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Understanding the complexities and uncertainties of climate change for effective adaptation to changing extreme weather events

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Background and objective

- Growing concerns about climate stress
  - resilience is an issue of the realization of smart cities
  - e.g., increases in sea level affect low-lying communities
- Complexities and uncertainties in climate information
  - occur in understanding of key climate and societal processes
  - affect decision making for mitigation of anticipated climate change and adaptation to changing environments
- Focus on adaptation to changing extreme weather events
  - in particular, tropical cyclones (TCs) that severely affect coastal regions
  - using a concept of pattern scaling to cope with the complexities and uncertainties of possible intensification of TCs
  - key uncertainties: socio-economic development that affect emissions, global climate response to radiative forcing, regional changes in climate elements (temperature, winds, etc.), changes in natural climate variability

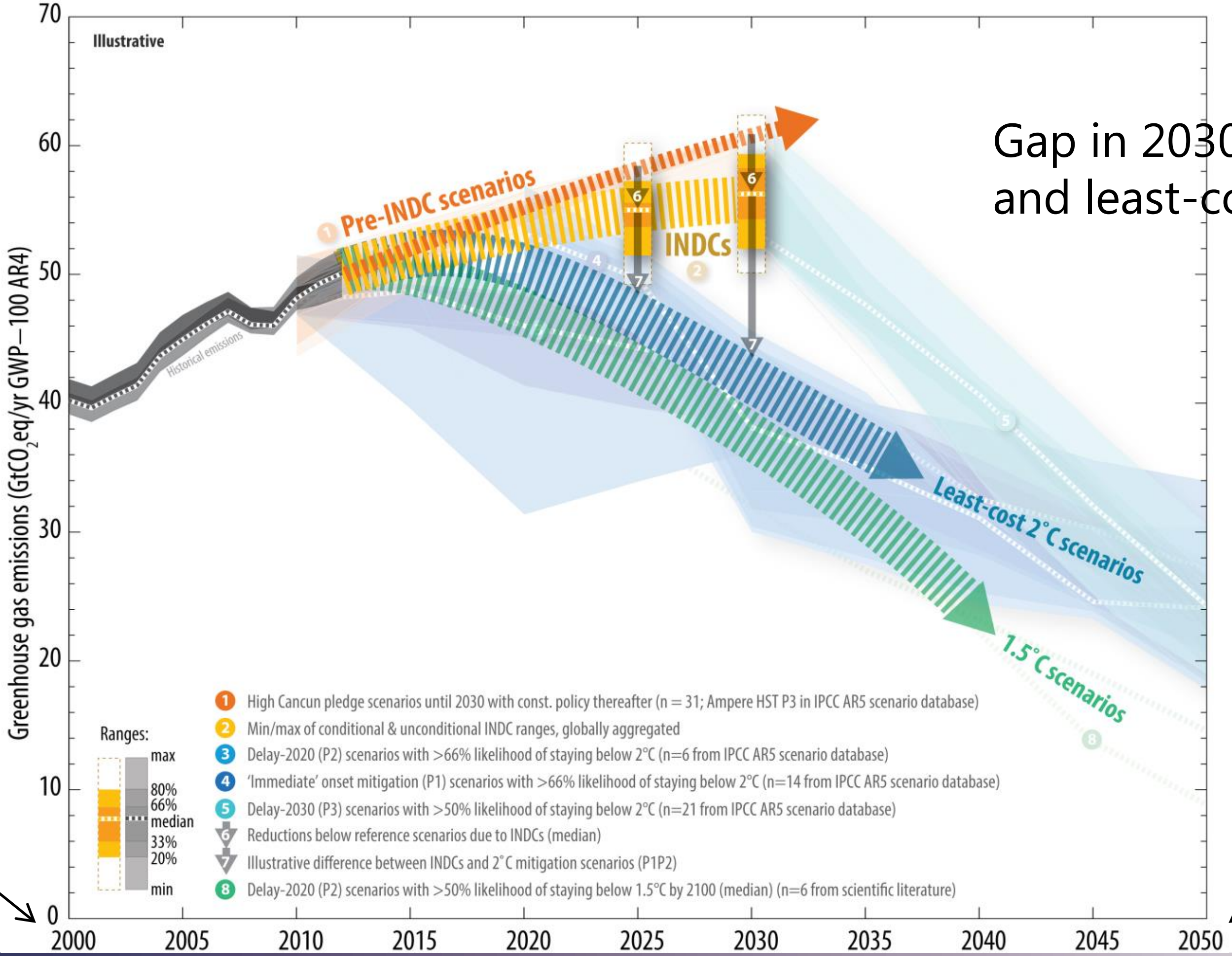
Paris Agreement

- Aims to strengthen the global response to the threat of climate change by
  - Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels,
  - Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, …
- In order to achieve the long-term temperature goal
  - Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, …, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, …

Gaps between the goal and reality

Comparison of global emission levels in 2025 and 2030 resulting from the implementation of the intended nationally determined contributions (NDCs) and under other scenarios.

Greenhouse gas emissions ($GtCO_2$)



Gap in 2030 between NDCs and least-cost 2 °C scenarios

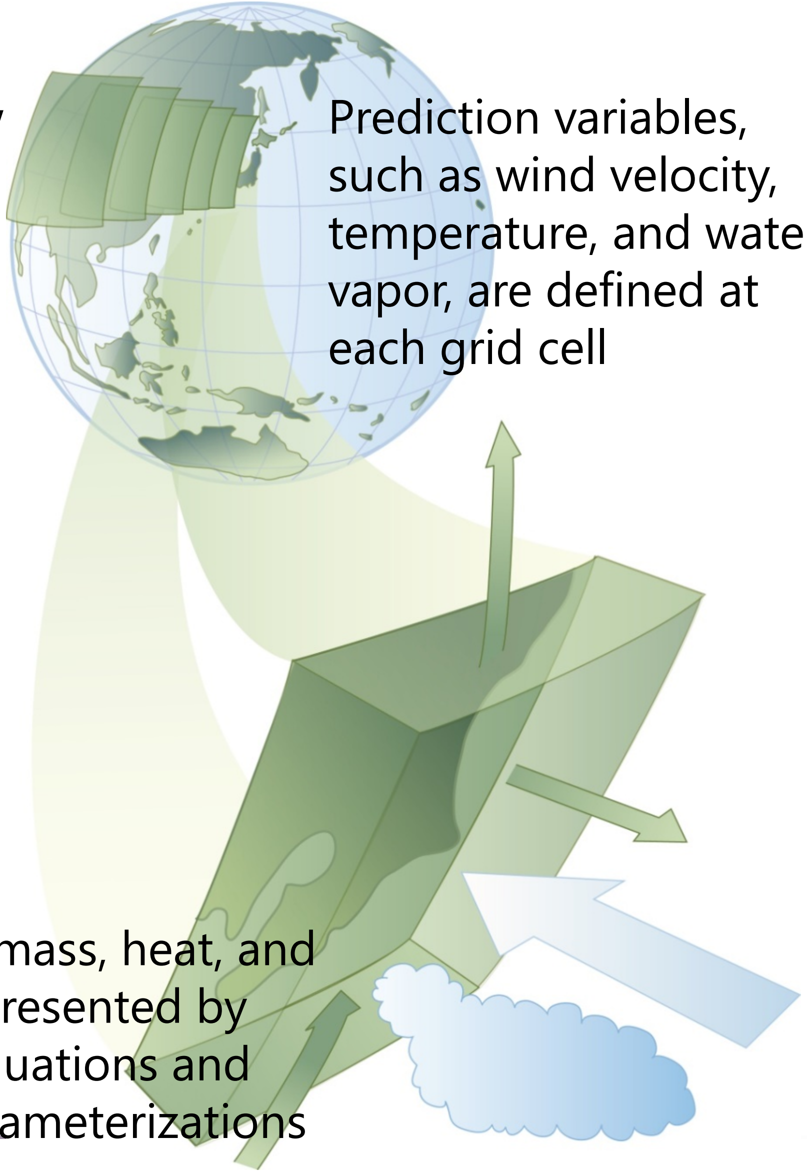
Source: UNFCCC secretariat (2016)

2000

2050

Climate model

- A numerical representation of the climate system consisting of the atmosphere, ocean, land, sea-ice, etc.
  - basic equations on a computation grid system
  - empirical schemes (parameterizations) for sub-grid scale phenomena
- A hierarchy of models of varying complexity differing in
  - the number of spatial dimensions,
  - the extent to which physical, chemical, or biological processes are explicitly represented,
  - or the level at which empirical parameterizations are involved



Prediction variables, such as wind velocity, temperature, and water vapor, are defined at each grid cell

Exchange of mass, heat, and water are represented by dynamical equations and empirical parameterizations

Hierarchy of climate models

increasing complexity →

Simple climate model

Atmosphere general circulation model (AGCM)

Regional climate model

Atmosphere-ocean coupled general circulation model (AOGCM)

Earth system model

	Simple model	Complex model (GCM)
Dimension	Reduced	Three-dimensional
Typical resolution	Globally averaged	~100 km
Model structure	Linear box model with key parameters tuned to GCM	Discretized nonlinear equations with parameterized physics
Computing load	Negligible	High (resolution dependent)
Application	Integrated assessment for many scenarios	Basic information on detailed climate change projections
Handling uncertainty	Use of different sets of parameters based on a PDF	Use of ensemble climate predictions by different models

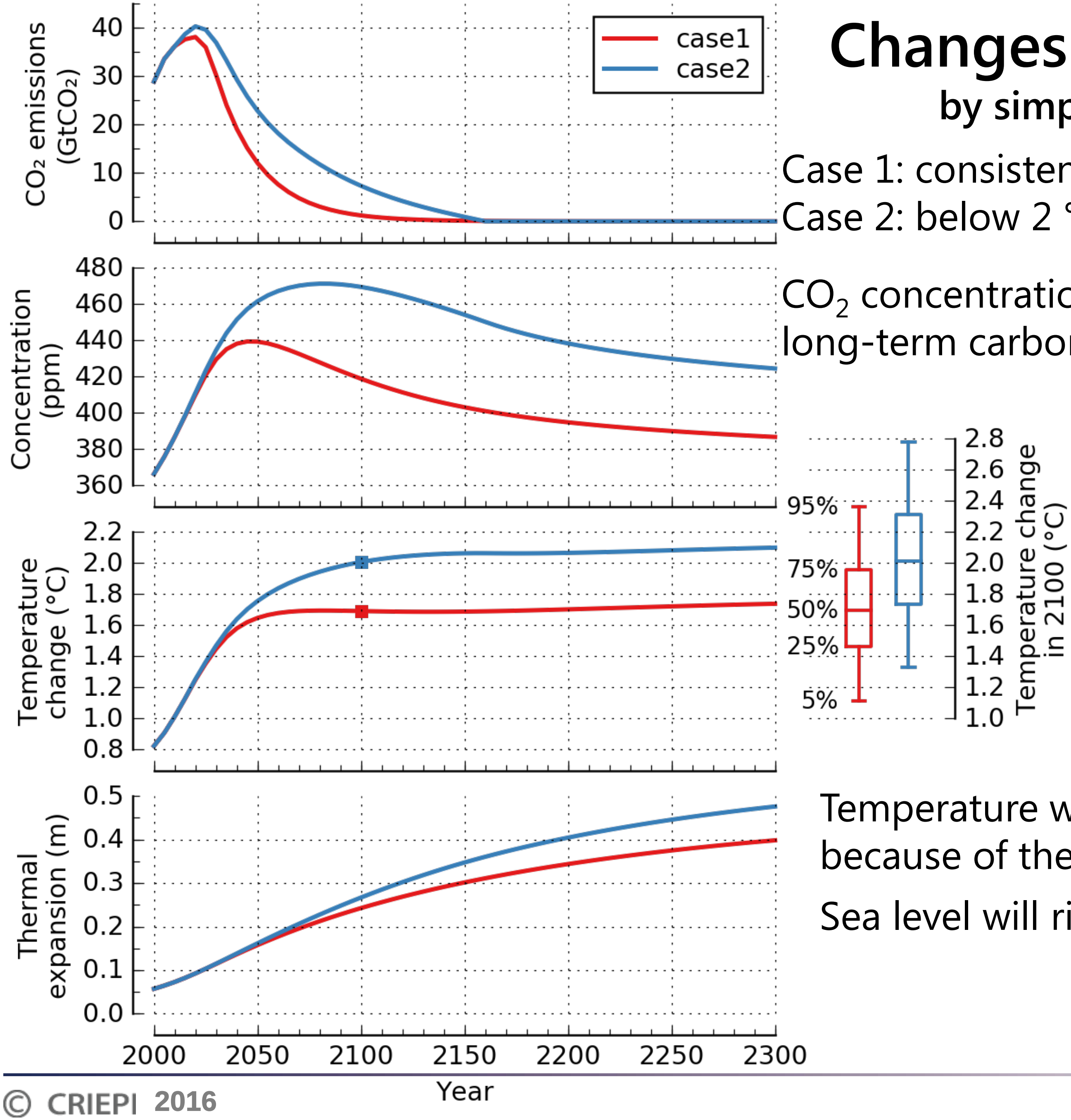
PDF: probability density function

Changes in mean states

by simple climate model

Case 1: consistent with the mitigation goal
Case 2: below 2 °C with 50% probability

CO_2 concentration will decrease due to long-term carbon uptake by the ocean



Probability distributions reflect differences of multiple complex models (Tsutsui, 2016)

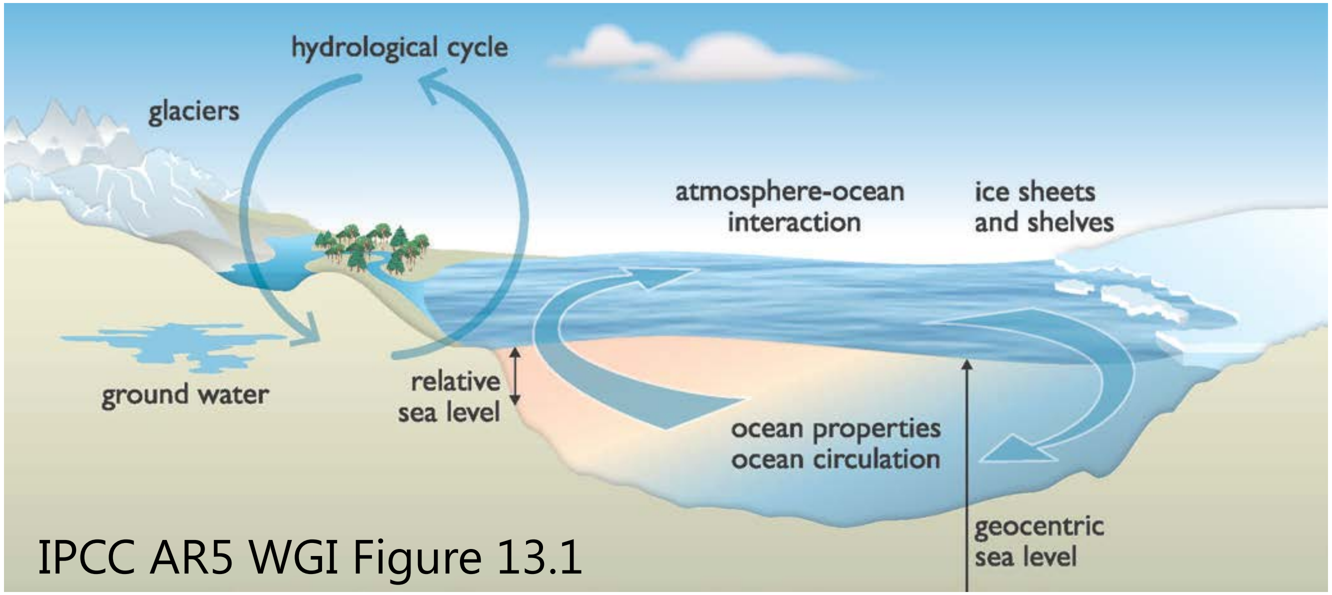
Temperature will not decrease soon because of thermal inertia of the ocean

Sea level will rise on a millennial scale

Factors of sea-level rise

- Global mean sea-level rise
  - Thermal expansion of sea water
  - Decrease in ice over land
  - Reduction of liquid water storage on land

- Local and short-term variability
  - Processes associated with melting ice
  - Climatic variability
  - Storms and ocean vortices
  - Vertical land motion



IPCC AR5 WGI Figure 13.1

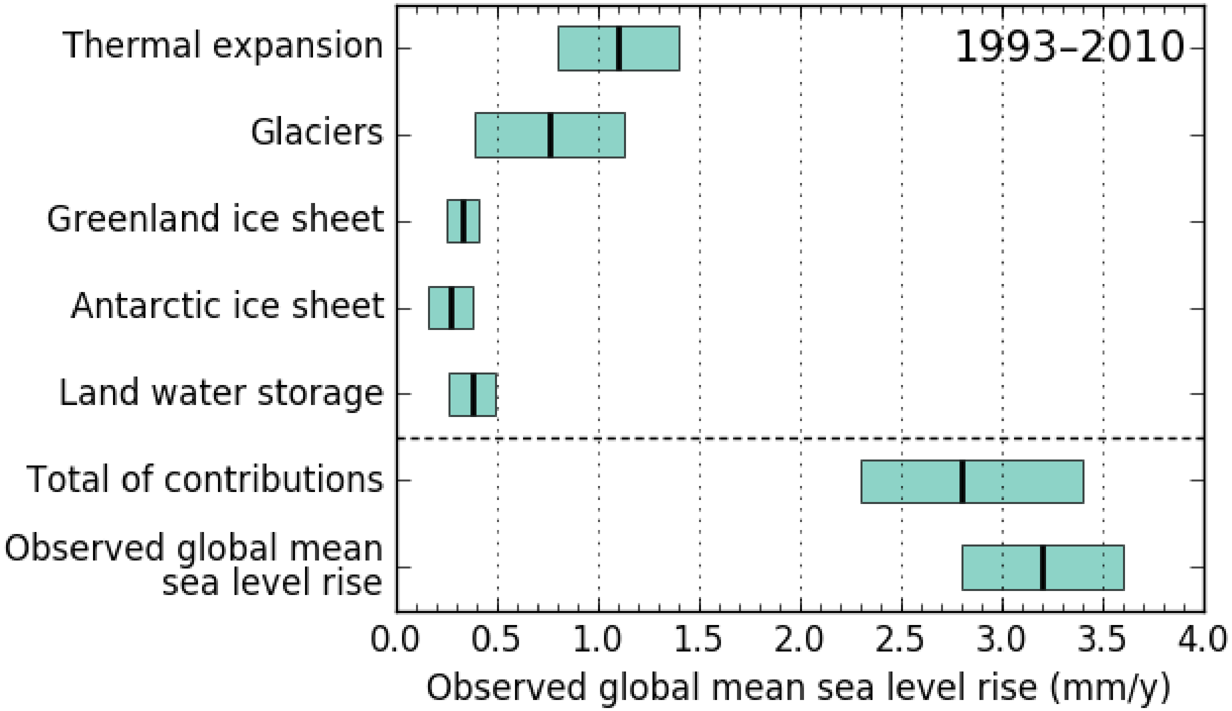
Relative sea level is also affected by land movement, ocean density and circulation, and distribution of mass on the Earth

AR5: Fifth Assessment Report

Figure 13.1 Climate-sensitive processes and components that can influence global and regional sea level and are considered in this chapter. Changes in any one of the components or processes shown will result in a sea level change. The term `ocean properties' refers to ocean temperature, salinity and density, which influence and are dependent on ocean circulation. Both relative and geocentric sea level vary with position. Note that the geocenter is not shown.

Observed sea level

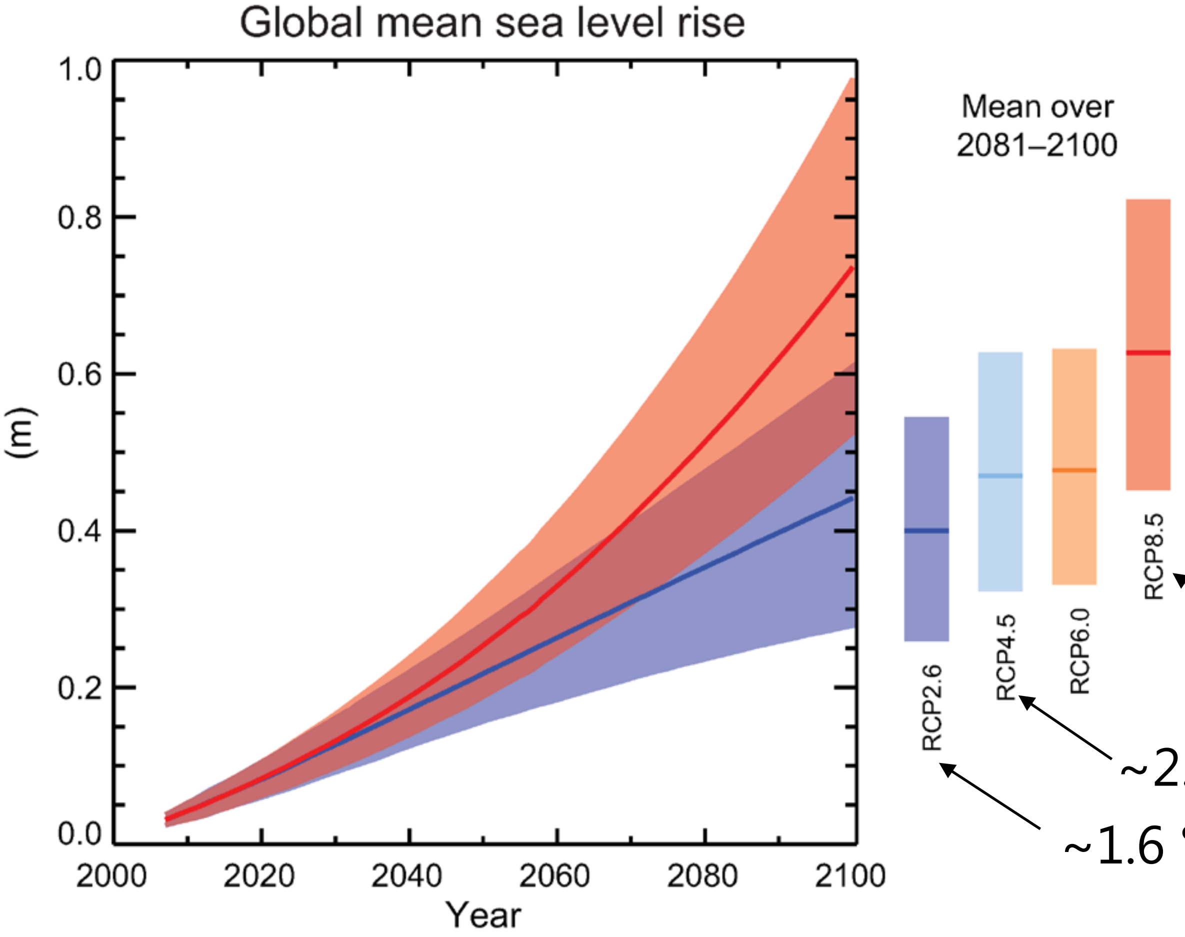
- Estimated to have risen about 20 cm since the late 19C,
  - mostly expansion and glaciers until 1990
- Rose at about 2 mm/y over the last half of the 20C,
- Increasing to about 3.2 mm per year from 1993 to 2010



Contribution of land water storage includes human-induced changes (reservoir impoundment and groundwater depletion)

Data source: IPCC WGI AR5 Table 13.1

Projection of 21C global sea level rise



~4.3 °C

~2.4 °C

~1.6 °C (2 °C-*likely*)

Source: IPCC WGI AR5

Medium confidence in *likely* ranges (>66%)

Very likely that the 21C mean rate will exceed that of 1971–2010 under all scenarios

RCP8.5: 0.53–0.98 m by 2100
8–16 mm/y during 2081–2100

RCP2.6: 0.28–0.61 m by 2100

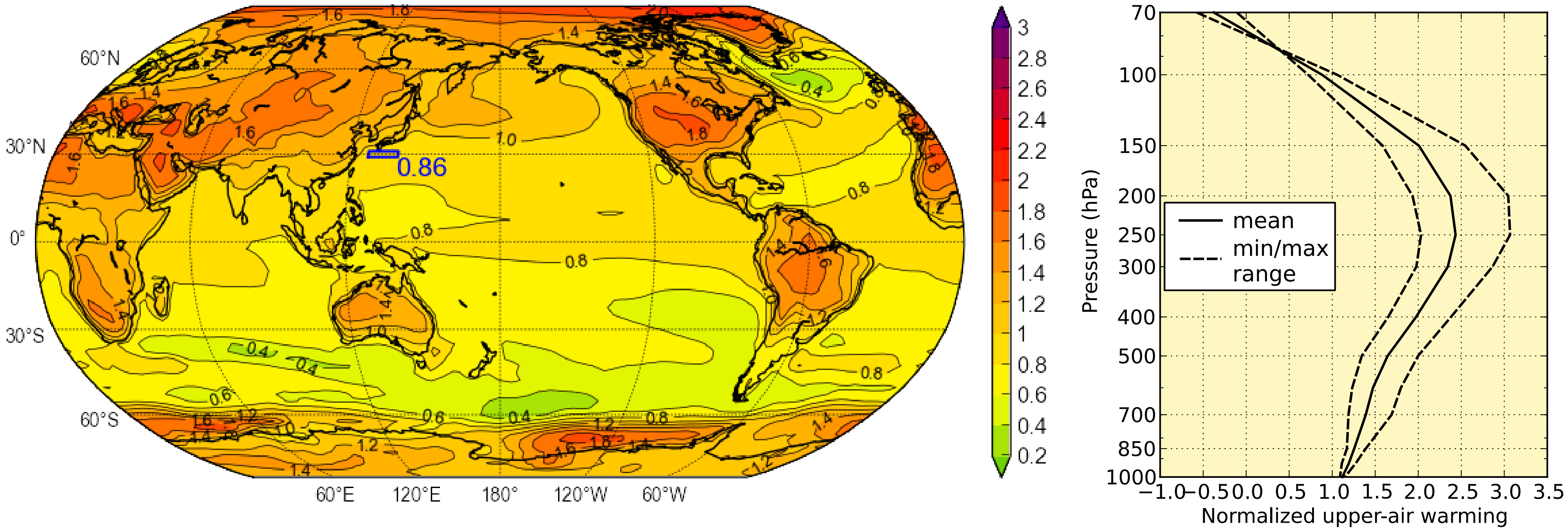
Figure SPM.9 Projections of global mean sea level rise over the 21st century relative to 1986--2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081--2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. For further technical details see the Technical Summary Supplementary Material {Table 13.5, Figures 13.10 and 13.11; Figures TS.21 and TS.22}

Pattern scaling for regional changes

An ensemble of complex climate models is mimicked by a combination of a simple climate model and pattern scaling

$$p^V(x,y,t,s) \approx p^V(x,y)G(t,s)$$

Change in variable v at location (x,y) at time t under scenario s can be approximated by the product of a stable, time- and scenario-independent, pre-estimated pattern and the change at time t in global average temperature under scenario s



Normalized global surface warming pattern and a profile of upper air warming at a selected region along 30°N in the western North Pacific in August-September

Tropical cyclone (TC) as a kind of heat engine

heat export at the low temperatures of the tropical upper troposphere

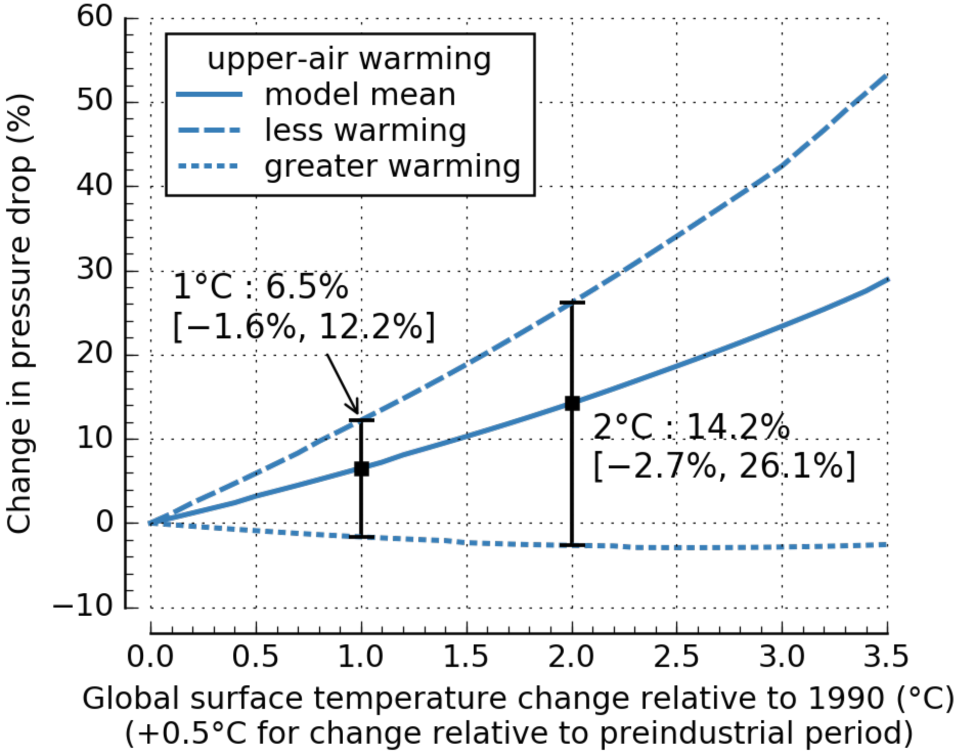
Refer to Figure 1 in Willoughby (1999)

Schematic structure of a mature TC adopted from Willoughby (1999)

extraction of latent heat from the ocean at high temperature

- A significant factor in driving TCs is the temperature difference between the sea surface and the upper atmosphere
- Amplification of GHG-induced upper air warming controls TC intensification

Pattern scaling and theoretical model for potential intensity of TC
Case study for a severe TC that makes landfall in Japan



Maximum pressure drop (p_c) is quantified by potential intensity theory

Fractional change in a rise of seawater by pressure drop

$$\frac{\delta\zeta_p}{\zeta_p} = \frac{\delta p_c}{p_c}$$

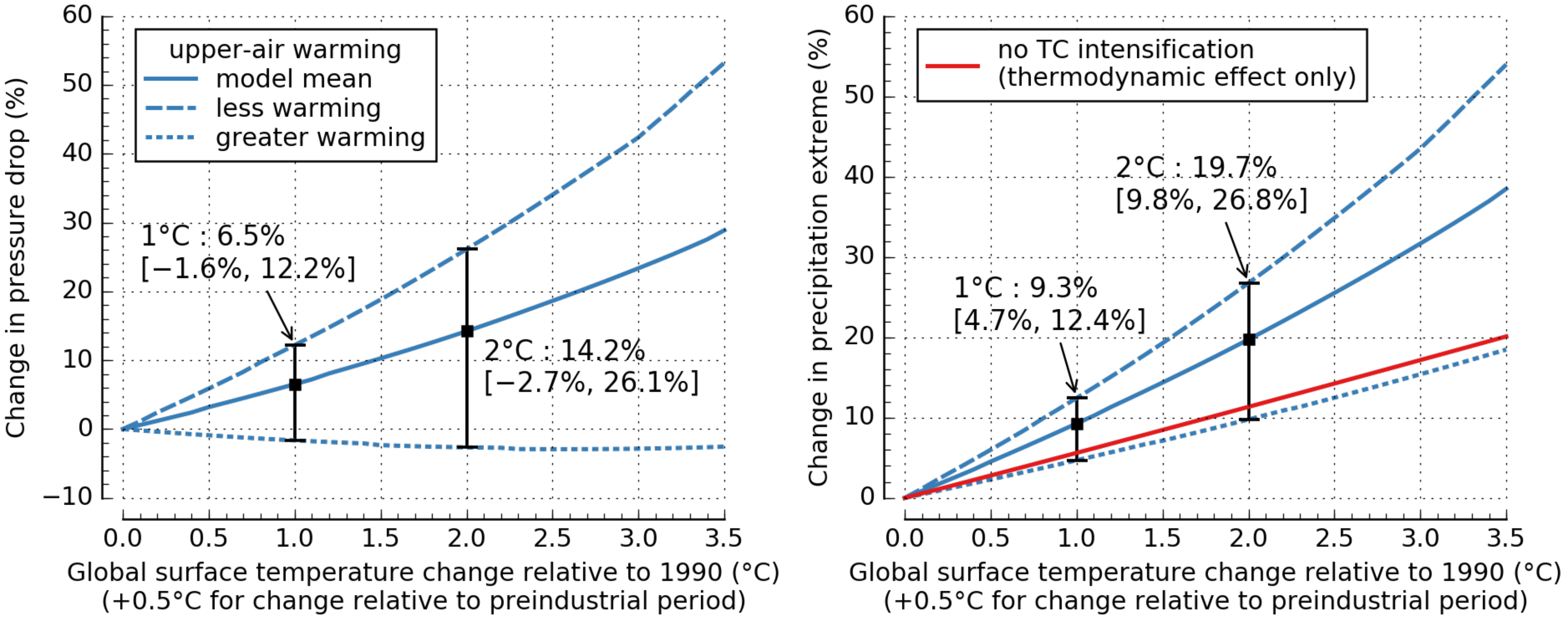
onshore surge of seawater by winds

$$\frac{\delta\zeta_w}{\zeta_w} = 2\frac{\delta v_s}{v_s} = 2\alpha\frac{\delta p_c}{p_c} \quad (\alpha = 0.6 \sim 0.8)$$

Both of these are scaled by fractional change in pressure drop

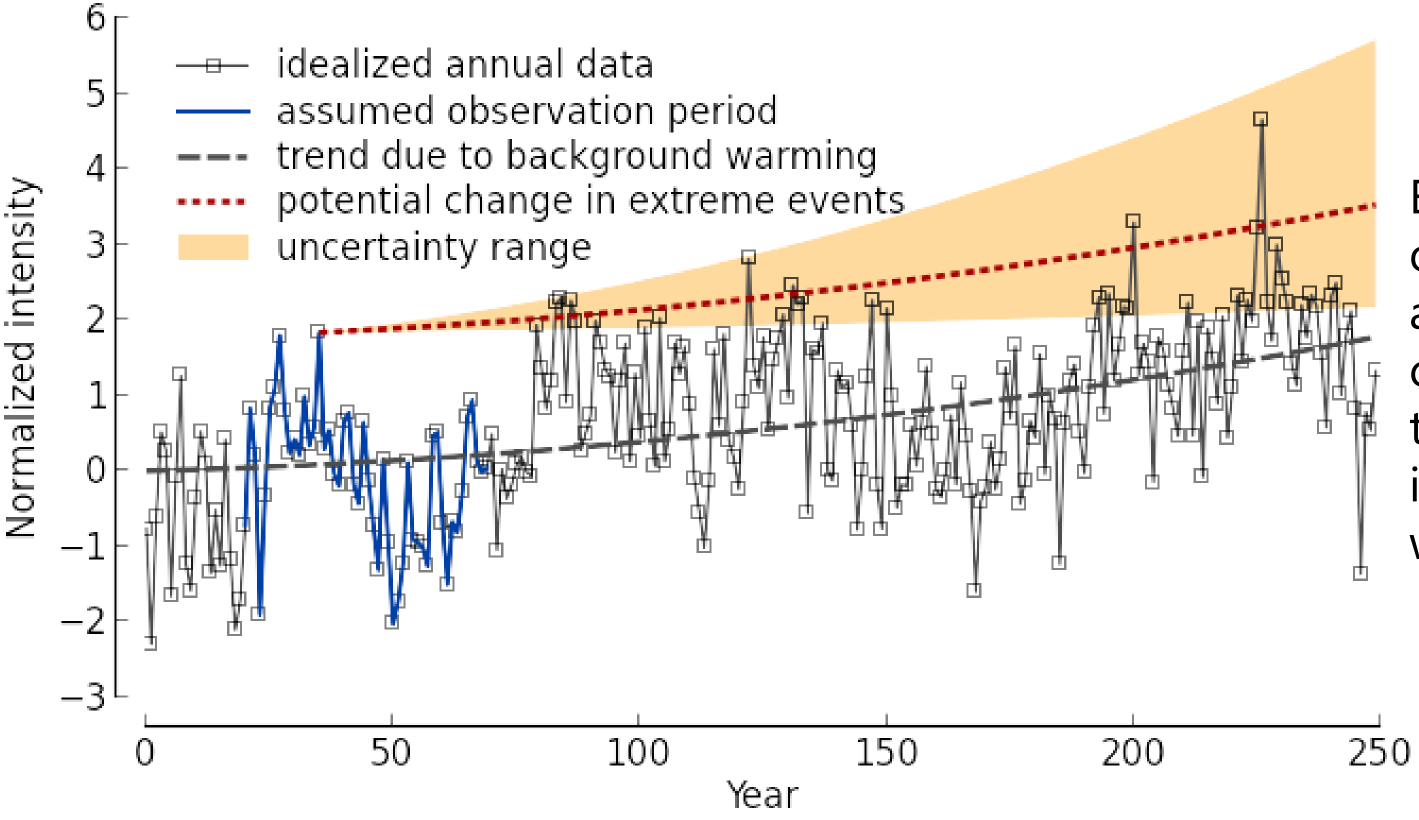
Potential intensity is based on Holland (1997) theory that calculates inner core processes of a TC to determine the maximum pressure drop, implemented by Tsutsui (2010, 2011). Uncertain range reflects variations in the amplification of upper air warming in the tropics.

Pattern scaling and theoretical model for potential intensity of TC Case study for a severe TC that makes landfall in Japan (continued)



Precipitation extreme is based on O'Gorman & Schneider (2009) theory representing water vapor condensation in a severe event. Changes are the result of a dynamic effect such that an intensified TC enhances water vapor transport, and a thermodynamic effect such that the amount of water vapor increases in a warmed climate.

GHG-induced change and natural variability



Extreme events occur even without anthropogenic climate change, but they may be intensified in warmed climate

Conceptual secular change in annual maximum of TC intensity in a specific region, comprising large natural variations and possible slow trend due to background warming.

Concluding remarks

- Although the long-term goal (1.5–2 °C) has been established, socio-economic pathways to the goal involve many uncertainties
- Adapting to possible changes in climate need a tool to derive adequate information from complex climate data considering uncertainties
- A simple modeling framework with pattern scaling is an effective tool for dealing with ensemble climate data in a comprehensive manner
- A theoretical model provides a basis for quantitative assessment of GHG-induced intensification of tropical cyclones and associated impact
- It is important to recognize changes in mean states and changes in extreme events as well as natural climate variability

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