TCC Training Seminar on Global Warming Projection Information

26 – 30 January 2015

Tokyo, Japan

Tokyo Climate Center

Japan Meteorological Agency

TCC Training Seminar on Global Warming Projection Information

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Contents

Schedule

TCC Training Seminar on Global Warming Projection Information

Tokyo, Japan, 26 -30 January 2015

Draft Schedule

Day 1 - Monday, 26 January		
10:00-10:30	1. Opening - Welcome Address - Self-introduction by participants - Group photo shooting - Courtesy call on JMA's Director-General	
10:30-10:45	Coffee Break	
10:45-11:00	2. Introduction	
11:00-12:45	3. Lecture: Necessity of Global Warming Projection Information	
12:45-14:15	Lunch	
14:15-16:00	4. Lecture: Introduction to IPCC AR5	
16:00-16:15	Coffee Break	
16:15-18:15	5. Lecture: Introduction to Global Warming Projection	
18:30-20:00	Reception	at KKR Hotel Tokyo
Day 2 - Tuesday, 27 January		
9:30-10:00	6. Lecture: Introduction to JRA-55	
10:00-12:30	7. Lecture and exercise: Introduction to GrADS	
Around 11:00	Coffee Break	
12:30-14:00	Lunch	
14:00-14:45	8. Lecture: How to make global warming projection for your country	
14:45-15:45	9. Lecture and exercise: Check of reproducibility	
15:45-16:00	Coffee Break	
16:00-17:00	10. Lecture and exercise: Assessment of future climate change	
17:00-18:00	11. Lecture and exercise: Uncertainty check of the results	
Day 3 - Wednesday, 28 January		
9:30-12:30	12. Exercise: Global warming projection for your country	
Around 11:00	Coffee Break	
12:30-14:00	Lunch	
14:00-18:00	12. Exercise: Global warming projection for your country (cont.)	
Around 16:00	Coffee Break	
Day 4 - Thursday, 29 January		
9:30-11:30	12. Exercise: Global warming projection for your country (cont.)	
Around 10:30	Coffee Break	
11:30-12:30	Lunch	
13:00-16:00	13. Symposium: "Science on Climate Change and our Future"	at Hitotsubashi Hall
16:30-18:15	12. Exercise: Global warming projection for your country (cont.)	
Day 5 - Friday, 30 January		
9:30-12:45	14. Presentation by participants	Presentation (12 min.) followed by Q&A (3 min.)
Around 11:00	Coffee Break	
12:45-13:00	15. Wrap up and Closing	
13:00-14:00	Lunch	
14:00-18:30	Technical Tour	

List of Participants

Provisional List of participants

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Mr Yasushi Takatsuki
Mr Kazuyoshi Yoshimatsu
Mr Shuhei Maeda
Mr Norihisa Fujikawa
Mr Akihiko Shimpo
Mr Shotaro Tanaka
Mr Yoshinori Oikawa
Ms Ayako Takeuchi
Mr Kengo Miyaoka

Ms Teruko Manabe
Mr Atsushi Goto
Mr Yasushi Mochizuki

Necessity of Global Warming Projection Information

TCC Training Seminar on Global Warming Projection Information
11:00 – 12:45 on 26 January 2015

Necessity of Global Warming Projection Information

Koji Ishihara
Hirokazu Murai
Nubuyuki Kayaba
Souichirou Yasui
Shunya Wakamatsu
And some other staffs will help you!

Schedule of this seminar

1st Day (26 January)
- Lectures on global warming, IPCC AR5 and experimental design of GWP
- Reception

2nd Day (27 January)
- Lectures on JRA55 and outline of our work
- Lectures and exercises : check of reproducibility, assessment of future climate change and uncertainty check of the results

3rd Day – 4th Day (28 - 29 January)
- Exercise of global warming projection for your country

4th Day (29 January)
- 13:00- 16:00 Symposium (Science of climate change and our future)

5th Day (30 January)
- Your presentation (15 minutes per person)
- Technical tour

History of the Earth

Earth's formation
(4.6 billion years
before present)

January 1st 00:00

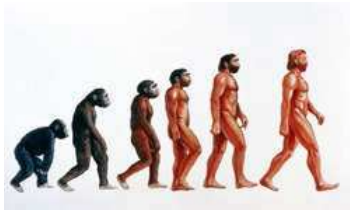
Beginning of life
(4 billion years
before present)

Date & Time?

Disappearance of the dinosaurs
(65 million years before present)

Date & Time?

Dawn of humanity
(5 million years before present)



Date & Time?

Foundation of Japan
(2,000 years before present)

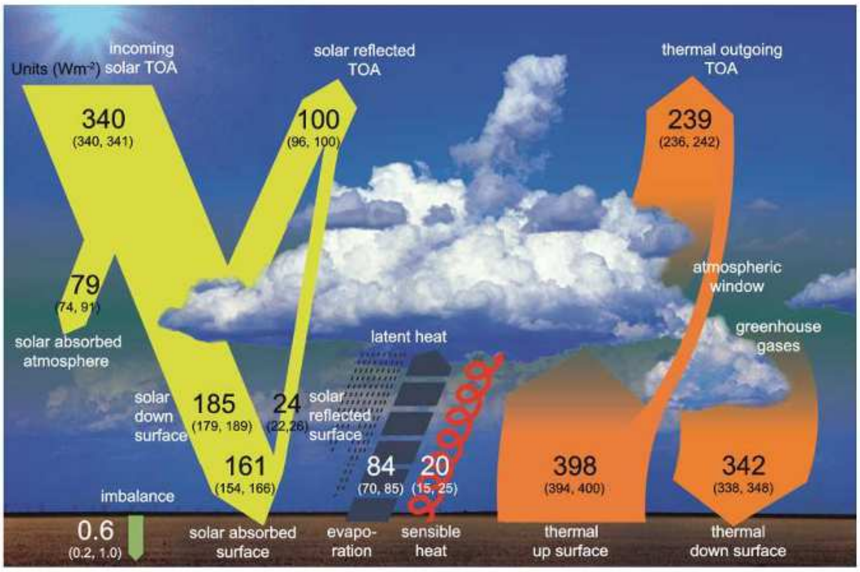
Date & Time?

Present

December 31st 24:00

3

Energy Budget & Global Warming



Natural greenhouse gases such as carbon dioxide, methane and nitrous oxide have an important role to play in balancing the earth's temperature by trapping, absorbing and re-radiate the Sun's warmth, and maintaining the Earth's surface temperature at a level necessary to support life.
Increasing concentrations of greenhouse gases due to human activities like burning of fossil fuels 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.

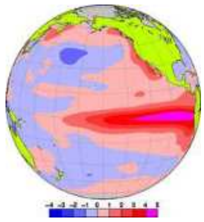
IPCC Fifth Assessment Report

4

Factors of Climate Change

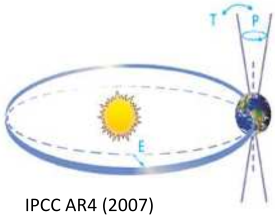
Natural Internal Variability

- El nino phenomena



Natural External Factor

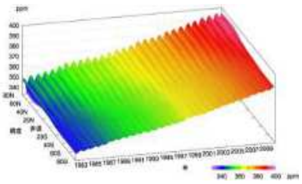
- Eruption of volcano
- Fluctuations of Sun's activity



IPCC AR4 (2007)

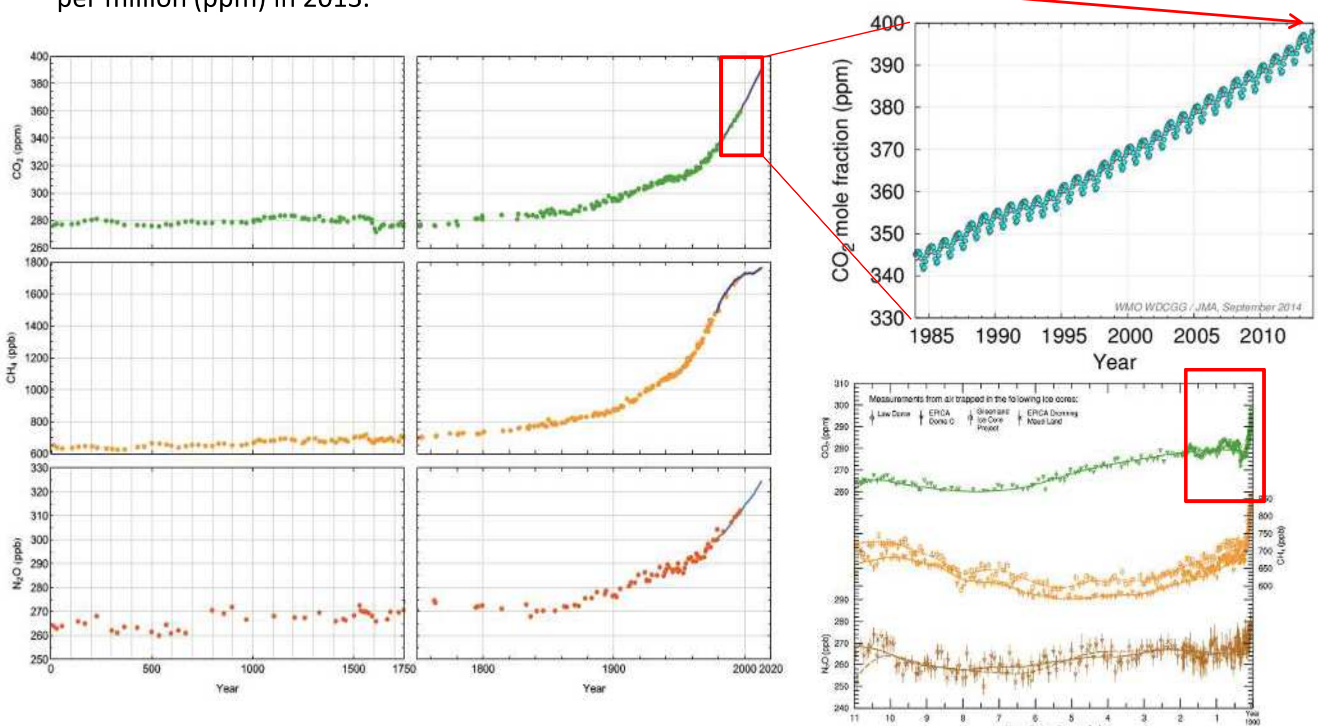
Anthropogenic Factor

- Change of land use
- Emission of greenhouse gases



Long-term change of CO2 concentration

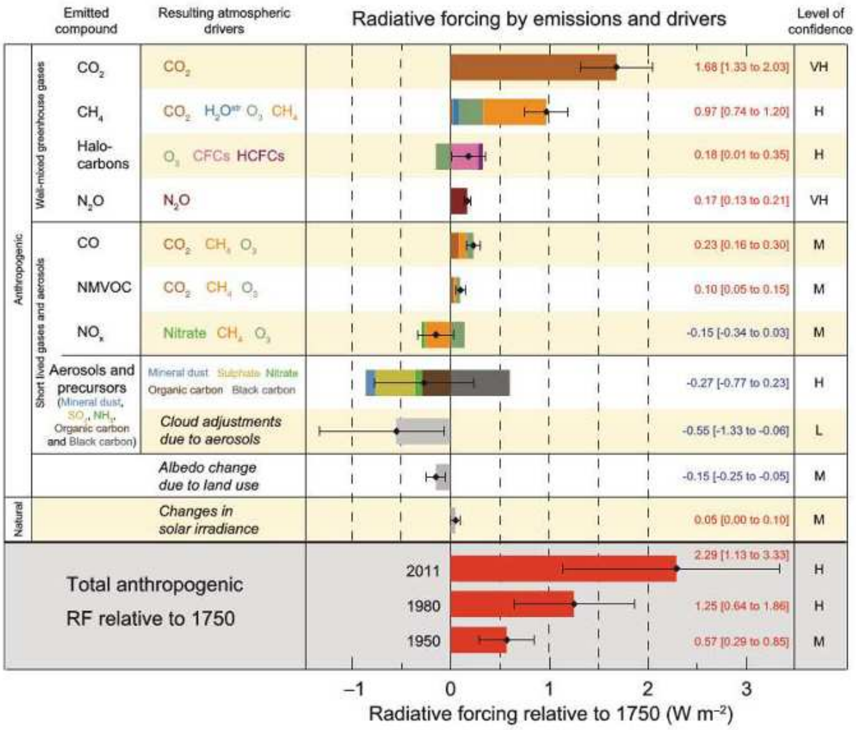
the amount of CO2 in the atmosphere reached 396.0 parts per million (ppm) in 2013.



https://www.wmo.int/pages/mediacentre/press_releases/pr_1002_en.html

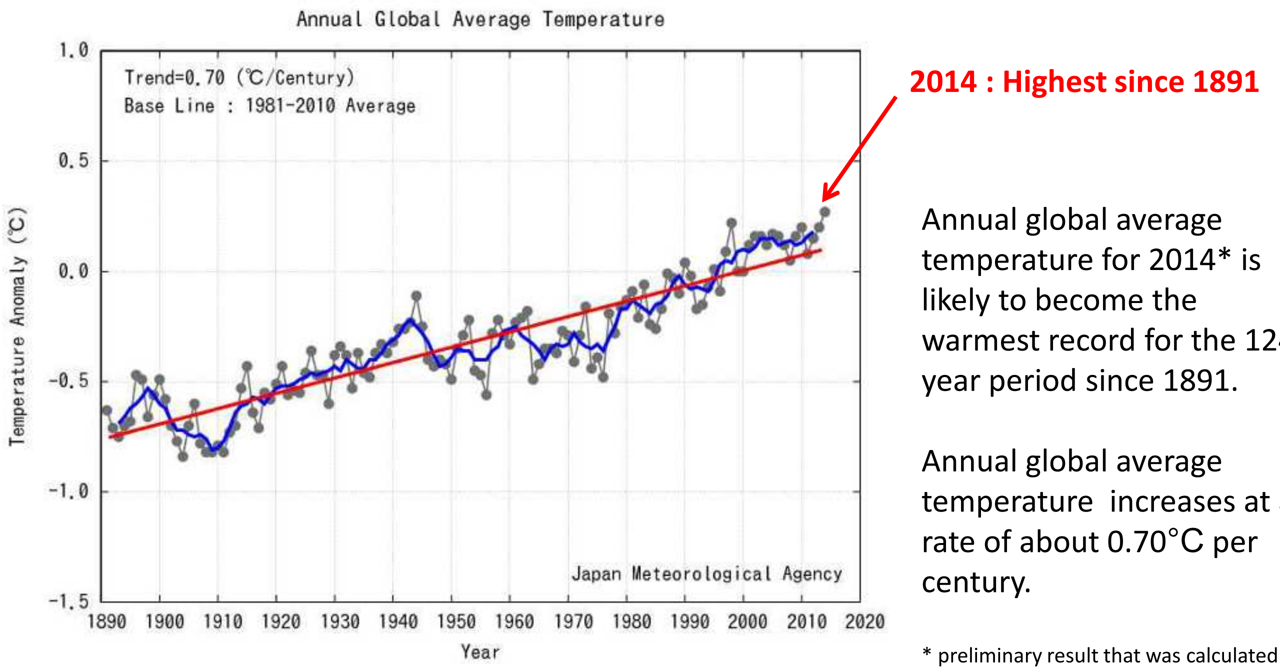
IPCC Fifth Assessment Report

Radiative Forcing



RF is the change in energy flux caused by a driver, and is calculated at the tropopause or at the top of the atmosphere. This change reflects the scientific progress from previous assessments and results in a better indication of the eventual temperature response for these drivers.

Long-term change of global temperature



Anomalies are deviation from baseline (1981-2010 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.

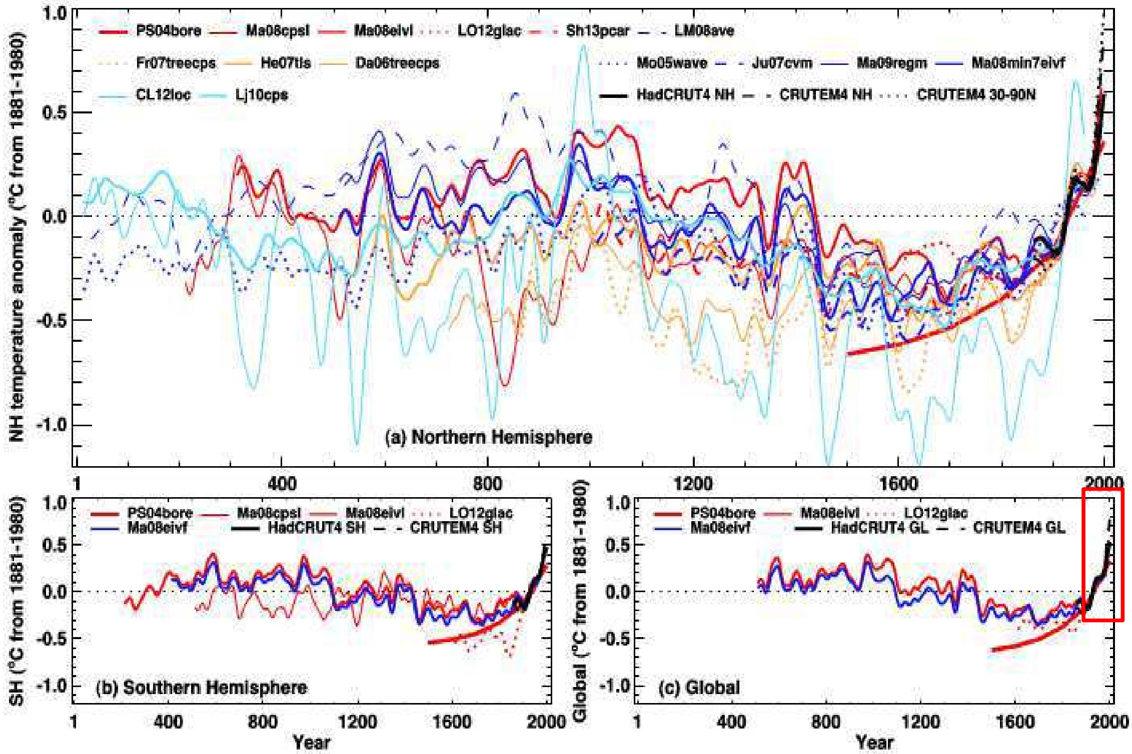
Annual global average temperature for 2014* is likely to become the warmest record for the 124-year period since 1891.

Annual global average temperature increases at a rate of about 0.70°C per century.

* preliminary result that was calculated based on temperature observations for the period of January to November in 2014.

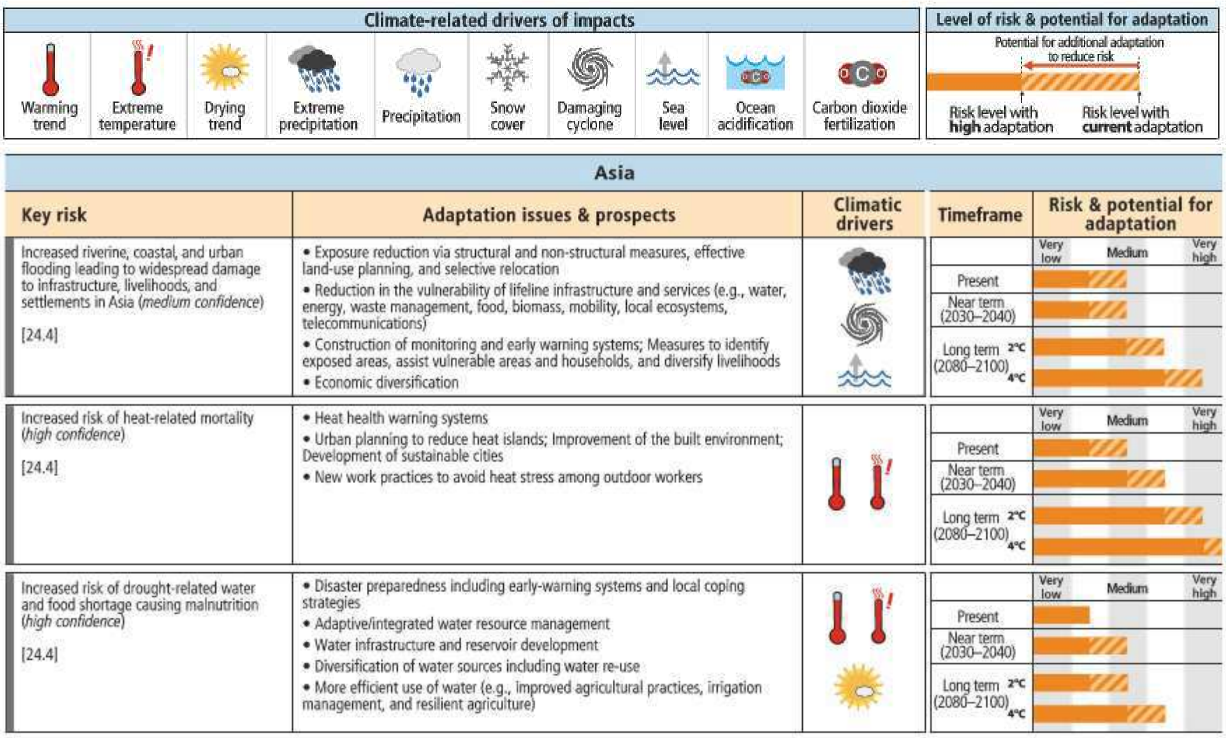
http://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/ann_wld.html

Long-term change of global temperature



IPCC Fifth Assessment Report (Fig. 5.7)

Key Regional Risks in Asia

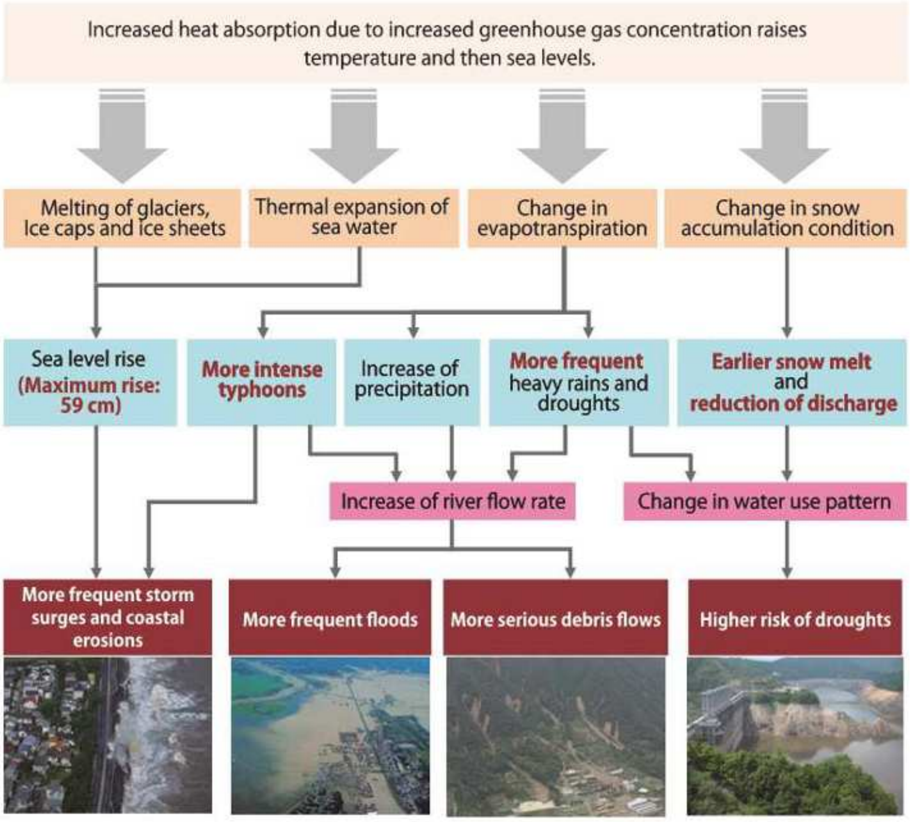


Asia

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; Measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high
Increased risk of heat-related mortality (*high confidence*) [24.4]	• Heat health warning systems • Urban planning to reduce heat islands; Improvement of the built environment; Development of sustainable cities • New work practices to avoid heat stress among outdoor workers		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high
Increased risk of drought-related water and food shortage causing malnutrition (*high confidence*) [24.4]	• Disaster preparedness including early-warning systems and local coping strategies • Adaptive/integrated water resource management • Water infrastructure and reservoir development • Diversification of water sources including water re-use • More efficient use of water (e.g., improved agricultural practices, irrigation management, and resilient agriculture)		Present Near term (2030–2040) Long term (2080–2100) 2°C / 4°C	Very low / Medium / Very high

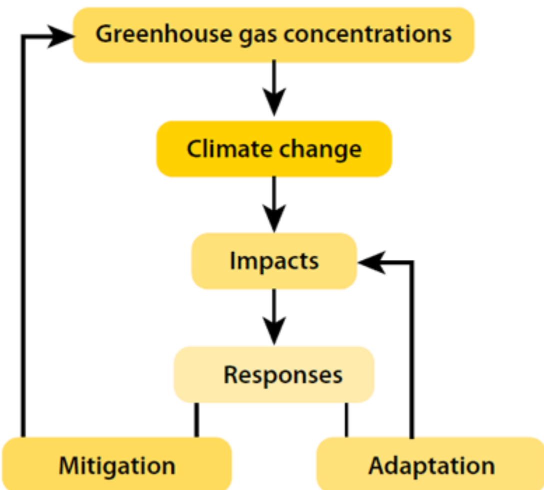
5

Global warming threats the water sector



Ministry of Land, Infrastructure, Transport and Tourism, Japan.
Practical Guidelines on. Strategic Climate Change. Adaptation Planning. -*Flood Disasters*-

Adaptation and Mitigation



A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

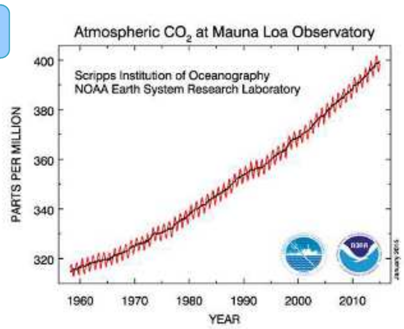
Actions and strategies intended to minimize the effects that global warming will have on humans and nature.

History of Global Warming

1824 Joseph Fourier indicated the existence of greenhouse effect.

1859 John Tyndall verified the existence of greenhouse effect.

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



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) ⇒ **Next lecture**

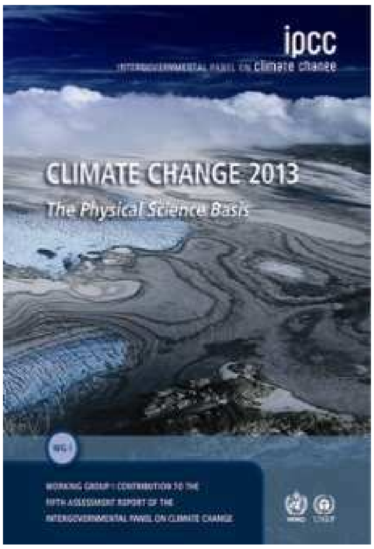
Scientific intergovernmental body under the auspices of the United Nations, and established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). IPCC reports cover "the scientific, technical and socio-economic information relevant to understanding 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)“.

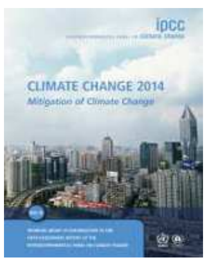
IPCC Fifth Assessment Report (AR5)

Working Group I Report (the first part of AR5)



The Summary for Policymakers (SPM) of the IPCC WGI AR5 was approved at the Twelfth Session of IPCC Working Group I meeting in Stockholm, Sweden, 23 to 26 September 2013 and was released on 27 September.

SPM of Working Group II Report (on 31 March 2014)
SPM of Working Group III Report (on 13 April 2014)
SPM of Synthesis Report (on 2 November 2014)



http://www.ipcc.ch/news_and_events/docs/ar5/press_release_ar5_wgi_en.pdf

38th Session of IPCC at Yokohama on 25-29 March 2014


Pacifico Yokohama

Opening Ceremony


Discussion

Closing Ceremony (30 March!!)

Major Discussions in International Negotiation

COP (Conference of the Parties) is annually held in the framework of the UNFCCC.

Kyoto Protocol (COP3, 1997)

KP applies to only developed countries.

2008

KP First commitment period

2012

2013

KP second commitment period

2020

Cancun Agreements (COP16, 2010)

This agreement calls on
Developed countries to reduce their emissions,
Developing countries to plan to reduce their emissions.

independent efforts!

2013

2020

8

Durban Platform (COP17, 2011)

New and universal greenhouse gas reduction protocol, legal instrument or other outcome with legal force by 2015 for the period beyond 2020

COP21, 2015

2020

My Pictures

Additional meetings in Bonn, German

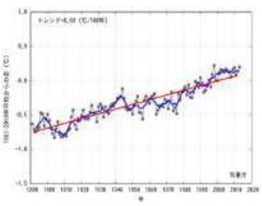
COP18 (26 November- 6 December 2012 in Doha, Qatar)

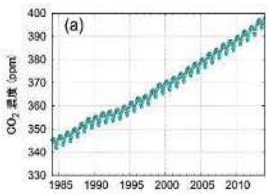
Additional meetings in Bangkok, Thailand

COP19 (11-22 November 2013 in Warsaw, Poland)

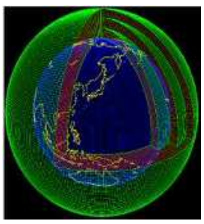
Role of JMA

Observation and Monitoring





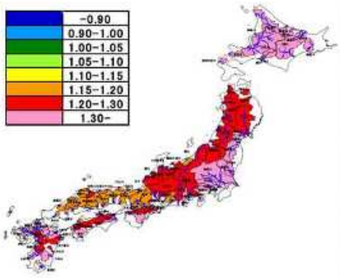
Projection and analysis



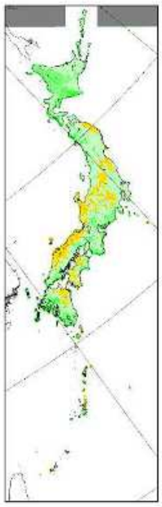
Provision of data and information
Training

Role of Global Warming Projection Information

For Adaptations



Detailed estimation for impacts on each sector is important.



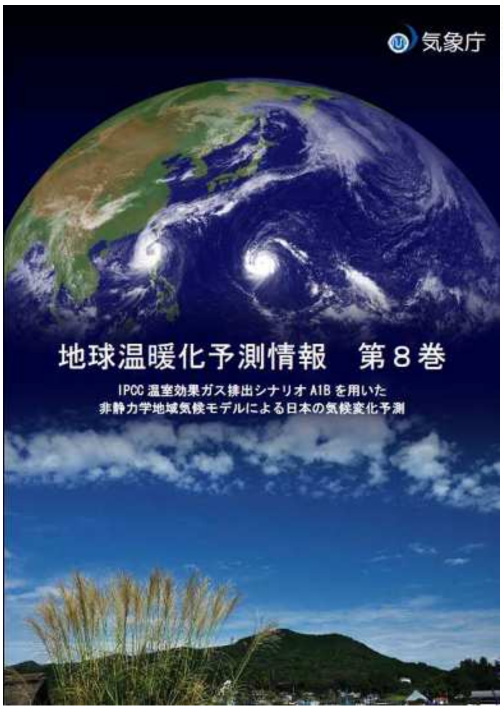
Detailed climate change projection is needed as the most basic information.

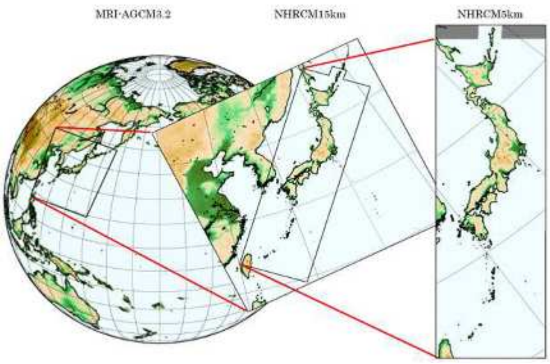
For Mitigation

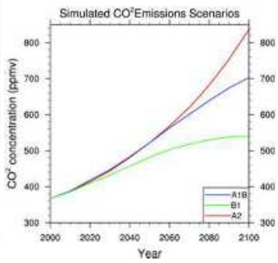
To know the future climate change over our country is a good opportunity for taking actions to tackle measures against global warming.

JMA's latest Global Warming Projection

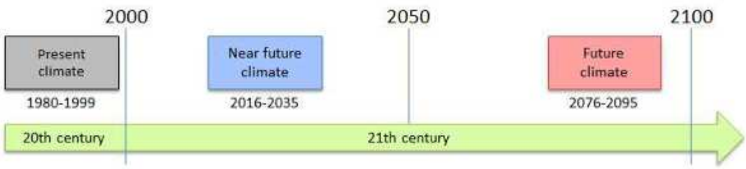
Global Warming Projection volume 8 (JMA, 2013)

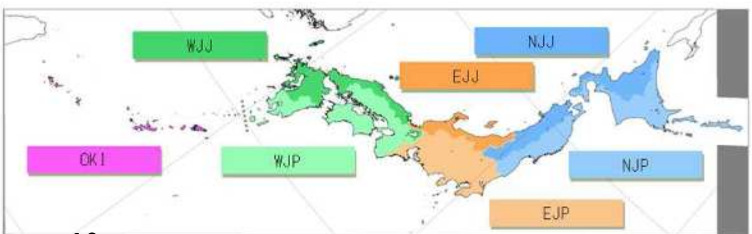






Greenhouse gas emission scenario : SRES A1B

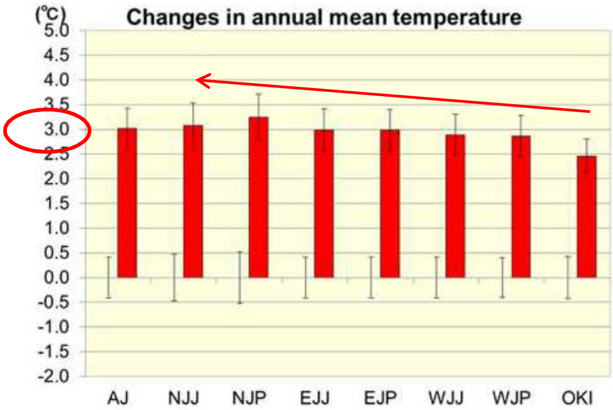


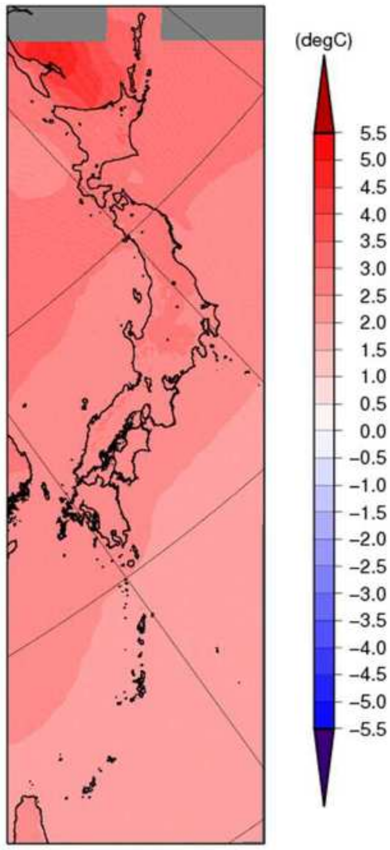


http://ds.data.jma.go.jp/tcc/tcc/products/gwp/gwp8/index.html

Future change in annual mean temperature

The annual mean temperature is projected to increase by about 3°C in all regions.
In particular, the northern part of Japan is expected to see the most significant rise (more than 3°C).

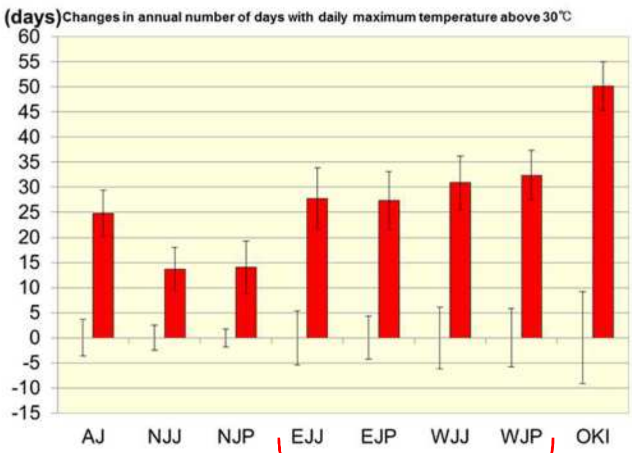


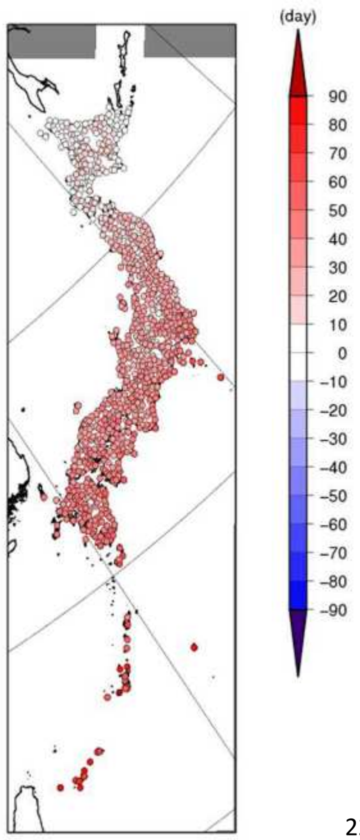


Red bar : future change
Black bar : standard deviation of interannual variability

GWP8 (JMA, 2013)

Future change in the annual number of days with daily maximum temperatures above 30°C



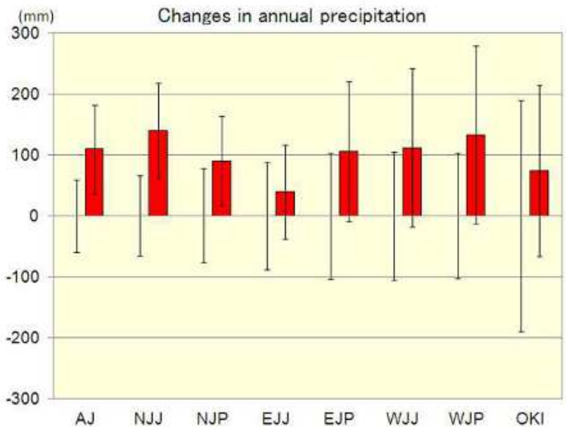


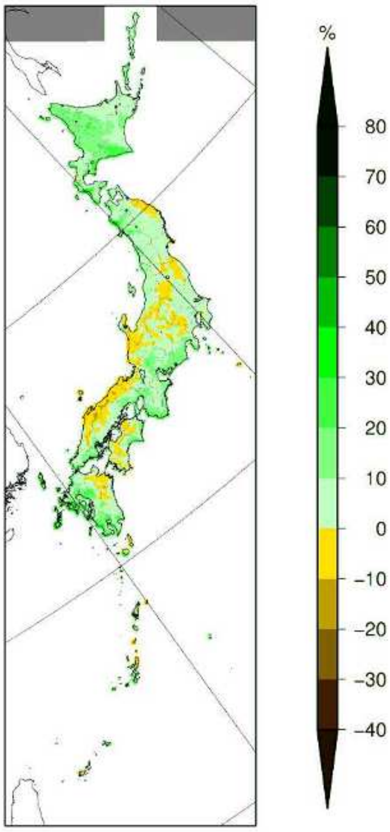
Red bar : future change
Black bar : standard deviation of interannual variability

GWP8 (JMA, 2013)

Future change in annual precipitation

Annual precipitation averaged is projected to increase slightly.
This tendency is not significant, compared to temperature.



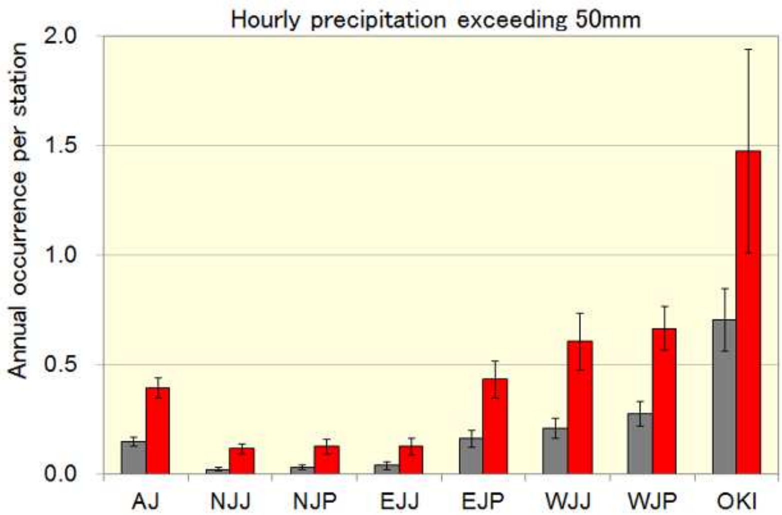


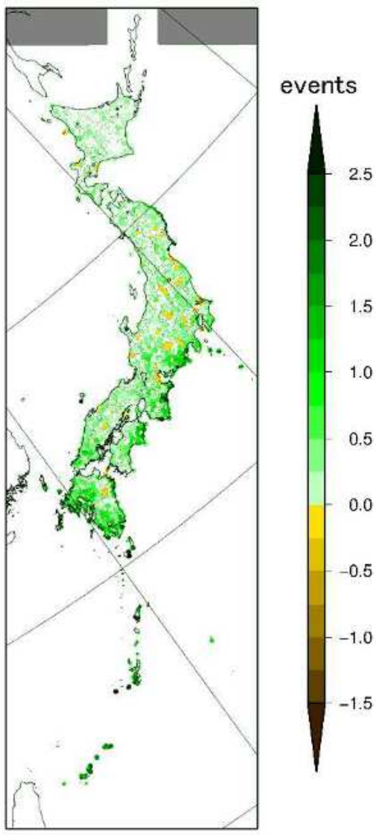
Red bar : future change
Black bar : standard deviation of interannual variability

GWP8 (JMA, 2013)

Future change in annual frequency of hourly precipitation exceeding 50 mm

The frequency of intense precipitation is projected to increase in most regions.



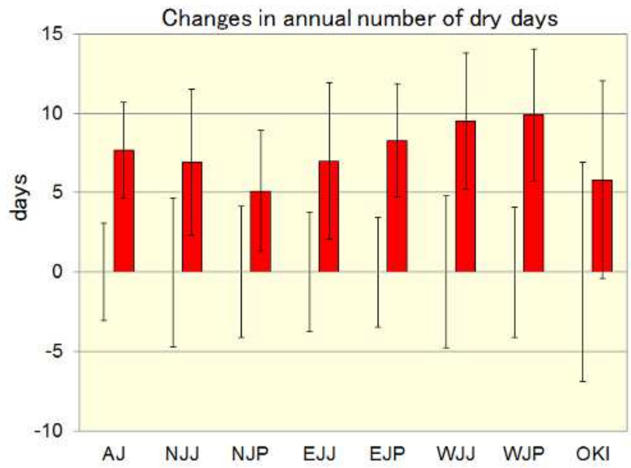


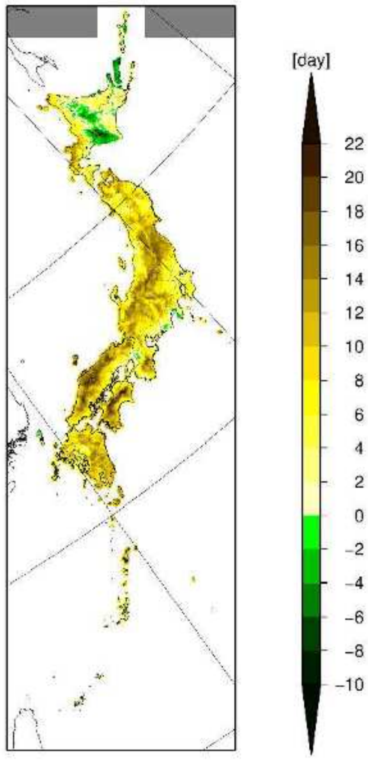
Grey bar : present climate
Red bar : future climate
Black bar : standard deviation of interannual variability

GWP8 (JMA, 2013)

Future change of annual number of dry days with daily precipitation of less than 1mm

The number of dry days with daily precipitation of less than 1 mm is also expected to rise.

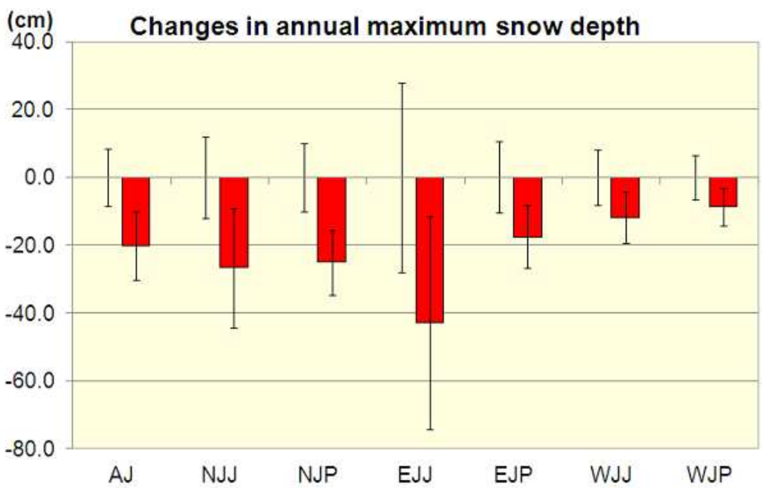


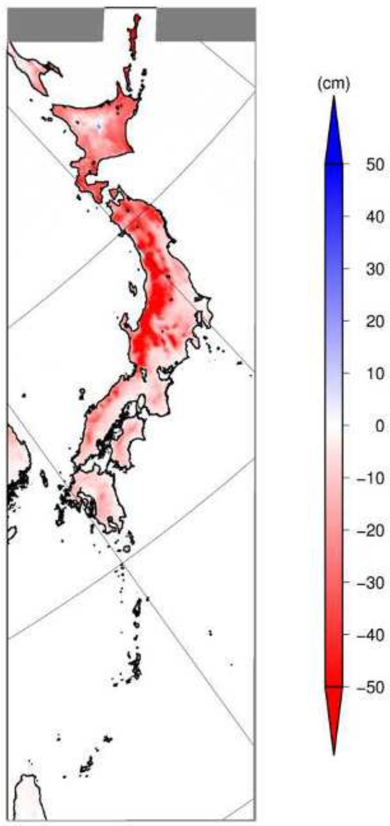


Red bar : future change
Black bar : standard deviation of interannual variability

Future Change in annual maximum snow depth

The annual maximum snow depth is projected to decrease in most regions, although it may increase in colder areas such as inland Hokkaido.



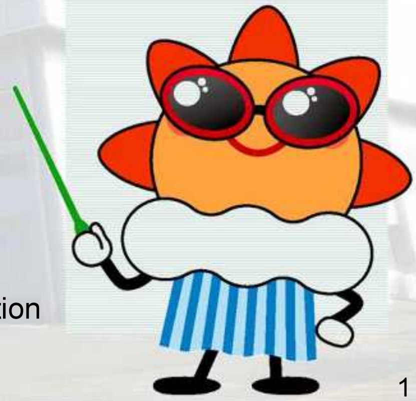


Red bar : future change
Black bar : standard deviation of interannual variability

Introduction to IPCC AR5

4. Lecture:
Introduction to IPCC AR5

Hirokazu Murai
Climate Prediction Division
Japan Meteorological Agency



TCC Training Seminar on , Global Warming Projection Information

26 January 2015 (Tokyo, Japan)

1

This Lecture’s Schedule

<u>14:15 – 16:00</u>

1. About IPCC and its reports
2. What is written in the IPCC AR5
3. Let’s explore IPCC AR5

2

What's IPCC

Intergovernmental Panel on Climate Change

Establishment :

WMO ✖ UNEP 1988 ➡ INTERGOVERNMENTAL PANEL ON climate change

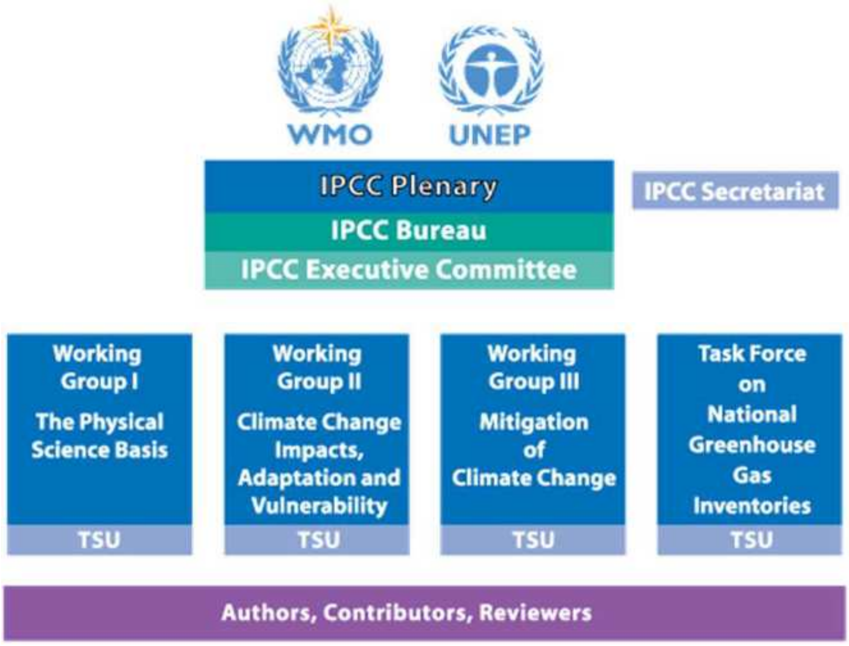
Purpose : To provide Scientific view in…

- Climate change
- Environmental and socio-economic impacts

History of IPCC

- First Assessment Report (FAR, 1990)
- Second Assessment Report (SAR, 1995)
- Third Assessment Report (TAR, 2001)
- Fourth Assessment Report (AR4, 2007)
- Fifth Assessment Report (AR5, 2013-2014)

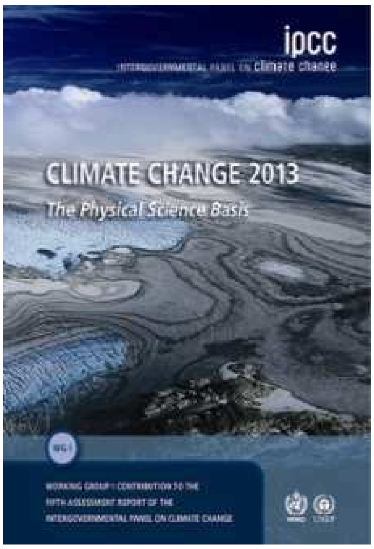
Working Group of IPCC



http://www.ipcc.ch/organization/organization_structure.shtml

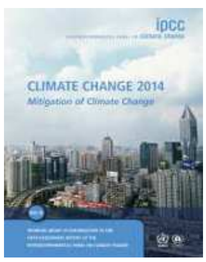
IPCC Fifth Assessment Report (AR5)

Working Group I Report (the first part of AR5)



The Summary for Policymakers (SPM) of the IPCC WGI AR5 was approved at the Twelfth Session of IPCC Working Group I meeting in Stockholm, Sweden, 23 to 26 September 2013 and was released on 27 September.

SPM of Working Group II Report (on 31 March 2014)
SPM of Working Group III Report (on 13 April 2014)
SPM of Synthesis Report (on 2 November 2014)



http://www.ipcc.ch/news_and_events/docs/ar5/press_release_ar5_wgi_en.pdf

Configuration of WG1 report

Summary for Policymakers (SPM)

Chapters (1-14)
- Executive Summary
- Body
- FAQ

Technical Summary (TS)

Annexes

Chapters	
1	Introduction
2	Observations : Atmosphere and Surface
3	Observations : Ocean
4	Observations : Cryosphere
5	Information from Paleoclimate Archives
6	Carbon and Other Biogeochemical Cycles
7	Clouds and Aerosols
8	Anthropogenic and Natural Radiative Forcing
9	Evaluation of Climate Models
10	Detection and Attribution of Climate Change : from Global to Regional
11	Near-term Climate Change : Projections and Predictability
12	Long-term Climate Change : Projections, Commitments and Irreversibility
13	Sea Level Change
14	Climate Phenomena and their Relevance for Future Regional Climate Change

7

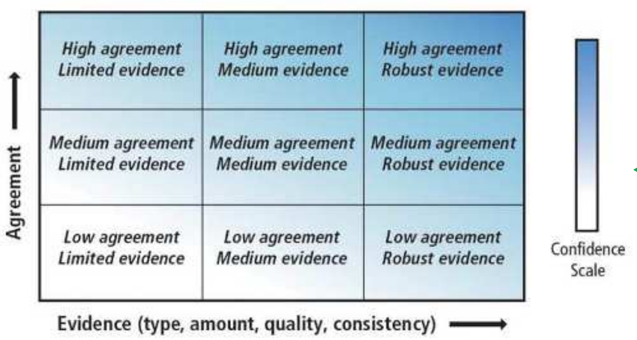
Likelihood and Confidence

- This report is using a consistent expression of likelihood and confidence

Likelihood

Term	Likelihood of the outcome
Virtually certain	99-100% probability
Extremely likely	95-100% probability
Very likely	90-100% probability
Likely	66-100% probability
More likely than not	50-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Extremely unlikely	0-5% probability
Exceptionally unlikely	0-1% probability

Confidence



Very high
High
Medium
Low
Very low

This Lecture's Schedule

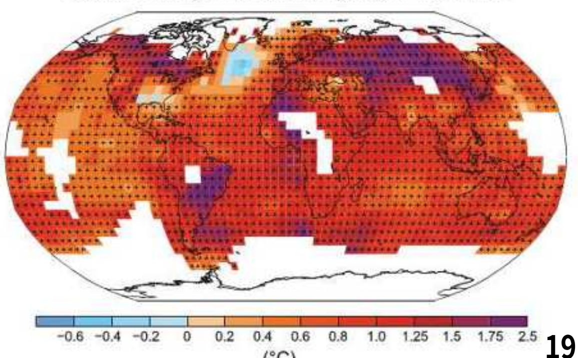
<u>14:15 – 16:00</u>

1. About IPCC and its reports
2. What is written in the IPCC AR5 ?
3. Let's explore IPCC AR5

Observed Climate Change (1)

- Warming of the climate system is unequivocal.
- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.
- For the longest period when calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming.

Observed change in surface temperature 1901–2012



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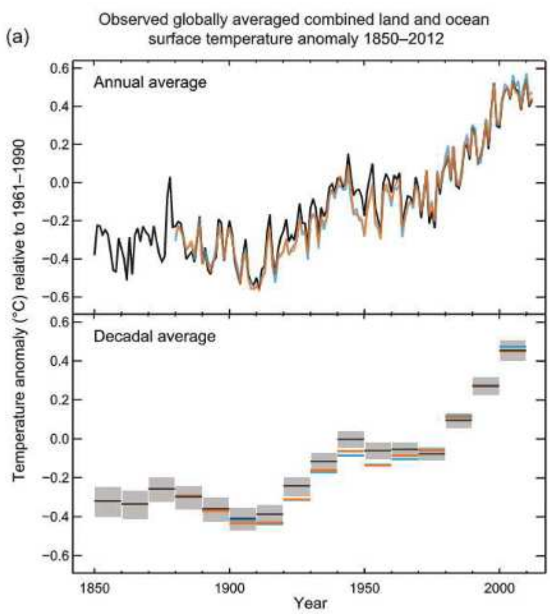
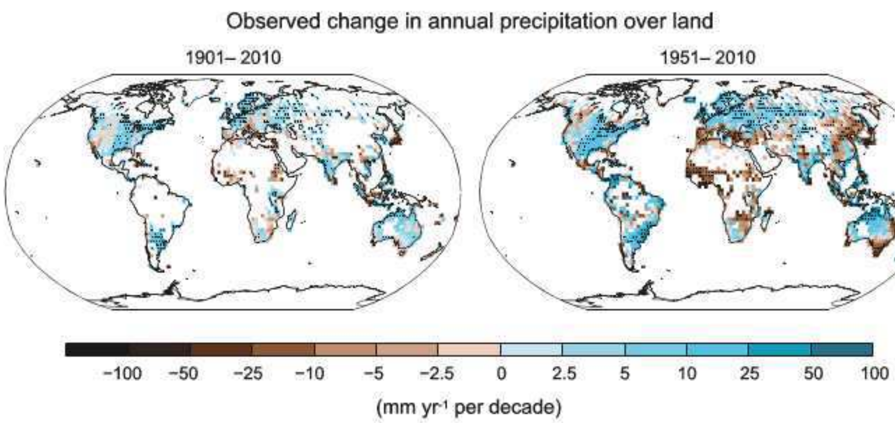


Top panel : annual mean values.
Bottom panel : decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961−1990.

SPM of WGI AR5

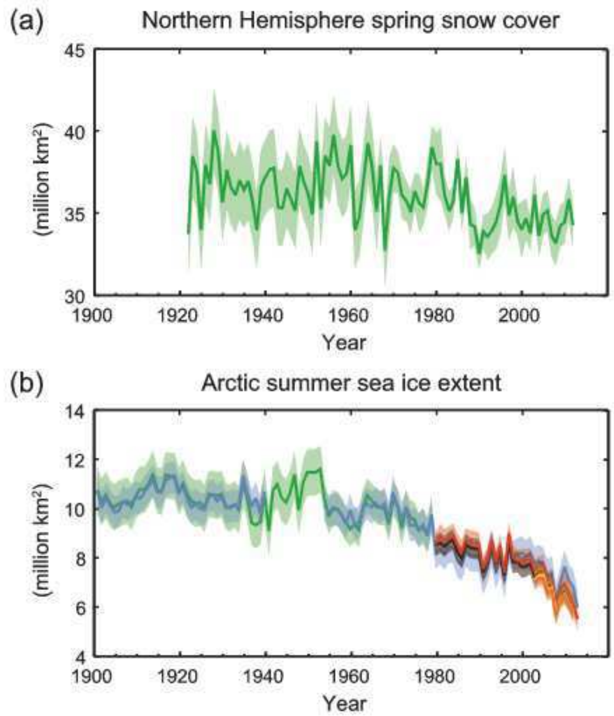
Observed Climate Change (2)

- Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterwards.
- Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951).
- For other latitudes area-averaged long-term positive or negative trends have low confidence.



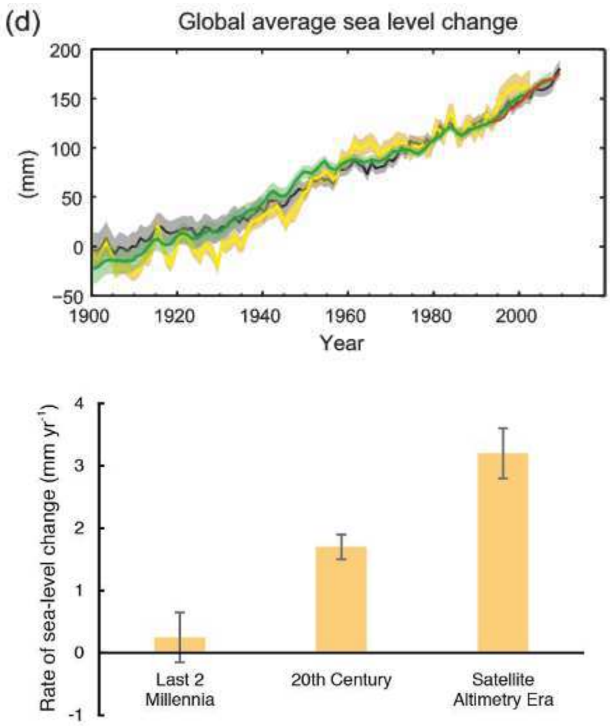
Observed Climate Change (3)

- Northern Hemisphere spring snow cover and Arctic sea ice have continued to decrease in extent (high confidence).
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide.



Observed Climate Change (4)

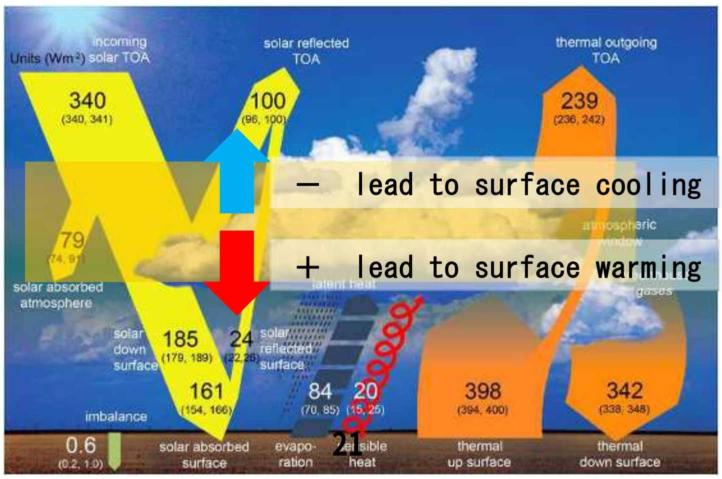
- Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence).
- Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise.



SPM of WGI AR5

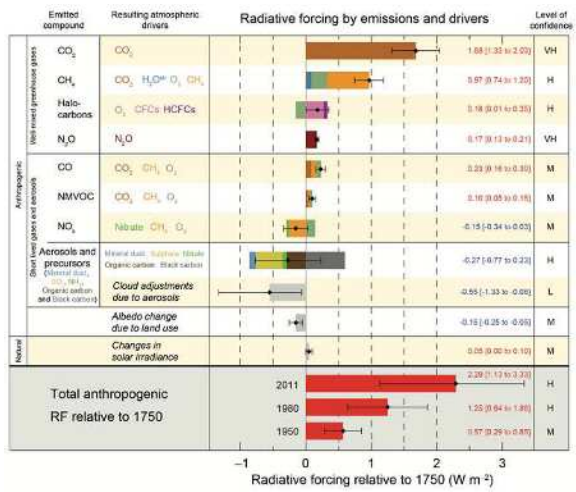
Drivers of Climate Change (1)

- Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change.
- The strength of drivers is quantified as Radiative Forcing (RF) in units watts per square metre as in previous IPCC assessments.
- RF quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated.
- Positive RF leads to surface warming, negative RF leads to surface cooling.



Drivers of Climate Change (2)

- The RF can be reported based on the concentration changes of each substance. Alternatively, the emission-based RF of a compound can be reported, which provides a more direct link to human activities.
- Total radiative forcing is positive, and has led to an uptake of energy by the climate system.
- The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO2 since 1750.



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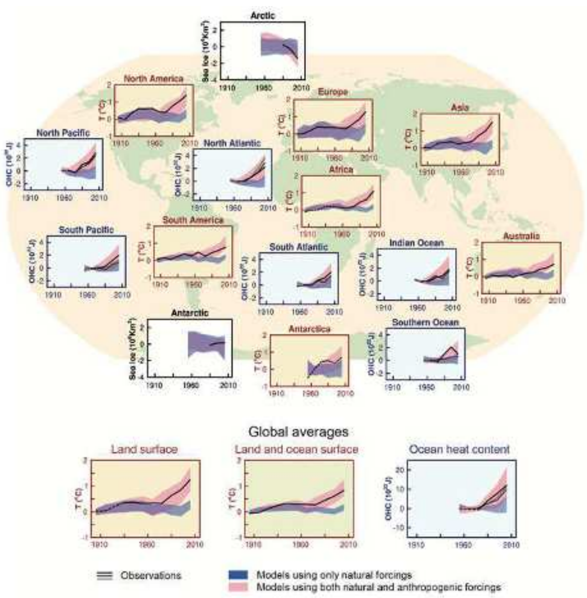
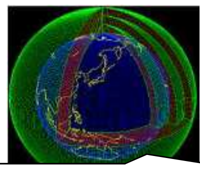
Drivers of Climate Change (3)

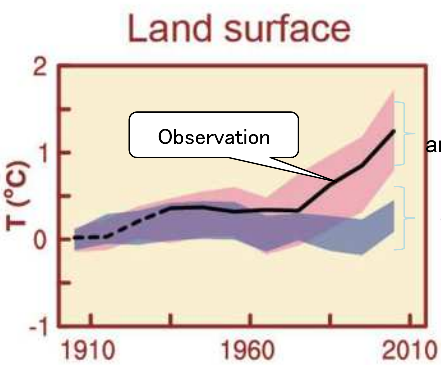
- It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

Comparison of observed and simulated climate change





Climate models using...



both natural and anthropogenic forcings

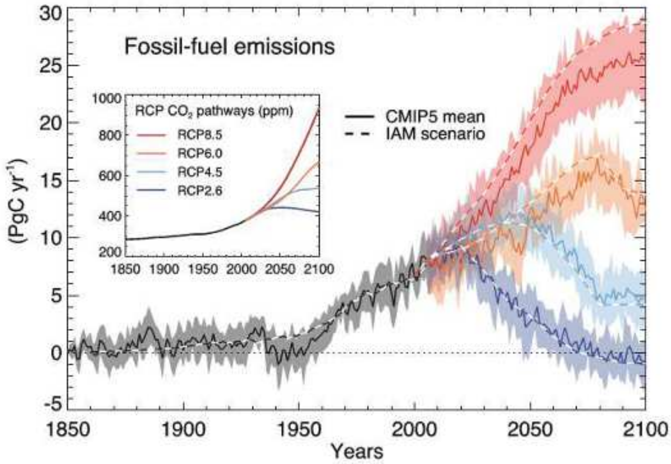
only natural forcings

SPM of WGI AR5

Before explaining future climate change…

Representative Concentration Pathways (RCPs)

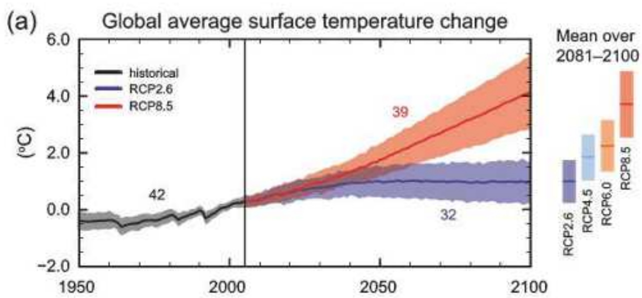
- RCPs are four scenarios of assumed pathway in order to predict climate change in the future.
- RCP8.5 is a scenario which assumes no additional mitigation.
- RCP2.6 is a scenario which assumes keeping the temperature rise from pre-industrial to less than 2 deg C.

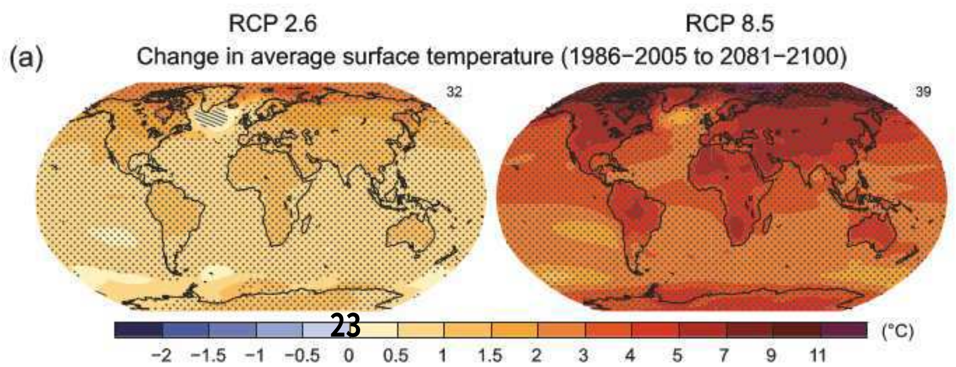


Technical Summary of WGI AR5

Future Climate Change (1)

- Increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to 0.3-1.7°C (RCP2.6), 1.1-2.6°C(RCP4.5), 1.4-3.1°C (RCP6.0), 2.6-4.8°C (RCP8.5).
- The Arctic region will warm more rapidly than the global mean, and mean warming over land will be larger than over the ocean (very high confidence).

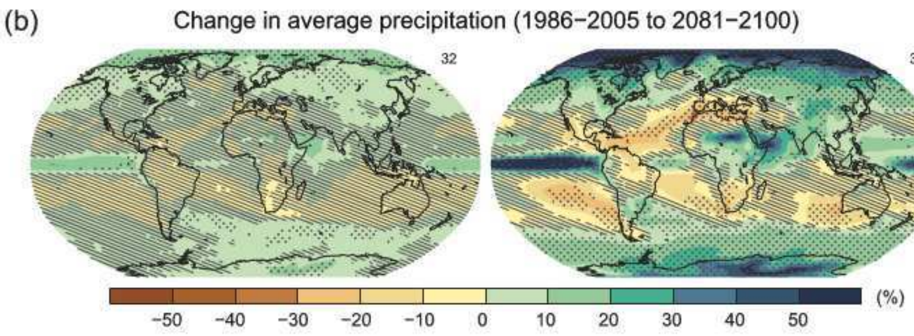




SPM of WGI AR5

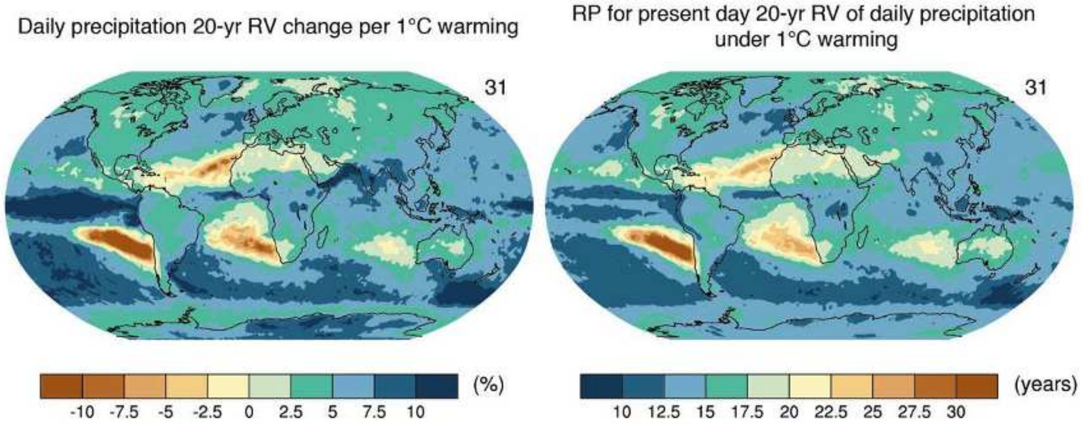
Future Climate Change (2)

- Changes in the global water cycle in response to the warming over the 21st century will not be uniform.
- The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.



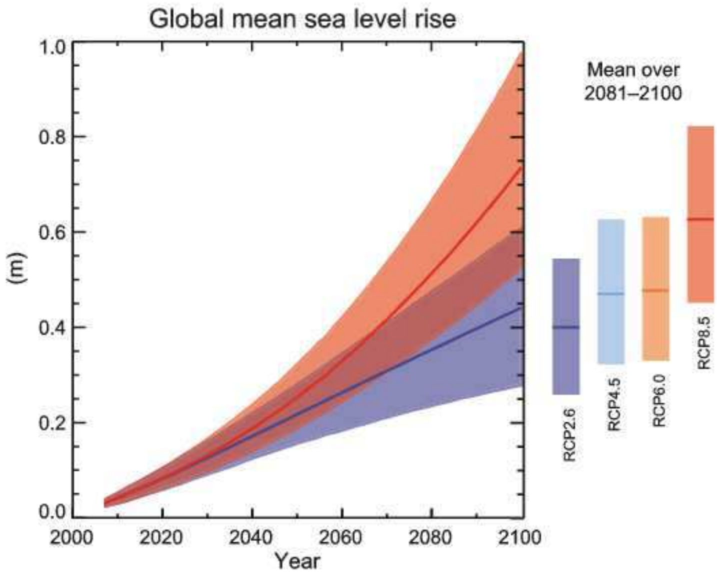
Future Climate Change (3)

- Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases.



Future Climate Change (4)

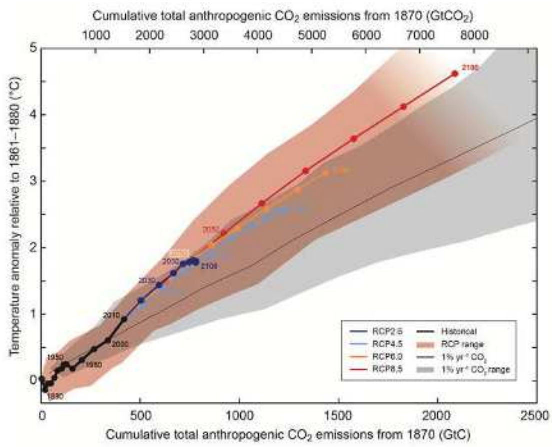
- Global mean sea level will continue to rise during the 21st.
- Under all RCP scenarios, the rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.
- Global mean sea level rise for 2081–2100 relative to 1986–2005 will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5.



Projections of global mean sea level rise over the 21st century relative to 1986–2005.
The assessed likely range is shown as a shaded band.

Future Climate Change (5)

- Cumulative total emissions of CO2 and global mean surface temperature response are approximately linearly related.
- Any given level of warming is associated with a range of cumulative CO2 emissions, and therefore, e.g., higher emissions in earlier decades imply lower emissions later.



Upper amount of cumulative total emissions of CO2 (GtC)

Limiting the warming with a probability to less than 2 deg C since the period 1861-1880	Only anthropogenic CO2 emissions	Accounting for non-CO2 forcings as in rCP2.6
> 33 %	About 1570	About 900
> 50 %	About 1210	About 820
> 66 %	About 1000	About 790

・An amount of 515 [445 to 585] GtC was already emitted by 2011.

Impacts of climate change

- In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans.
- Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.

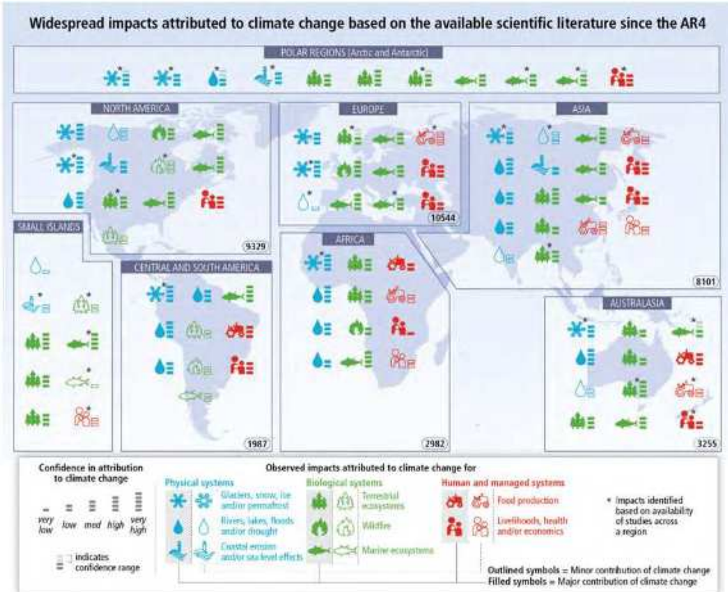
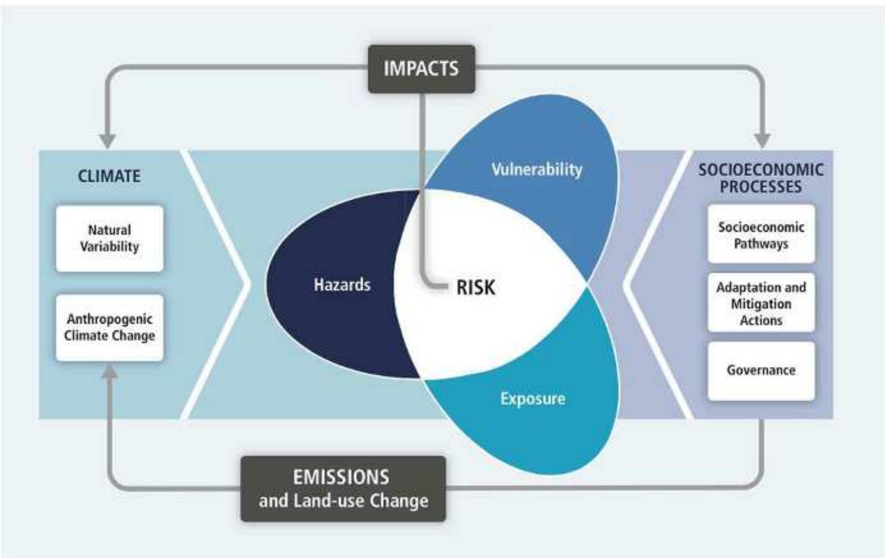


Illustration of the core concepts of the WGII AR5

- Risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems.
- Changes in both the climate system and socioeconomic processes including adaptation and mitigation are drivers of hazards, exposure, and vulnerability.



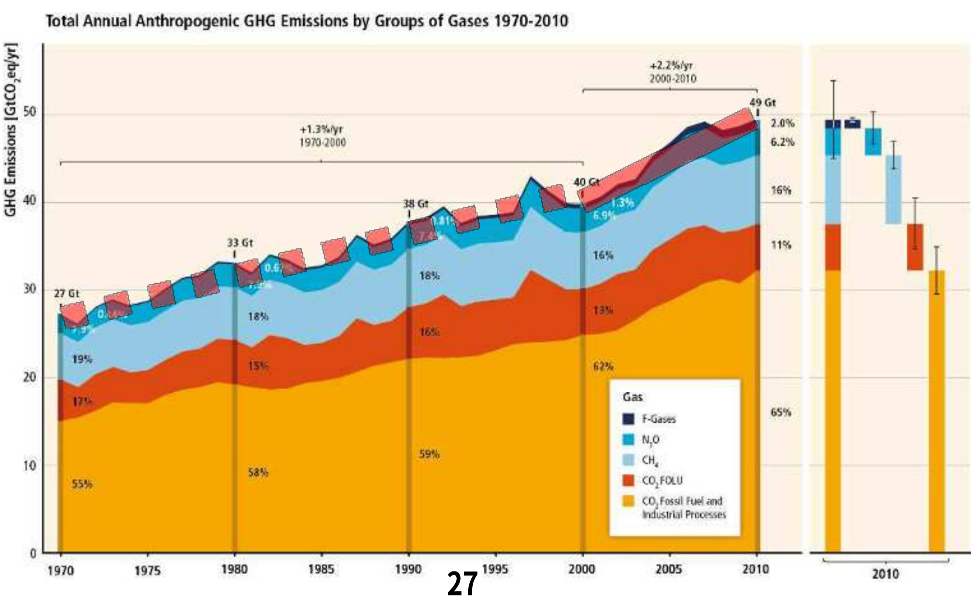
Risk & potential for adaptation

- Adaptation is place- and context-specific, with no single approach for reducing risks appropriate across all settings.

Asia				
Key risk	**Adaptation issues & prospects**	**Climatic drivers**	**Timeframe**	**Risk & potential for adaptation**
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; Measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Increased risk of heat-related mortality (*high confidence*) [24.4]	• Heat health warning systems • Urban planning to reduce heat islands; Improvement of the built environment; Development of sustainable cities • New work practices to avoid heat stress among outdoor workers		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high
Increased risk of drought-related water and food shortage causing malnutrition (*high confidence*) [24.4]	• Disaster preparedness including early-warning systems and local coping strategies • Adaptive/integrated water resource management • Water infrastructure and reservoir development • Diversification of water sources including water re-use • More efficient use of water (e.g., improved agricultural practices, irrigation management, and resilient agriculture)		Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	Very low / Medium / Very high

Total annual anthropogenic greenhouse gas emissions

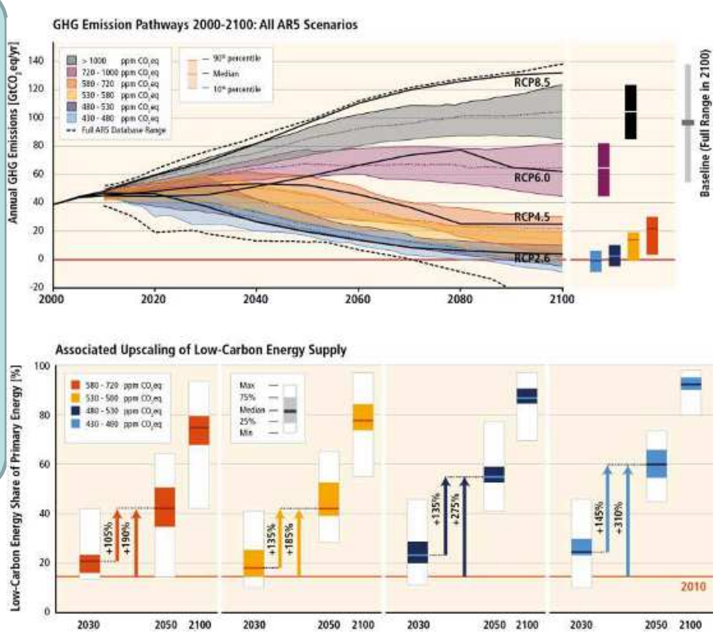
- Annual GHG emissions grew on average by 2.2 % per year from 2000 to 2010 compared to 1.3 % per year from 1970 to 2000.
- About half of cumulative anthropogenic CO2 emissions between 1750 and 2010 have occurred in the last 40 years.



27

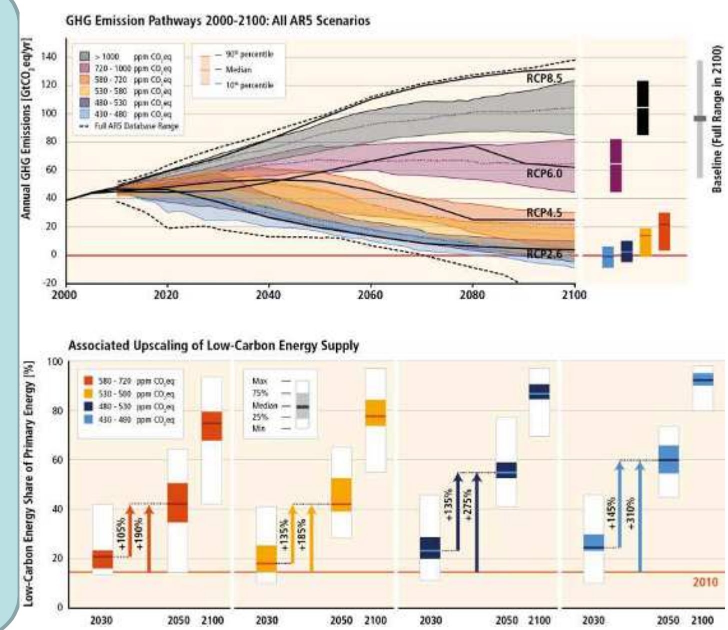
Characteristics of mitigation pathways (1)

- There are multiple mitigation pathways that are likely to limit warming to below 2° C relative to preindustrial levels.
- These pathways would require substantial emissions reductions over the next few decades and near zero emission of CO2 and other long-lived GHGs by end of the century.



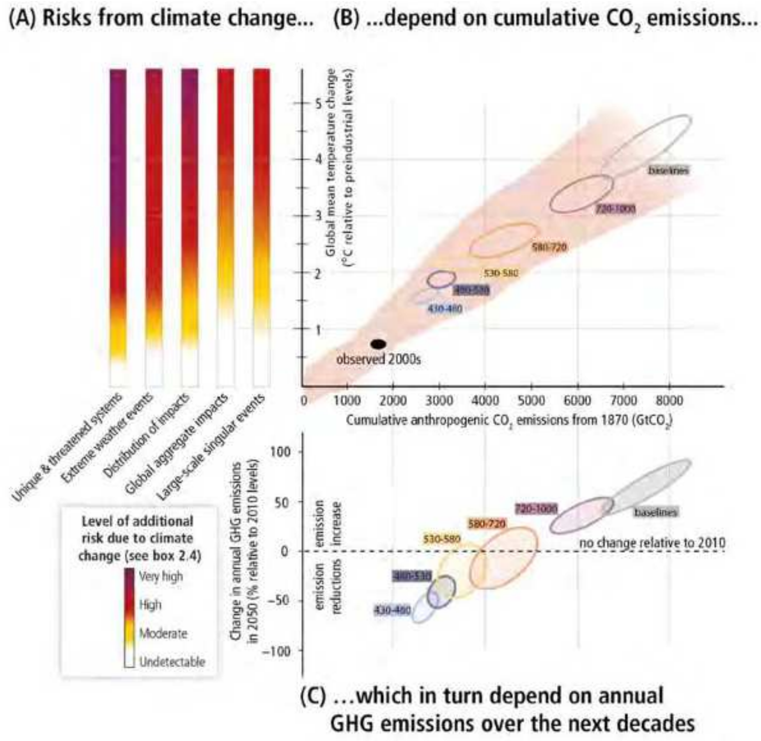
Characteristics of mitigation pathways (2)

- At the global level, scenarios reaching about 450 ppm CO2eq are also characterized by more rapid improvements in energy efficiency and a tripling to nearly a quadrupling of the share of zero- and low- carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050



Risks from climate change…

- The relationship between risk from climate change, temperature change, cumulative CO2 emissions, and changes in annual GHG emissions by 2050.



29

Introduction to Global Warming Projection

Introduction to Global Warming Projection

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Climate Research Department, Meteorological Research Institute (MRI/JMA)
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1. Global Warming Projection

According to WMO website, “At the simplest level the weather is what is happening to the atmosphere at any given time. Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time.”. Although climate is the synthesis of the weather, climate is not maintained only by atmosphere itself but is formed in the interactions among many components of the Earth. This system is named as climate system (Fig.1). These components interact on various spatial and temporal scales through the exchanges of heat, momentum, radiation, water and materials.

Atmospheric initial states and their dynamical evolution may be key processes for daily weather predictions. Atmosphere itself includes short-period internal instability mechanisms, typically the baroclinic instability around the extratropical westerly jets, so that it may be considered as chaotic or unpredictable beyond a few weeks. Atmosphere-ocean interactions produce longer time-scale variability in atmosphere with periods beyond months up to several and decadal years. A typical example is ENSO (El Niño / Southern Oscillation) with the period of 2-7 years. Oceanic initial states and their dynamical evolution may be key processes for ENSO and related seasonal climate predictions.

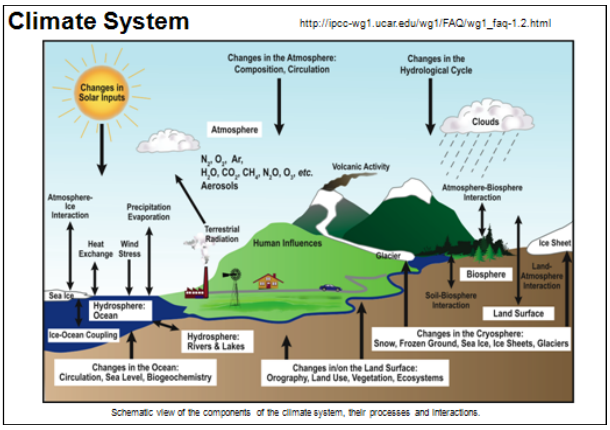


Figure 1 Climate system.
(From 4th IPCC 2007)

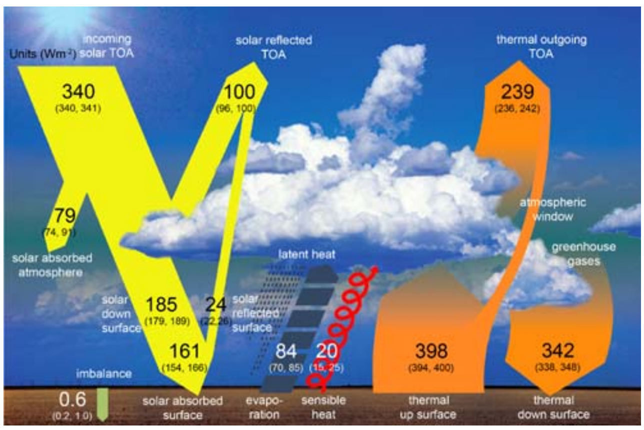


Figure 2 Global mean energy budget.
(From 5th IPCC 2013)

Change in external conditions of climate system (e.g., aerosol by volcano eruption) forces climate to change. It has been widely recognized that human activity also changes external conditions of the climate system, typically radiative forcings due to the anthropogenic increase of greenhouse gases (CO_2, CH_4, N_2O, etc.) which causes the energy imbalance with less outgoing radiation and leads to warmer climate during relatively short periods (Fig.2). Various (positive and negative) feedbacks may be caused in the climate change process through fast and slow responses of the climate system components, in particular, radiatively important components of snow, clouds and dust (Fig.3), and huge heat capacity components such as deep ocean circulations and polar ice sheets.

The purpose of the lecture is to introduce global warming projection and the application of 20-60km and 2-5km high resolution atmospheric models to the study on future risk information.

2. Future Global Climate

Energy (heat and water and so on) budget is an essential process for global warming projection. Therefore, at least, major climate-system components associated with the Earth energy budget and their physical processes must be included appropriately within projection models. Usually, climate projections are performed under given future scenarios of human activity causing anthropogenic climate changes (Fig.4).

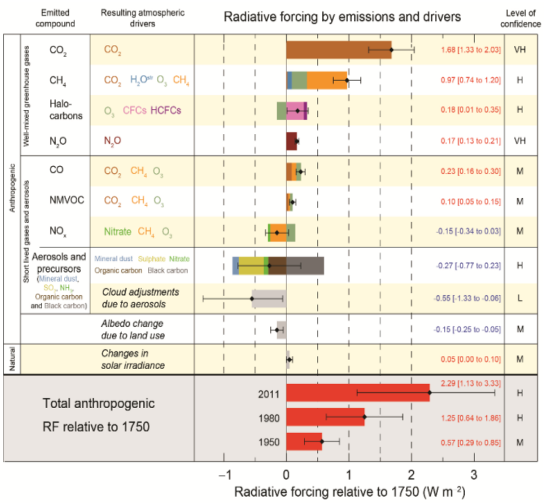


Figure 3 Radiative forcing by emission. (From 5th IPCC 2013)

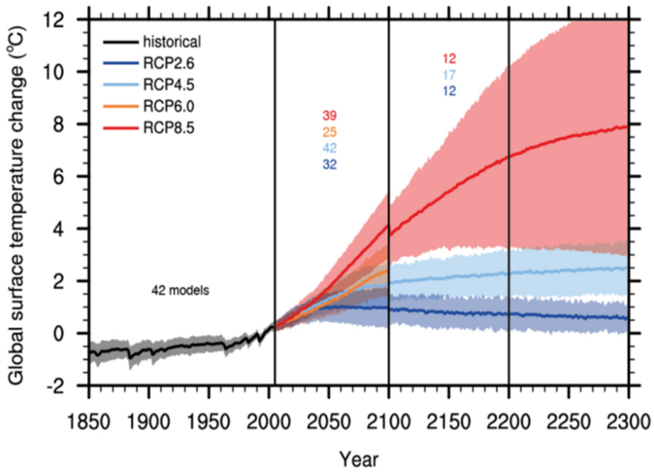
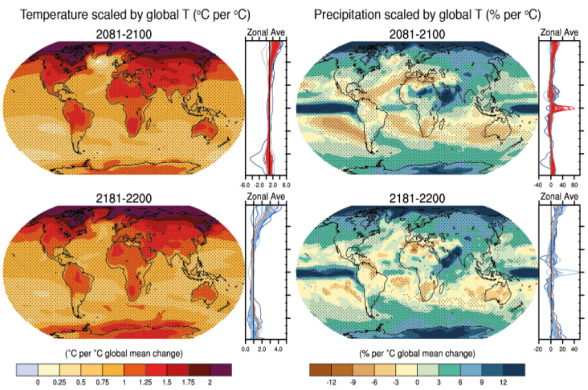


Figure 4 Projection of global surface temperature change. (From 5th IPCC 2013)

Dynamics (or heat and moisture transport processes) becomes more important for considering regional precipitation change under the global warming. The global warming increases surface air temperature more or less over most regions of the world. On the contrary, precipitation increases somewhere and decreases somewhere (Fig.5). Generally, increased moisture flux in warmed air accelerates wet climate in the present wet region and dry climate in the dry region. However, it is not necessarily so simple because increased vertical static stability results in suppressed vertical motions over the regions with vertical motions prevailing at the present (Fig.6). Besides, the future increase of sea surface temperature (SST) is not even but has a geographical variability, which is also influential to future change in precipitation. Changed moisture transport may be interactive with mountain barriers. After all, only three-dimensional climate system models are able to show physically explainable results after the interactions between all the above processes.



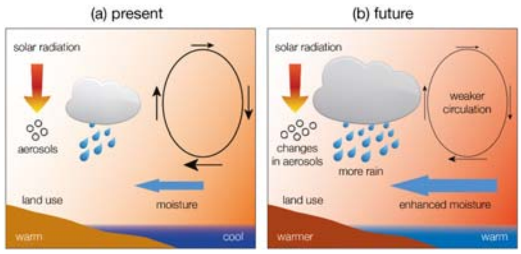
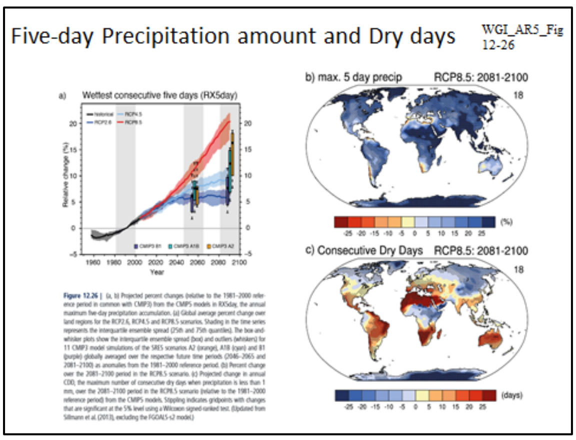


Figure 5　Future changes in (left) temperature and (right) precipitation scaled by global increase for (upper) 2081-2100 and (lower) 2181-2200. (From 5th IPCC 2013)

Figure 6　Changes in moisture budget and others. (From 5th IPCC 2013)

Total precipitation is considered as precipitation amount per one event multiplied by precipitation frequency. Effect of increased moisture in the global warming tends to appear clearly in short-term heavy precipitation rather than total precipitation (Fig.7). On the other hand, suppressed vertical motion on average due to vertically more stable atmosphere in the future may result in less frequency of precipitation occurrences, which indicates increase of dry days (Fig.7).



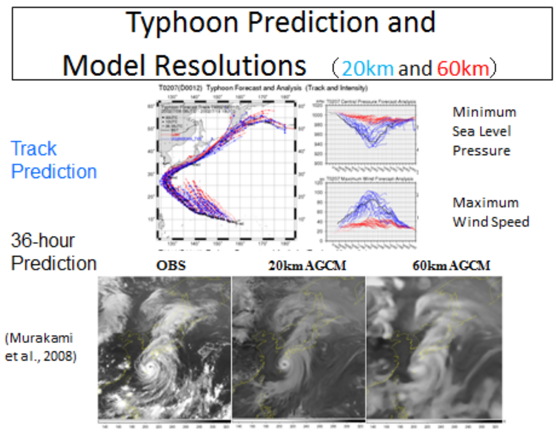


Figure 7 (Left) wettest consecutive 5 days, (upper-right) maximum 5 day precipitation and (lower-right) consecutive dry days. (From 5th IPCC 2013)

Figure 8　Comparison of a typhoon prediction between 20km and 60km global atmospheric models (Murakami et al. 2008).

3. Application of High-resolution Atmospheric Model to Risk Information Research

Future projection of change in regional climate and extreme climate is significantly important for people lives and society in views of disaster risk prevention and resilience. High resolution atmospheric models have advantages for these projections. Based on the JMA operational numerical prediction model with 20km and 60km resolutions (Fig. 8), high-resolution (20km and 60km) Atmospheric General Circulation Models (AGCMs) have been developed as climate models at MRI/JMA (e.g., Mizuta et al. 2012). In the research projects for the past decade, sponsored by the Japanese Ministry of Education, Culture, Sports, Science and Technology (J-MEXT) (Fig.9) (Kitoh et al., 2009), these AGCMs were applied to future projections for regional climates and extreme climates such as the statistics of tropical cyclones and heavy precipitation, and the outputs were used for further downscaling for projections of extreme precipitation and fine regional climatology using 2 to 5 km mesh regional models (Fig.10).

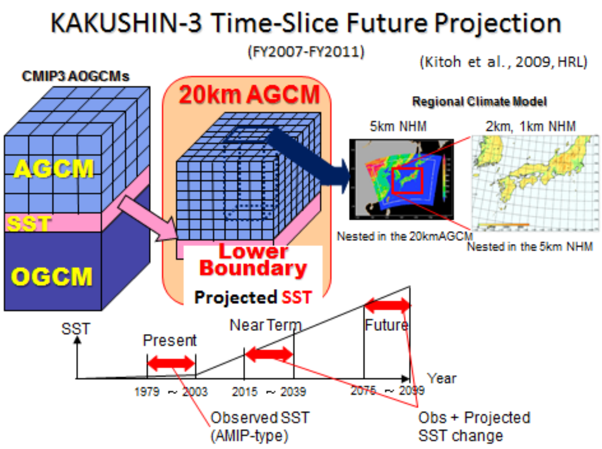


Figure 9 Projection for regional climate and extreme climate, using high-resolution atmospheric models. (Kitoh et al. 2009)

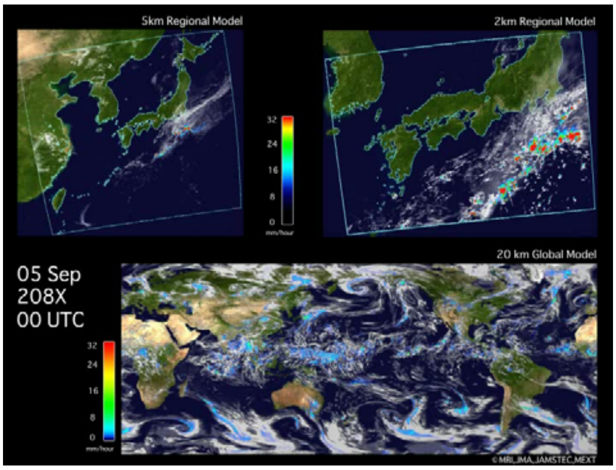


Figure 10 Snap pictures of future projection by 20km, 5km and 2km atmospheric models. (Copy right by MRI, JMA, JAMSTEC and MEXT)

Use of high resolution AGCMs provides significant merits. (1) Simulated present-day climatology is much better than those of coupled models because of real sea surface temperatures specified in AGCMs. This is critical for studying regional climate change (Kusunoki et al. 2006) and downscaling (Kanada et al. 2010). (2) High resolution models are able to represent realistic tropical cyclones (Murakami et al. 2012) (Fig.11) and extreme weathers as well as the effect of fine topography. (3) Variously controlled future projections are possible with the same AGCM. Actually, a CMIP3-ensemble-mean SST change was adopted for the ‘most reliable’ future projection in the J-MEXT KAKUSHIN project. Besides, uncertainty of projections was estimated by comparing the impact of different SST future changes and cumulus schemes in the ensemble projections (Endo et al. 2012).

4. Future Projection of Tropical Cyclones

Maybe for the same reason as the increase of heavy precipitation amount under the global warming, the frequency of strong tropical cyclones is increased in the future, and for the same reason as the increase of dry days, the frequency of weak or average tropical cyclones is projected to be decreased (Fig.12) (Sugi, 2012). The frequency of tropical cyclones is not decreased evenly over the world, and increased over some regions with the present-day's small frequency of tropical cyclones (Fig.13). Regional change in frequency of tropical cyclones is sensitive to change in occurrence frequency of the tropical cyclones which are affected by regional climate change, especially the change in vertical motions due to vertically stabilized atmosphere and due to geographical variability of increased SST (Fig.14). High resolution models may enable to show the change in regional landfalls of tropical cyclones along coasts. Along the East Asian coasts, the frequency of the landfalls is decreased except some regions, but the maximum intensity of future tropical cyclones is increased significantly (Fig.13).

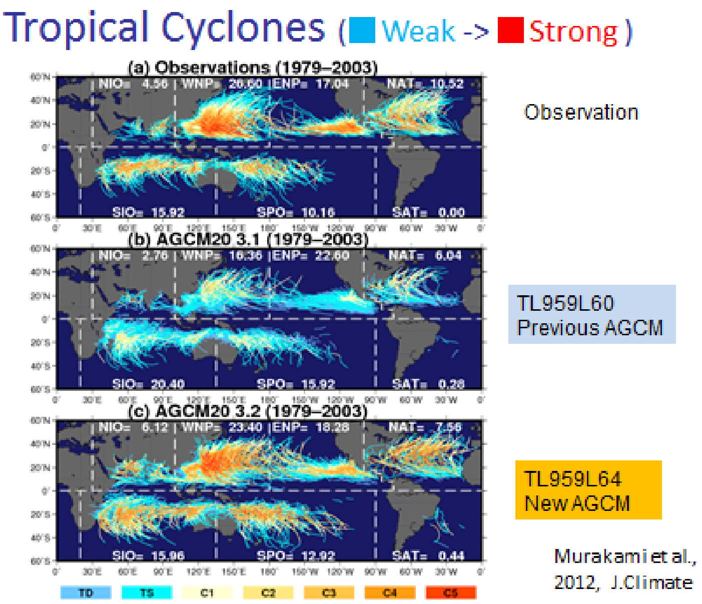


Figure 11 (Upper) observed tracks of tropical cyclones, (middle) the previous 20km MRI-AGCM (AGCM3.1S) and (lower) the new 20km MRI-AGCM (AGCM3.2S). (Murakami et al. 2012)

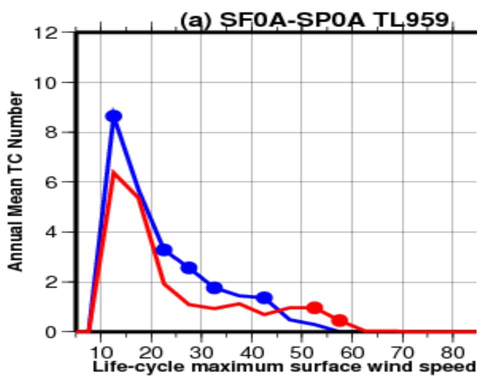
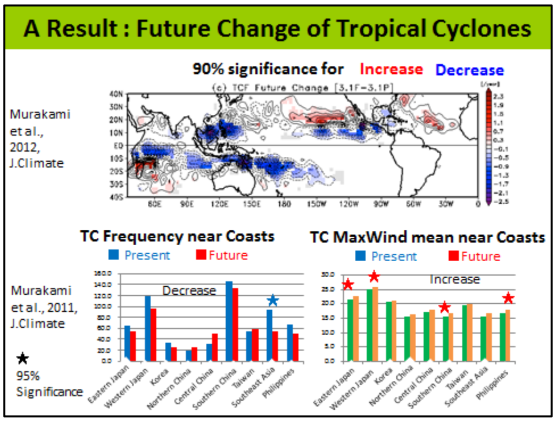


Figure 12 Annual mean number of tropical cyclones at the present day (blue) and the future (red), classified by their life-cycle maximum surface wind speed in the horizontal axis (Murakami et al. 2012).



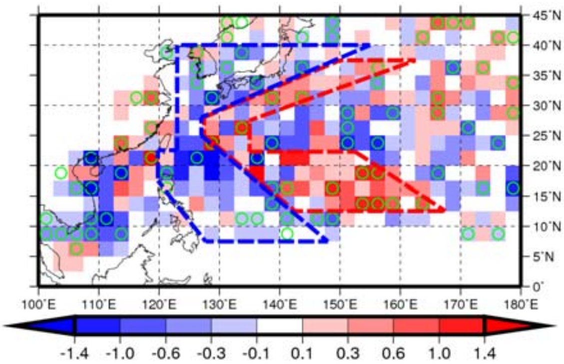
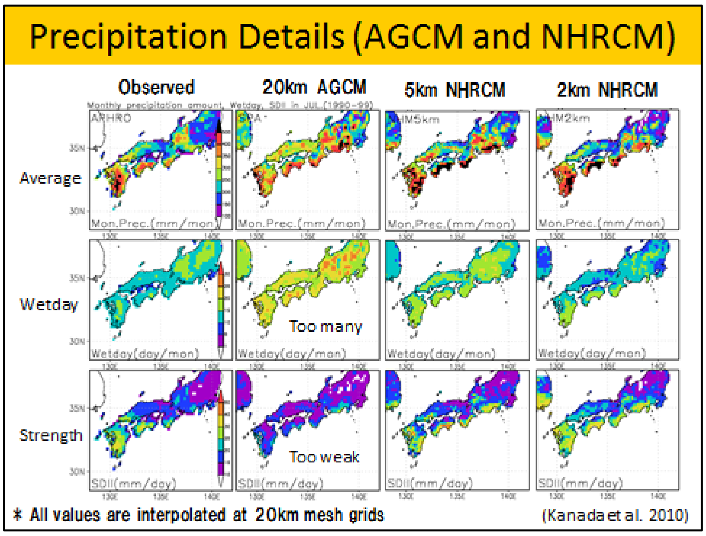


Figure 13 Future change in (upper) tropical cyclone frequency and (lower) landfall statistics (Murakami et al. 2012).

Figure 14 Details of future change in tropical cyclone frequency (Murakami et al. 2011).



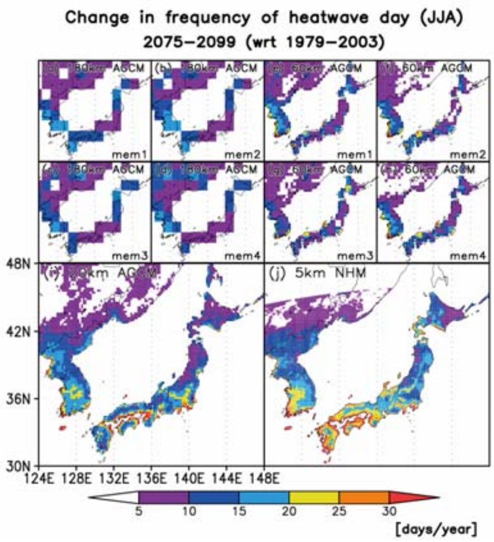


Figure 15 (Upper) July average precipitation, (middle) the number of wetday and (lower) strength of precipitation. (Left) observation, (2^{nd} left) 20km global model, (2^{nd} left) 5km and (left) 2km regional models (Kanada et al. 2010).

Figure 16 Change in frequency of heatwave day in 180km, 60km 20km and 5km models (from Kakushin Report 2012).

5. Further Downscaling of Projection

Sometimes, more detailed information of climate change such as extreme weathers and local climate are requested for local risk management. For the purposes, dynamical downscaling techniques are applied to the study on regional climate change with 2km to 5 km mesh non-hydrostatic regional models. In addition to realistic fine distribution of precipitation average, simulations for the present day wet-days (days with precipitation occurrence) and strength of precipitation are systematically improved by the regional models, compared with those the 20km global models providing the lateral boundary for the downscaling (Fig. 15).

Surface temperature increase is evenly distributed over relatively wide regions. However, extreme climatology of surface temperature change depends on geographical situations like plains and mountains (Fig.16), indicating that high resolution regional models representing fine topography are expected for realistic present-day climatology and future projections.

6. Summary and the SOUSEI-C Projection

Climate projection models and weather forecasting models are quite similar and almost the same in a view of their contents. In fact, the MRI climate models are built based on the JMA numerical (weather) prediction models. However, the basic methods for the global warming projection and weather predictions are completely different: the former one is to project a long-term response of the energy and moisture budget to external (anthropogenic radiative) forcing and the latter one is to forecast short-term evolution of atmospheric flow from its initial time state.

Under the global warming environment, in addition to the increase of surface temperature and moisture, the changes in vertical stability of the atmosphere and SST distribution create characteristic regional climate changes. These interactions can be represented only with the 3-dimensional models representing a full set of climate system components. At the MRI/JMA, the high resolution atmospheric models for climatology have been developed and used to project detailed regional climate and extremes.

A new J-MEXT project (SOUSEI-C) is started, where the 20km-resolution MRI-AGCM3.2 (MRI-AGCM3.2S) had been integrated for a four-member ensemble of RCP8.5-scenario future (2075-2099) projections specifying one CMIP5 ensemble mean and three statistically classified SST changes (Mizuta et al. 2014) as well as the present-day (1979-2003) simulation as SST boundary conditions (Figs.19 and 20). All these 20km AGCM outputs for further downscaling in any regions will be available as well as the outputs for analysis.

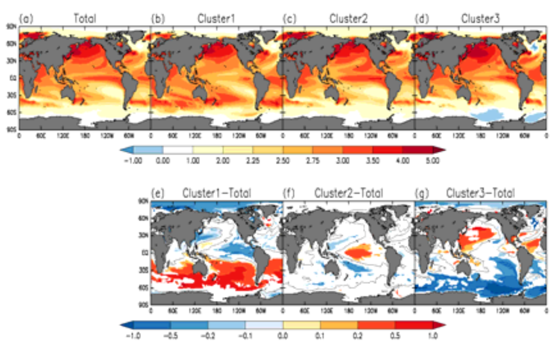


Figure 19 (Upper) one ensemble mean and three patterns of future SST increase obtained from the CMIP5 future projections by the statistical cluster analysis. (Lower) deviations of the three SST increases from the ensemble average one. (Mizuta et al. 2014)

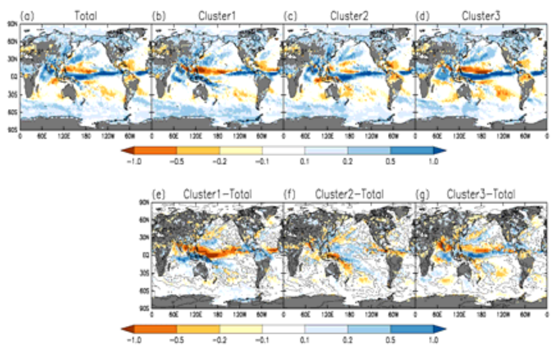


Figure 20 (Upper) future projection of precipitation changes in Jun-Jul-Aug of the ensemble SST increase. (Lower) deviations for the three SST increase cases from the ensemble average case. (SOUSEI-C Report, 2015)

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Introduction to JRA-55

Introduction to JRA-55

Kazutoshi ONOGI

1 Approaches in researches on the past climate

(1) Direct use of observational data

Historical in situ surface observational data have been accumulated for more than 100 years and upper air data for several decades, which can be a reliable data source to estimate the past climate quantitatively. In fact the Climatic Research Unit TEMperature (CRUTEM4, latest version) data (Jones et al., 2012) was produced as a reliable temperature database of land surface temperatures. The Global Climate Observing System (GCOS) established in 1992 organized the climate observing networks for surface (GCOS Surface Network; GSN) and for upper air (GCOS Upper Air Network; GUAN), each of which consists of selected high-quality observing stations. The GSN and GUAN data are quality controlled and accumulated in their data archive centers. Climate statistics using GUAN and other data (HadAT; Thorne et al. 2005) has been produced by United Kingdom Meteorological Office (UKMO) and National Climatic Data Center (NCDC), and a long-term tendency in radiosonde observations of GUAN was detected. However, even the best organized observational dataset covers mainly land areas and the observed meteorological variables are limited. Generally in many cases, past observational data were not well organized; they were accumulated separately in many countries and organizations with various data formats and units. These data can be used only locally even if they are available. The data as they are may not be adequate for a global climate study because the observational data are not distributed uniformly to represent global atmospheric situation homogeneously.

(2) Use of numerical assimilation and prediction techniques

On the other hand, in the advanced national meteorological centers in the US, Europe and Japan, global observational data are acquired via the global telecommunication system (GTS) and assimilated into numerical weather prediction (NWP) models. The global atmospheric status at a certain time can be assimilated to every grid point of the NWP model, as an analysis. The future atmospheric state is then predicted from the analysis. In consequence, global Data Assimilation (DA) systems were developed rapidly in major NWP centers. DA cycles have been operated since the 1980s.

The DA cycle is a core system of NWP system. In the DA cycle, data assimilation gives an initial condition for a forecast model, and short term forecast is performed and gives a first guess field to DA. The DA cycle is a continuous repetition of data assimilation and short-term forecasts. It is a quite important method for representing the global atmospheric situation in detail and to improve the forecast. The accumulated operational analysis data are useful data which give frequent three-dimensional high quality global grid point values (GPV) of many kinds of meteorological variables with a system specific resolution. It gives the most reliable data for meteorological and climate researches at the time. In particular, for operational climate monitoring and climate research, daily global atmospheric data with many kinds of variables for several decades are essential and necessary as basic data. The operational numerical analysis archives have been used as the basic data to calculate climate normal values of average for the past 30 years.

However, there are serious problems to use an operational analysis data as basic data for climate monitoring. About a half century has passed since the beginning of operational NWP at the major NWP centers in the world. During the years, operational NWP system and supercomputer system have developed significantly. The quality of numerical analysis largely depends on the techniques of data assimilation and the power of supercomputer system at the time of production. Therefore the quality of the latest operational analysis is quite different from older analyses. Obviously consistent climate monitoring for several decades is impossible if we use operationally archived analysis data.

2 Introduction to JRA-55 reanalysis

The Japan Meteorological Agency (JMA) conducted the second Japanese global atmospheric reanalysis, called the Japanese 55-year Reanalysis or JRA-55 (Kobayashi et al. 2015). It covers the period starting in 1958, when regular radiosonde observations began on a global basis. JRA-55 is the first comprehensive reanalysis that has covered the last half-century since the European Centre for Medium-Range Weather Forecasts 45-year Reanalysis (ERA-40, Uppala et al. 2005), and is the first one to apply four-dimensional variational analysis to this period. The main objectives of JRA-55 were to address issues found in previous reanalyses and to produce a comprehensive atmospheric dataset suitable for studies of multidecadal variability and climate change. This paper describes the observations, data assimilation system and forecast model used to produce JRA-55 as well as the basic characteristics of the JRA-55 product.

JRA-55 has been produced with the TL319 version of JMA's operational data assimilation system as of December 2009, which was extensively improved since the Japanese 25-year Reanalysis (JRA-25, Onogi et al. 2007). It also uses many newly available and improved past observations. The resulting reanalysis products are considerably better than the JRA-25 product. Two major problems of JRA-25 were a cold bias in the lower stratosphere, which has been diminished, and a dry bias in the Amazon basin, which has been mitigated. The temporal consistency of temperature analysis has also been considerably improved compared to previous reanalysis products. Our initial quality evaluation revealed problems such as a warm bias in the upper troposphere, a large upward imbalance in the global mean net energy fluxes at the top of the atmosphere and at the surface, excessive precipitation over the tropics, and unrealistic trends in analyzed tropical cyclone strength. This paper also assesses the impacts of model biases and changes in the observing system, and it mentions efforts to further investigate the representation of low-frequency variability and trends in JRA-55.

3. Data assimilation system and forecast model used in JRA-55

The JRA-55 data assimilation system is based on the low-resolution (TL319) version of JMA's operational data assimilation system as of December 2009 (JMA 2013), which has been improved extensively since JRA-25 as shown in Table 1.

Table 1. Data assimilation systems used for JRA-25 and JRA-55.

	JRA-25	JRA-55
Base system	JMA's operational system as of March 2004 (JMA 2002)	JMA's operational system as of December 2009 (JMA 2007, 2013b)
Horizontal grid system	Gaussian	Reduced Gaussian
Horizontal resolution	T106 (~110 km)	TL319 (~55 km)
Atmospheric analysis		
Vertical levels	Surface and 40 levels up to 0.4 hPa	Surface and 60 levels up to 0.1 hPa (Iwamura and Kitagawa 2008; Nakagawa 2009)
Analysis scheme	3D-Var with the T106 inner resolution	4D-Var with the T106 inner resolution
Background error covariances	Static	Static with the simple inflation factor of 1.8 applied before 1972
Bias correction for satellite radiances	*TOVS* Adaptive scheme using 1D-Var analysis departures (Sakamoto and Christy 2009) *ATOVS* Static (until July 2009) and adaptive (thereafter) schemes using radiosonde and supplemental background fields (Kazumori et al. 2004)	VarBC (Derber and Wu 1998; Dee and Uppala 2009; JMA 2013b)
Radiative transfer model for satellite radiances	*TOVS:* RTTOV-6 *ATOVS:* RTTOV-7	RTTOV-9.3
Surface analysis		
Screen-level analysis	2D-OI	2D-OI with the FGAT approach
Land surface analysis	Offline SiB with 6-hourly atmospheric forcing	Offline SiB with 3-hourly atmospheric forcing
Snow depth analysis	2D-OI	2D-OI

The forecast model used for JRA-55 is based on the TL319 spectral resolution version of the JMA global spectral model (GSM) as of December 2009 (JMA 2013), which has been extensively improved since JRA-25 as shown in Table 2.

Table 2. Forecast models used for JRA-25 and JRA-55.

	JRA-25	JRA-55
Base model	JMA GSM as of March 2004 (JMA 2002)	JMA GSM as of December 2009 (JMA 2007, 2013b)
Horizontal resolution	T106 (~110 km)	TL319 (~55 km)
Vertical levels	Surface and 40 levels up to 0.4 hPa	Surface and 60 levels up to 0.1 hPa (Iwamura and Kitagawa 2008; Nakagawa 2009)
Dynamics		
Horizontal grid system	Gaussian	Reduced Gaussian
Advection scheme	Euralian	Semi-Lagrangian
Radiation		
Longwave radiation	*Line absorptions* Random band model of Goody (1952) *Water vapor continuum (e-type)* Roberts et al. (1976) *Radiatively active gases* H_2O, O_3 and CO_2 (constant at 375 ppmv)	*Line absorptions* Pre-computed transmittance tables and *k*-distribution (Chou et al. 2001) *Water vapor continuum (e-type and p-type)* Zhong and Haigh (1995) with MK_CKD (Clough et al. 2005) *Radiatively active gases* H_2O, O_3, CO_2, CH_4, N_2O, CFC-11, CFC-12 and HCFC-22
Shortwave radiation	*Absorptions by H_2O, O_2, O_3 and CO_2* Briegleb (1992)	*Absorptions by H_2O* Briegleb (1992) *Absorptions by O_2, O_3 and CO_2* Freidenreich and Ramaswamy (1999)
Cloud radiation	*Longwave* Maximum-random overlap *Shortwave* Random overlap	*Longwave* Maximum-random overlap with the method of Räisänen (1998) *Shortwave* Random overlap
Aerosols	Atmospheric aerosol profiles from WMO (1986) (CONT-I over land and MAR-I over sea)	Atmospheric aerosol profiles from WMO (1986) (CONT-I over land and MAR-I over sea) with optical depths adjusted to 2-dimensional monthly climatology
Cumulus convection	Prognostic Arakawa-Schubert	Prognostic Arakawa-Schubert with DCAPE
Initialization	Nonlinear normal mode initialization	Not used
Boundary conditions and forcing fields		
SST and sea ice	COBE-SST (Ishii et al. 2005)	COBE-SST (Ishii et al. 2005)
Ozone	T42L45 version of MRI-CCM1 (Shibata et al. 2005)	*Until 1978* Climatology *From 1979 onward* T42L68 version of MRI-CCM1 (Shibata et al. 2005)

4. Basic performance of JRA-55

(1) Two-day forecast scores

To evaluate the temporal consistency of the product and the impact of changes in observing systems, a short-range forecast was carried out in JRA-55 from 12 UTC every day. Figure 1 shows the time series of RMS errors in these 2-day forecasts at a geopotential height of 500 hPa averaged over the extratropical northern and southern hemisphere from JRA-25, JRA-55, and the JMA operational system, as verified against their own analyses. Because the forecasts were carried out with their own forecast models, the comparison is not made based on a common standard; nevertheless, it can provide useful insights regarding the temporal consistency of each product.

The JMA operational system has been improved in many aspects since JRA-25, including a revision of the longwave radiation scheme and the introduction of 4D-Var and VarBC. The JRA-55 data assimilation system, which is based on the TL319 resolution version of the operational system as of December 2009, incorporates these improvements and has been used consistently throughout the reanalysis period. Thus, variations in the forecast scores of JRA-55 can be attributed solely to the changes in observing systems and natural variations of atmospheric predictability, whereas forecast scores of the operational system clearly show the effect of these improvements. These are evidence of the greater temporal consistency of the JRA-55 product. The forecast scores of the JRA-55 system are considerably better than those of the JRA-25 system, which is based on the T106 resolution version of the operational system as of March 2004. The improvement of forecast scores is particularly significant in the southern hemisphere, which is most likely because of the availability of new satellite observations as well as the improvement of the data assimilation system.

The forecast scores of JRA-55 show relatively large variations that correspond to the introduction of VTPR in 1973; the advent of satellite observing systems in the late 1970s, ATOVS in 1998, and GNSS-RO in 2006; and variations in coverage of TOVS observations, suggesting that performance under sparse observations is an important concern for future reanalyses. It should be noted that the forecast scores in the southern hemisphere tend to be degraded during the pre-satellite era, whereas the number of used obsevations rather increased (Fig 2d, 2e). This inconsistency may indicate that the JRA-55 data assimilation system did not perform well during this period.

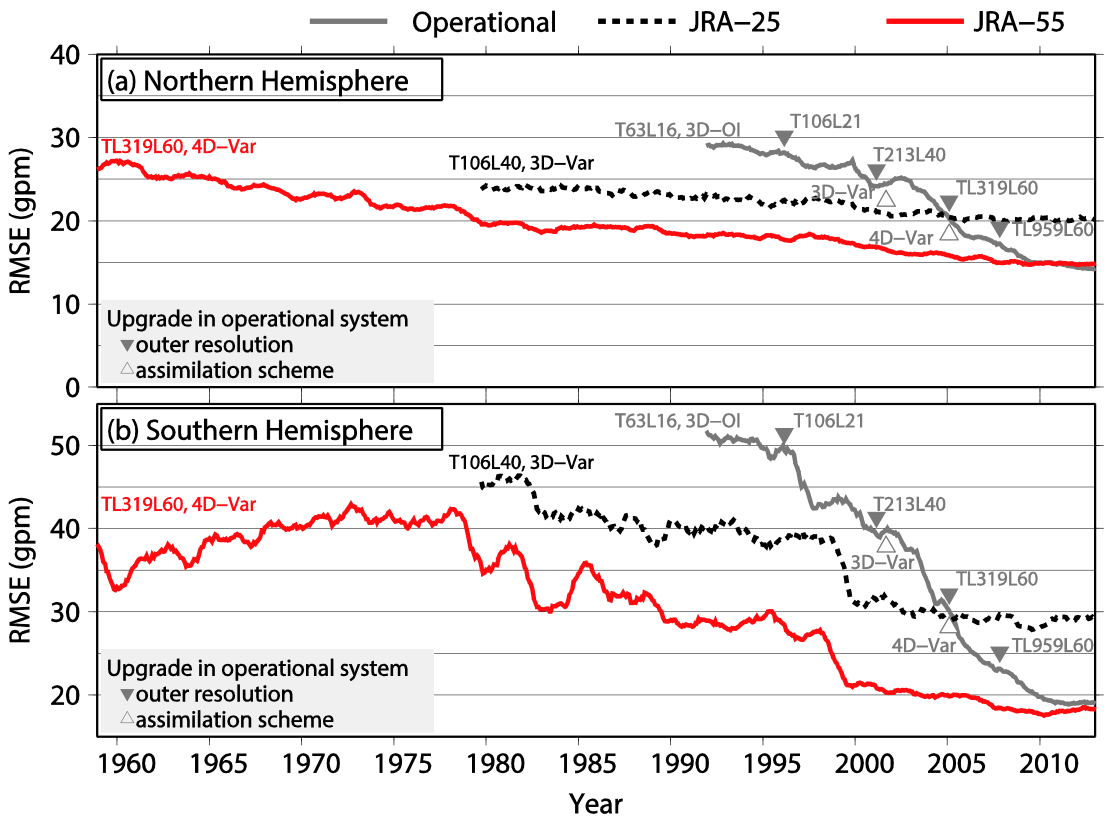

Figure 1　RMS errors of 2-day forecasts of the geopotential height at 500 hPa averaged over the extratropics of the (a) Northern and (b) Southern Hemispheres from JRA-25, JRA-55 and JMA operational system, verified against their own analyses.　Changes in the assimilation scheme and resolution of the outer model are also noted. Each value represents the average for the last 12 months.

(2) Precipitation

Figure 2 shows the climatology of global precipitation distributions in JRA-55, JRA-25, ERA-Interim, ERA-40, the Modern-Era Retrospective Analysis for Research and Applications (MERRA, Rienecker et al. 2011), and GPCP (Adler et al. 2003) as an observational dataset. While precipitation in middle and high latitudes are underestimated in most reanalyses, this feature is improved in JRA-55, especially in the Pacific and Atlantic Oceans north of 30°N. On the other hand, JRA-55 overestimates precipitation in the tropics compared with GPCP. The regions where JRA-55 overestimates precipitation tend to exhibit the spin-down problem (precipitation is excessive immediately after the start of forecasts and then gradually decreases) (not shown).　Therefore, the excessive precipitation in the tropics in JRA-55 is most likely related to the dry bias and the spin-down problem of the forecast model in regions of deep convection.

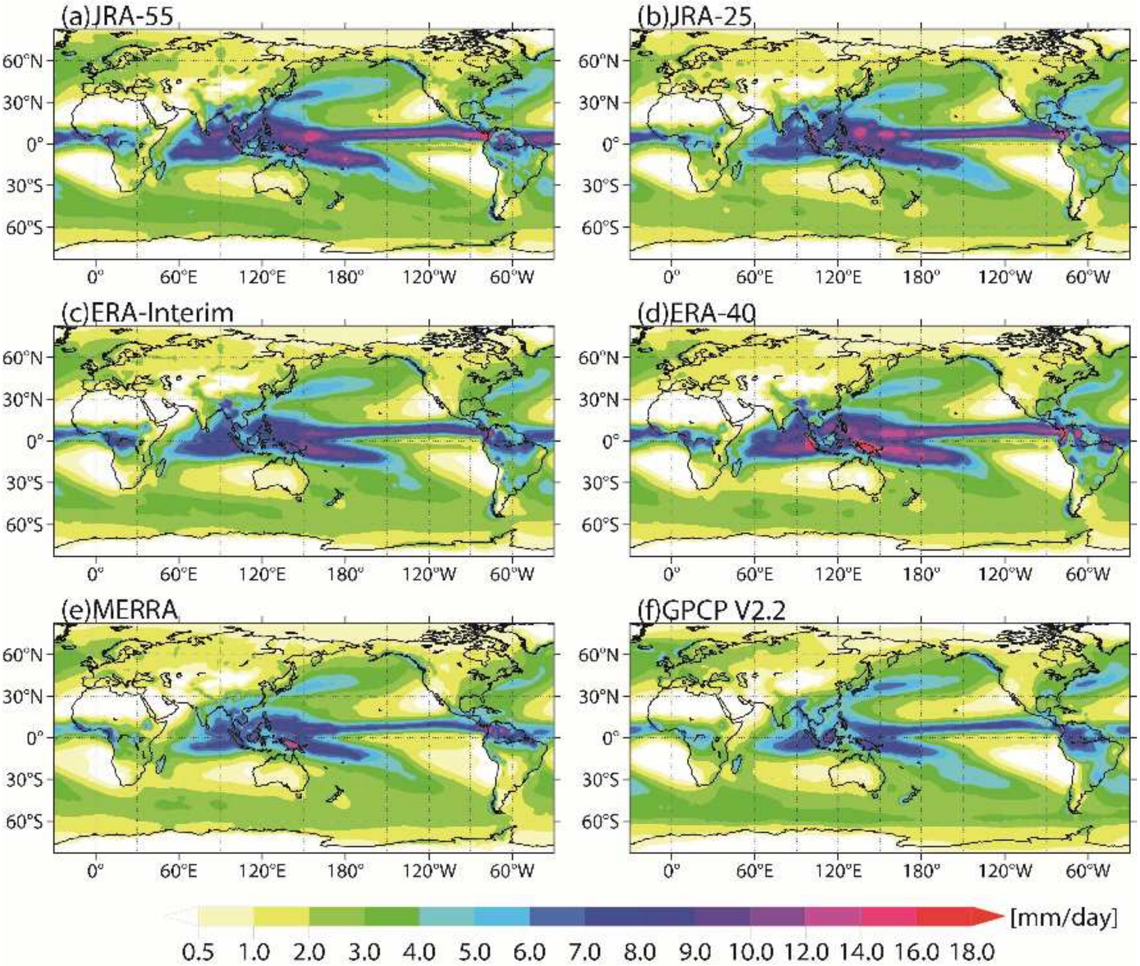

Figure 2 Climatological annual mean precipitations in (a) JRA-55, (b) JRA-25, (c) ERA-Interim, (d) ERA-40, (e) MERRA, and (f) GPCP V2.2, averaged over 1980–2001.

5. JRA-55 homepage

The JRA-55 data can be downloaded from the JRA-55 homepage (http://jra.kishou.go.jp/JRA-55/index_en.html) as shown in Figure 3. The data can be downloaded not only from JMA Data Distribution System (JDDS) but also DIAS managed by University of Tokyo, CCS of Tsukuba university, NCAR in the US, and ESGF of NASA. You are required only registration.

Figure 3　JRA-55 Homepage in English

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Introduction to GrADS

7. Lecture and exercise: Introduction to GrADS

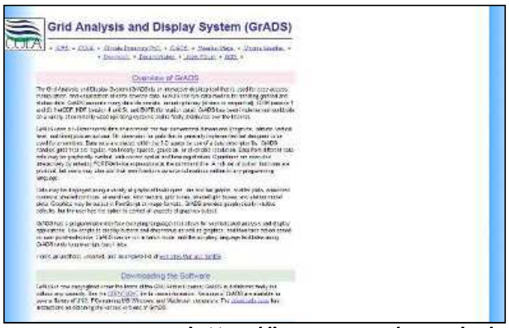
Climate Prediction Division
Japan Meteorological Agency

TCC Training Seminar on , Global Warming Projection Information

26 January 2015 (Tokyo, Japan)

What is GrADS

Introduce



http://iges.org/grads/

GrADS:
The Grid Analysis and Display System (GrADS) is an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data.

http://opengrads.org/

Open GrADS:
Windows users should install only one tool “OpenGrADS” .

The procedure for installing “OpenGrADS” is described website.

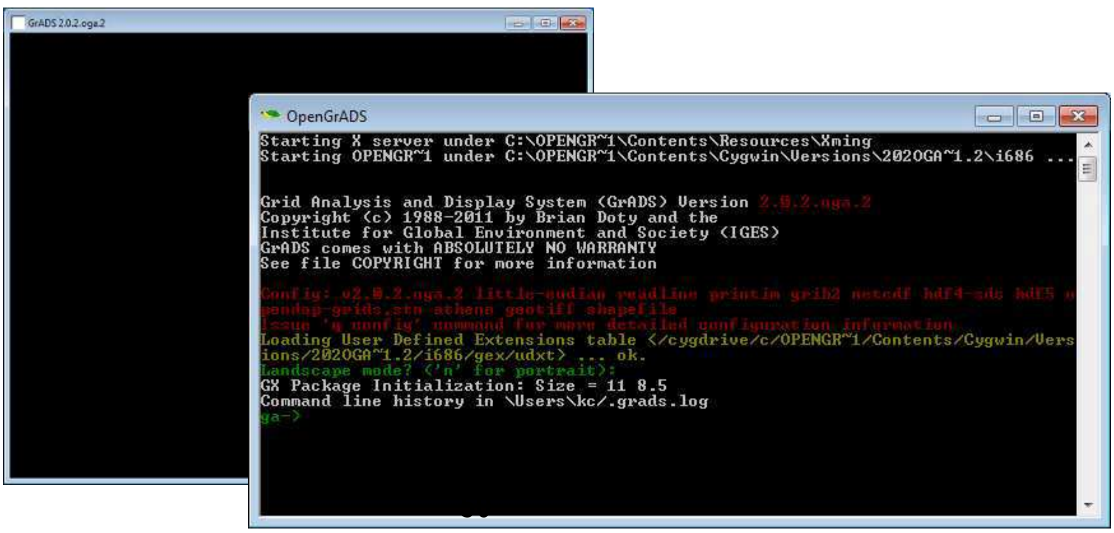
Practice

How to draw the JRA-55 data

Utilization of GPV

Click icon of “OpenGrADS” on your desktop.

Type “Enter” to “Landscape mode?”, then Open two windows.



Utilization of GPV

help

Gives a summary list of operations essential to do anything in GrADS.

```
ga-> help
```

```
For Complete Information See:  http://grads.iges.org/grads

Basic Commands:
 OPEN <descr>        opens a data file
 Query               shows current status
 Clear               clears graphics window
 SET <args>          sets options
 Display expr        displays a variable graphically
 QUIT                exits the program
```


Utilization of GPV

Basic command

Open a control file

```
ga-> open file_name
```

Draw contour map

```
ga-> display (or just d)  element_name
```

Clear display

```
ga-> clear (or just c)
```

Exit from GrADS

```
ga-> quit
```

Reinitial

```
ga-> reinit
```

Utilization of GPV

Setting and realizing work space

1. !pwd ：Show current directory.

```
ga-> !pwd
/cygdrive/c/OpenGrADS/Contents/Resources/SampleDatasets
```

To the external command, you need put a “!: exclamation mark” at the first.

2. cd *directory* ：Change directory to “/cygdrive/c/TCC_2014/Data”

```
ga-> cd  /cygdrive/c/OpenGrADS/TCC_2014
New directory: /cygdrive/c/OpenGrADS/TCC_2014/
```

3. !ls ： Show directorys and files in current directory.

```
ga-> !ls
 JRA55
```


Utilization of GPV

Initialize

4. reinit ：Initialize Grads to its initial state

```
ga-> reinit
No hardcopy metafile open
All files closed; all defined objects released;
All GrADS attributes have been reinitialized
```

Open datafile and realizing (1)

5. open *ctlfile* ： Open the grads control file

```
ga-> open JRA55/tas.clim.ctl
```

filename

```
Scanning description file:  JRA55/tas.clim.ctl
Data file JRA55/./data/tas.clim%m2.grd is open as file 1
LON set to 0 360
LAT set to -90 90
LEV set to 0 0
Time values set: 9999:1:1:0 9999:1:1:0
E set to 1 1
```

6. query *file* ： Get information about the grads control file

```
ga-> query file 1
```

```
File 1 :
  Descriptor: JRA55/tas.clim.ctl
  Binary: JRA55/./data/tas.clim%m2.grd
  Type = Gridded
  Xsize = 288  Ysize = 145  Zsize = 1  Tsize = 12  Esize = 1
  Number of Variables = 1
     tas  0  99  2m Temperature(K)
```

element

You have to remember this element name

Open datafile and realizing (2)

7. open *ctlfile* ： Open the grads control file

```
ga-> open JRA55/pr.clim.ctl
```

filename

```
Scanning description file:  JRA55/pr.clim.ctl
Data file JRA55/./data/pr.clim%m2.grd is open as file 2
```

8. query *file* ： Get information about the grads control file

```
ga-> query file 2
```

```
File 2 :
  Descriptor: JRA55/pr.clim.ctl
  Binary: JRA55/./data/pr.clim%m2.grd
  Type = Gridded
  Xsize = 288  Ysize = 145  Zsize = 1  Tsize = 12  Esize = 1
  Number of Variables = 1
     pr  0  99  Precipitation(mm/day)
```

element

You have to remember this element

Utilization of GPV

Set area and time

9. set lon *val1 val2* ： Set longitude to vary from *val1 val2*

```
ga-> set lon 0 360
LON set to 0 360
```

10. set lat *val1 val2* ： Set latitude to vary from *val1 val2*

```
ga-> set lat -90 90
LAT set to -90 90
```

11. set t *val* ： Set time at *val(month)*

```
ga-> set t 1
Time values set: 9999:1:1:0 9999:1:1:0
```


Utilization of GPV

Set map projection and resolution

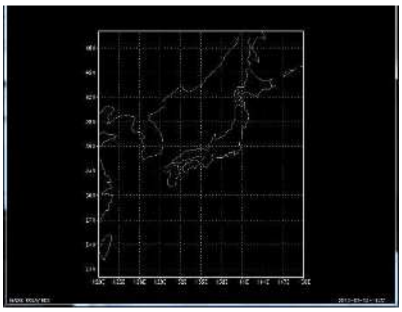
12. Set mproj *proj* ： Sets current map projection (*proj*：latlon,robinson,mollweide,orthogr etc...)

```
ga-> set mproj latlon
```

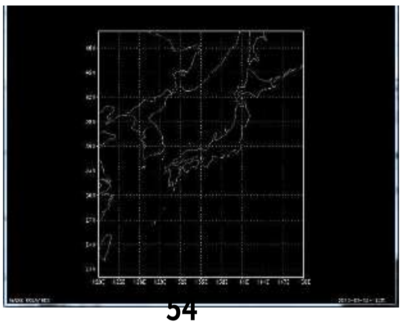
13. set mpdset *res* ： Set map data resolution (res：*lowres,mres ,hires*)

```
ga-> set mpdset lowres
MPDSET file name = lowres
```

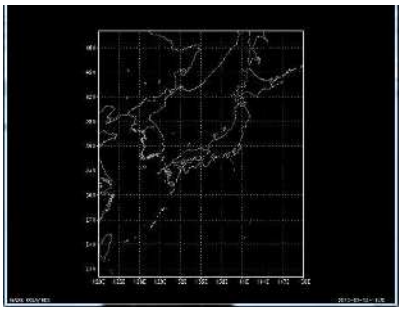
lowres



mres



hires



Set graphic colors

14. set gxout *graphics_type* ：Set graphics output types
(*graphics_type*：shaded,contour, grfill etc…)

```
ga-> set gxout shaded
```

15. define_colors ：Set colors

```
ga-> define_colors
```

16. set clevs *vals* ：Set contour levels

```
ga-> set clevs -12 -8 -4 0 4 8 12 16 20 24 28 32
Number of clevs = 12
```

17. set ccols *vals* ：Set color numbers

```
ga-> set ccols 9 14 4 11 5 13 3 10 7 12 8 2 6
Number of ccols = 13
```

Color index（rainbow color）

9	14	4	11	5	13	3	10	7	12	8	2	6

Set graphic contour colors

18. display *element* ：Display data via the graphics output window

```
ga-> display tas.1-273.15
Contouring at clevs = -12 -8 -4 0 4 8 12 16 20 24 28 32
```

K → degC

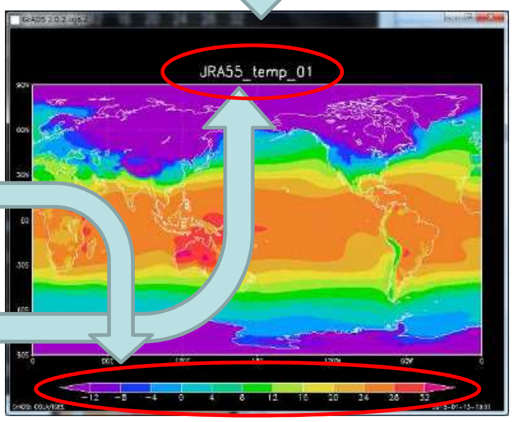
You can type just “d” instead “display”

19. cbarn：Draw a color bar next to shaded plots

```
ga-> cbarn
```

20. draw title *String*：Creating titles

```
ga-> draw title JRA55_temp_01
```



Utilization of GPV

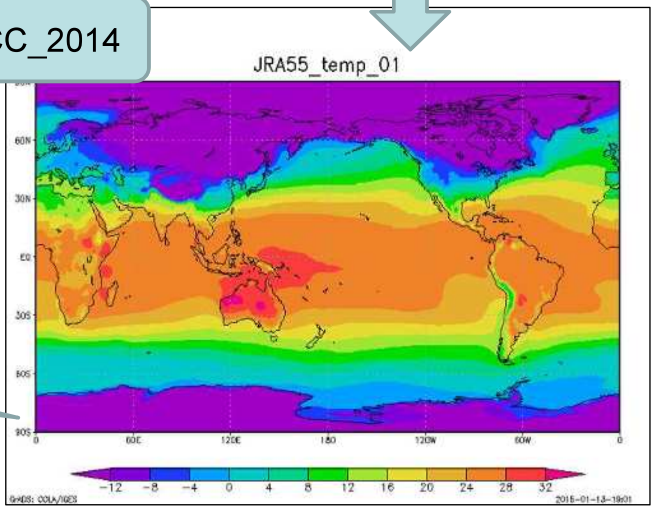
Output image files

21. printim *outfile colors* ：Produce a image file based on the current directory

```
ga-> printim  jra_tas_1.png  white
```

Check saved image file from explorer

▸ Computer ▸ Local Disk (C:) ▸ TCC_2014



background color is white

Utilization of GPV

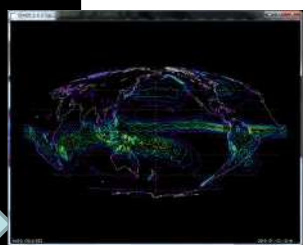
Set graphic contour colors and display data file 2

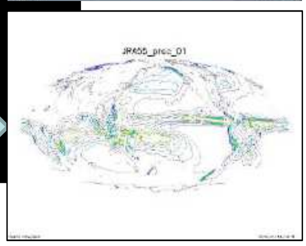
22. clear ：Clears graphics window

```
ga-> clear
```

You can type just "c" instead "clear"

```
ga-> set  gxout  contour
ga-> define_colors
ga-> set  clevs  0  2  4  6  8  10  12  14  16  18  20  22
Number of ccols = 13
ga-> set  ccols  9  14  4  11  5  13  3  10  7  12  8  2  6
Number of clevs = 12
ga-> set  mproj  mollweide
ga-> display  pr.2
Contouring at clevs =  0 2 4 6 8 10 12 14 16 18 20 22
ga-> draw  title  JRA55_prec_01
ga-> printim  jra_pre_1.png  white
```





Color index of GrADS

0	1	2	3	4	5	6	7

8	9	10	11	12	13	14	15

49	48	46	44	42	62	64	66	68	69

79	78	76	74	72	32	34	36	38	39

59	58	56	54	52	22	24	26	28	29

Check of reproducibility

9. Lecture and Exercise: Check of Reproducibility

CLIMATE PREDICTION DIVISION
JAPAN METEOROLOGICAL AGENCY

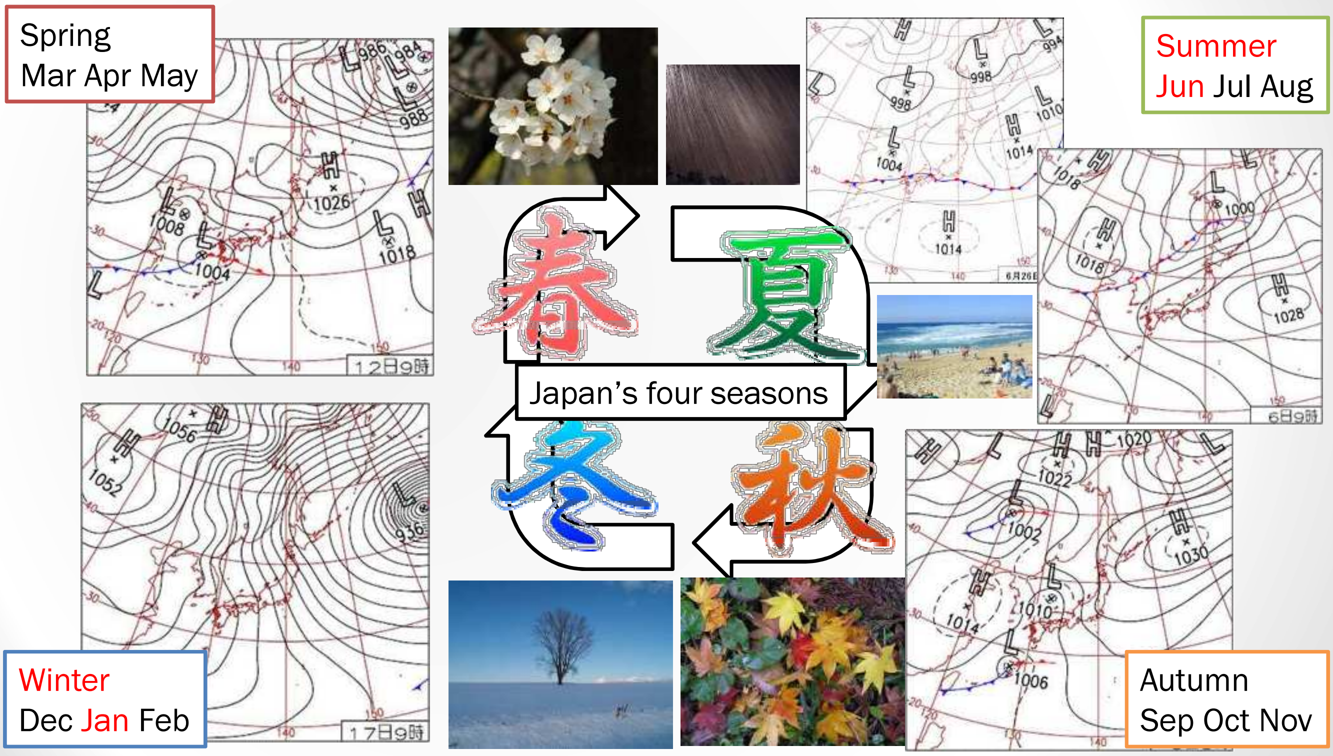
TCC Training Course,
27 January 2015 (JMA, Tokyo)

Why should we check the reproducibility?

- The reproducibility is judged by calculating the bias. Bias is defined here as Simulation minus Reanalysis.
  - $B = S - R$
  - Simulation is the forecast which is conducted by climate models.
  - Reanalysis is nearly the same as observation which we think of as true value.
- Simulation and Reanalysis cannot be exactly the same result. Every model has its own bias.
  - Based on physics, parameterizations and so on.
- If there are the areas the bias is as large as future changes, you should mention it when you say something about future changes in that area.
  - Bias correction is the way to overcome the problem, which adjusts present simulation to observation. For example, a simple way is:
    - $Future_{Bias\ corrected} = Future - (Present - Observation)$

We focus on Japan's climatology of January and June

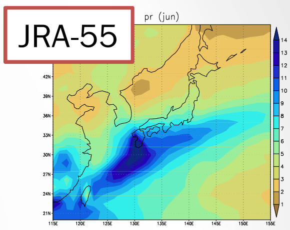
- Here we focus on analyzing the Japan's climatology of January (Winter) and June (Summer).



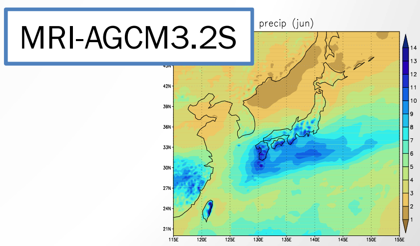
Photos are from Wikimedia Commons

Outline

1. Draw monthly mean climatology of Japan using JRA-55 reanalysis data.
   - □Monthly mean precipitation (mm/day)
   - □Monthly mean 2m temperature (℃)

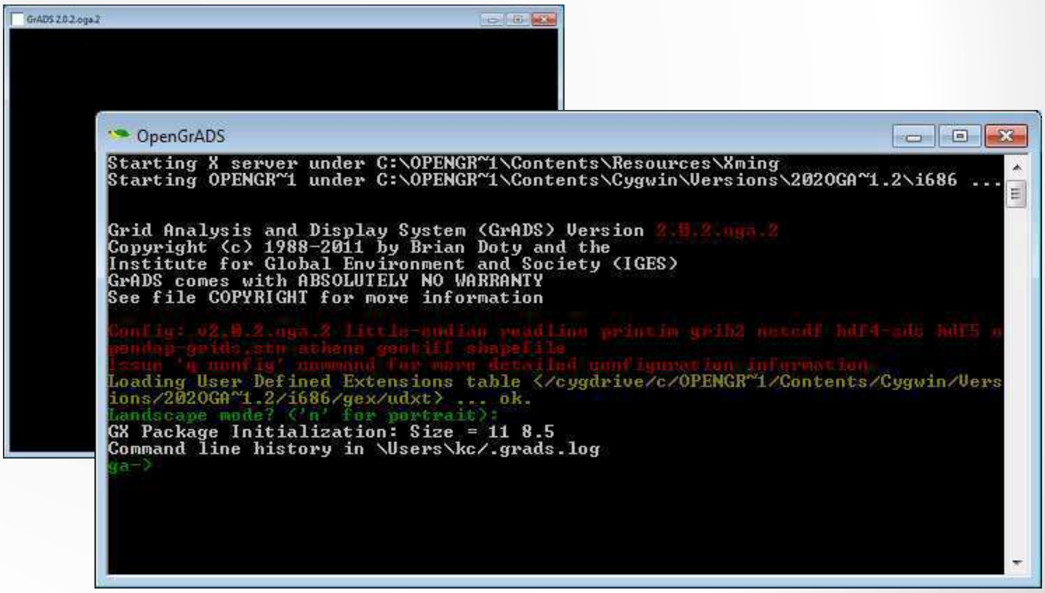


2. Compare the present climate simulated by MRI-CGCM3.2S with the JRA-55 climatology.
   - □Based on the reproducibility of MRI-CGCM3.2S, we have to analyze its future climate change.



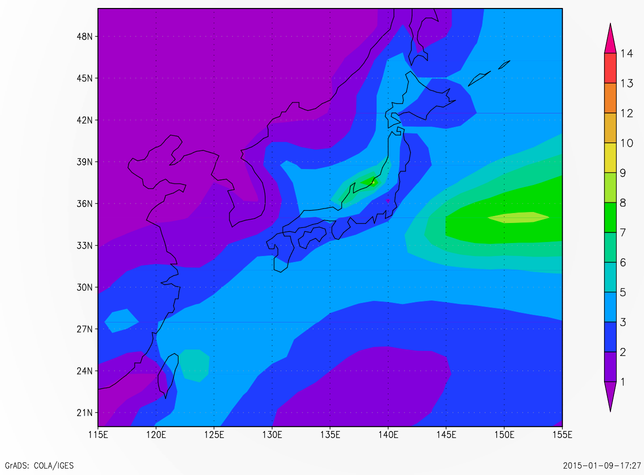
Using JRA-55 reanalysis data

1. Click the icon “OpenGrADS” on your desktop.
2. Type “Enter” to set Landscape mode.
3. Type “cd /cygdrive/c/DIRECTORY/Data” .



JRA-55 monthly mean precipitation (mm/day) (January)

JRA-55

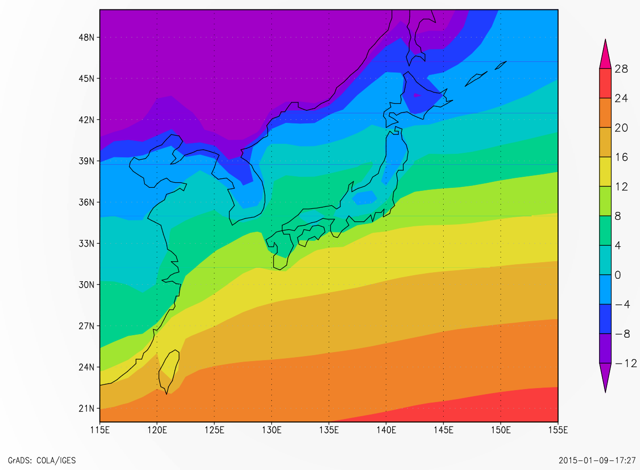



```
reinit
open JRA55/pr.clim.ctl
set gxout shaded
set lon 115 155
set lat 20 50
set clevs 1 2 3 4 5 6 7 8 9 10 11 12 13 14
set t 1
d pr
cbarn
printim pr-jan.png white
```

- reinit: Reinitializing the state
- open JRA55/pr.clim.ctl: Open a file
- set gxout shaded: Shaded contour plot
- set lon 115 155 / set lat 20 50: Longitude and latitude (115E~155E, 20N~50N)
- set t 1: January
- d pr: Display data
- cbarn: Color bar script. To use simply, just type “cbarn”.
- printim pr-jan.png white: Save as png

JRA-55 monthly mean 2m temperature (℃) (January)

JRA-55

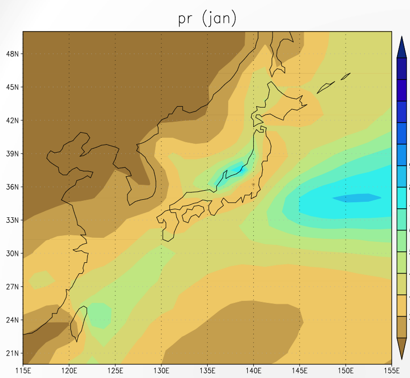



```
reinit
open JRA55/tas.clim.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set clevs -12 -8 -4 0 4 8 12 16 20 24 28

set t 1

d tas-273.15
cbarn

printim tas-jan.png white
```

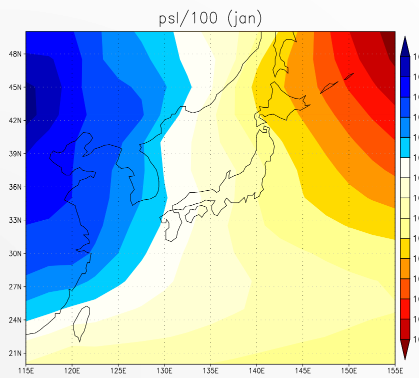
K → degC

JRA-55 monthly mean climatology of Japan (January)

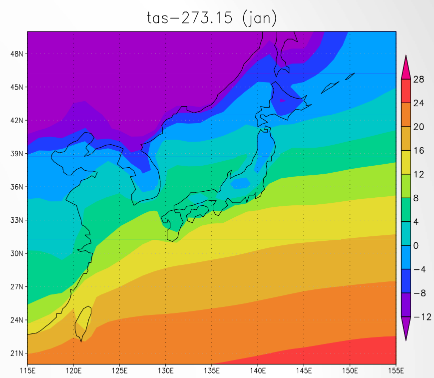
Precipitation (mm/day)



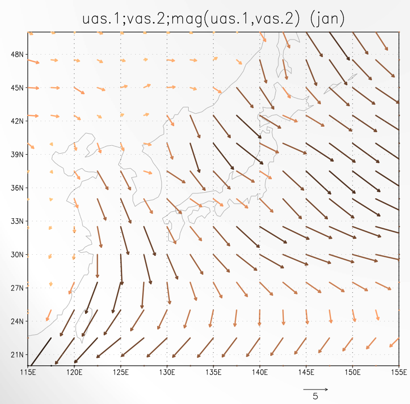
Sea Level Pressure (hPa)



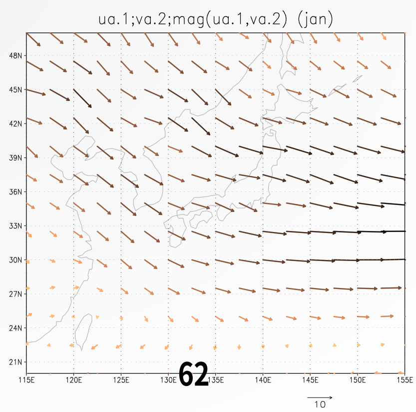
2m Temperature (℃)



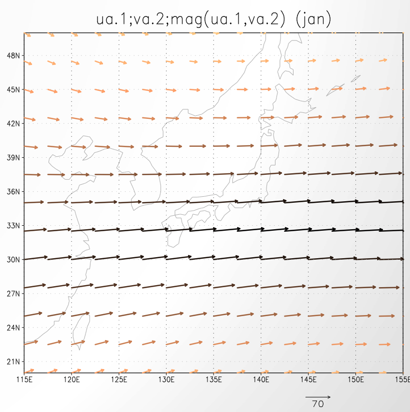
Near-Surface Wind (m/s)



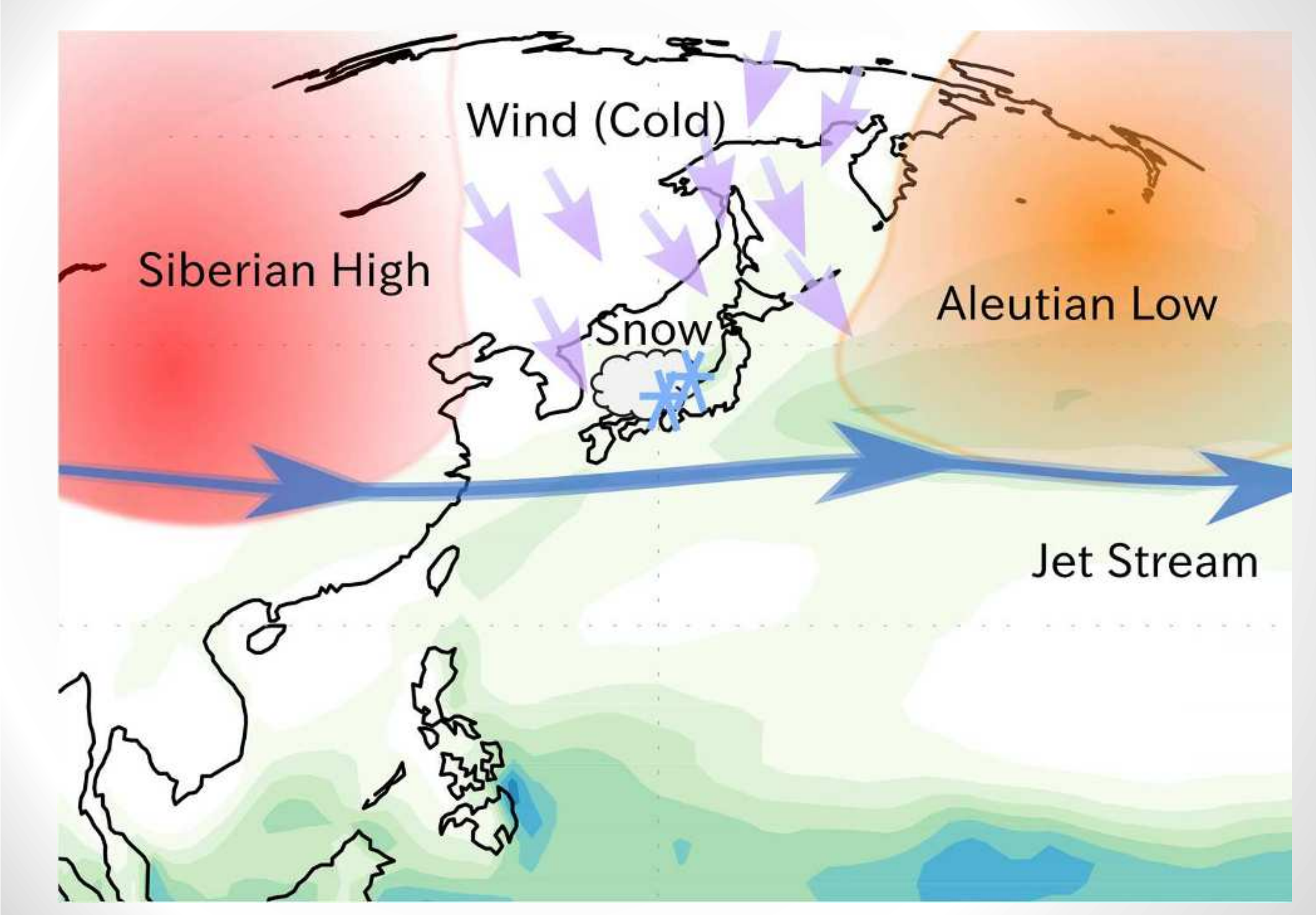
Wind (m/s) at 850 hPa



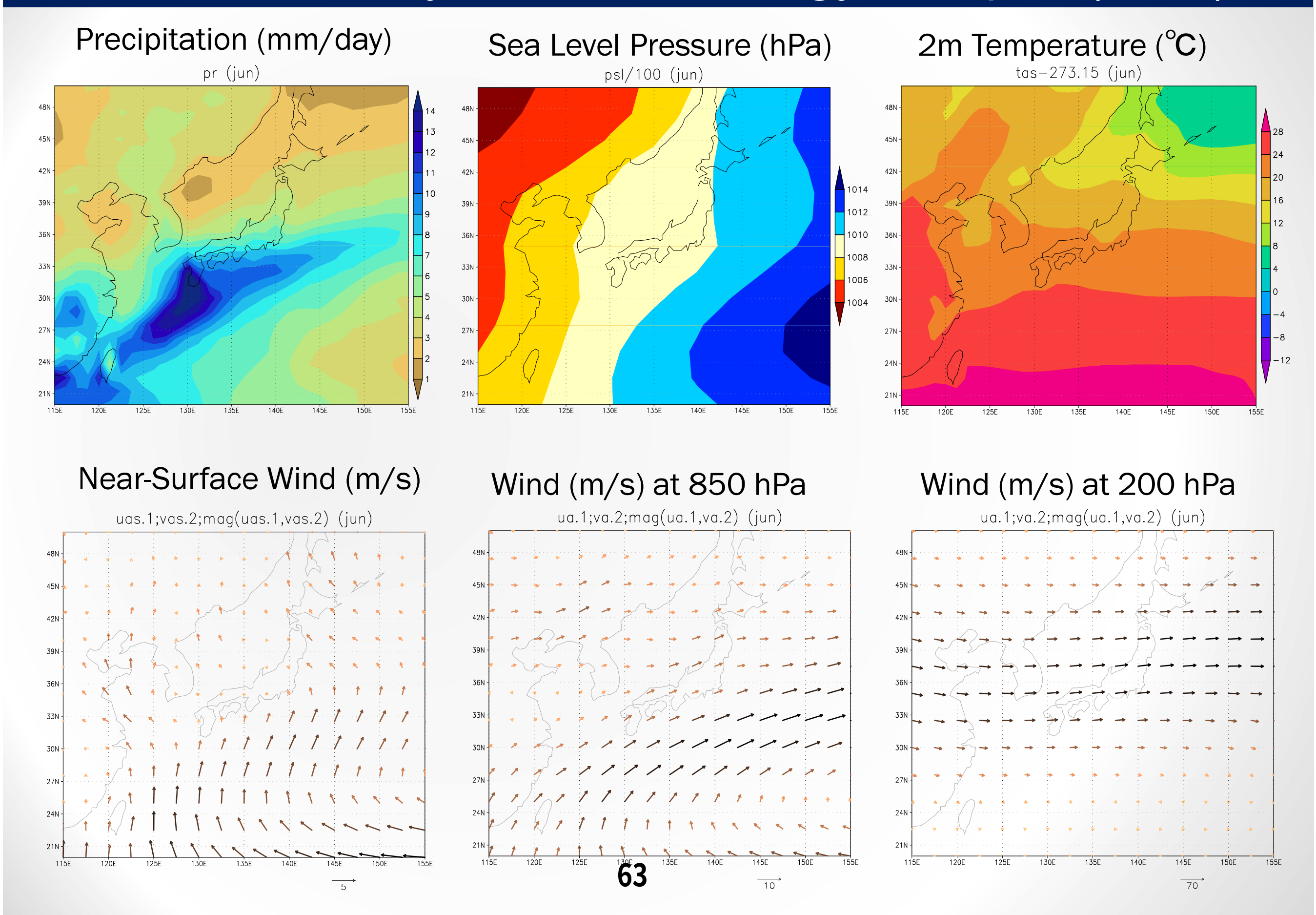
Wind (m/s) at 200 hPa



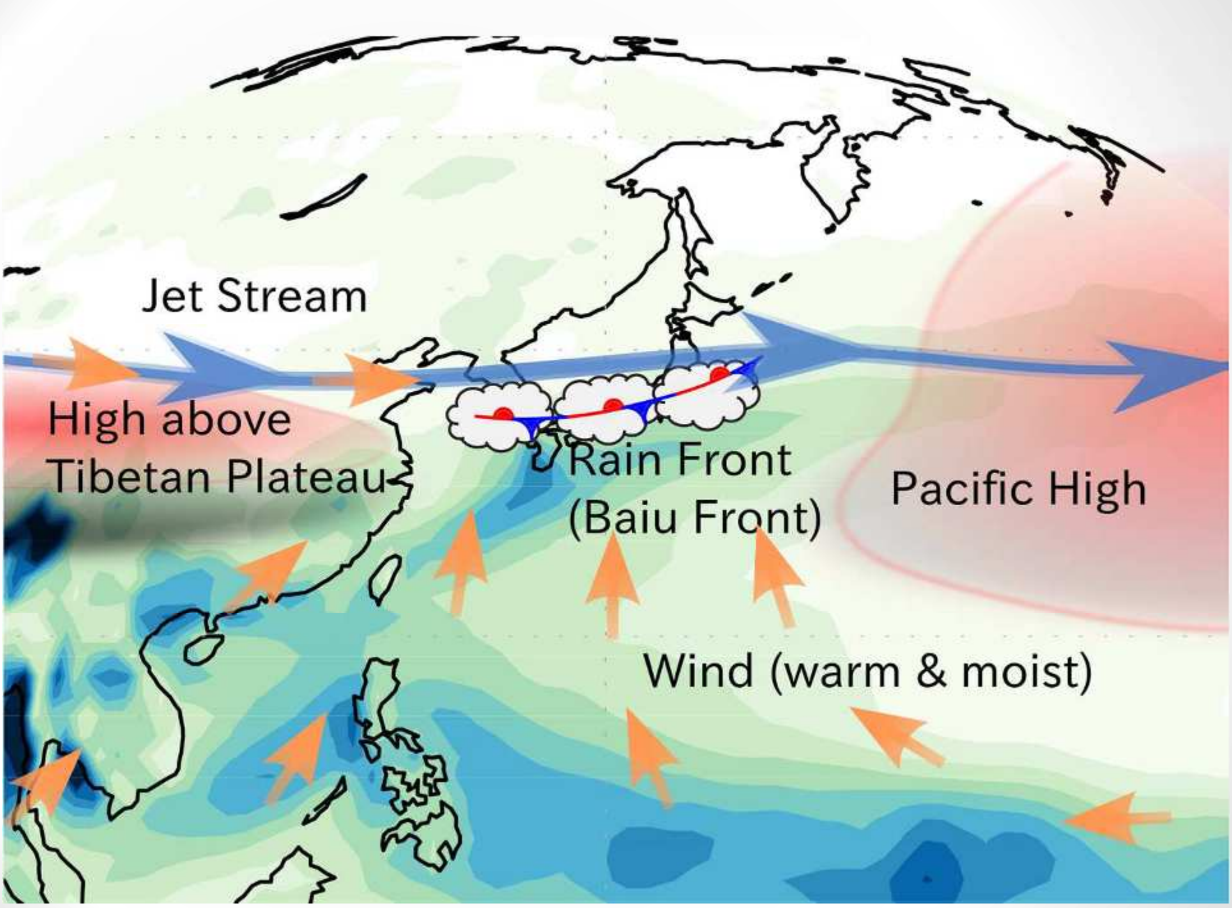
Schematic climatology of Japan (January)



JRA-55 monthly mean climatology of Japan (June)

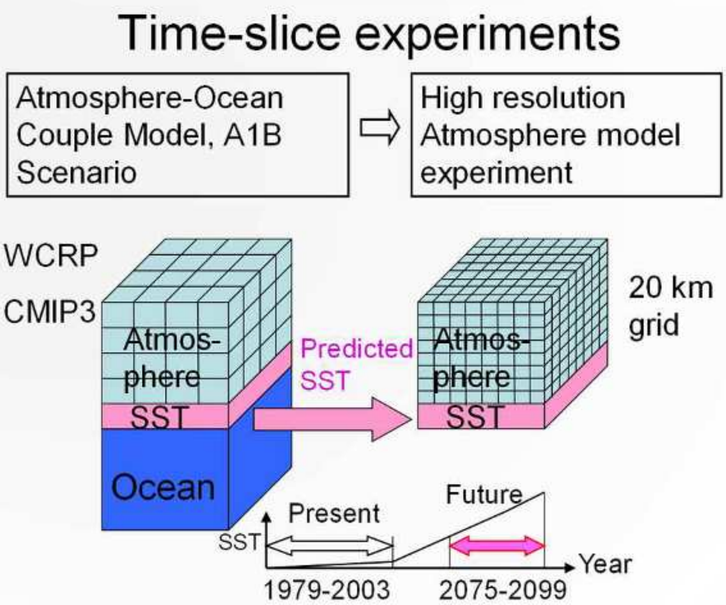


Schematic climatology of Japan (June)



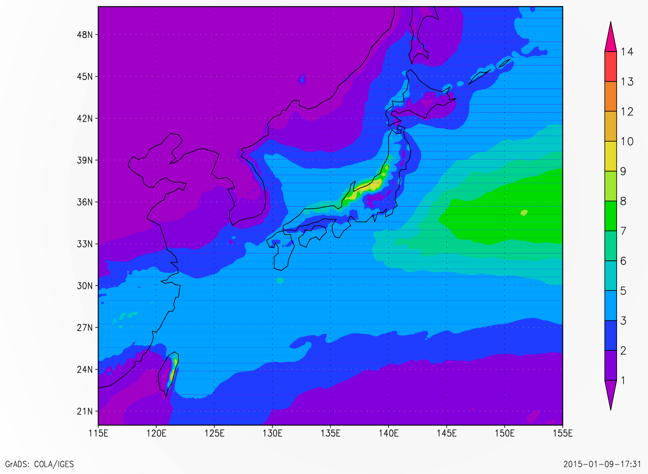
AGCM present-day simulation data

- We have conducted global warming projections using an Atmospheric General Circulation model (AGCM) with 20-km mesh (MRI-AGCM3.2S).
- Present-day simulation was conducted between 1979-2003.



AGCM monthly mean precipitation (mm/day) (January)

MRI-AGCM3.2S

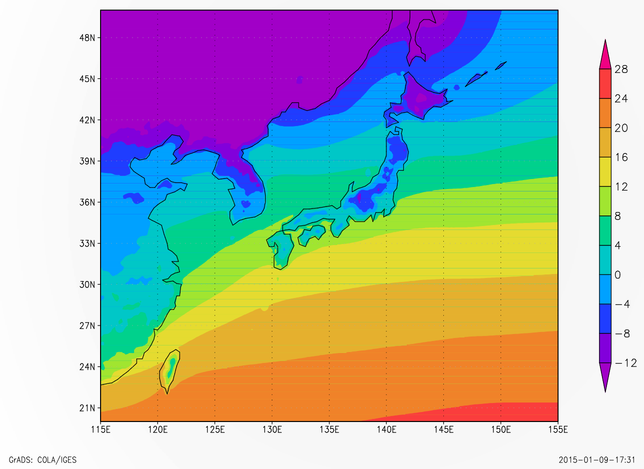



```
reinit
open AGCM/precip-P.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set clevs 1 2 3 4 5 6 7 8 9 10 11 12 13 14

set t 1

d precip
cbarn

printim precip-P-jan.png white
```

January

AGCM monthly mean 2m temperature (℃) (January)

MRI-AGCM3.2S

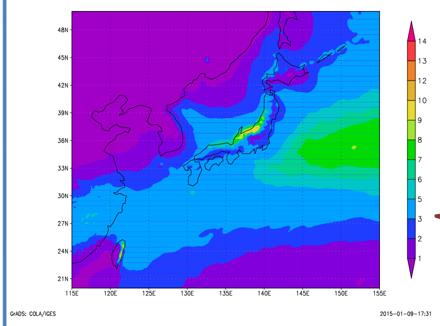



```
reinit
open AGCM/t2m-P.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set clevs -12 -8 -4 0 4 8 12 16 20 24 28

set t 1

d t2m
cbarn

printim t2m-P-jan.png white
```

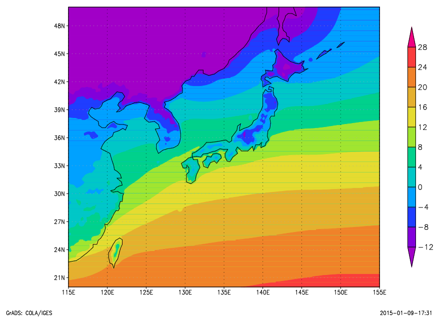
AGCM monthly mean climatology of Japan (January)

MRI-AGCM3.2S

Precipitation (mm/day)



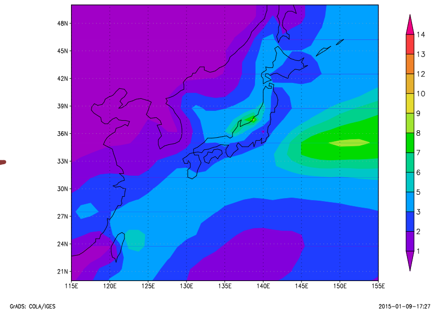
2m Temperature (℃)



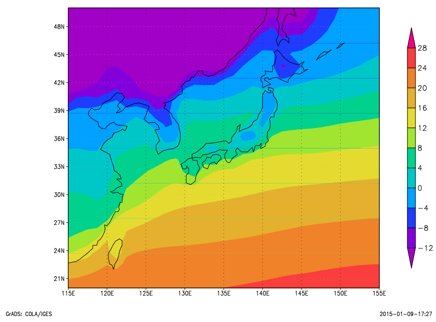
What's the difference?

JRA-55

Precipitation (mm/day)

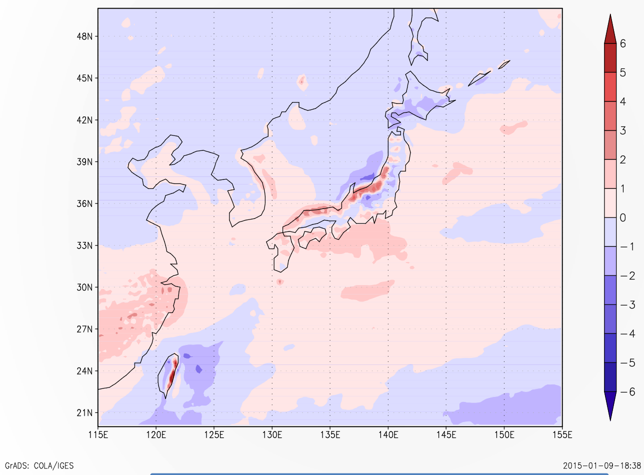


2m Temperature (℃)



AGCM monthly mean precipitation bias (mm/day) (January)

MRI-AGCM3.2S - JRA-55



Iterp performs interpolation which is needed to compare between different resolution results.

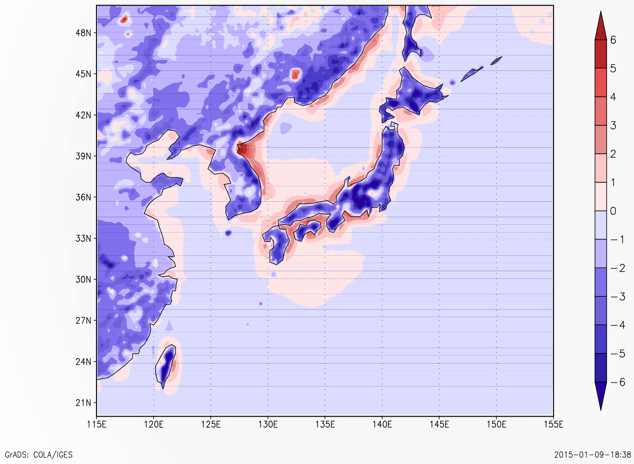
```
reinit
open JRA55/pr.clim.ctl
open AGCM/precip-P.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set clevs -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
define_colors
set rbcols 59 58 57 56 55 54 53 52 51 61
62 63 64 65 66 67 68 69

d precip.2(t=1)-lterp(pr.1(t=1),precip.2(t=1))
cbarn

printim precip-bias-jan.png white
```

Set colors manually

January

AGCM monthly mean 2m temperature bias (℃) (January)

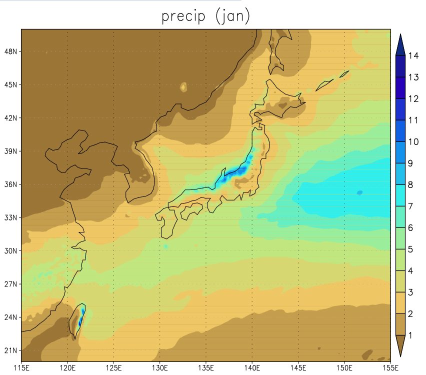
MRI-AGCM3.2S - JRA-55




```
reinit
open JRA55/tas.clim.ctl
open AGCM/t2m-P.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set clevs -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
define_colors
set rbcols 59 58 57 56 55 54 53 52 51 61
62 63 64 65 66 67 68 69

d t2m.2(t=1)-lterp(tas.1(t=1),t2m.2(t=1))+273.15
cbarn

printim t2m-bias-jan.png white
```

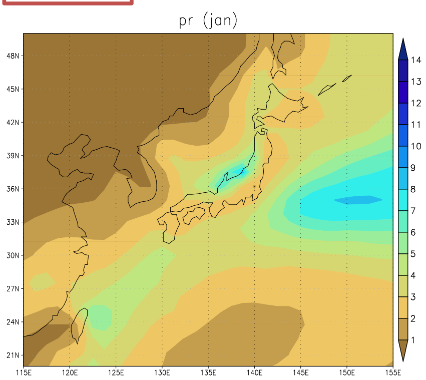
AGCM monthly mean climatology bias (January)

MRI-AGCM3.2S



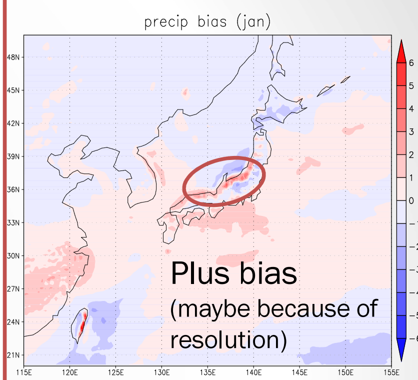
Precipitation (mm/day)

JRA-55



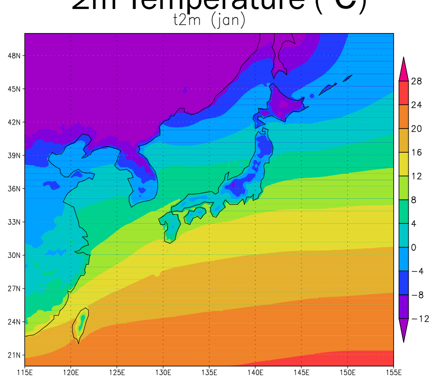
Precipitation (mm/day)

MRI-AGCM3.2S - JRA-55

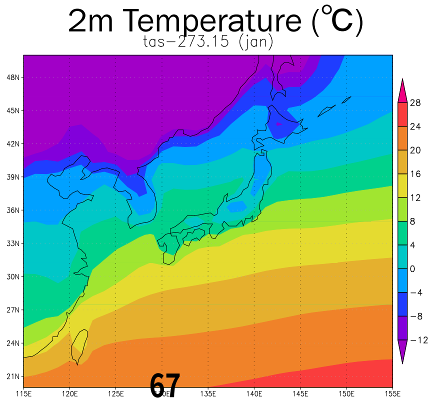


Precipitation (mm/day)

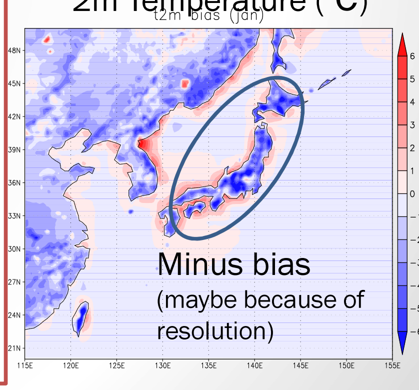
2m Temperature (℃)



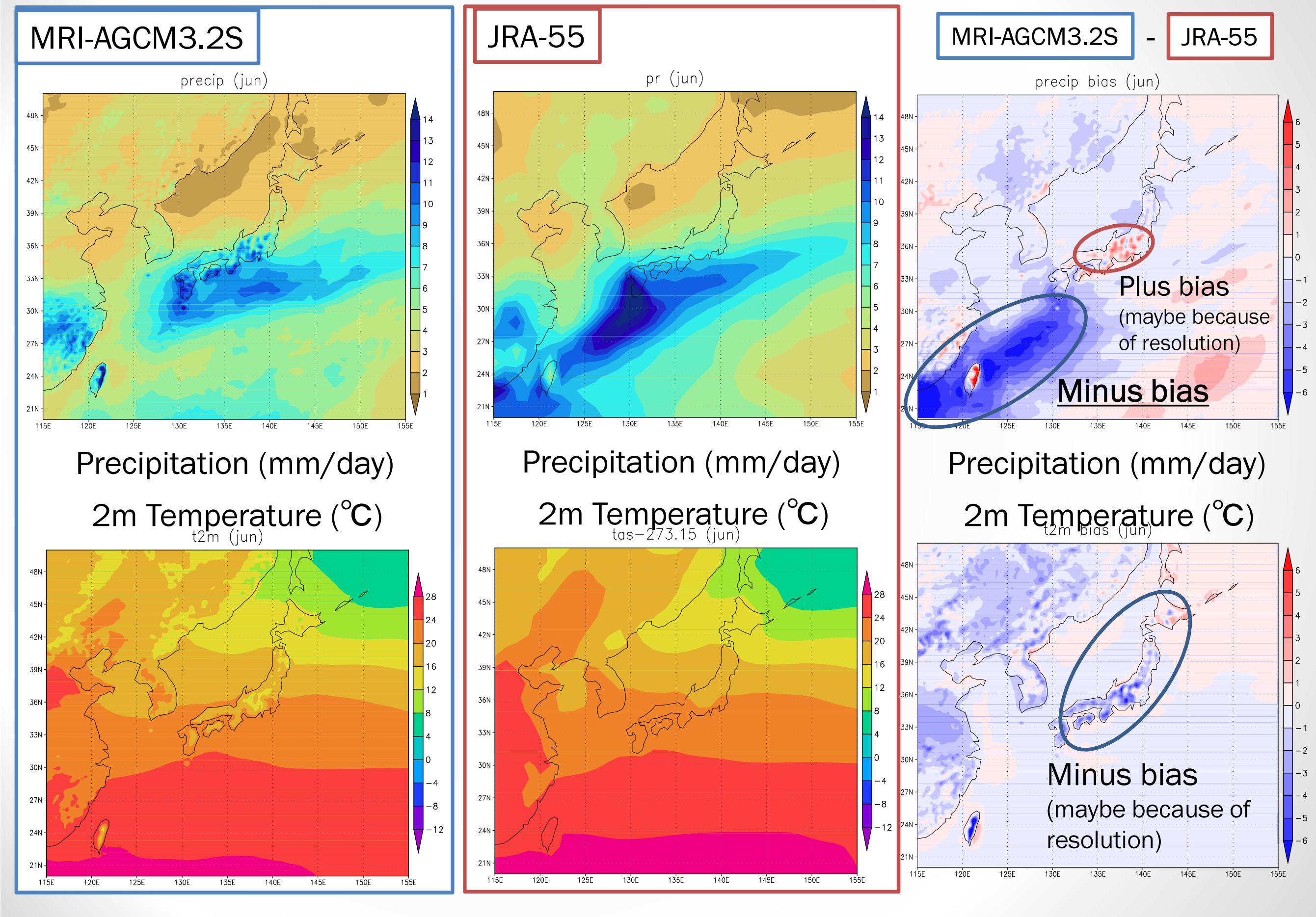
2m Temperature (℃)



2m Temperature (℃)

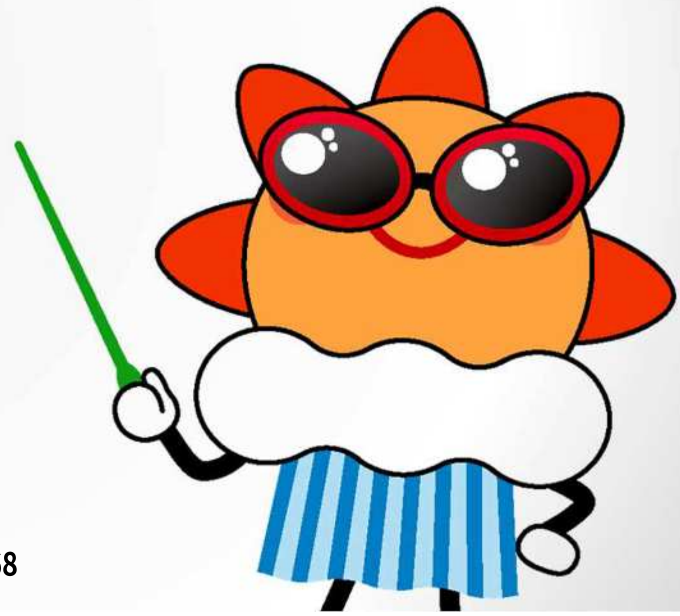


AGCM monthly mean climatology bias (June)



And it's your turn!

■Follow today's procedure and check the AGCM's reproducibility for your country.

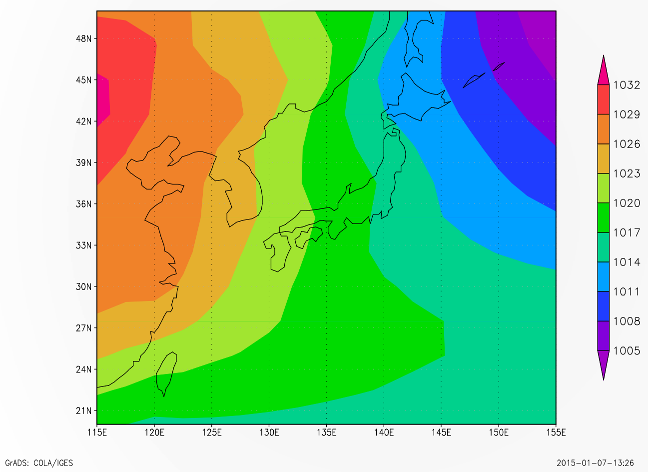


FROM JRA-55

FURTHER READING: OTHER ELEMENTS

Sea Level Pressure (hPa) (January)

JRA-55

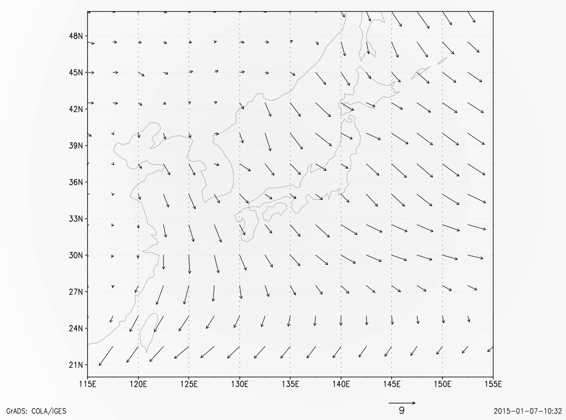



```
reinit
open JRA55/psl.clim.ctl
set gxout shaded

set lon 115 155
set lat 20 50

set t 1

d psl/100
cbarn
```

Pa → hPa

Near-Surface Wind (m/s) (January)

JRA-55

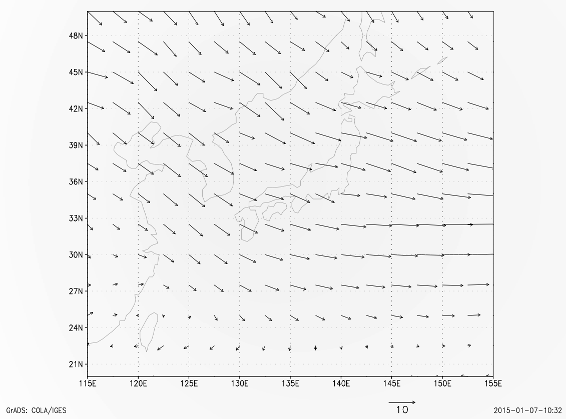


```
reinit
open JRA55/uas.clim.ctl
open JRA55/vas.clim.ctl

set lon 115 155
set lat 20 50

set t 1

d uas.1;vas.2
```

Display as vectors

Wind (m/s) at 850 hPa (January)

JRA-55

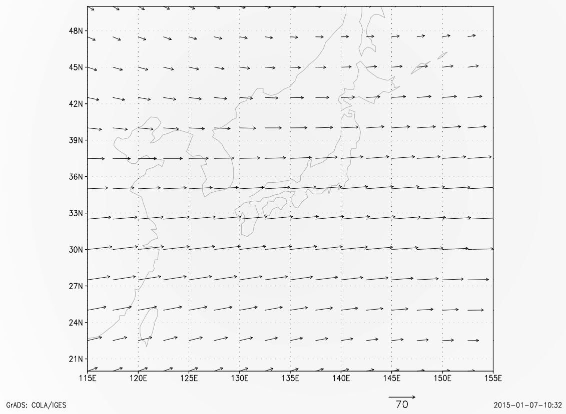


```
reinit
open JRA55/ua.clim.ctl
open JRA55/va.clim.ctl

set lon 115 155
set lat 20 50

set lev 850
set t 1

d ua.1;va.2
```

at 850 hPa

Wind (m/s) at 200 hPa (January)

JRA-55




```
reinit
open JRA55/ua.clim.ctl
open JRA55/va.clim.ctl

set lon 115 155
set lat 20 50

set lev 200
set t 1

d ua.1;va.2
```

at 200 hPa

Assessment of future climate change

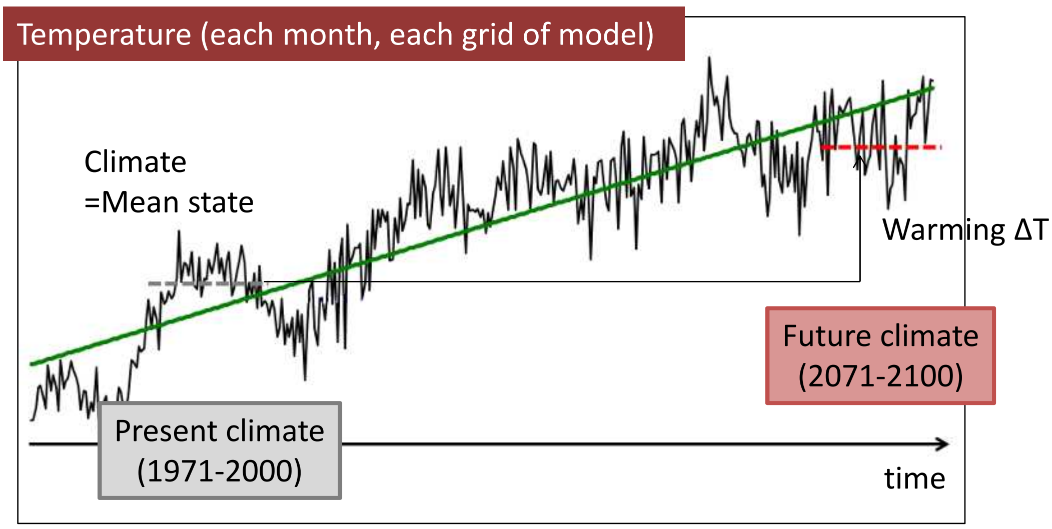
Lecture and exercise: Assessment of future climate change

TCC Training Seminar on Global Warming Projection Information @JMA

26 – 30 January 2015

Future climate change

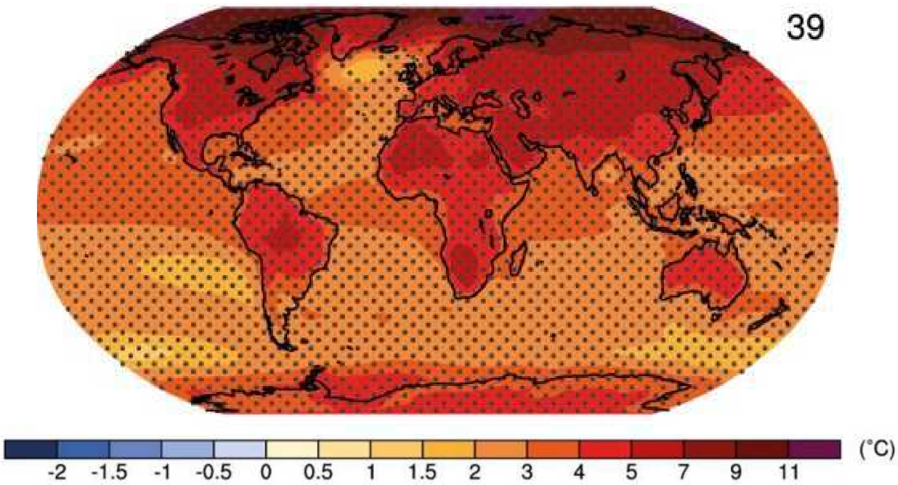
- Compare future climate (2071-2100) with present climate(1971-2000) .



- The predictability of annual to decadal mean in the future is no confidence.
- “Future climate” will be partially determined by external forcing due to human activity. (an ability to predict future climate)

IPCC AR5 change in temperature

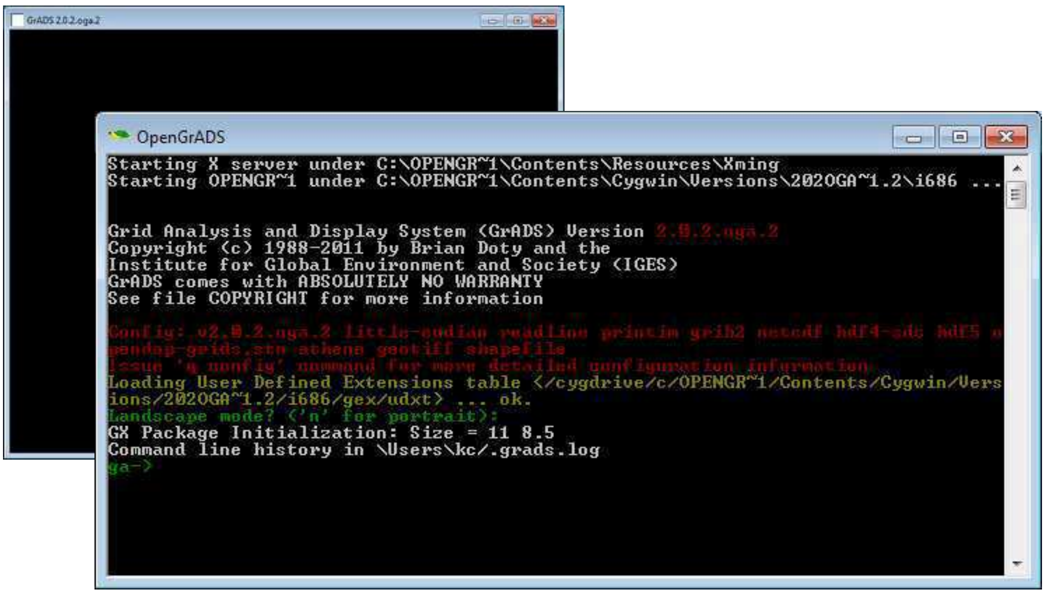
Projected change in temperature from models, annual mean relative to present climate for future climate.



- Temperature will continue to rise over the 21st century if greenhouse gas emissions continue unabated.
- Temperature change will not be regionally uniform.
- Warming over land will be larger than over the ocean.
- The region at high latitude will warm more rapidly.

Future change climate using GrADS

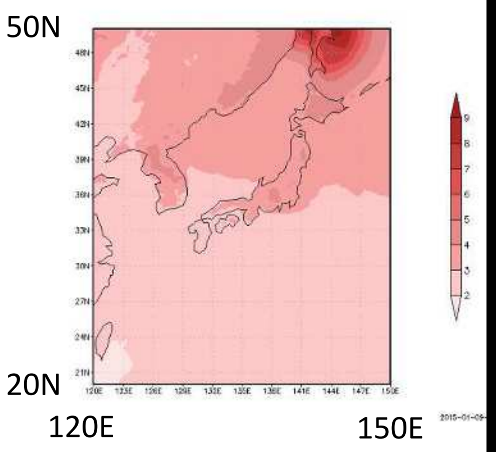
Click the icon "OpenGrADS" on your desktop.



Try to display the following data

- present climate
- Future climate
- Comparison of future climate with present climate

Future change temperature using GrADS




```
ga-> reinit
ga-> open file1.ctl
ga-> open file2.ctl

ga-> set lat 20 50
ga-> set lon 120 150
ga-> set t 1

gs-> set gxout shaded
gs-> define_colors
ga-> set clevs 2 3 4 5 6 7 8 9 10
ga-> set ccols 61 62 63 64 65 66 67 68 69

ga-> d elm.2 - elm.1

ga-> cbarn

ga-> printim pngfile1.png white
```

Open the GrADS control files

Modify the area of interest (ex. Japan)

Set monthly (ex. January)

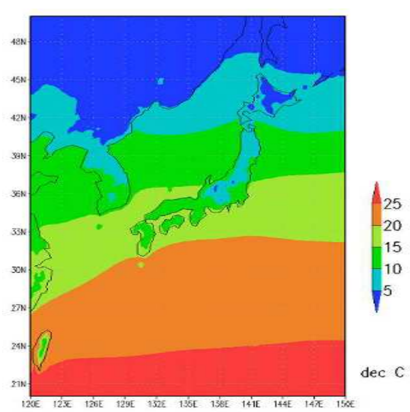
Set graphics output types
Set contour levels
Set color numbers

Calculate the difference between Future climate and Present climate

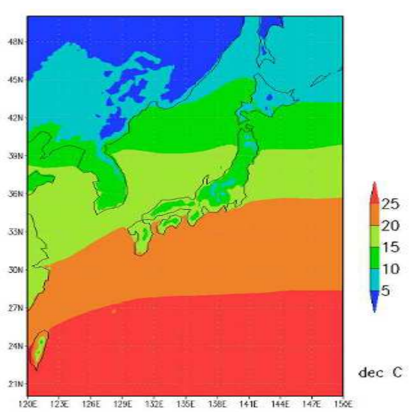
Use GrADS Scripts to draw a color bar next to shaded plots

Save your map

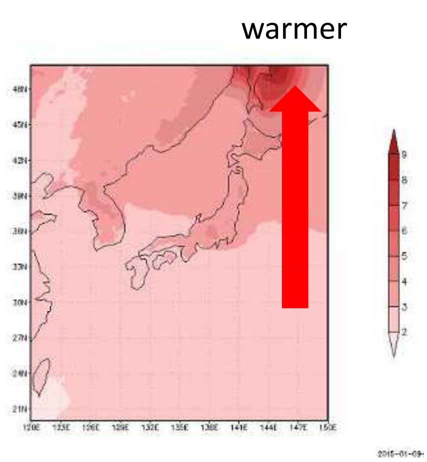
Discussion : change in surface air temperature



Present climate
(1971-2000)



Future climate
(2071-2100)



Change(Future - Present)

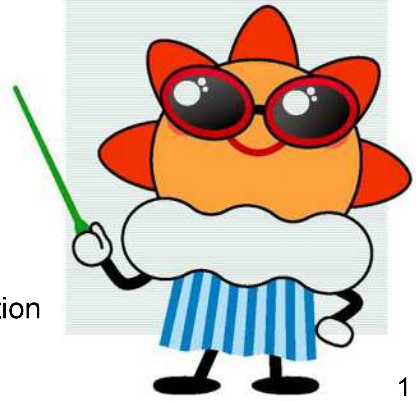
- ✓ Temperatures around Japan are projected to increase between 2 to 4 deg C.
- ✓ The largest temperature increases are projected at high latitude.

Uncertainty check of the results

XI. Lecture and Exercise: Uncertainty Check of the Results

Hirokazu Murai
Climate Prediction Division
Japan Meteorological Agency

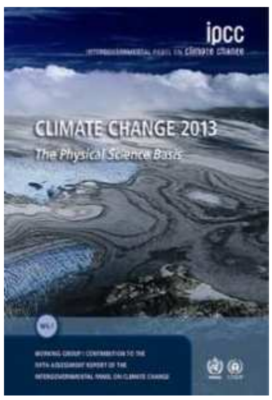
TCC Training Seminar on , Global Warming Projection Information
27 January 2015 (Tokyo, Japan)



1

Uncertainties in global warming prediction

- Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions. (WG1 AR5 SPM)



2

Uncertainties in global warming prediction

- However, the global warming prediction contains many uncertainties.

- Therefor, we cannot say the results are correct predictions without considering the uncertainties.

It is necessary to consider the uncertainties !!

3

Uncertainties in global warming prediction

- There are two check points.

1. Reproducibility
   a. Incompleteness of climate model
   b. Regionality

2. Contingency
   a. Natural internal variability
   b. Short period for calculation
   c. Regionality

4

Check of reproducibility

1. Reproducibility
   a. Incompleteness of climate model
   b. Regionality

- Compare the model value and the observed data in selected area and selected element.
- Can the results reproduce characteristic phenomenon ?
- Let's analyze considering the confirmed error.

5

Check of contingency

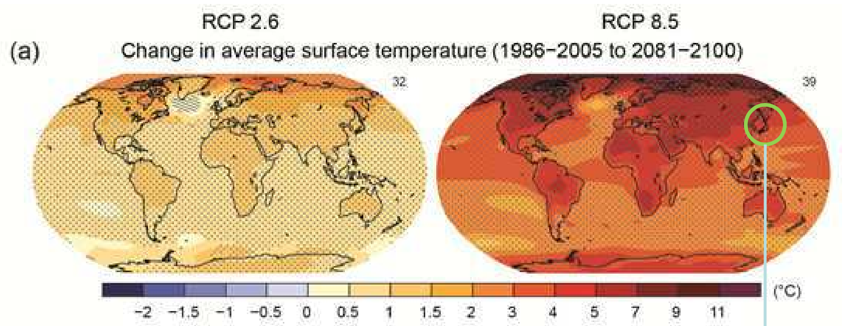
2. Contingency
   a. Natural internal variability
   b. Short period for calculation
   c. Regionality

- Check points.
  - Can you qualitatively explain the predicted results ?
  - Are these predicted results consistent with the predicted results of other elements ?
  - Are these predicted results consistent with the global predicted results?
  - Are these predicted results consistent with the predicted results of other area ?
- How to check them ?
  - Let’s check the AR5 for a knowledge of global and regional.
  - Try to check the predicted result of changing area and elements.

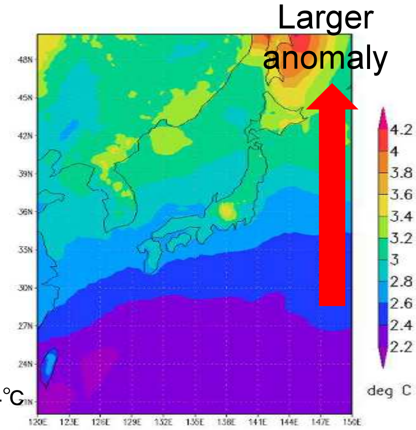
6

Uncertainty Check of the Results

Larger anomaly



More change over about 4℃



AR5 WG1 Fig SPM-8(a)

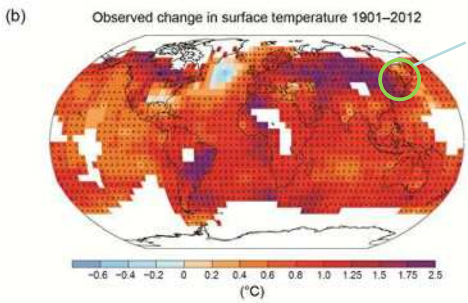
Change (F–P)

✓ Both results are similar in pattern and magnitude after accounting for scenario differences.

7

Use of IPCC AR5

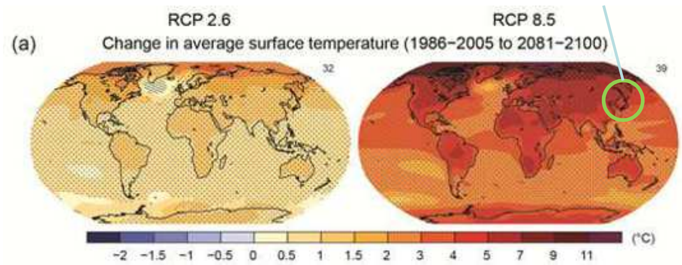
Example,



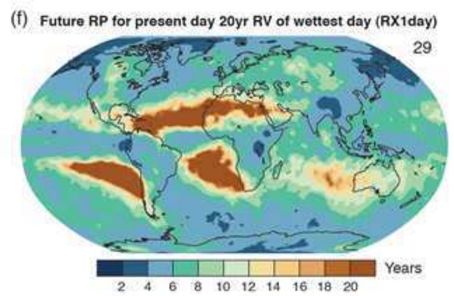
Change over 1.5℃

FigSPM-1(b)

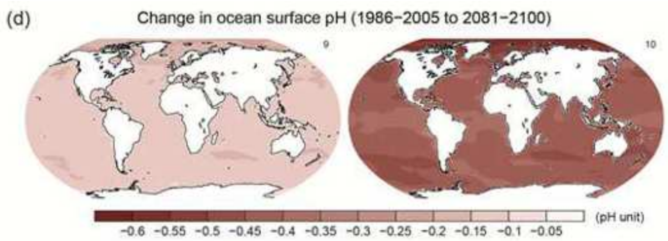
More change over about 4℃



FigSPM-8(a)



TFE.9, Figure 1(f)



FigSPM-8(d)

8

Use of IPCC AR5

Example,

Figure TS.26

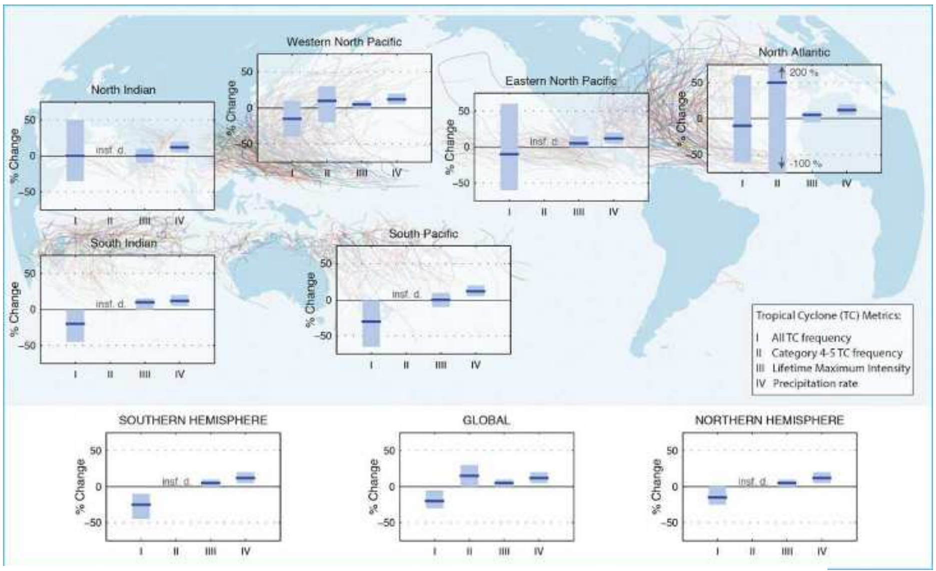


Table SPM.1 (excerpt)

Phenomenon and direction of trend	**Likelihood of further changes**	
	Early 21st century	**Late 21st century**
Increases in intense tropical cyclone activity	*Low confidence* {11.3}	***More likely than not*** in the Western North Pacific and North Atlantic[j] {14.6}
		More likely than not in some basins *Likely*