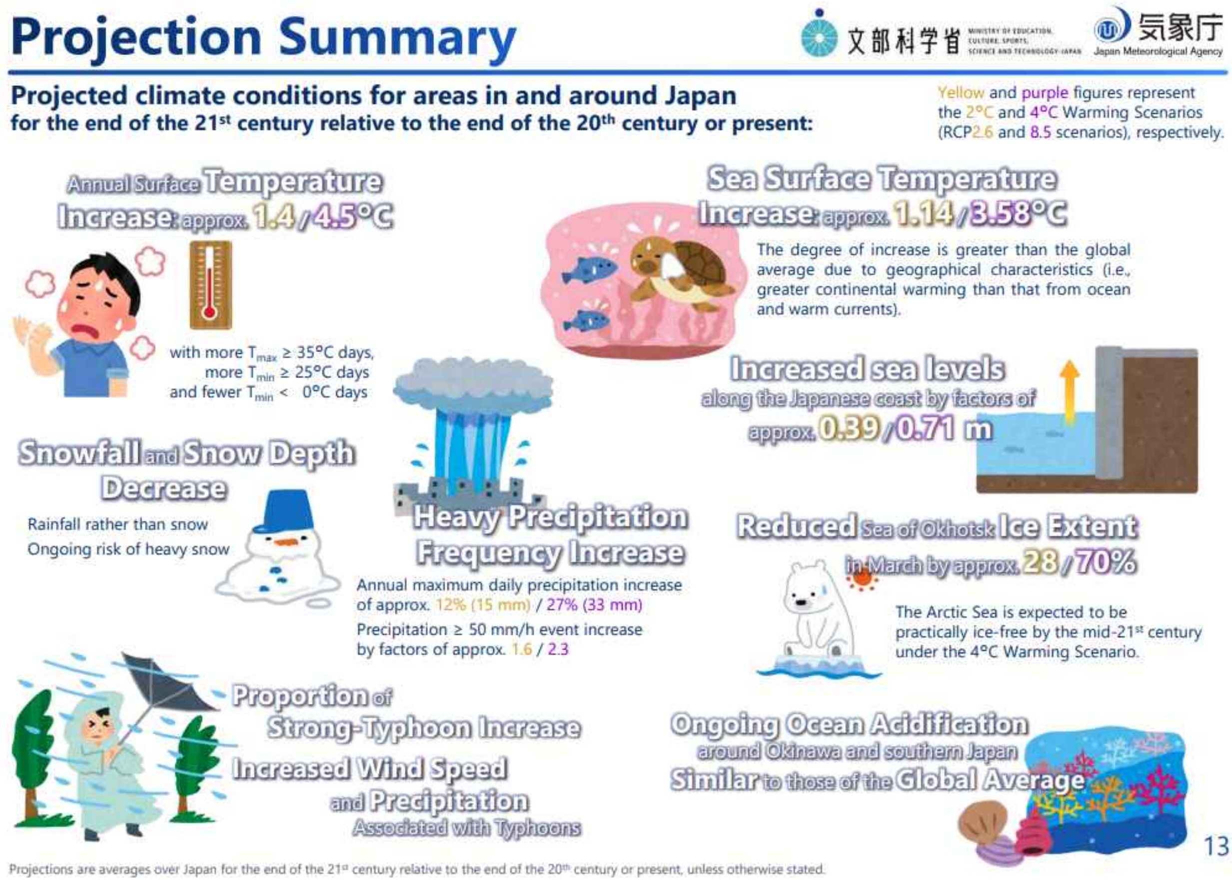
Maximum snow depth in winter for the end of the 21st century (2076 – 2095 average) standardized by that for the end of the 20th century (1980 – 1999 average) for A) all Japan; B) Sea of Japan side of northern Japan; C) Pacific side of northern Japan; D) Sea of Japan side of eastern Japan; E) Pacific side of eastern Japan; F) Sea of Japan side of western Japan; and G) Pacific side of western Japan. Grey, blue and red bars represent 1) observations for the end of the 20th century, and projections for the end of the 21st century under the 2) 2°C and 3) 4°C Warming Scenarios, respectively.

- Outside inland Hokkaido, snowfall and snow depth are expected to decrease as global warming progresses, with a higher likelihood of rain.
- Reduced snowfall amounts do not necessarily correspond to reduced risk of exceedingly rare incidences of extremely heavy snowfall. It should be noted that the confidence level of this projection is low.

Projections are averages over Japan for the end of the 21st century relative to the end of the 20th century or present, unless stated otherwise.

Future changes stated in the report

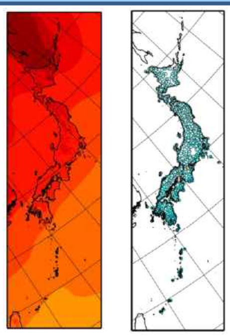
Japan Meteorological Agency



Role of Global Warming Projection Information

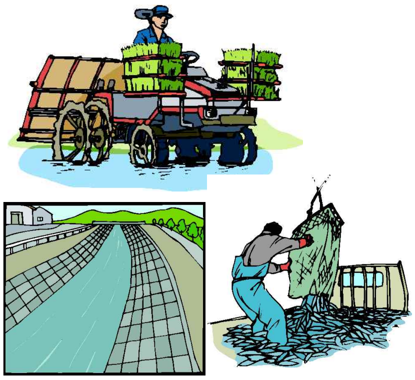
Japan Meteorological Agency

Basic data for adaptations



Detailed climate change projection information

Detailed estimation for impacts on each sector



Appropriate adaptations

Basic data for mitigations

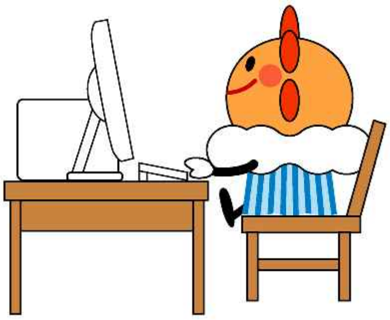
GHG emission reduction target
Planning our future society

Educational activities

Including TCC training seminar

Promotion of people's eco-friendly activity and understanding of the government's efforts
Environmental education

Thank you for your attention!



Production of Global Warming Projection Information

– Introduction to the global warming projection data –

Assessment of Future Climate Change
Introduction to the Exercises

WAKAMATSU Shunya

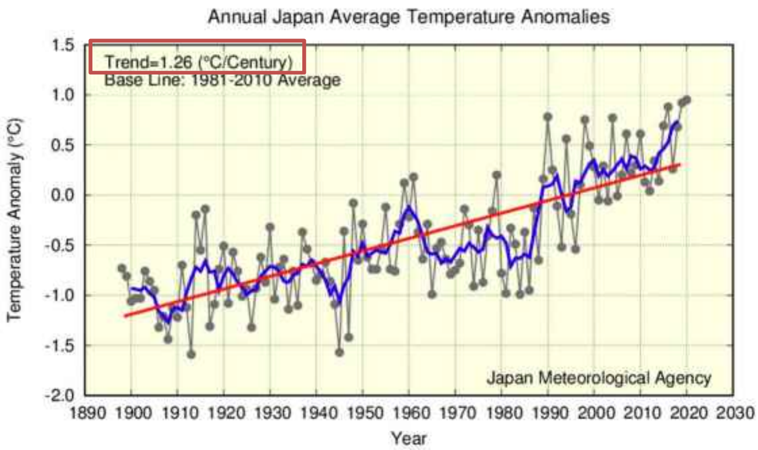
Table of Contents

1. How to calculate long-term trends in observation
2. How to calculate bias-corrected future changes
3. How to check the reliability

Description of a long-term trend

Japan Meteorological Agency

- JMA Climate Change Monitoring Report 2020
  - On a longer time scale, it is virtually certain that the annual mean surface temperature over Japan has risen at a rate of 1.26ºC per century (statistically significant at a confidence level of 99%).



Long-term trend

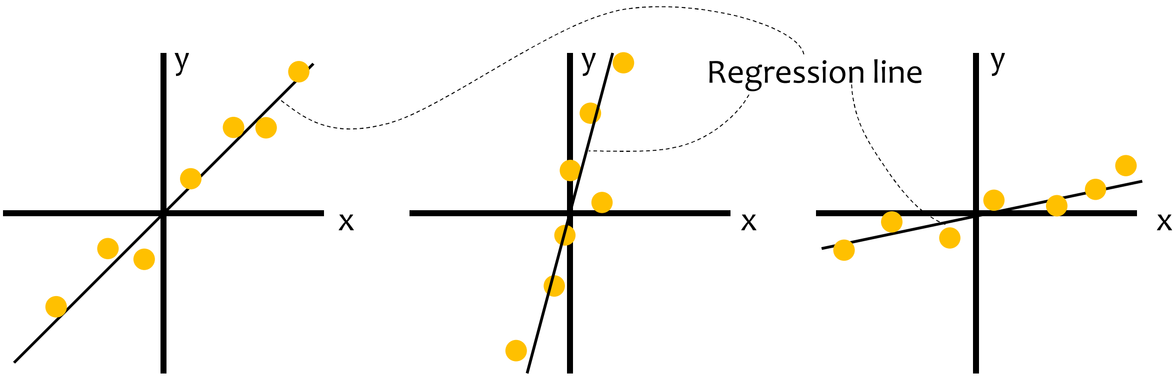
Significant test

https://www.jma.go.jp/jma/en/NMHS/ccmr/5_Chapter2.pdf

Linear regression analysis

Japan Meteorological Agency

- When data has a linear relationship, a linear regression coefficient (a slope of a regression line) is data's trend.
- Since the slope is given by $\Delta y/\Delta x$, regression coefficients mean how much the variable y changes when the variable x changes.

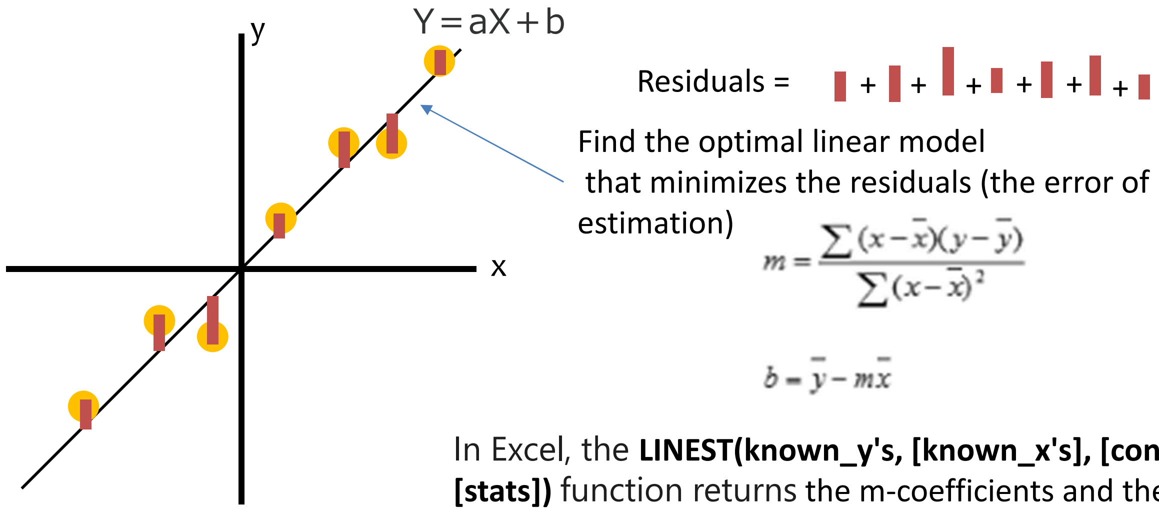


Least-squares method

Japan Meteorological Agency

Least-squares method

- a standard approach in linear regression analysis, by minimizing the sum of the squares of the residuals between observed values and the fitted values.



Find the optimal linear model that minimizes the residuals (the error of estimation)

$$m = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$$

$$b = \bar{y} - m\bar{x}$$

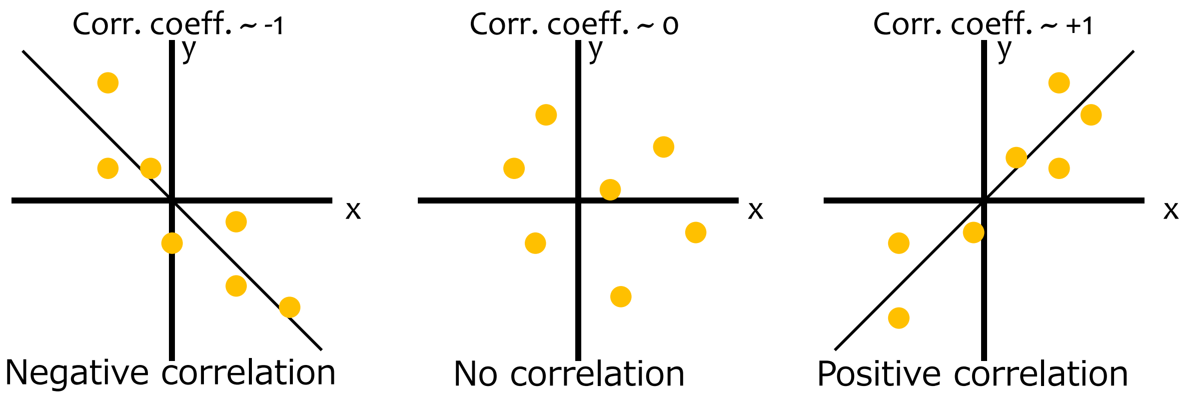
In Excel, the **LINEST(known_y's, [known_x's], [const], [stats])** function returns the m-coefficients and the constant b.

Correlation analysis

Japan Meteorological Agency

Correlation coefficient: How close they have a linear relationship

- Correlation coefficient values are between -1 and +1.
- The value close to +1 (or -1) means there is a clear positive (negative) linear relationship between the targeted data pair, and the value around zero means there is little (or weak) relation between them.



Pearson correlation coefficient

Japan Meteorological Agency

- Pearson correlation coefficient
  - The ratio between the covariance of two variables and the product of their standard deviations (normalizing the covariance to a value between -1 and 1)

$$\frac{\text{Covariance of x and y}}{\text{(Standard deviation of x) x (Standard deviation of y)}} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y})^2}} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

xi, yi: single value of dependent variable
X, Y: mean of all values of independent variable
n: population count

In Excel, the **CORREL(array1, array2)** function returns the correlation coefficient of two cell ranges.

Statistical test (Student's *t*-test)

Japan Meteorological Agency

- Does the long-term trend (=correlation) exist?
  - Null hypothesis: "the true correlation coefficient is equal to 0 (no correlation)."
  - Check whether the sample data are inconsistent with the null hypothesis or not
  - if they are inconsistent, then reject the null hypothesis (no correlation) and conclude that "the true correlation coefficient is not 0 (correlation exists)".
  - If the underlying variables have a bivariate normal distribution, Since the sampling distribution of the specific correlation coefficient **T** (Pearson's correlation coefficient divided by the standard error) follows Student's t-distribution with degrees of freedom n-2, if t is significantly (e.g., 99%) unlikely to have occurred in the Student's t-distribution, the null hypothesis is rejected.

$$T = \frac{|r|\sqrt{n-2}}{\sqrt{1-r^2}}$$

Type I and type II errors

気象庁 Japan Meteorological Agency

- Even if the null hypothesis is rejected at a confidence level of 95%, this does not means the decision is 100% correct.
- Type I error (false positive)
  - Rejecting the null hypothesis which is actually true in reality.
- Type II error (false negative)
  - Not rejecting the null hypothesis which is actually not true in reality.
- Neyman-Pearson lemma
  - Retaining a prespecified level of type I error, subsequently minimize type II error.
- Use the test with the most power at a prespecified confidence level
  - Usually, Student's *t*-test is the good choice.

		Decision about null hypothesis	
		reject	Don't reject
Null hypothesis is	Actually false	○	Type II error (false negative)
	Actually true	Type I error (false positive)	○

Type III error

気象庁 Japan Meteorological Agency

- Type III error (Another definitions also exist)
  - Choosing the test falsely to suit the significance of the sample.
- The assumptions underlying a *t*-test are:
  - <u>Normality</u> (Samples from Normal Distribution)
  - Independent samples (No autocorrelation. Past values does not affect future one)
  - Homogeneity of variance (from past to future)
- In general, precipitation data does not have normality.
  - If you choose t-test for precipitation, type III error occurs.
  - You have to choose one of the nonparametric statistics, which does not require the assumptions of normality.
    - E.g., Kendall rank correlation coefficient

Kendall rank correlation coefficient

- Kendall rank correlation coefficient measure the <u>ordinal association</u> between two measured quantities.

(Example)

x	2001	2002	2003	2004	2005
y	1300	1350	1200	1250	1400

2001 -> 2003
2001 -> 2004
2002 -> 2003
2002 -> 2004

(number of concordant pairs) = P = 6   (number of discordant pairs) = Q = 4

(number ways to choose) = ${}_nC_2 = \frac{n(n-1)}{2}$ The binomial coefficient

The Kendall τ coefficient is defined as: $\tau = \frac{P-Q}{\frac{n(n-1)}{2}} = \frac{6-4}{10} = 0.2$

When there are ties, the formula becomes more complicated! I recommend you use R software.

With the independence and <u>larger samples</u> of X and Y, it is common to use an approximation to the normal distribution, with mean zero and variance $\frac{2(2n+5)}{9n(n-1)}$

Therefore, we can conduct statistical test with a standard normal distribution with the modified τ.

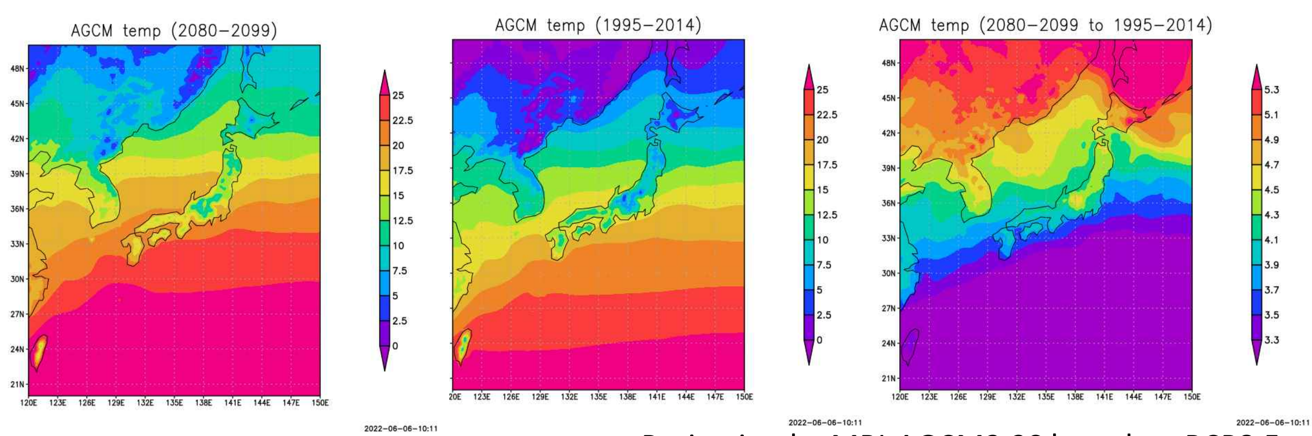
$$\frac{\tau}{\sqrt{\frac{2(2n+5)}{9n(n-1)}}} \sim 0.49$$

To be precise, this value is incorrect because of its small sample size. You can calculate the exact value by using R software.

Description of future change

- In general, future changes of climate are described as the difference of <u>climate model</u> outputs between present and future.
  - In this training seminar, we use MRI-AGCM3.2 as the model.

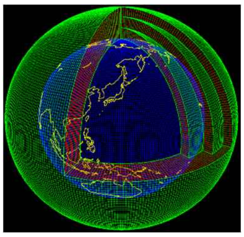
Future (Climate model) − Present (Climate model) = Future change (F–P)



Projection by MRI-AGCM3.2S based on RCP8.5

About MRI-AGCM projection data

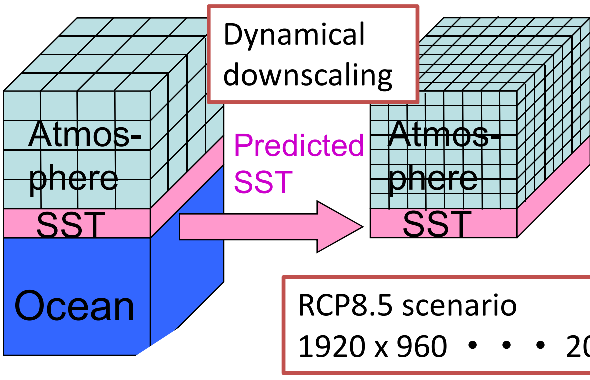
■ MRI-AGCM3.2S, the model joining in the CMIP6 (HighResMIP).



MRI-AGCM projection Data

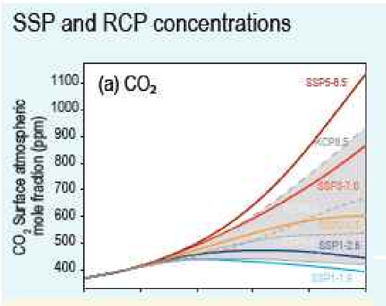
Atmosphere-Ocean Couple Model RCP8.5 Scenario	⇨	High resolution Atmosphere model experiment

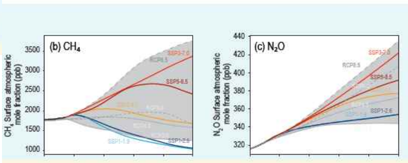
WCRP
CMIP5



20 km grid

RCP8.5 scenario
1920 x 960 ・・・ 20km mesh !!





AR6 WG1 Cross-Chapter Box 1.4, Figure 2

How to obtain MRI-AGCM projection data

■ Data can be obtained from the WCRP website.

https://esgf-data.dkrz.de/search/cmip6-dkrz/

File Name	Content
tas_Amon_MRI-AGCM3-2-S_highresSST-future_r1i1p1f1_gn_207101-209012.nc tas_Amon_MRI-AGCM3-2-S_highresSST-future_r1i1p1f1_gn_209101-209912.nc	AGCM temperature (monthly, future) [K]
tas_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_199001-200912.nc tas_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_201001-201412.nc	AGCM temperature (monthly, present) [K]

File Name	Content
pr_Amon_MRI-AGCM3-2-S_highresSST-future_r1i1p1f1_gn_207101-209012.nc pr_Amon_MRI-AGCM3-2-S_highresSST-future_r1i1p1f1_gn_209101-209912.nc	AGCM precipitation (monthly, future) [kg m-2 s-1]
pr_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_199001-200912.nc pr_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_201001-201412.nc	AGCM precipitation (monthly, present) [kg m-2 s-1]

How to obtain MRI-AGCM projection data

- By using GrADS or OpenGrADS, time series of output values can be obtained easily.
  - However, the operation of GrADS or OpenGrADS is beyond the scope of this training seminar.
  - In this training seminar, simplified csv data prepared by lecturer will be provided for time saving.

Grid Analysis and Display System (GrADS)

OpenGrADS "Opening GrADS to a World of Extensions"

http://cola.gmu.edu/grads/
http://opengrads.org/

```
ga-> sdfopen temp/tas_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_199001-200912.nc
ga-> set lon 139.75
ga-> set lat 35.69
ga-> set gxout print
ga-> set prnopts %7.3f 1 1
ga-> set time jan1995 dec2009
ga-> d tas
```

Open a file

Longitude and Latitude Setting

Print format

Set time range and Draw

```
ga-> sdfopen temp/pr_Amon_MRI-AGCM3-2-S_highresSST-present_r1i1p1f1_gn_199001-200912.nc
ga-> set lon 139.75
ga-> set lat 35.69
ga-> set gxout print
ga-> set prnopts %10.3e 1 1
ga-> set time jan1995 dec2009
ga-> d pr
```

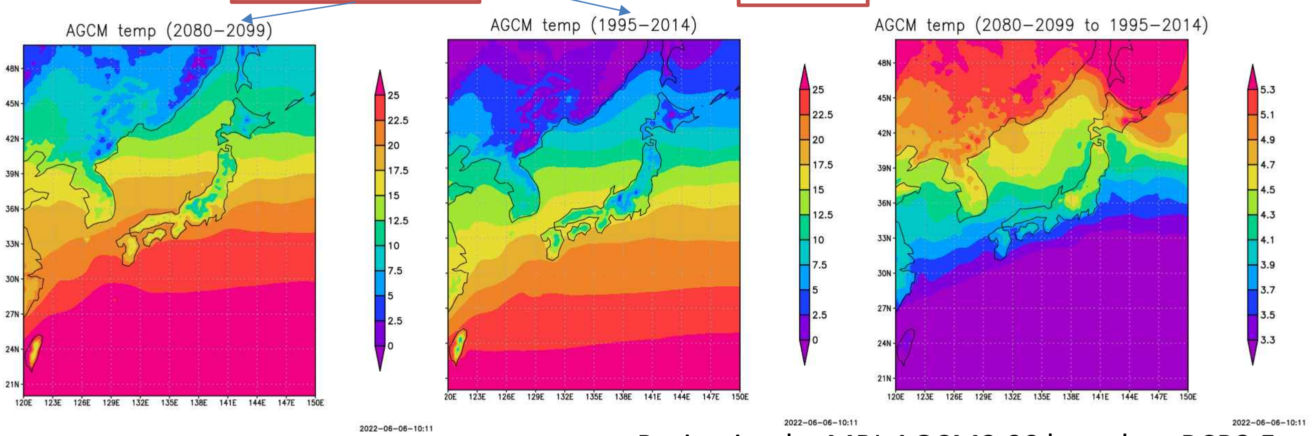

Concerns when describing the future change

- In general, future changes of climate are described as the difference of climate model outputs between present and future.
  - There are several points to be included into consideration.

Future (Climate model) − Present (Climate model) = Future change (F–P)

Mean climate state?

Realistic?



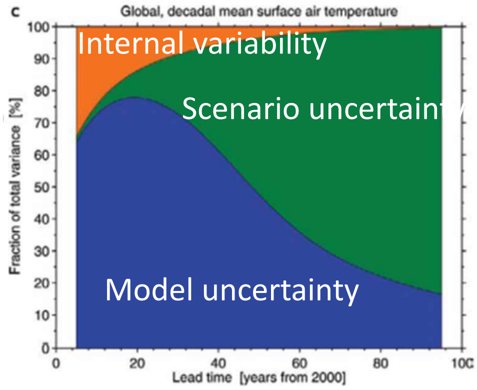
Projection by MRI-AGCM3.2S based on RCP8.5

Reliable?

Uncertainties in global warming projection

Japan Meteorological Agency

- Global warming projection contains many uncertainties. Therefore, we cannot say the results are correct projections without considering the uncertainties.
- Types of uncertainty
  - Natural climate variability
  - Regional scale
  - Incompleteness of climate model
  - Short period for calculation

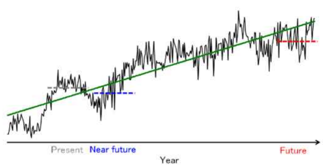


(Hawkins and Sutton 2009)

Remarks on interpretation of key uncertainties

Japan Meteorological Agency

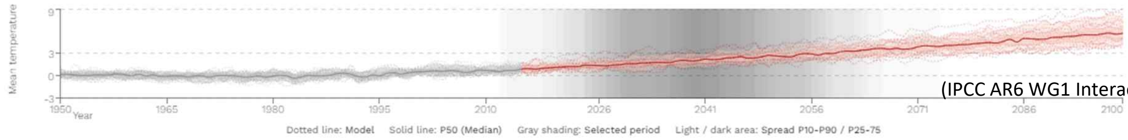
- The aim is to project climate change signals rather than natural climate variability.
  - Even state-of-the-art climate models cannot predict natural variability.
  - The 20-year average of results from the climate model are used for global warming projection.
- Uncertainties in regional-scale climate projections are greater than those in global-scale climate projections.
  - It is necessary to examine whether projected regional-scale climate change is consistent with broader-scale climate change.
- Uncertainties in near-future climate projections are larger than those in future climate projections.
  - As the level of greenhouse gas concentration in near-future projections is expected to be lower than that in future projections, less pronounced climate change signals may be dominated by natural variability.



http://ds.data.jma.go.jp/tcc/tcc/products/gwp/gwp8/html/section1_3.html

Remarks on interpretation of key uncertainties

- Uncertainties exist even in long-term trends.
  - Future climate projection uncertainties can be estimated via multi-model or multi-parameter experiments.
- The ability of models to project future climate conditions is limited.
  - Large-scale patterns averaged over a broader area provide a more meaningful picture than changes on a single-grid scale.
- Uncertainties in future projections depend on the variables used.
  - Detecting climatological trends for precipitation is more difficult than that for temperature because extreme rainfall events are rare by definition and occur on relatively limited spatial and temporal scales.
- Future projections depend on the greenhouse gas emissions scenario used.



(IPCC AR6 WG1 Interactive Atlas)

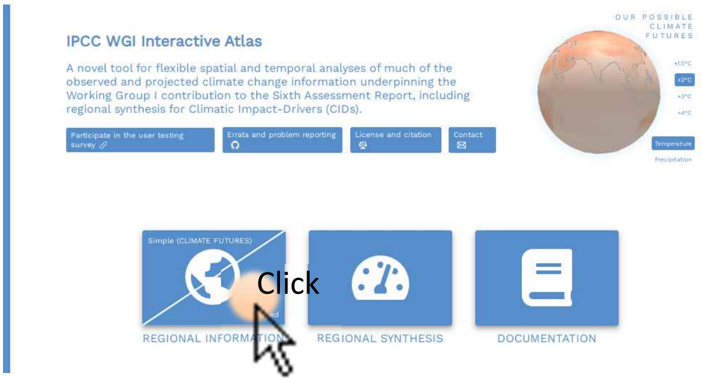
http://ds.data.jma.go.jp/tcc/tcc/products/gwp/gwp8/html/section1_3.html

Tackle the uncertainty (example)

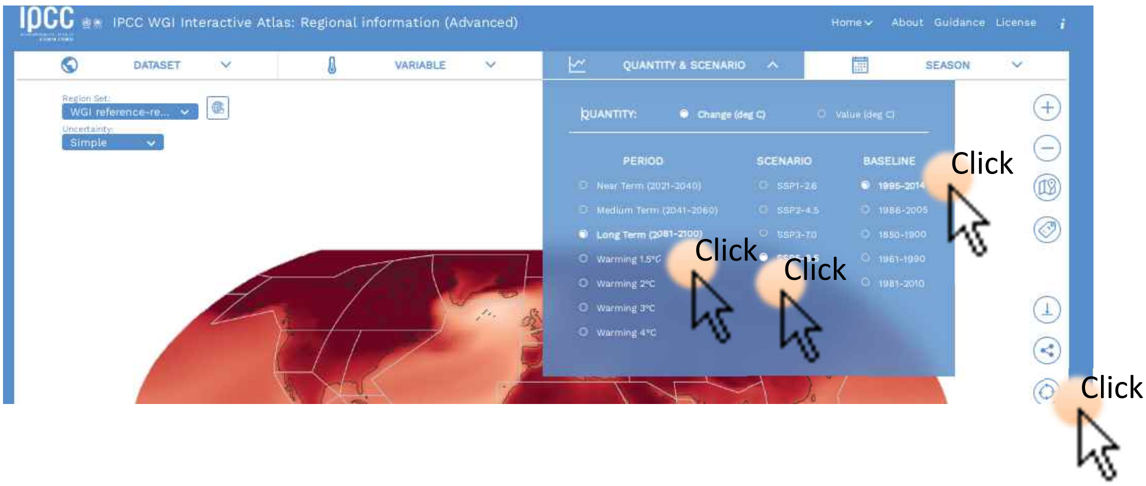
- Natural climate variability
  - Choose longer mean period than natural variability
    - In this training seminar, we choose 20-years mean
- Regional scale
  - Check the regional response as a part of the wider area
    - In this training seminar, we check the wider response by IPCC reports.
- Incompleteness of climate model (Model bias)
  - Check the reproducibility of the model
    - Take some bias correction method to correct the response
      - In this training seminar, we take a simple bias correction method.
- Short period for calculation
  - See the long-term climate change in the model
    - In this training seminar, we see the response at the end of 21st century.

Further explanation is in the following slide.

Comparing the regional response with the wider response: How to get the value from IPCC WG1 Interactive Atlas



- Go to the website
  - https://interactive-atlas.ipcc.ch/
- Click “Advanced”
- Hover over “Quantity & Scenario”
- Click “Long Term (2081-2100)”
- Click “SSP8-8.5”
- Click “1995-2014”
- Click “Point Information”
- Click the point in your country/region



Checking reproducibility and correcting bias

気象庁 Japan Meteorological Agency

- Bias (systematic errors) in climate models is defined as certain tendency for errors in climate models.
  - E.g., the model tends to project warmer than observation (positive bias).
- The reproducibility can be judged by calculating the bias. Bias can be defined here as Simulation minus Observation.
  - Simulation is the forecast which is conducted by climate models.
  - Observation is the values which the model tries to reproduce.
- Simulation and Observation cannot be exactly the same result. Every model has its own bias.
  - Arising from simplified physics, parameterizations, rack of resolution and so on.
- Bias correction is the way to overcome the problem, which adjusts present simulation to observation. For example, a simple way (Delta method) is:
  - (Temp.) $\mathrm{Future}_{\mathrm{Bias\ corrected}} = \mathrm{Observation} + \mathrm{Future} - \mathrm{Present}$
  - (Precip.) $\mathrm{Future}_{\mathrm{Bias\ corrected}} = \mathrm{Observation} * \left(\frac{\mathrm{Future}}{\mathrm{Present}}\right)$