

ipcc  
INTERGOVERNMENTAL PANEL ON climate change

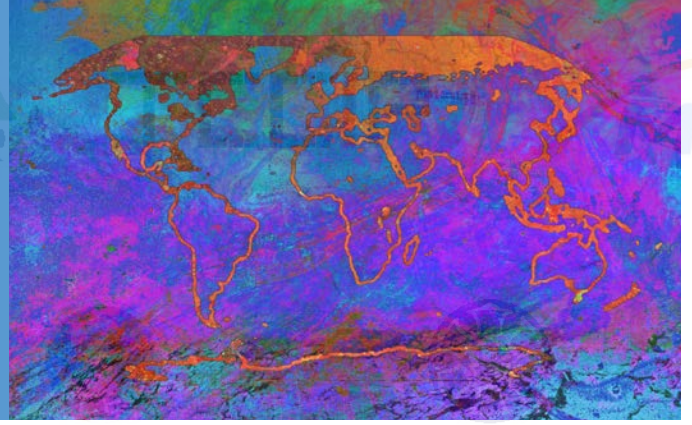
# Climate Change 2021

## The Physical Science Basis

WGI

Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

WMO UNEP



# 挖掘真相：氣候系統的變化

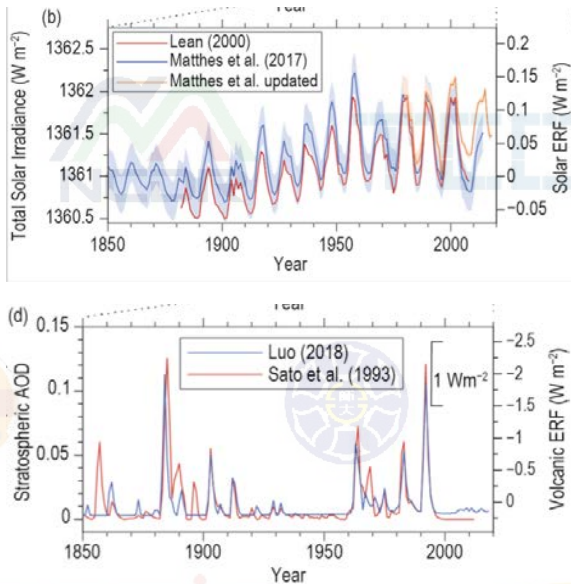
## IPCC 氣候變遷第六次評估報告第2至5章

國立台灣師範大學地球科學系教授 陳正達



- 氣候系統的變化（我們觀測到什麼？）
- 人類對氣候系統的影響（是不是人類活動所造成的？）
- 未來全球氣候：不同情境下的長期推估與近期改變
- 全球的碳與其他生地化循環與反饋

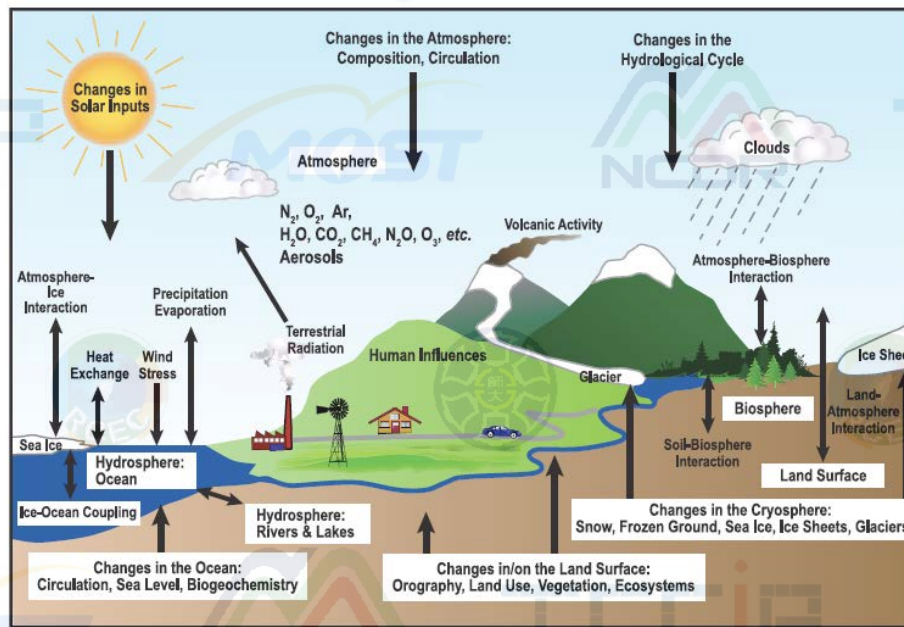
## 太陽輻射變動



火山爆發所產生的懸浮微粒

IPCC (2001, 2007, 2013, 2021)

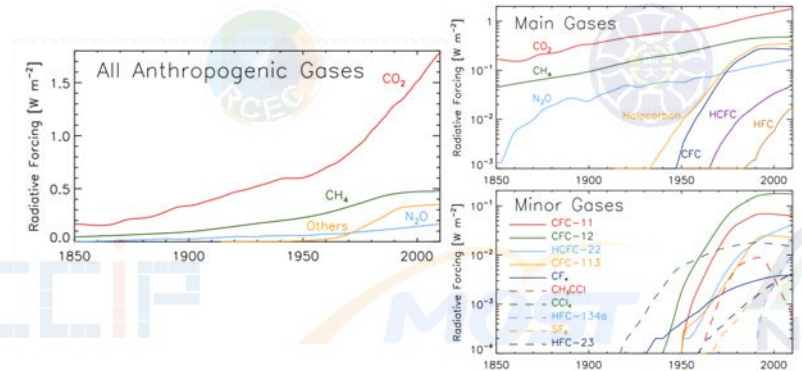
自然驅動力



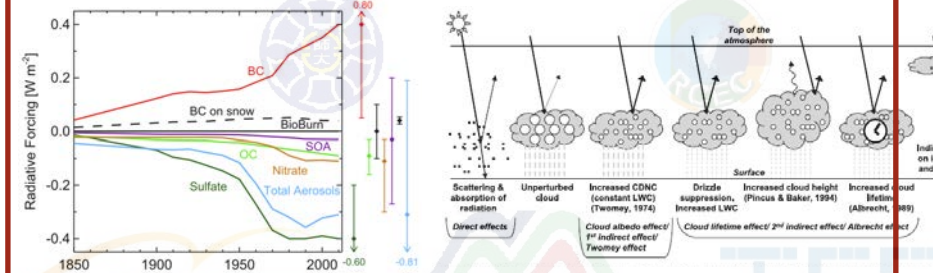
FAQ 1.2, Figure 1. Schematic view of the components of the climate system, their processes and interactions.

人為驅動力

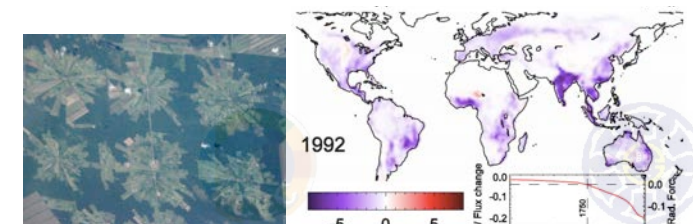
## 溫室氣體排放



## 人為造成大氣中的氣膠變化



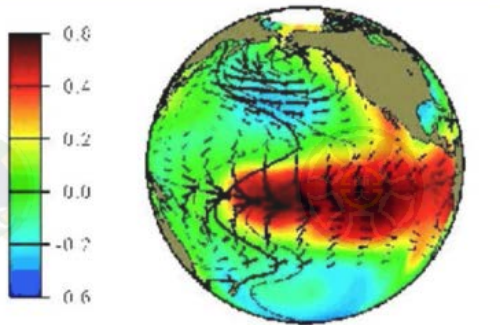
## 人為造成地表特性改變



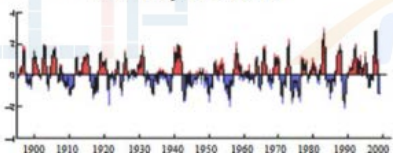
## 氣候系統還有自然內部變動

## Climate Variability and Climate Change

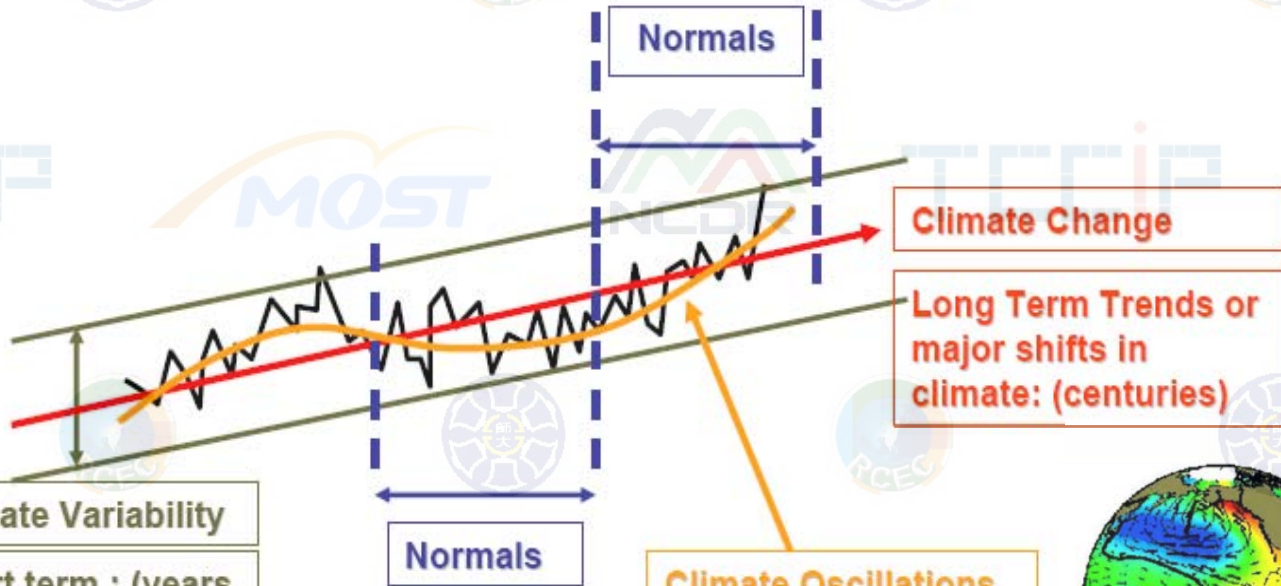
### 年際變化



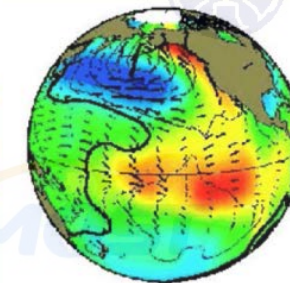
El Niño Southern Oscillation  
A history of ENSO



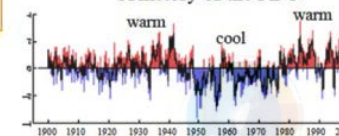
**Climate Variability**  
Short term : (years to decadal) rises and falls about the trend line (ENSO)



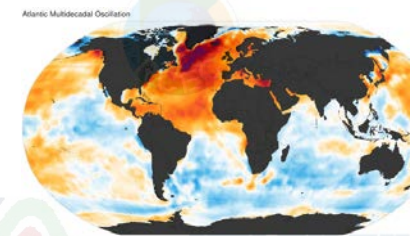
### 年代際變化



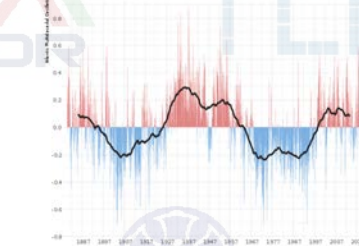
Pacific Decadal Oscillation  
A history of the PDO



**Climate Oscillations**  
Multi-decadal oscillations in regional climate: (e.g. PDO, NAO, AMO)

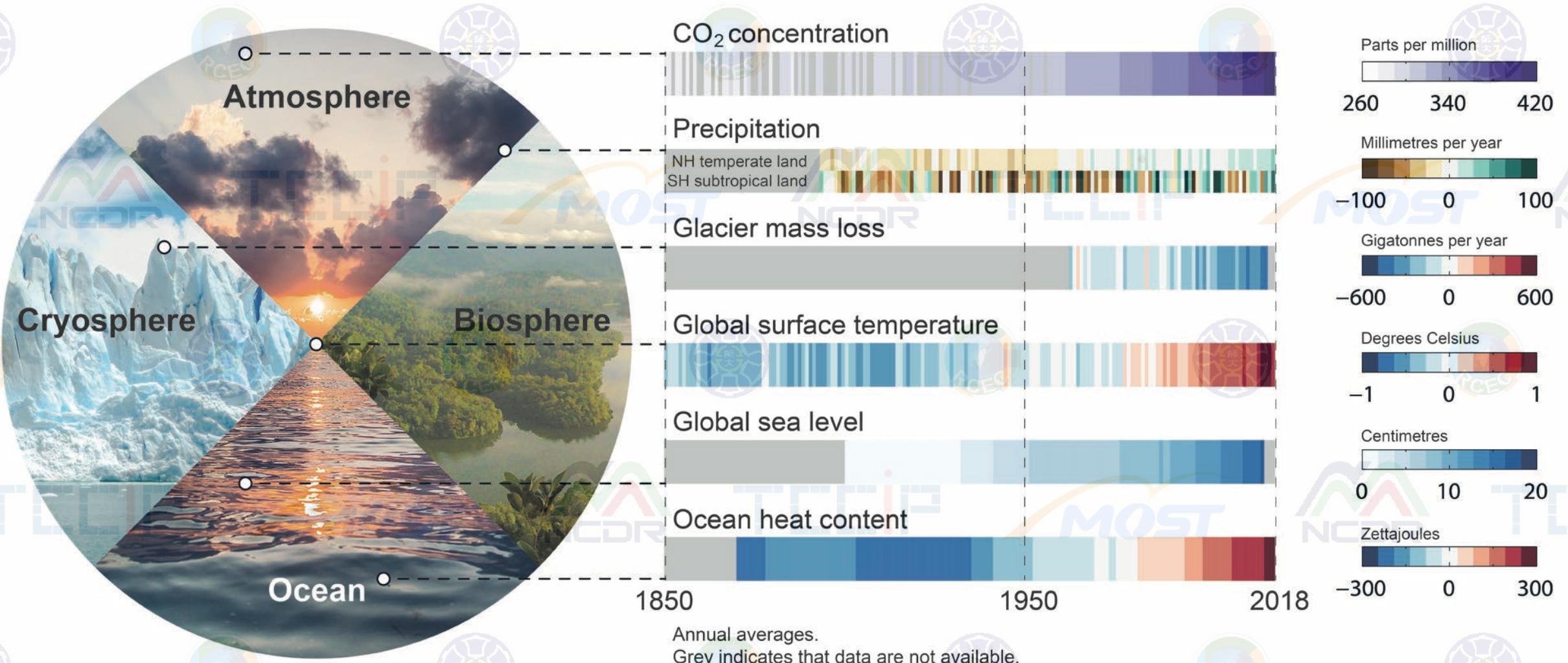


Atlantic Multidecadal Oscillation



# 氣候系統的變化

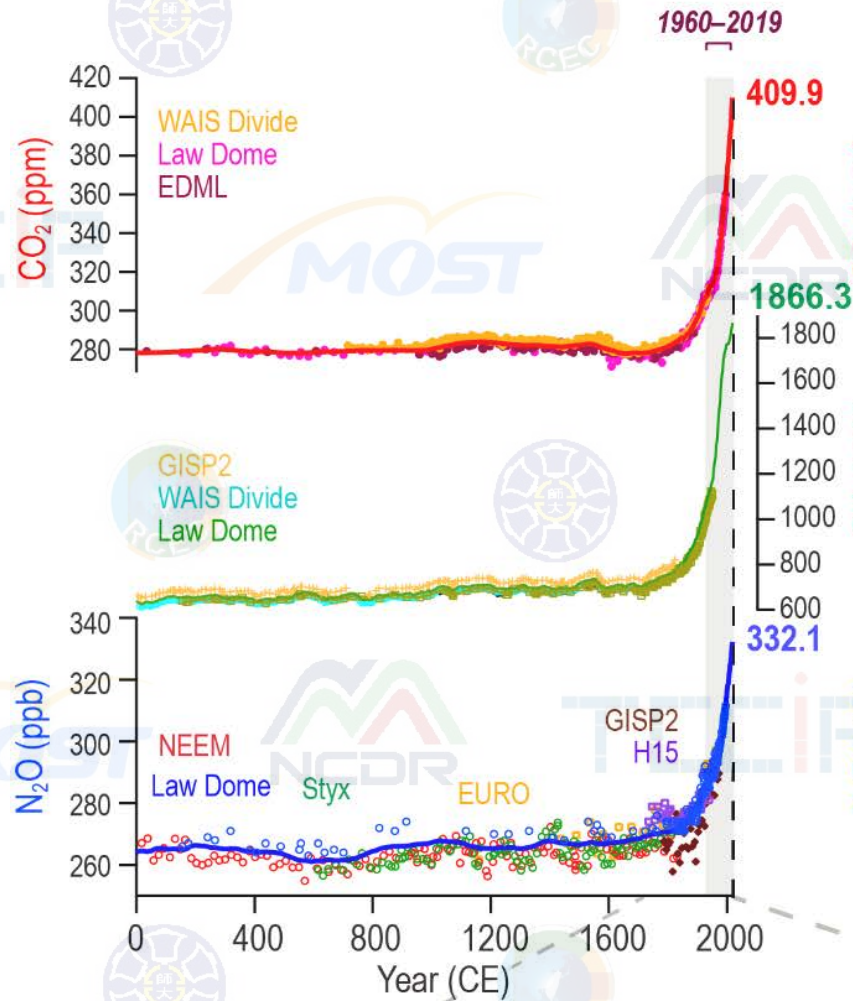
## 多面向地檢視地球氣候系統中的各種變化



# 氣候系統的變化

溫室氣體  
的增加  
是過去  
2000年以來  
最快速的

(b) Information from multiple ice cores depict a strong increase of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O since the 19th century.



(c) Since 1960-1980 several high accuracy global networks measure surface concentrations of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O. Current concentrations are higher than measured in ice cores during the last 800,000 years.

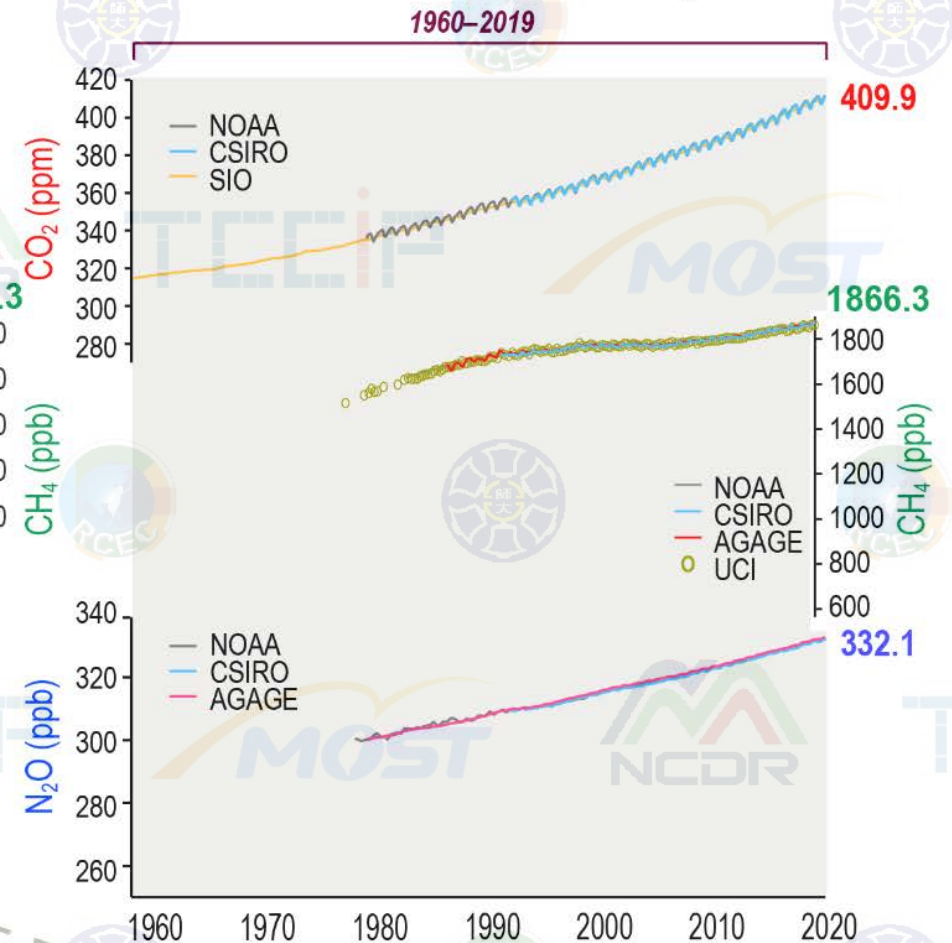
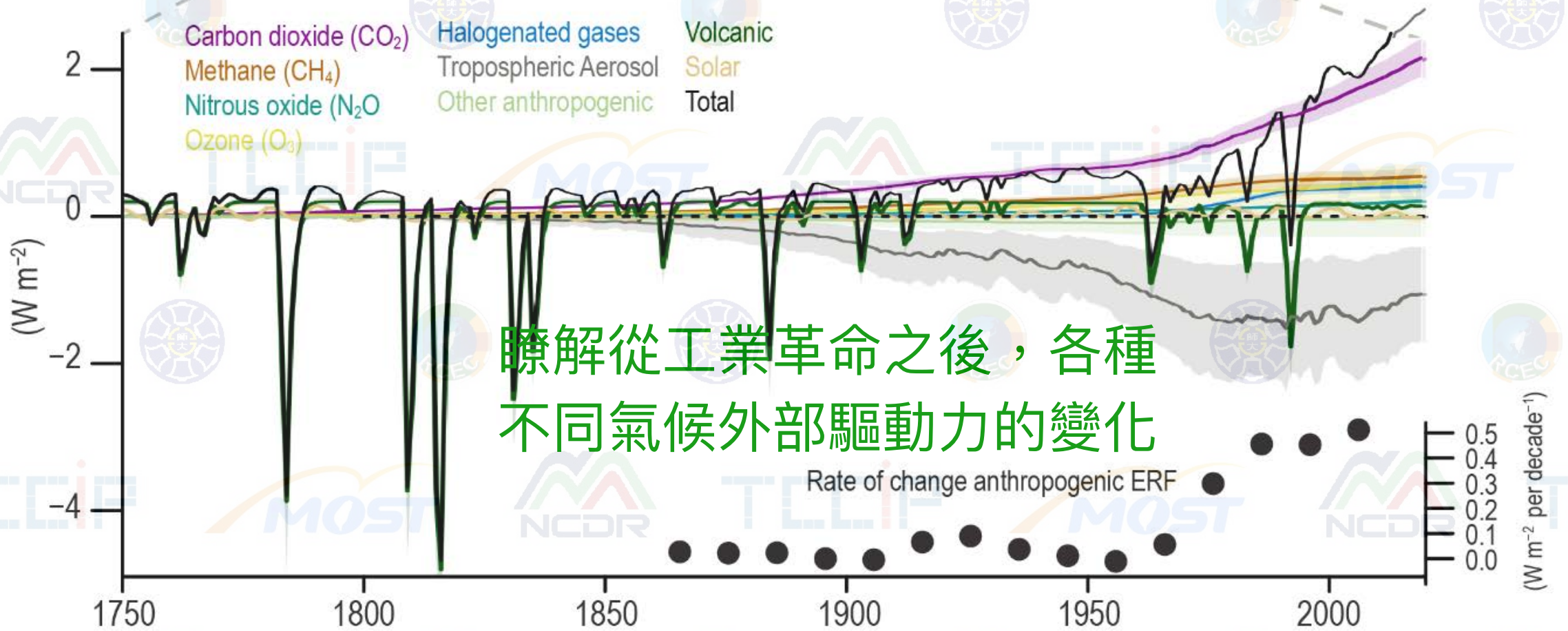


Figure TS.4

# 氣候系統的變化

(d) The increase in effective radiative forcing since the late 19th century is driven predominantly by warming GHGs and cooling aerosol. ERF is changing at a faster rate since the 1970s.



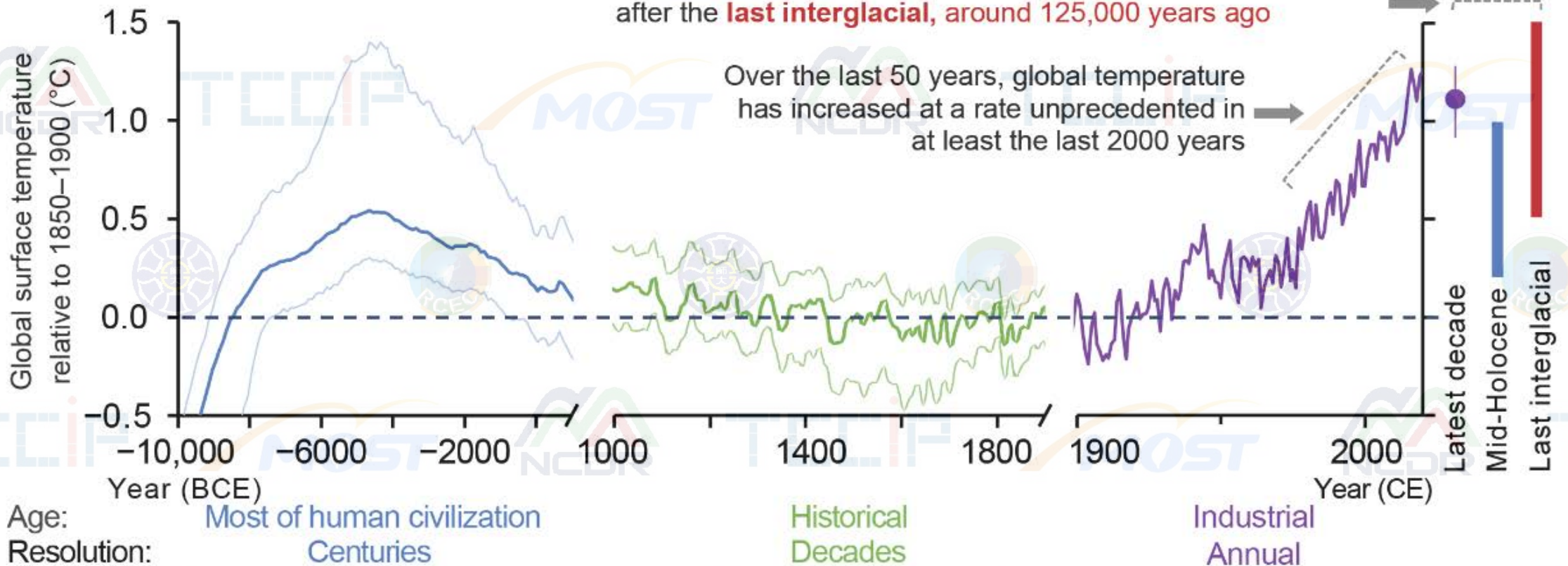
瞭解從工業革命之後，各種不同氣候外部驅動力的變化

## 全球氣溫在過去的改變

(a) Recent global temperatures are unprecedented in the era of human civilization

The **latest decade** was warmer than any multi-century period after the **last interglacial**, around 125,000 years ago

Over the last 50 years, global temperature has increased at a rate unprecedented in at least the last 2000 years



Cross-Section Box TS.1, Figure 1



過去百年全球平均氣溫增暖的速度是過去2000年以來未曾見過

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and **observed** (1850-2020)

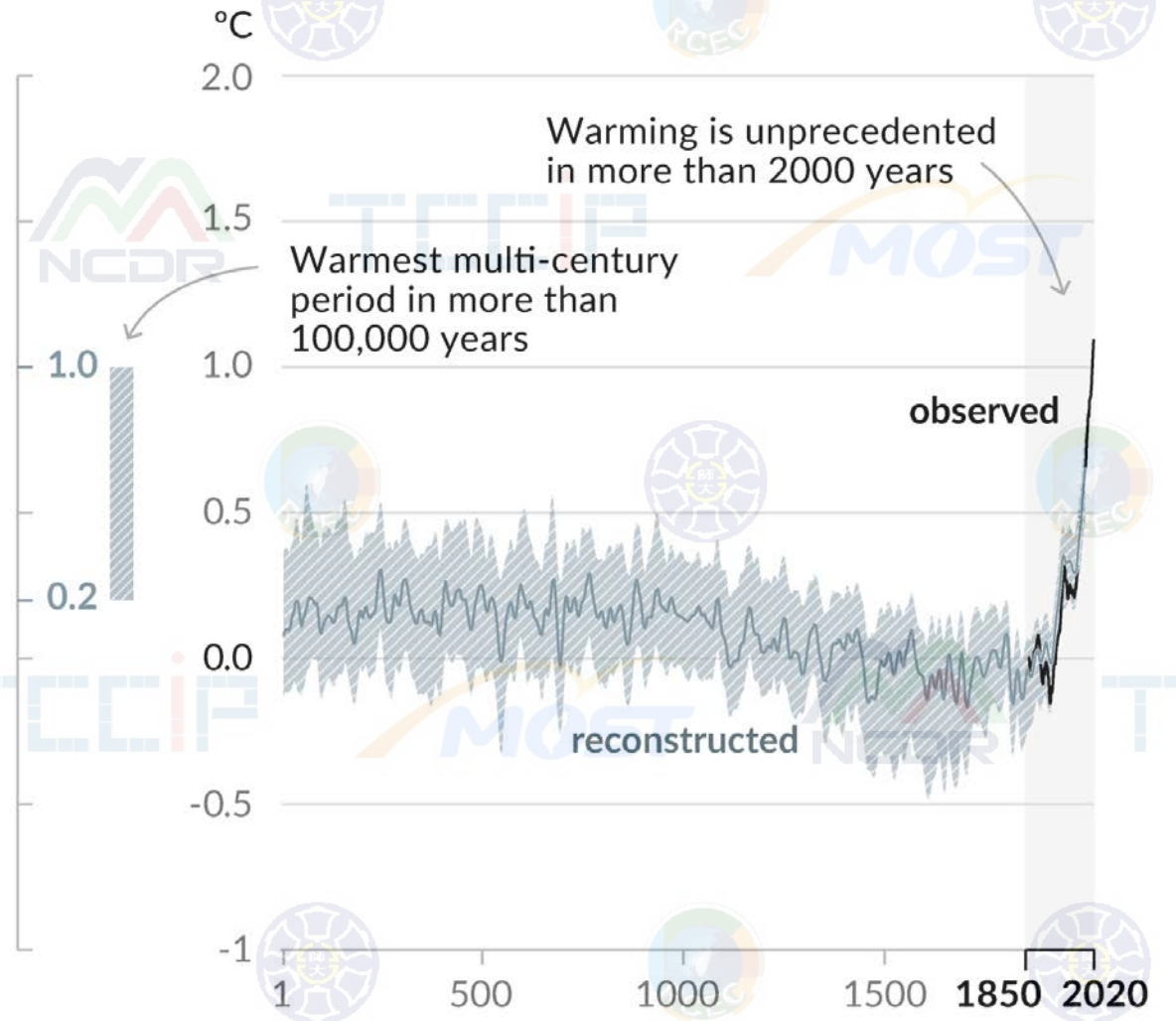


Figure SPM.1

# 人類對氣候系統的影響

過去百年全球平均氣溫增暖的速度是過去2000年以來未曾見過而且是人類活動所造成的 (毋庸置疑 unequivocal)

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

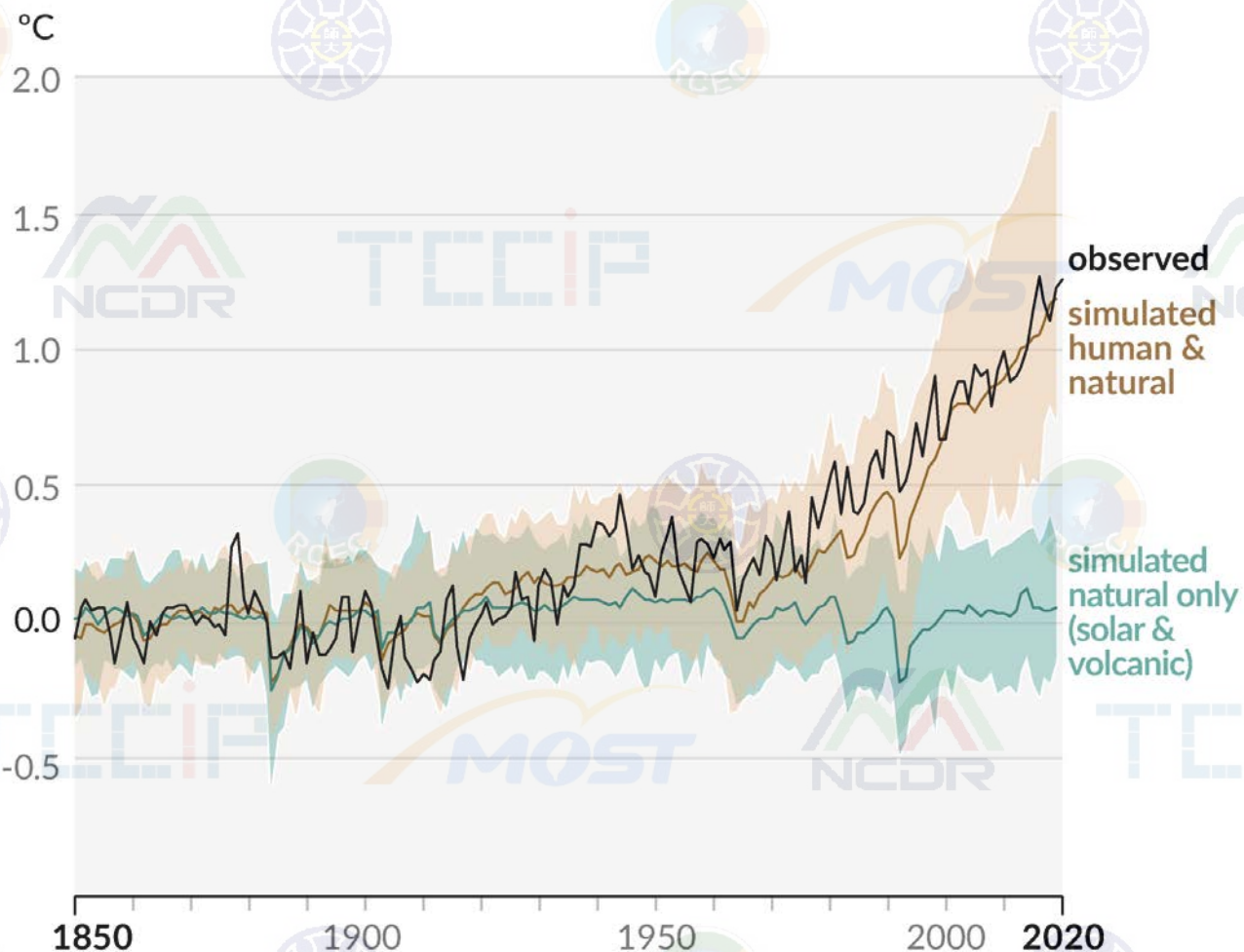


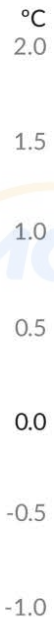
Figure SPM.1

# 人類對氣候系統的影響

觀測的增溫是由人類活動所排放的物質所造成，其中溫室氣體所造成的暖化被氣膠所帶來的冷卻效應部分抵銷

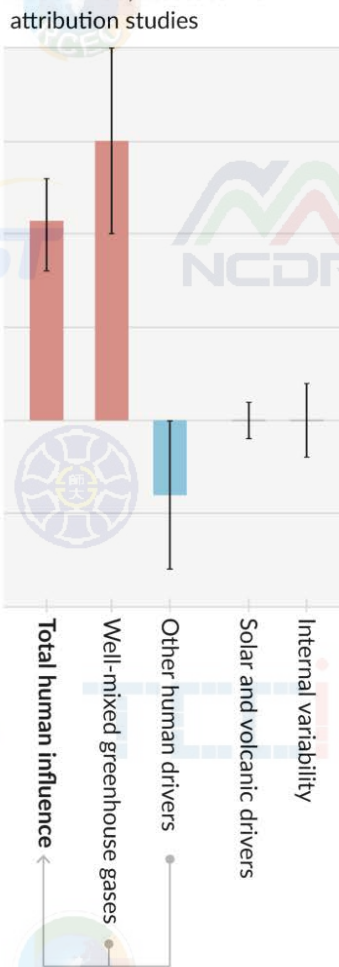
Observed warming

a) Observed warming 2010-2019 relative to 1850-1900

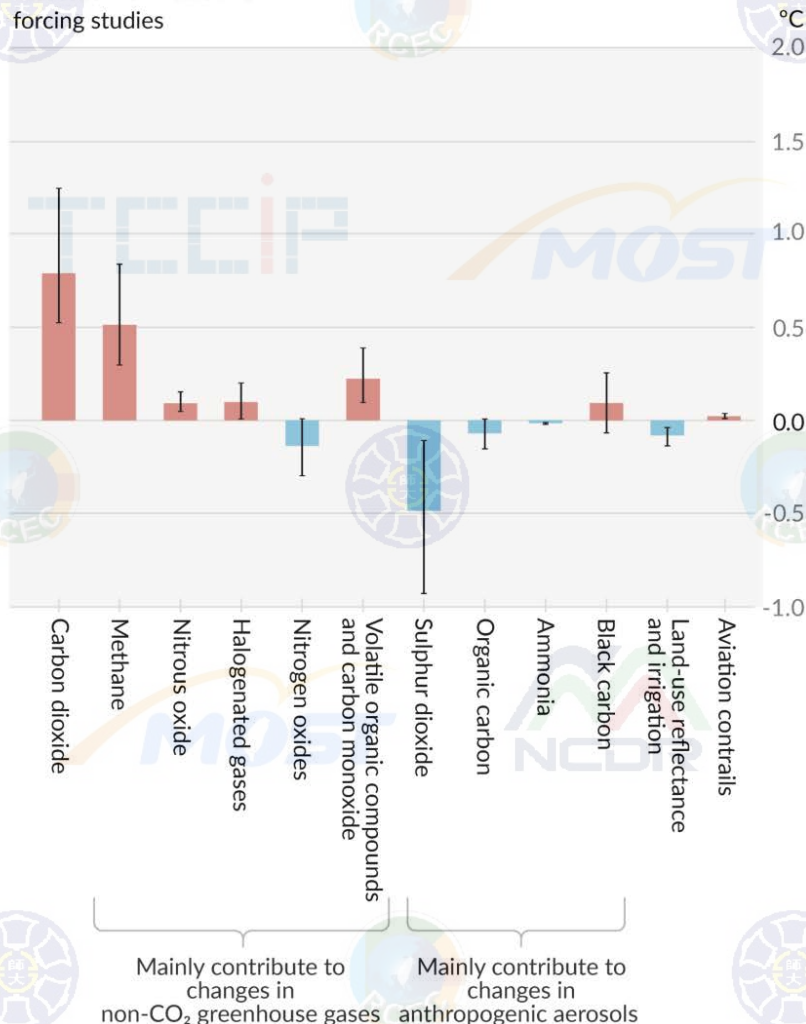


Contributions to warming based on two complementary approaches

b) Aggregated contributions to 2010-2019 warming relative to 1850-1900, assessed from attribution studies



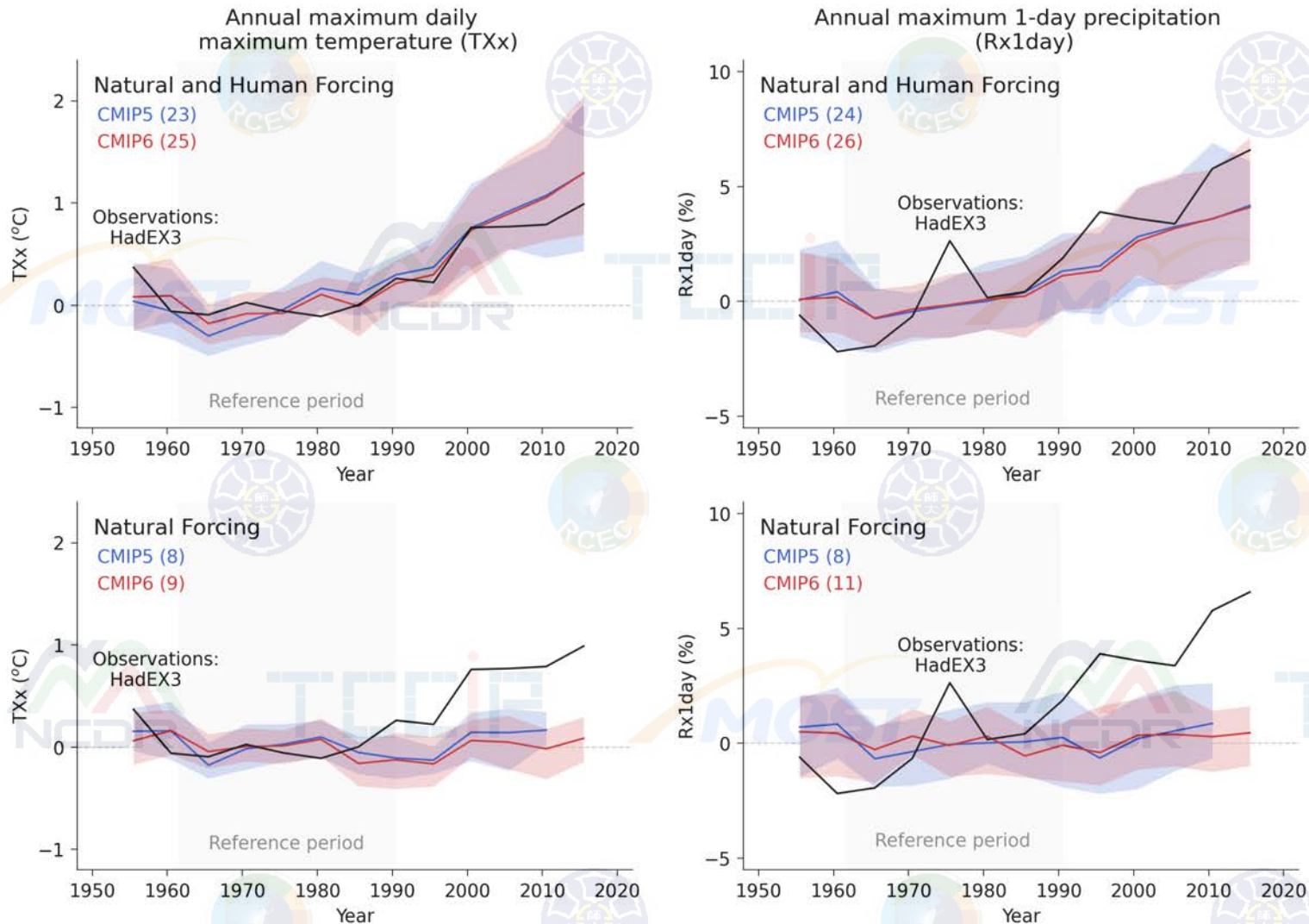
c) Contributions to 2010-2019 warming relative to 1850-1900, assessed from radiative forcing studies



不只是全球平均  
氣溫增加是人類  
活動所造成

極端氣溫與極端  
降雨增加也同樣  
無法只透過自然  
驅動力獲得

Climate Extremes Indices



# 人類對氣候系統的影響

## Temperature response (Attribution 歸因)

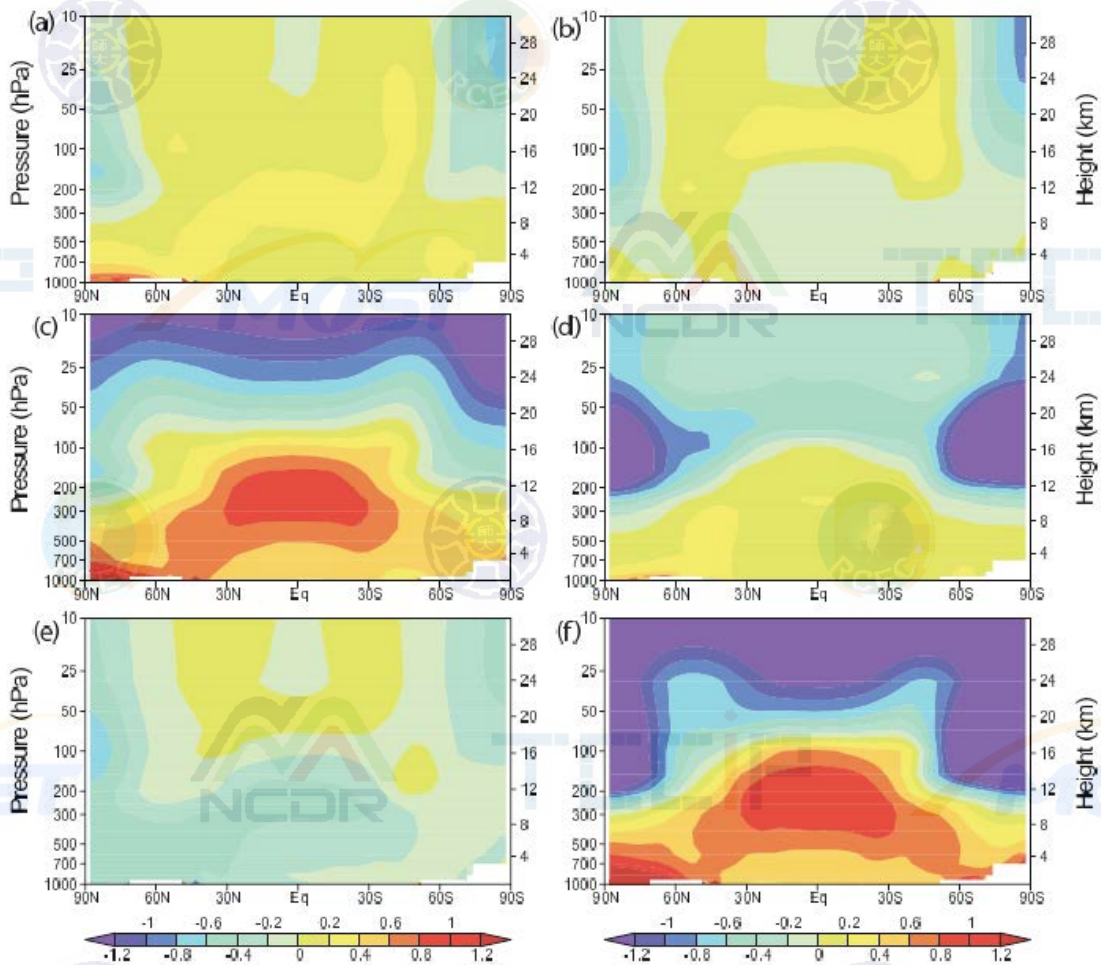


Figure 9.1. Zonal mean atmospheric temperature change from 1890 to 1999 ( $^{\circ}\text{C}$  per century) as simulated by the PCM model from (a) solar forcing, (b) volcanoes, (c) vs mixed greenhouse gases, (d) tropospheric and stratospheric ozone changes, (e) direct sulphate aerosol forcing and (f) the sum of all forcings. Plot is from 1,000 hPa to 10 (shown on left scale) and from 0 km to 30 km (shown on right). See Appendix 9.C for additional information. Based on Santer et al. (2003a).

太陽輻射變動 Solar forcing

均勻混合 溫室氣體 Well-mixed greenhouse gases

人為造成的 氣膠變化 (直接效應) Aerosol (direct)

Volcanoes 火山爆發所產生的懸浮微粒

Ozone 臭氧

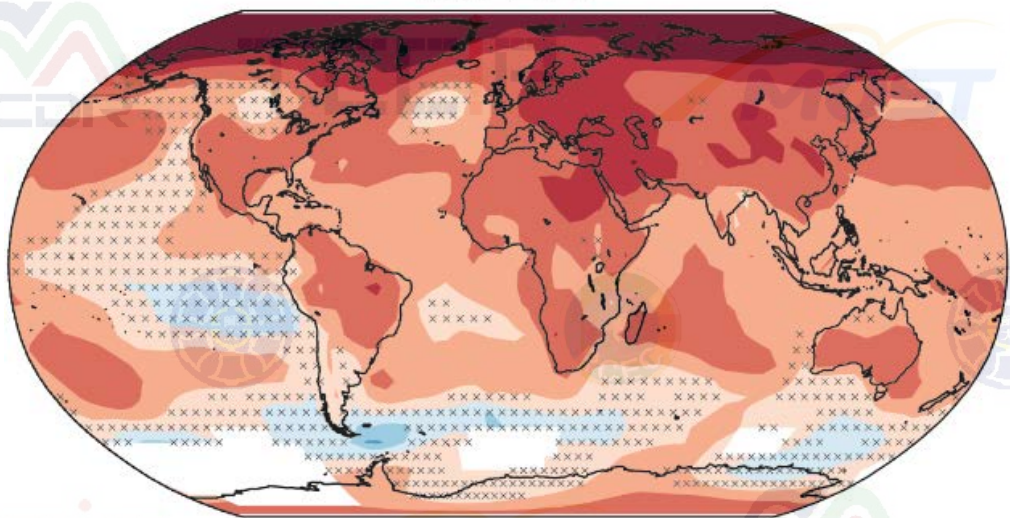
All forcings 所有驅動力

## 暖化特徵：陸地比海洋增溫大，極區增溫比中低緯度更顯著

(b) Observed and projected warming are stronger over land than oceans, and strongest in the Arctic

x = non-significant trend

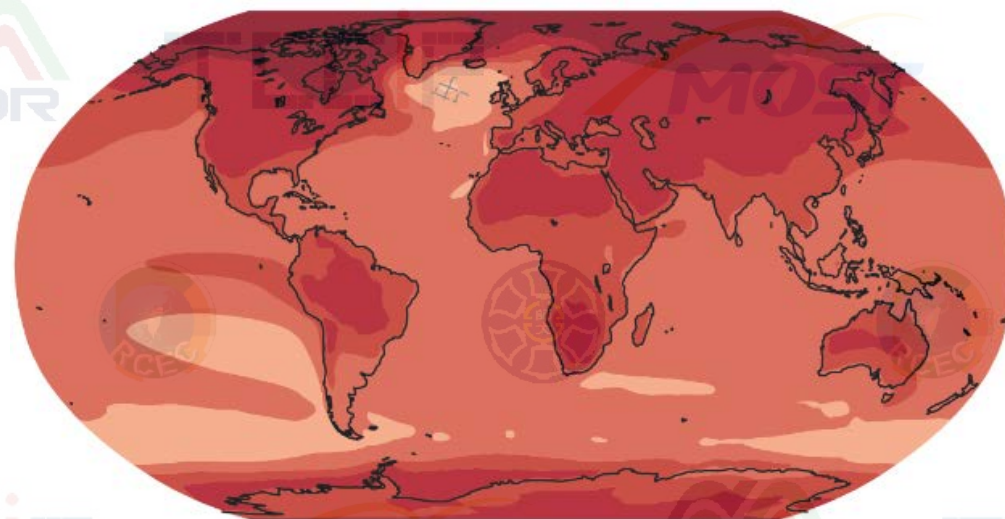
1981–2020



-0.6 -0.4 -0.2 -0.1 0.0 0.1 0.2 0.4 0.6

Trend (°C per decade)

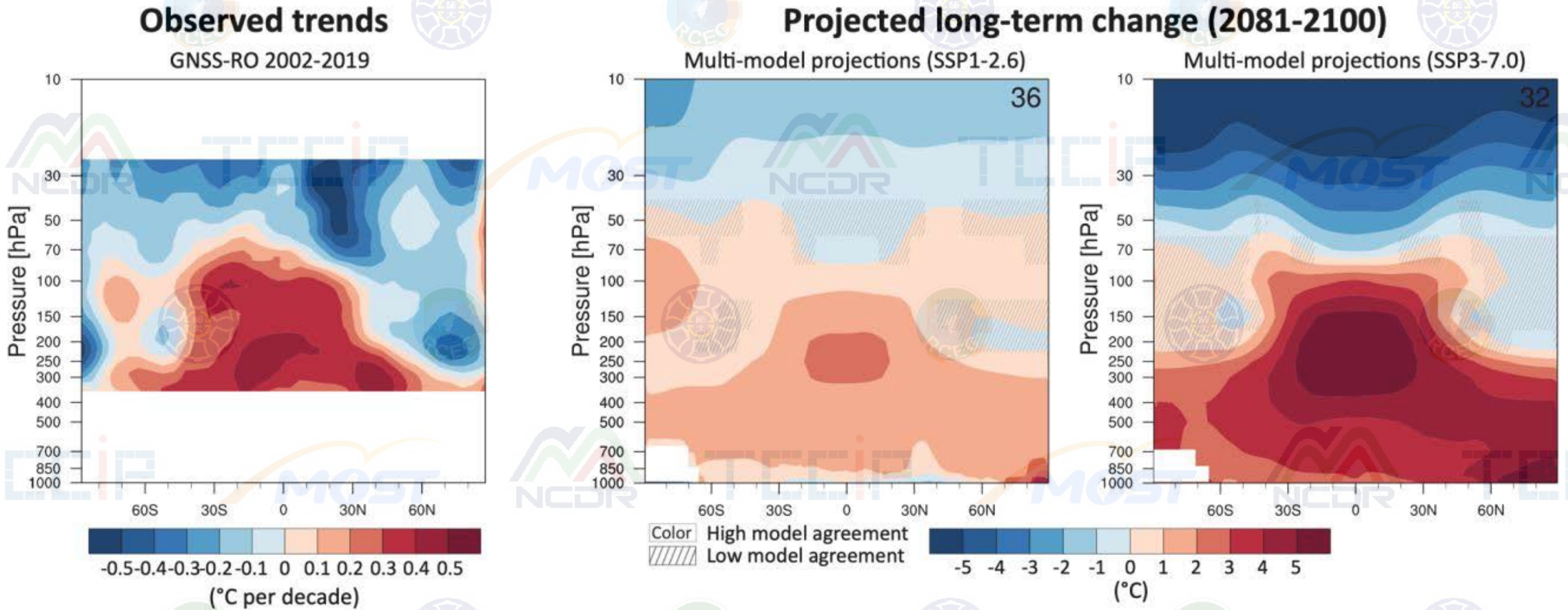
SSP3-7.0 (2081-2100)



-6 -4 -3 -2 -1 -0.5 0 0.5 1 2 3 4 6

Total change (°C)

## 對流層增溫，平流層冷卻



## 近地面與整層的水氣含量都有長期增加的趨勢

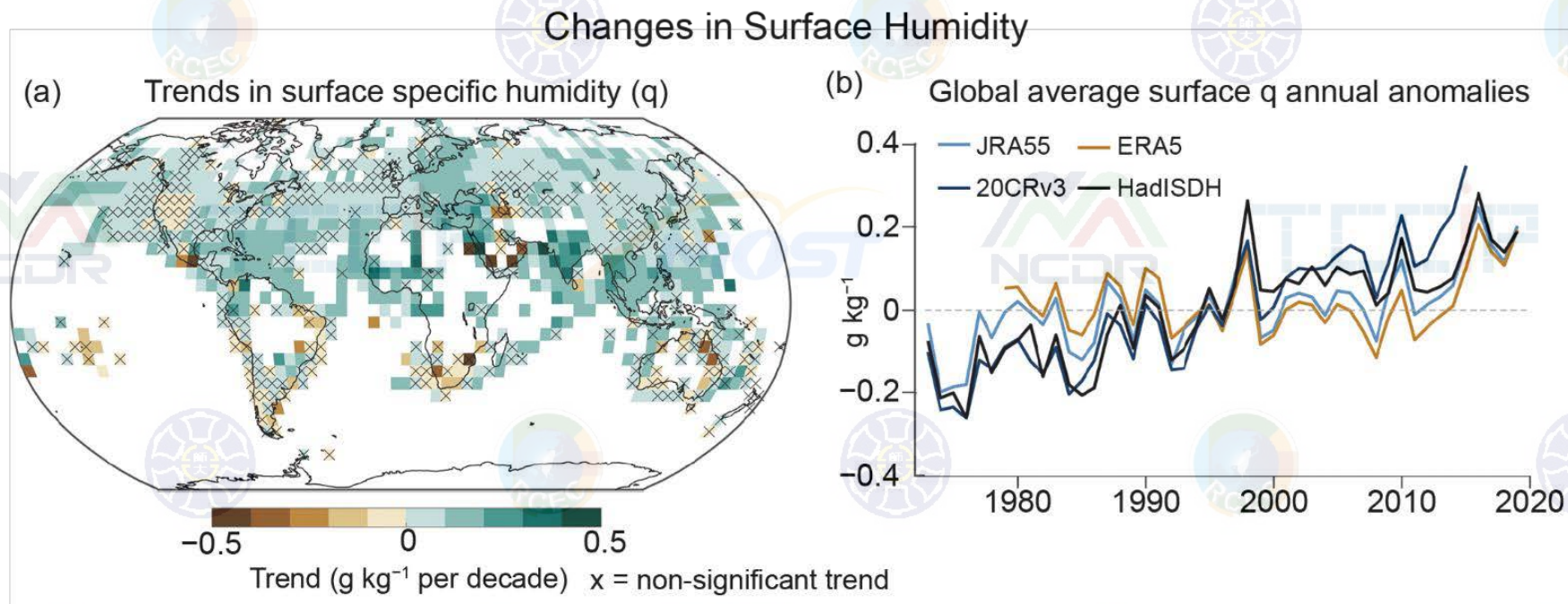
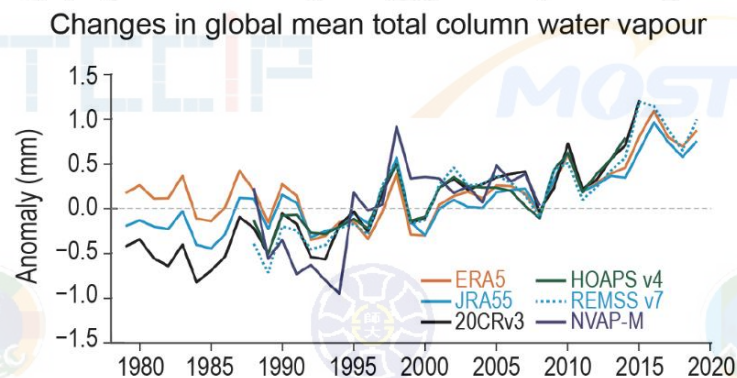


Figure 2.13, 2.14





雖然水氣變多，降雨受到大氣環流變動的影響，較無一致性的長期變化

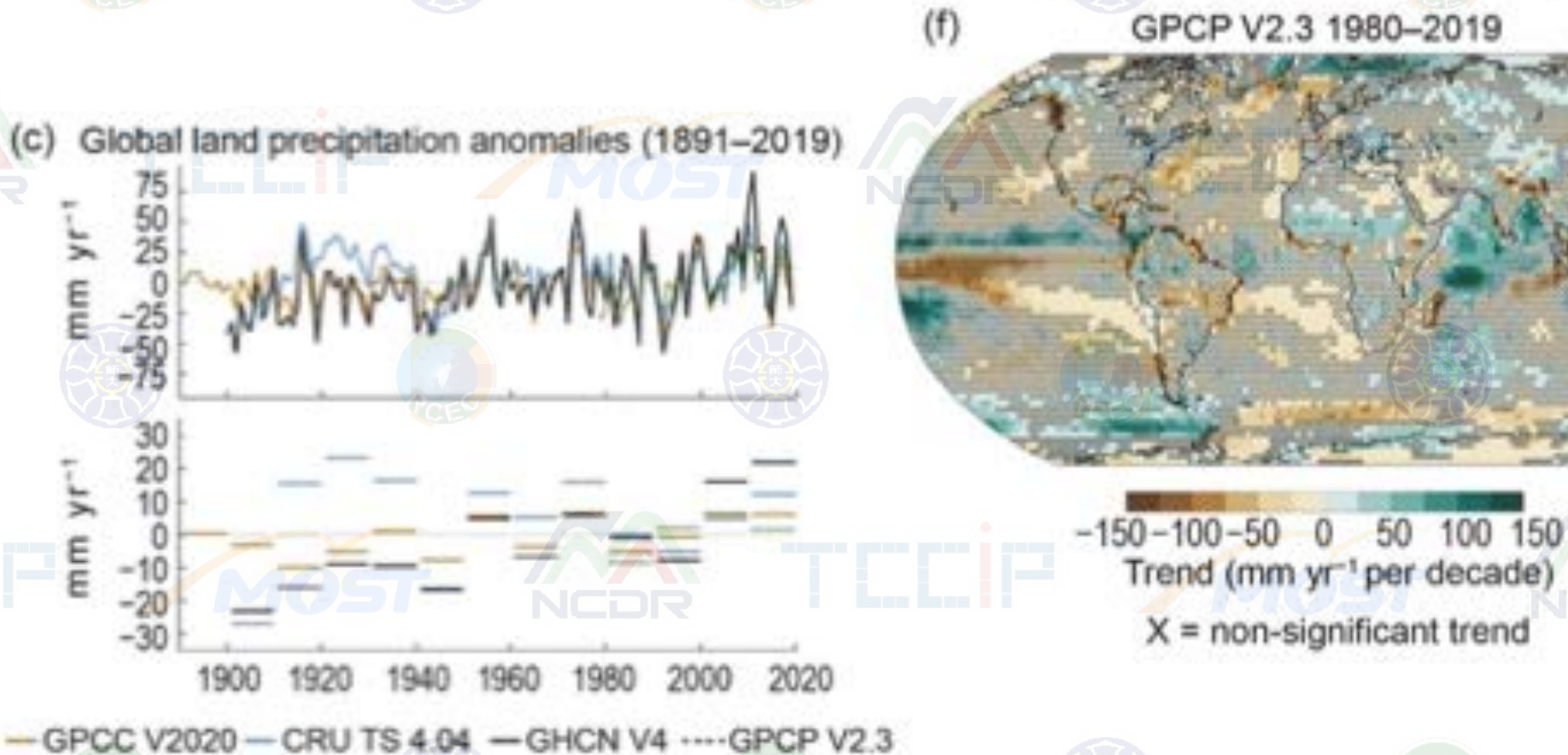
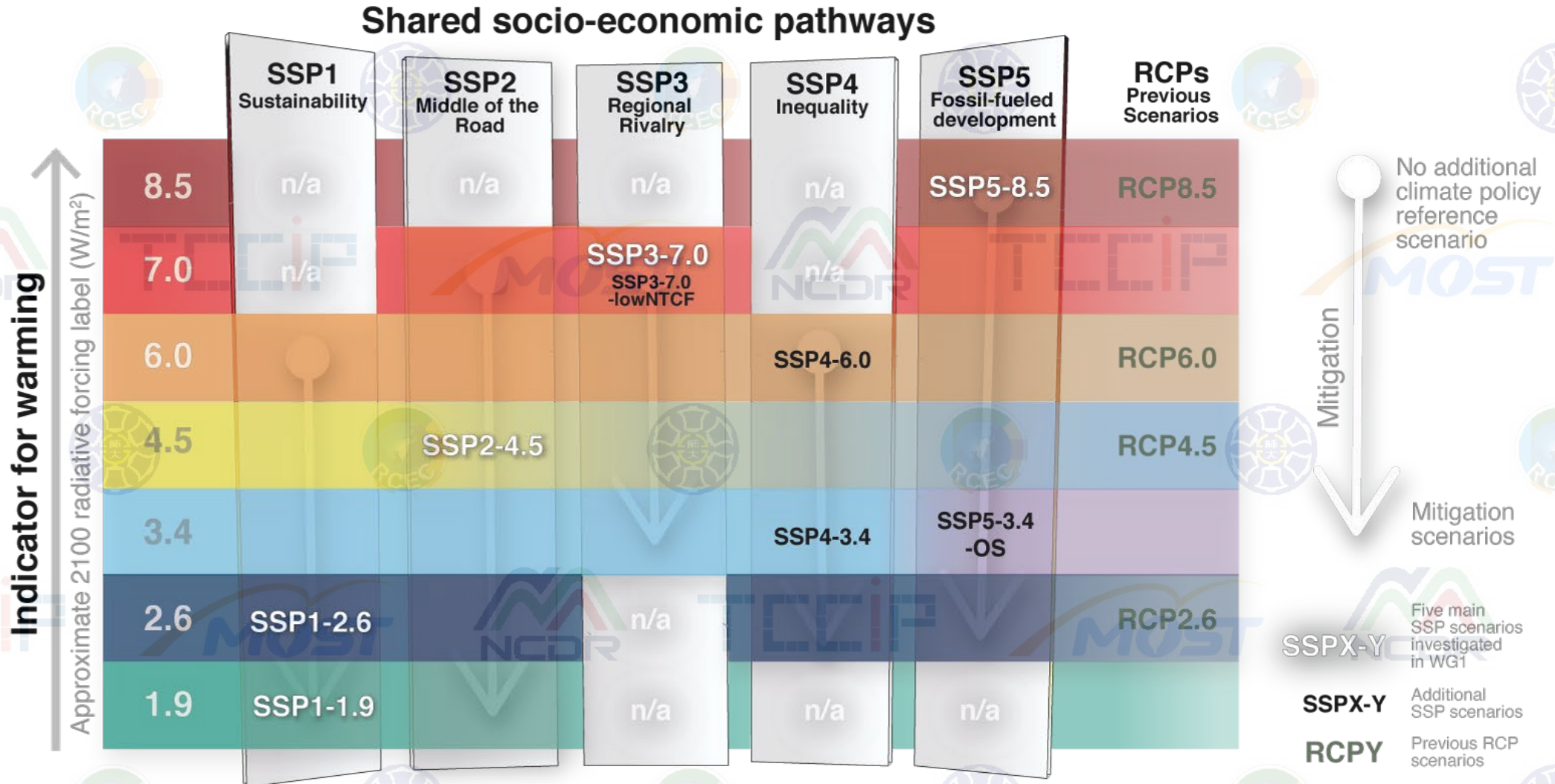


Figure 2.15

# 未來全球氣候：不同情境下的長期推估與近期改變



Cross-Chapter Box 1.4, Figure 1

# 未來全球氣候：不同情境下的長期推估與近期改變

a) Future annual emissions of CO<sub>2</sub> (left) and of a subset of key non-CO<sub>2</sub> drivers (right), across five illustrative scenarios

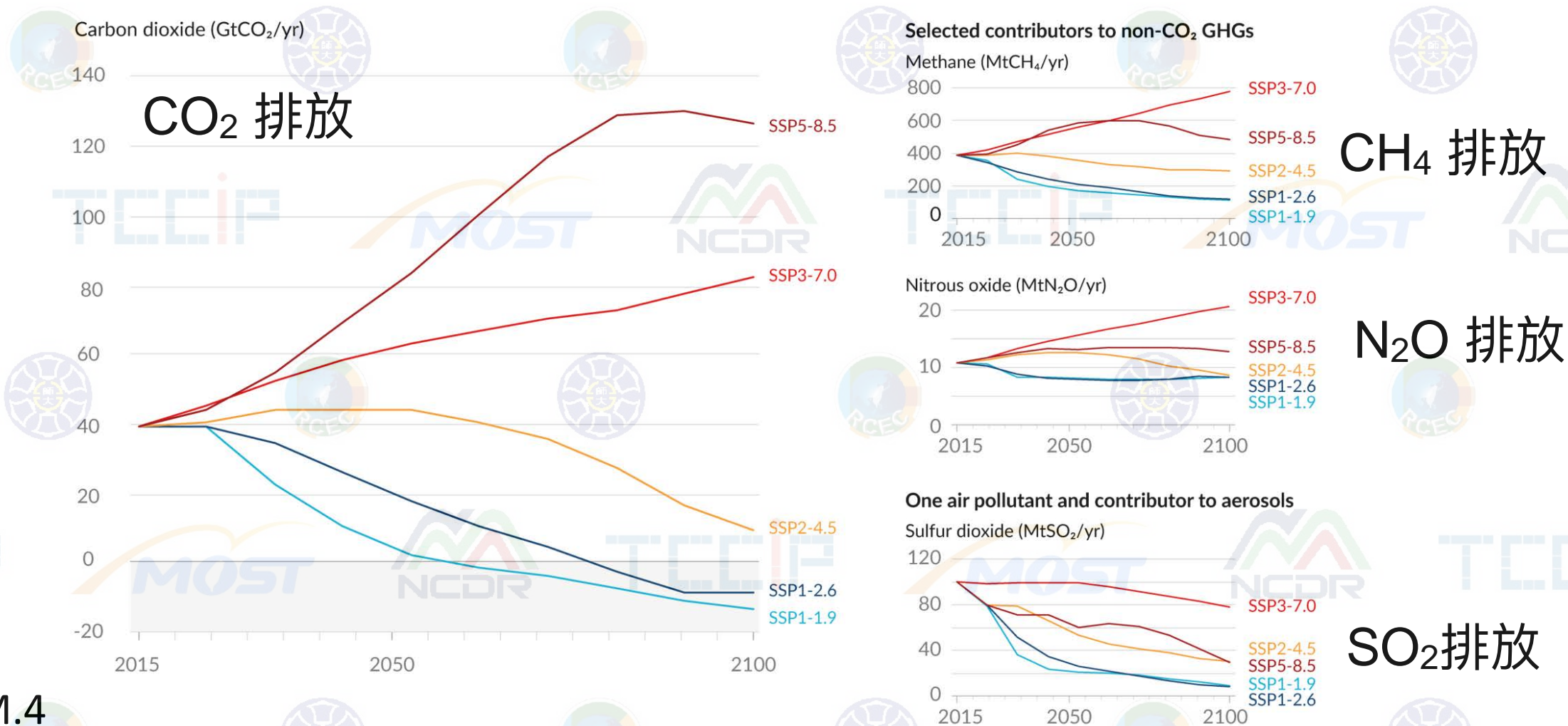


Figure SPM.4

# 未來全球氣候：不同情境下的長期推估與近期改變

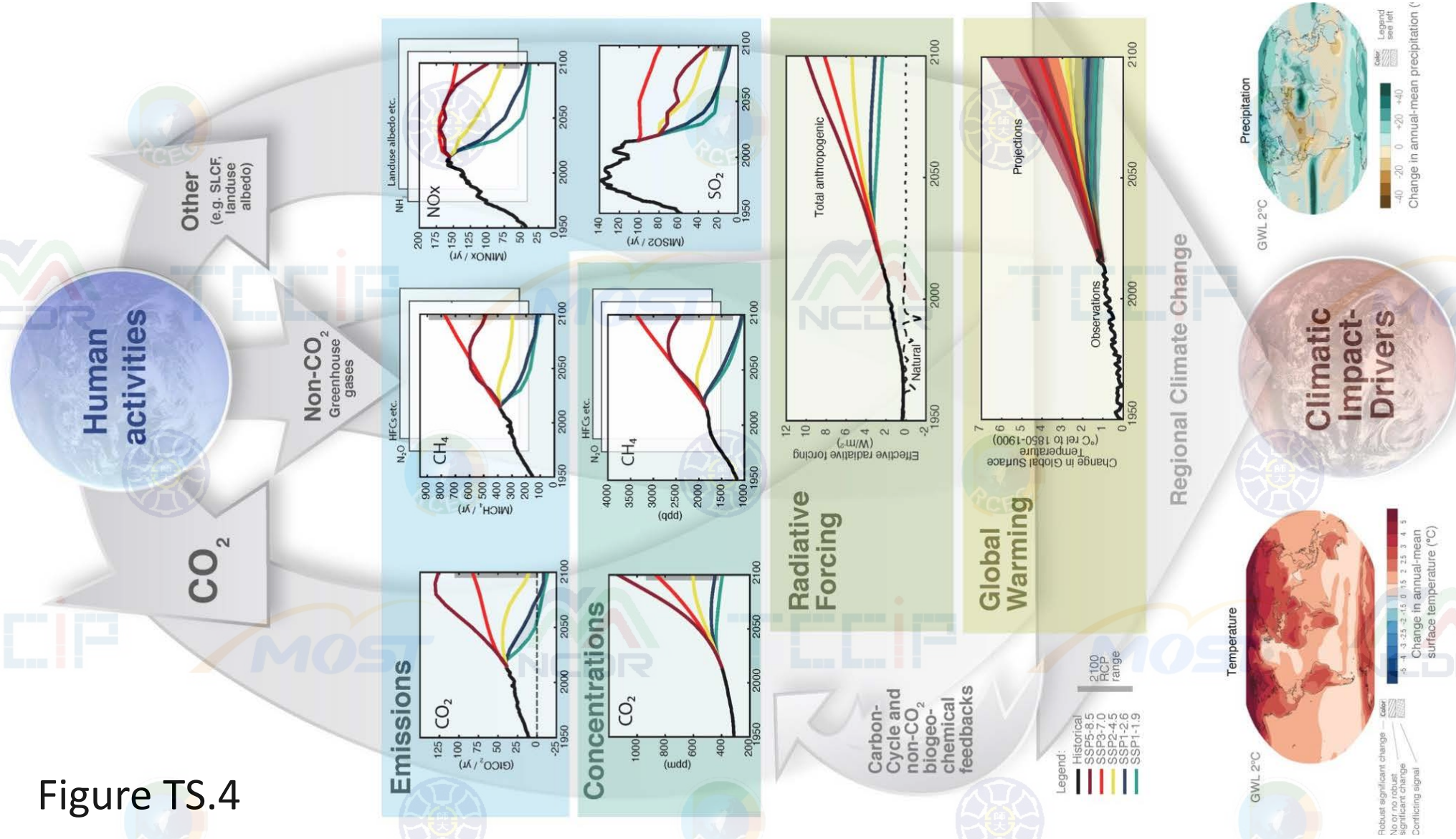


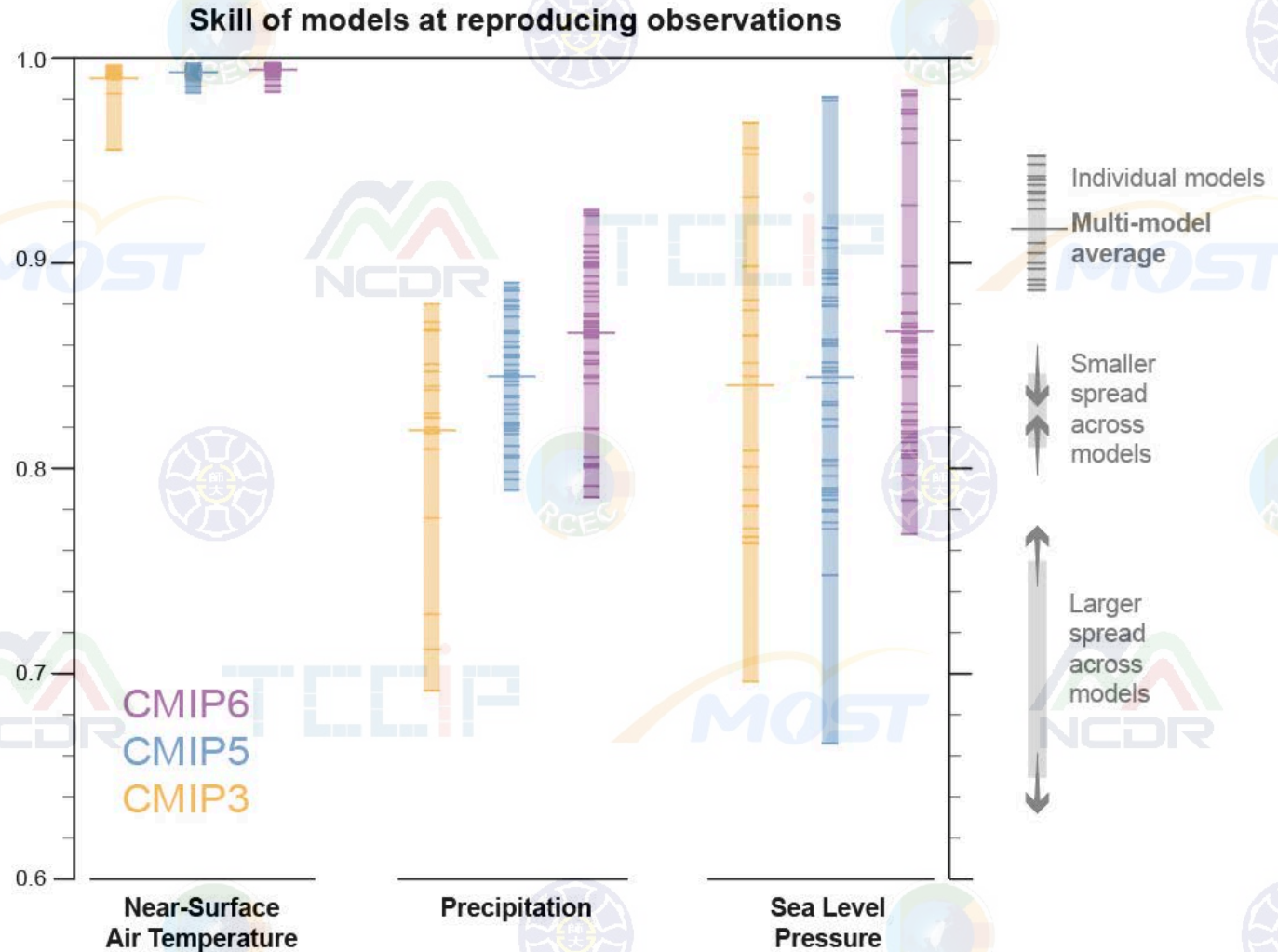
Figure TS.4

# 未來全球氣候：不同情境下的長期推估與近期改變

## FAQ 3.3: Are Climate Models Improving?

Yes, climate models have improved with increasing computer power and better understanding of climate processes.

氣候模式的模擬  
表現持續提升



FAQ 3.3, Figure 1

# 未來全球氣候：不同情境下的長期推估與近期改變

## Future emissions cause future additional warming

a) Global surface temperature change relative to 1850-1900

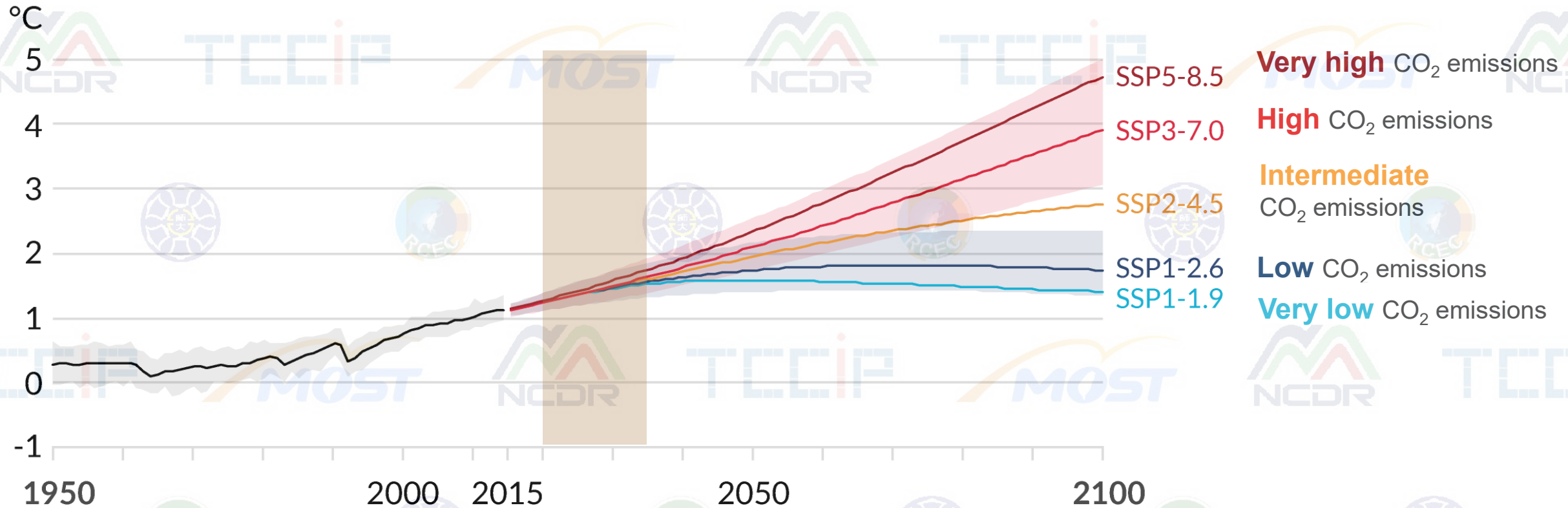
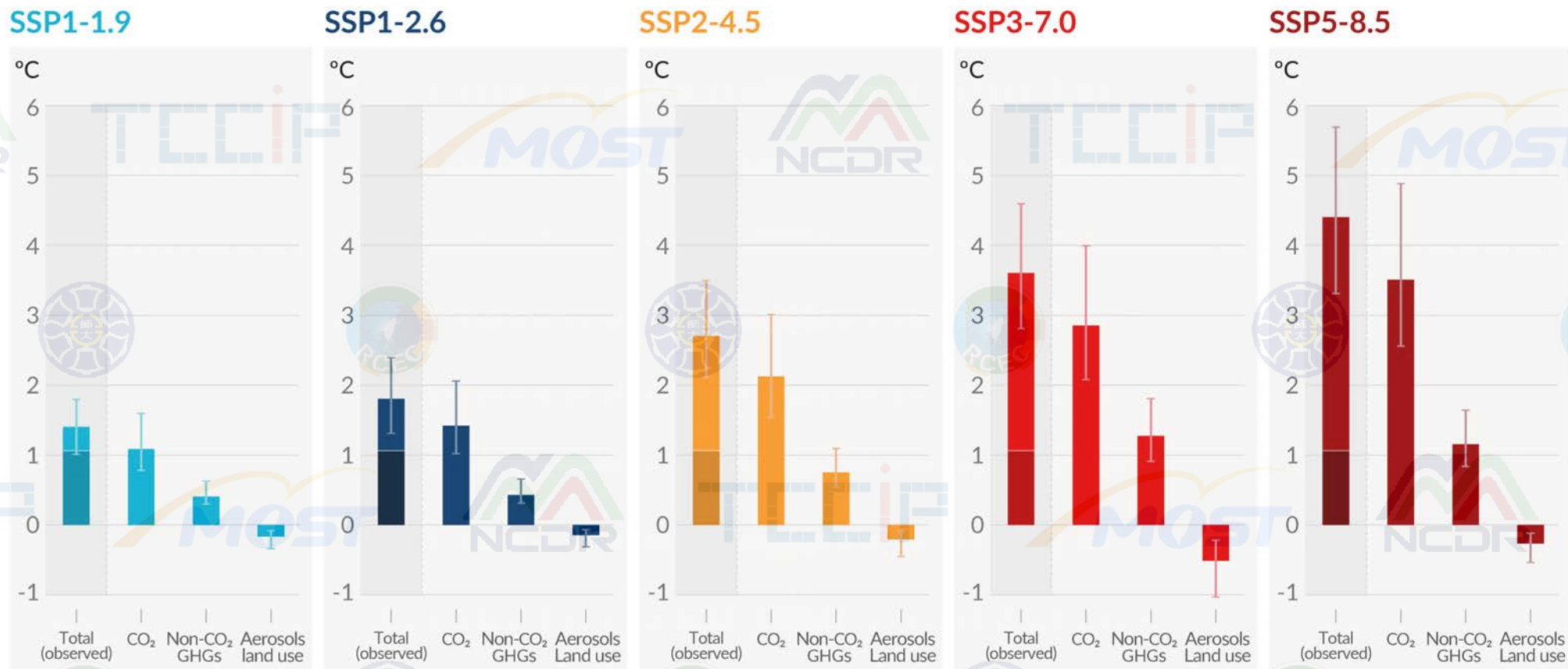


Figure SPM.8

# 未來全球氣候：不同情境下的長期推估與近期改變

## 推估未來的暖化主要還是來自二氧化碳的貢獻

Change in global surface temperature in 2081-2100 relative to 1850-1900 (°C)



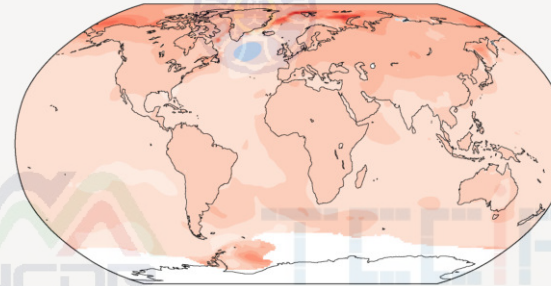
# 氣候系統的變化與未來氣候推估

With every increment of global warming, changes get larger in regional mean temperature

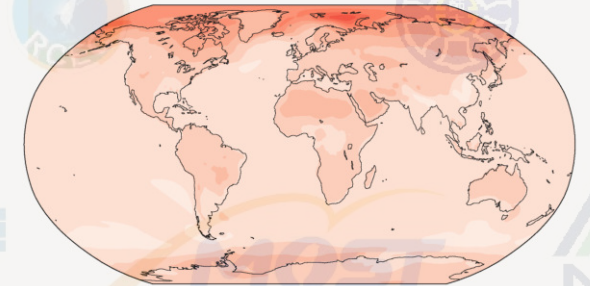
a) Annual mean temperature change (°C) at 1 °C global warming

Warming at 1 °C affects all continents and is generally larger over land than over the oceans in both observations and models. Across most regions, observed and simulated patterns are consistent.

Observed change per 1 °C global warming



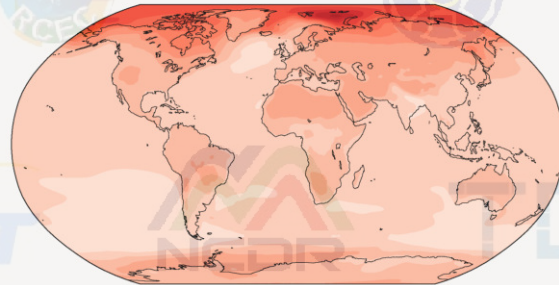
Simulated change at 1 °C global warming



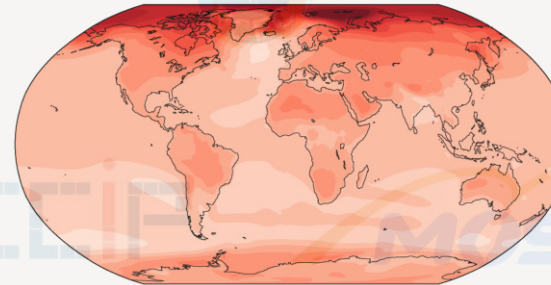
b) Annual mean temperature change (°C) relative to 1850-1900

Across warming levels, land areas warm more than oceans, and the Arctic and Antarctica warm more than the tropics.

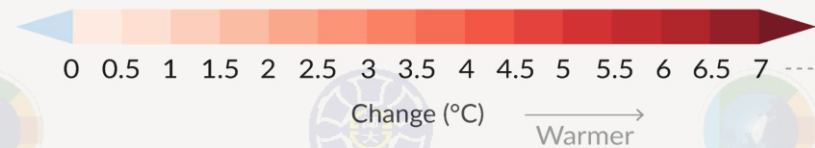
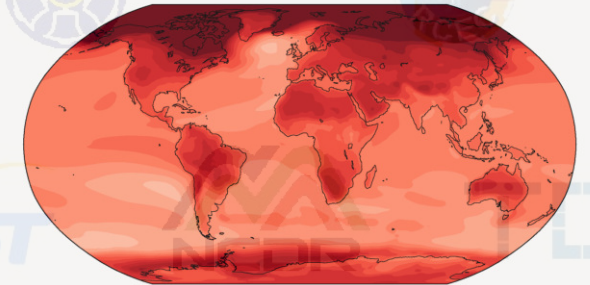
Simulated change at 1.5 °C global warming



Simulated change at 2 °C global warming



Simulated change at 4 °C global warming





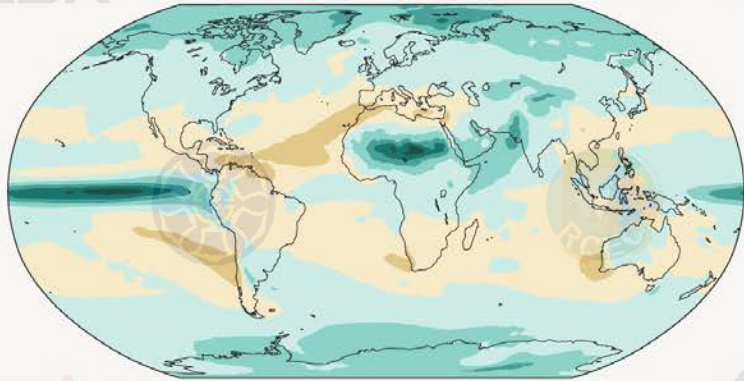
# 氣候系統的變化與未來氣候推估

With every increment of global warming, changes get larger in regional mean precipitation

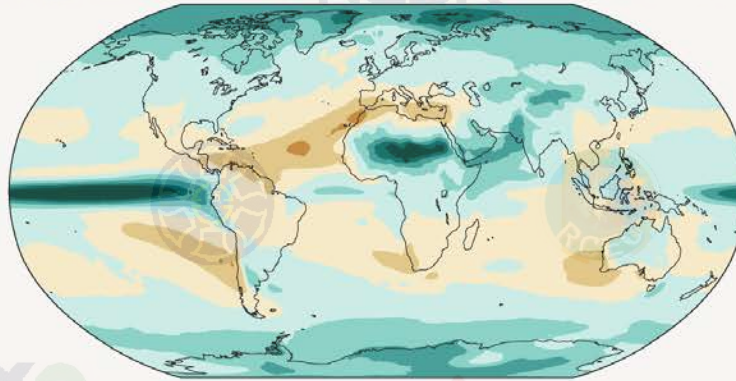
c) Annual mean precipitation change (%) relative to 1850-1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

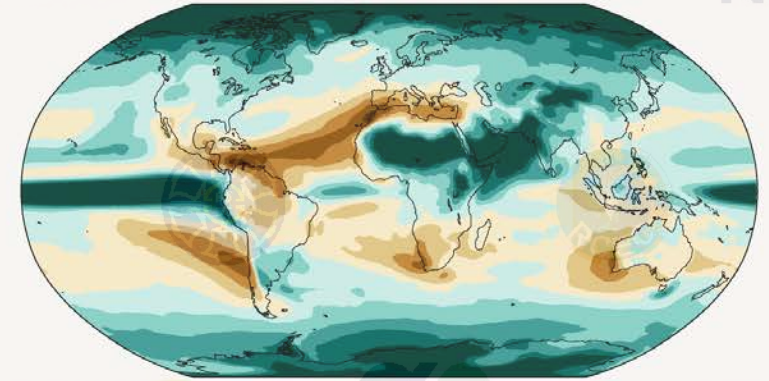
Simulated change at 1.5 °C global warming



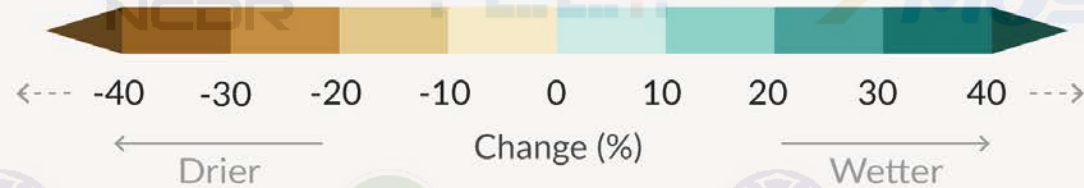
Simulated change at 2 °C global warming



Simulated change at 4 °C global warming



Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions



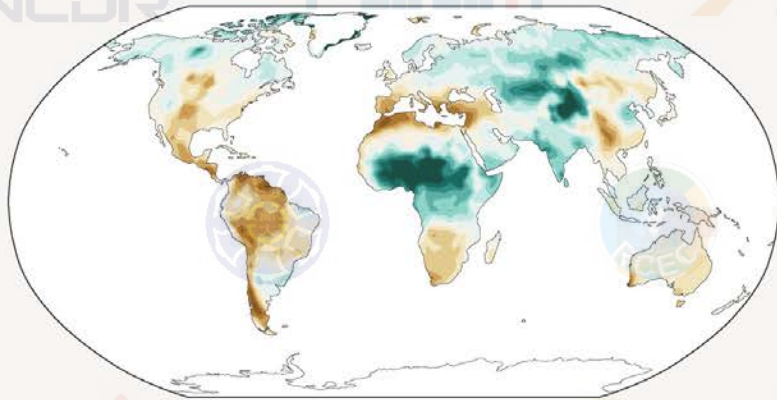
# 氣候系統的變化與未來氣候推估

With every increment of global warming, changes get larger in regional mean soil moisture

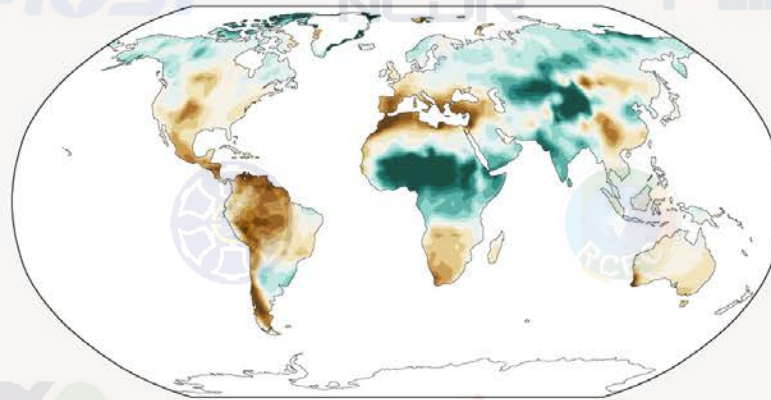
d) Annual mean total column soil moisture change (standard deviation)

Across warming levels, changes in soil moisture largely follow changes in precipitation but also show some differences due to the influence of evapotranspiration.

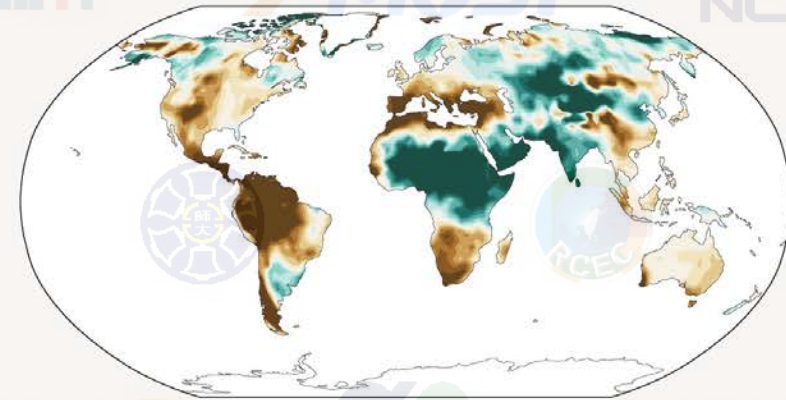
Simulated change at 1.5 °C global warming



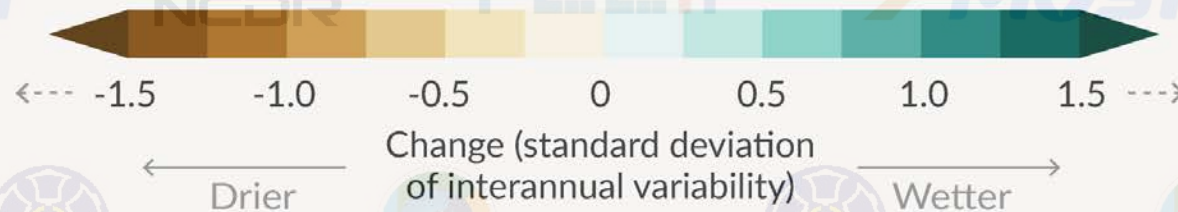
Simulated change at 2 °C global warming



Simulated change at 4 °C global warming



Relatively small absolute changes may appear large when expressed in units of standard deviation in dry regions with little interannual variability in baseline conditions



# 氣候系統的變化與未來氣候推估

Observed, simulated and projected changes compared to the 1995–2014 average in global surface air temperature through to 2100 differentiated by SSP scenario pathways

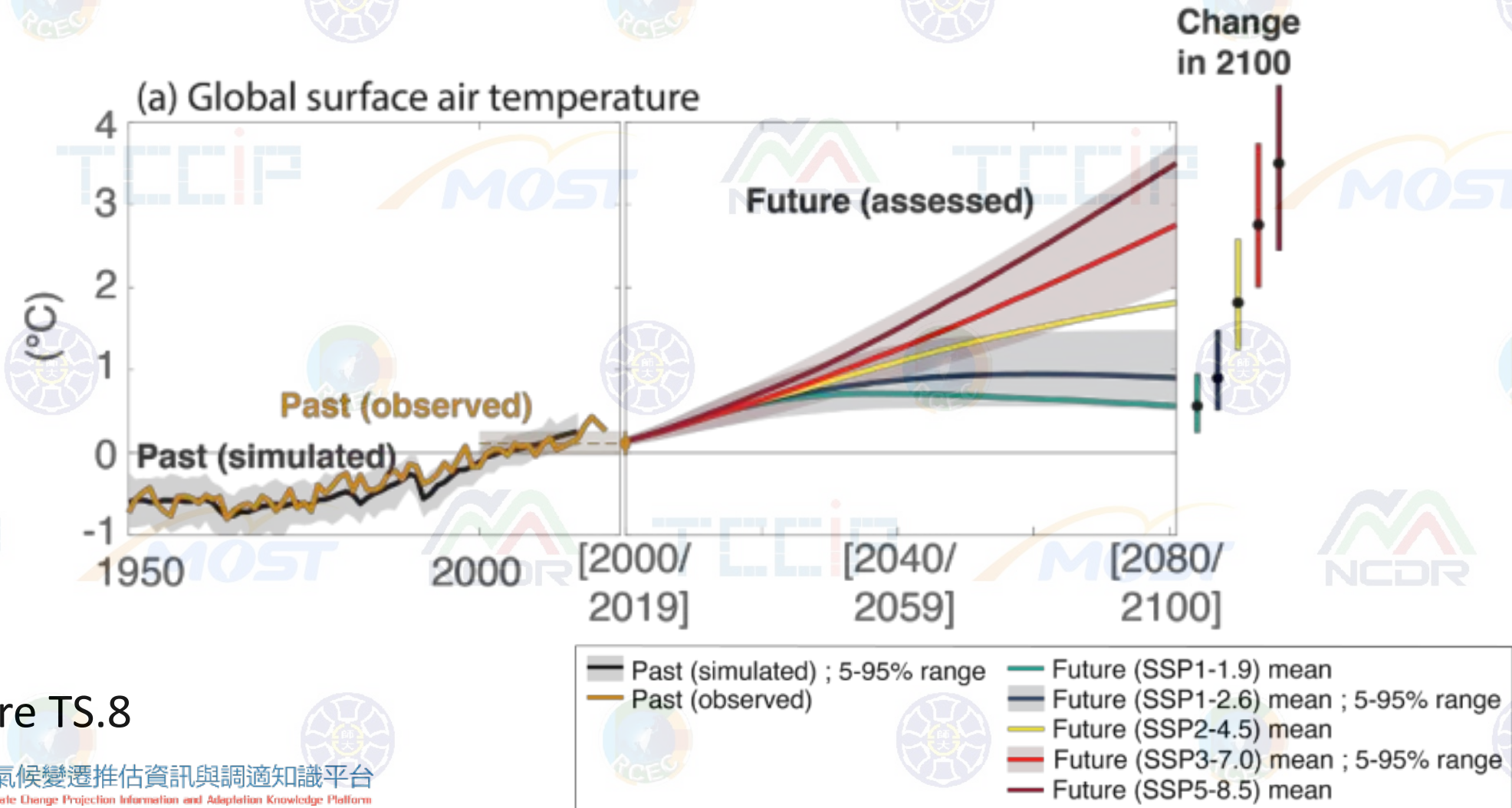


Figure TS.8

# 氣候系統的變化與未來氣候推估

Observed, simulated and projected changes compared to the 1995–2014 average in global ocean heat content and thermometric sea level through to 2100 differentiated by SSP scenario pathways

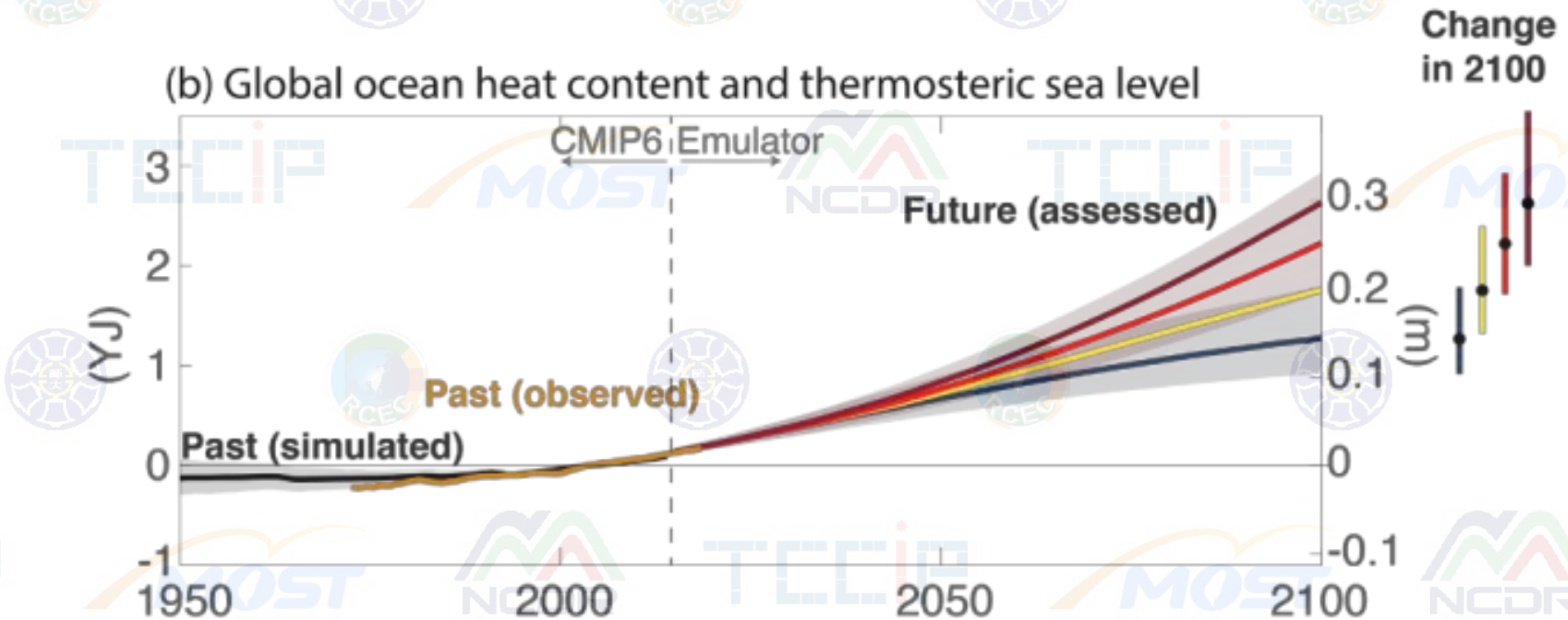


Figure TS.8

# 氣候系統的變化與未來氣候推估

Observed, simulated and projected changes compared to the 1995–2014 average in Arctic September sea ice area through to 2100 differentiated by SSP scenario pathways

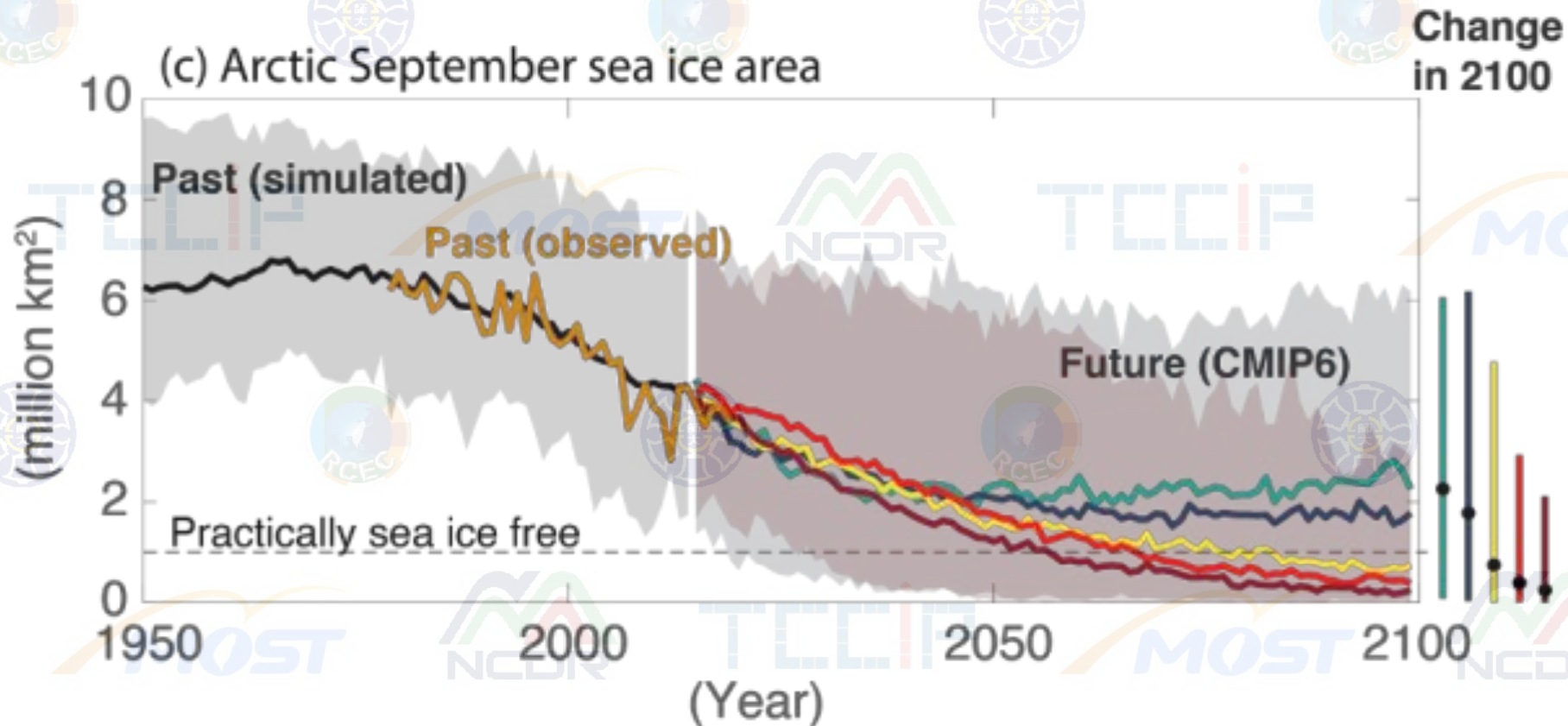
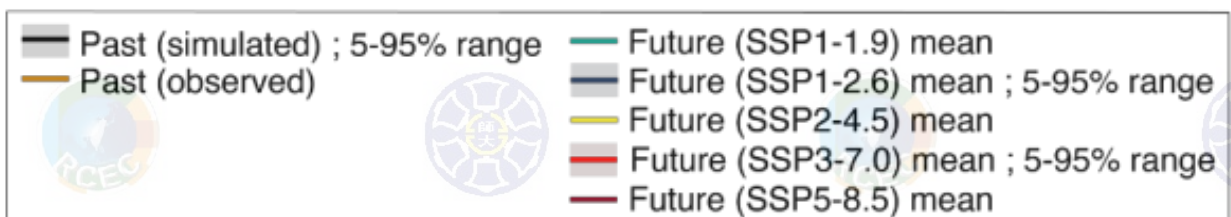


Figure TS.8



# 氣候系統的變化與未來氣候推估

Observed, simulated and projected changes compared to the 1995–2014 average in global land precipitation through to 2100 differentiated by SSP scenario pathways

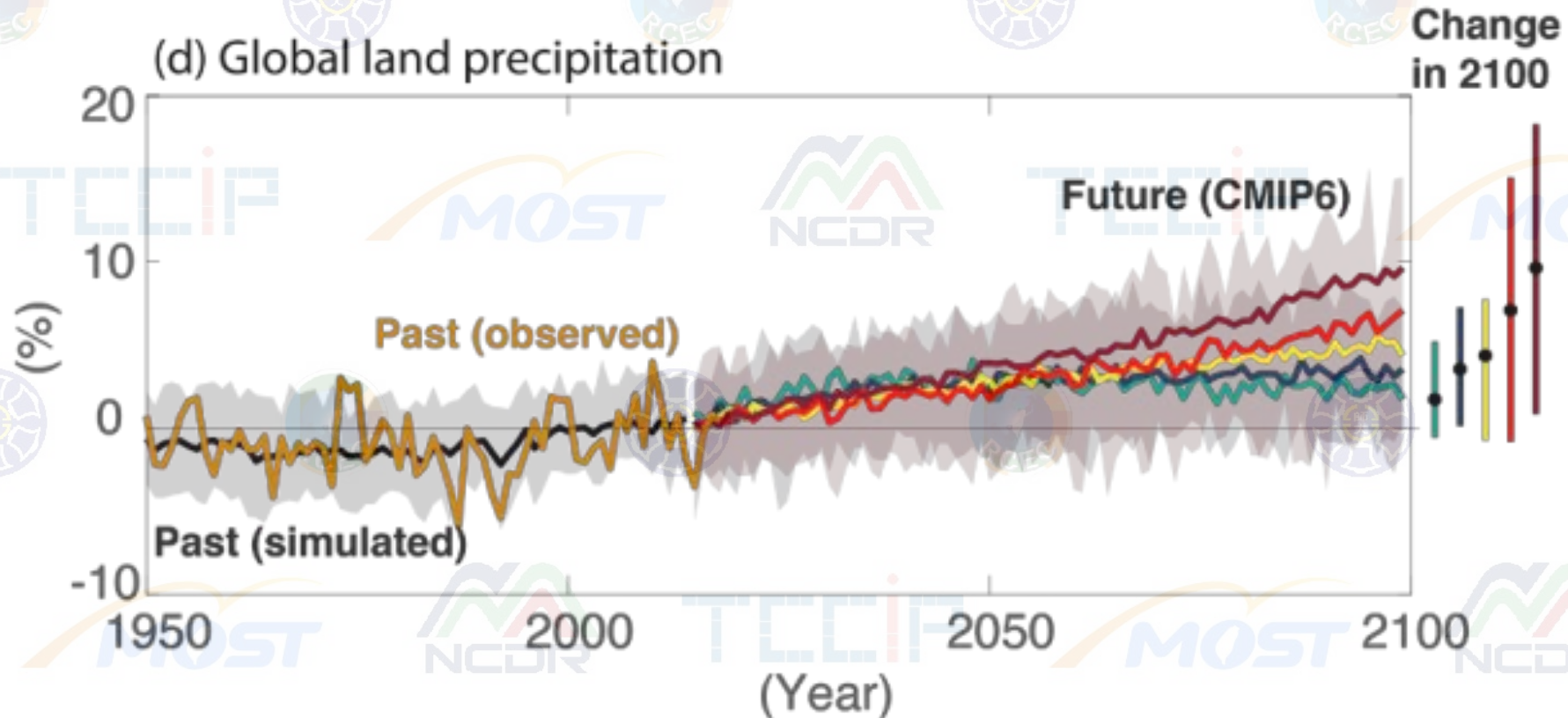
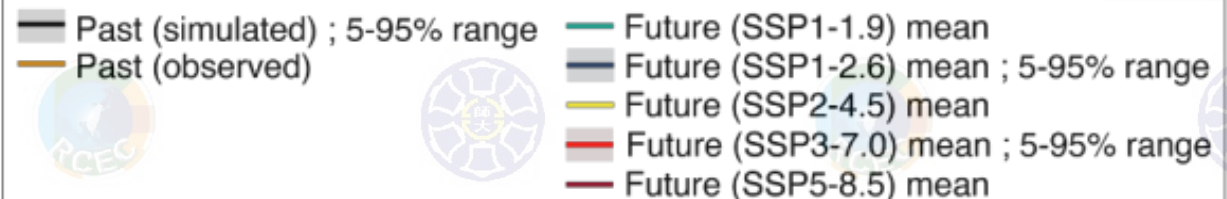


Figure TS.8



# 氣候系統的變化與未來氣候推估

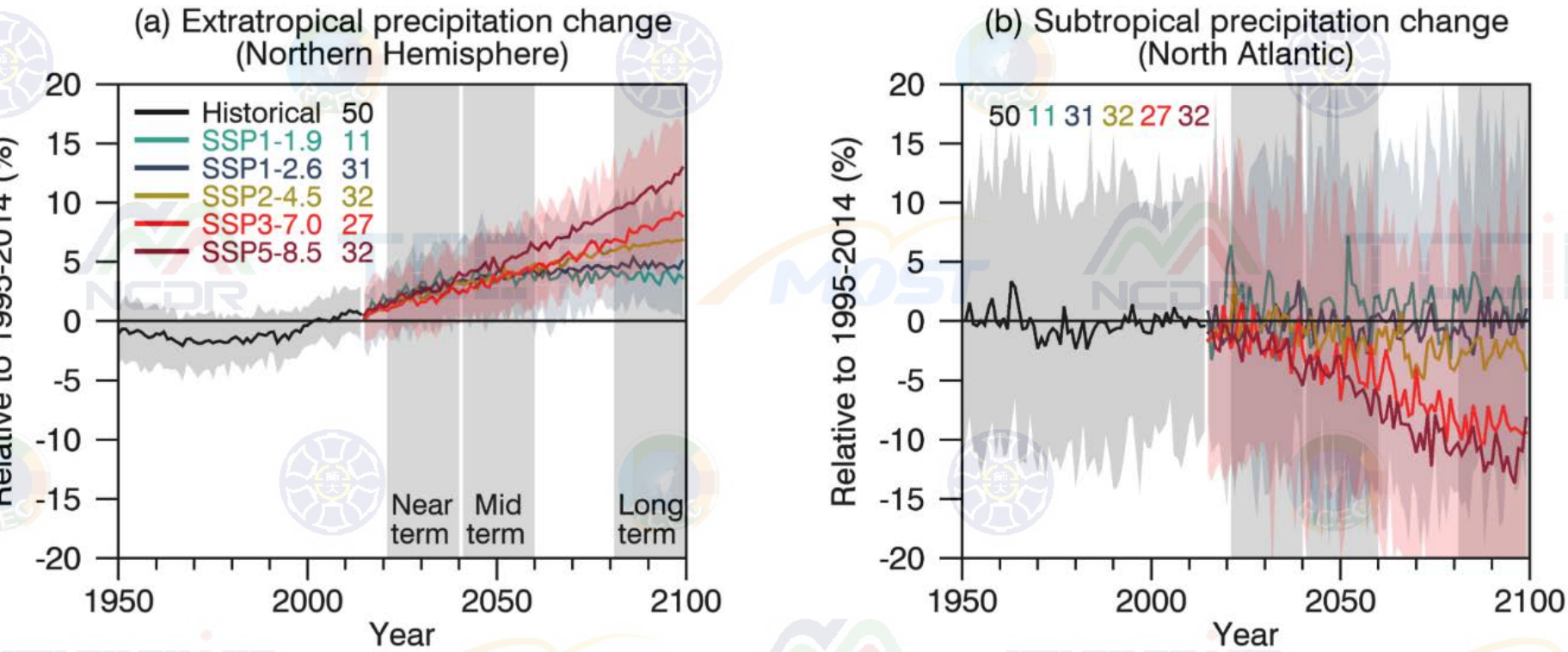
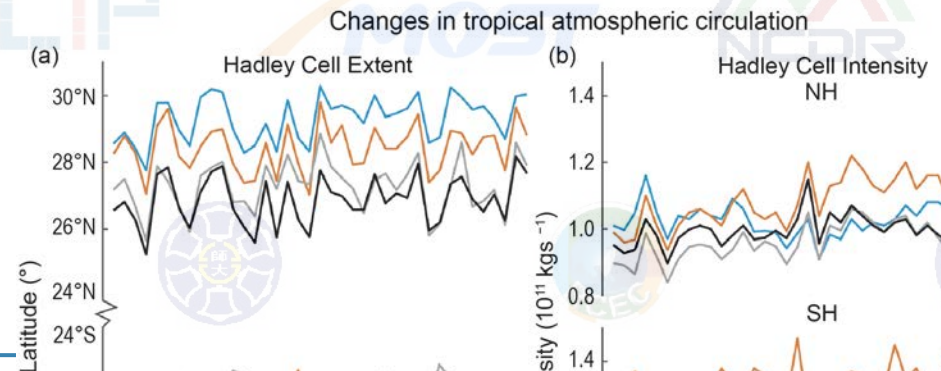


Figure 4.4

Figure 2.17



# 氣候系統的變化與未來氣候推估

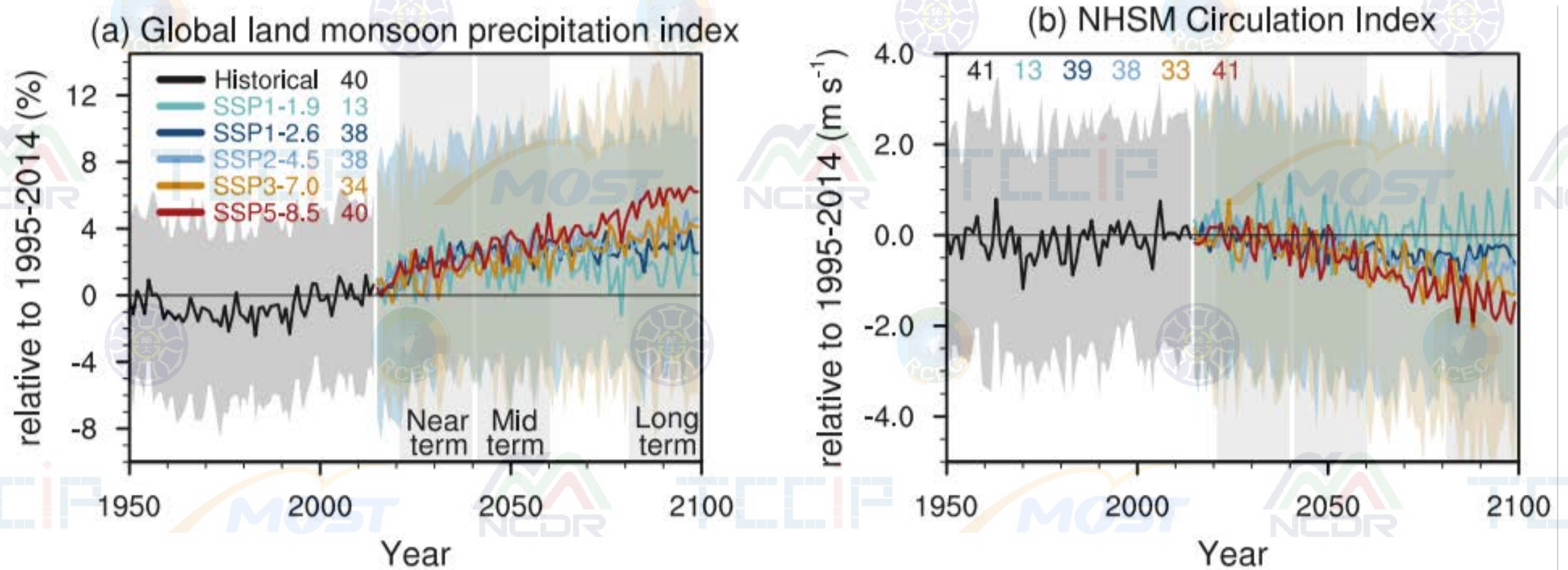


Figure 4.14



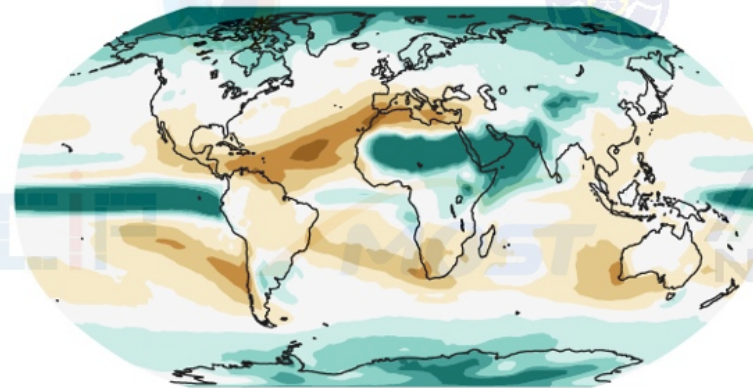
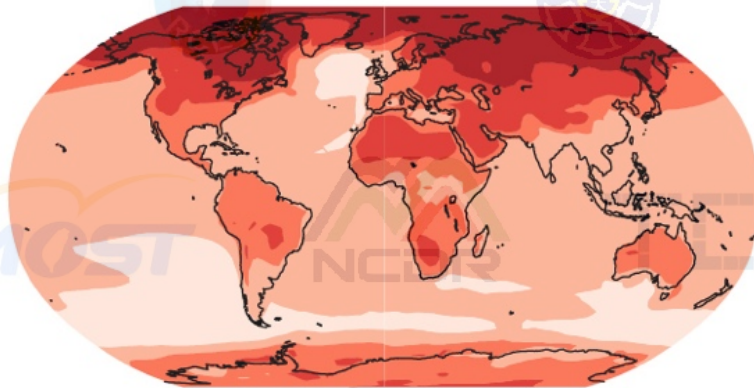
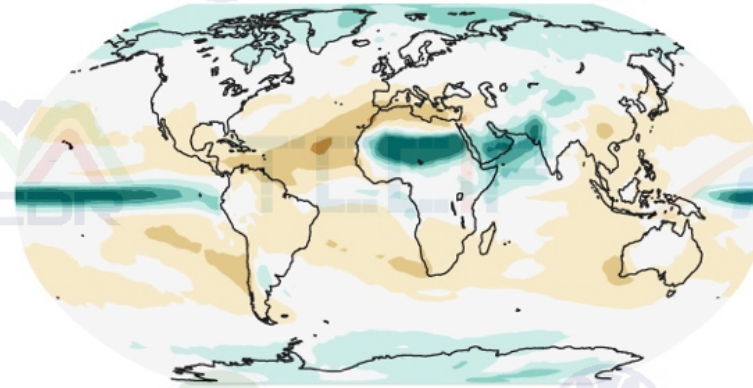
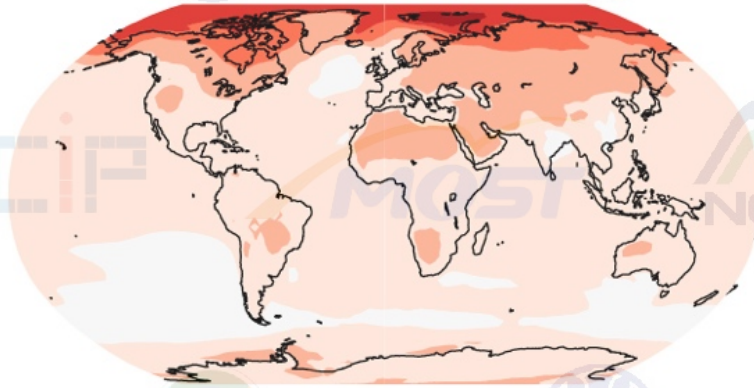
# 氣候系統的變化與未來氣候推估

## FAQ 4.3: Climate change and regional patterns

Climate change is not uniform and proportional to the level of global warming.

Warming will be **stronger** in the Arctic, on land and in the Northern Hemisphere

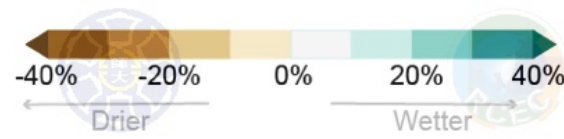
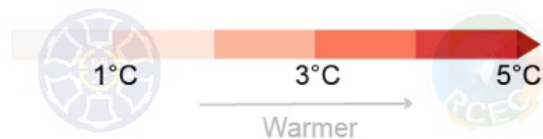
Precipitation will **increase** in high latitudes, the tropics and monsoon regions and **decrease** in the subtropics



北極  
陸地  
北半球  
增溫較大

高緯度  
熱帶  
季風區  
降雨增加

副熱帶  
降雨減少



FAQ 4.3, Figure 1

## 中緯度 Storm Tracks 往北偏移

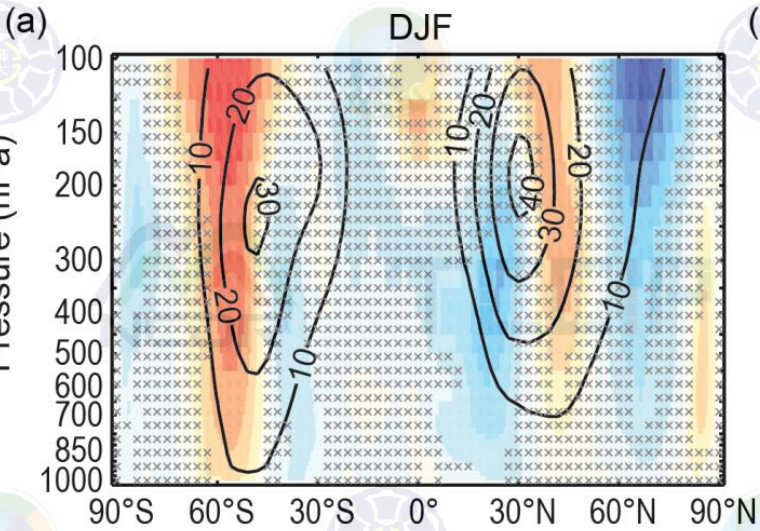
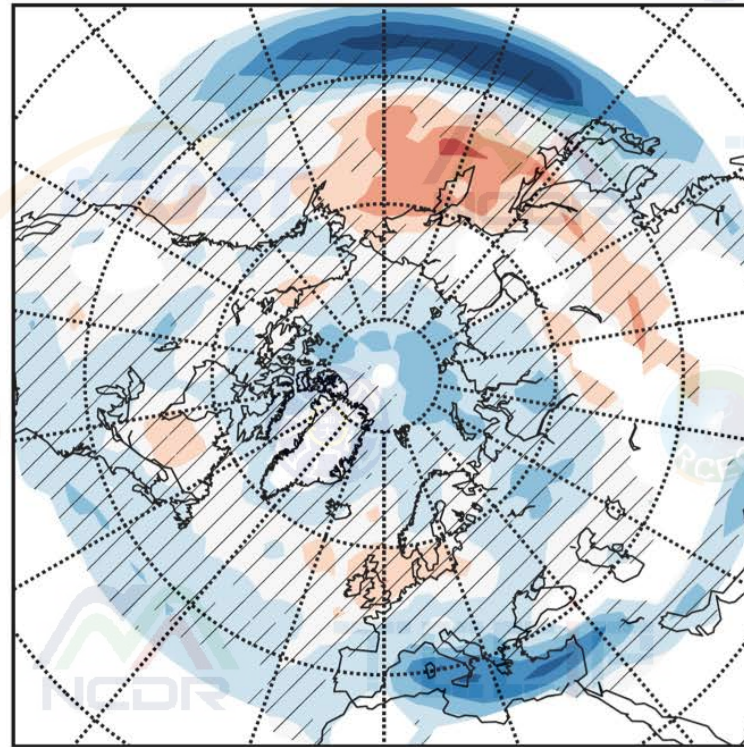


Figure 2.18

(a) NH DJF 2080-2100 (13)



(b) SH JJA 2080-2100 (13)

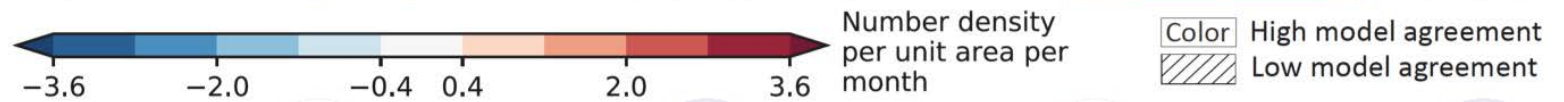
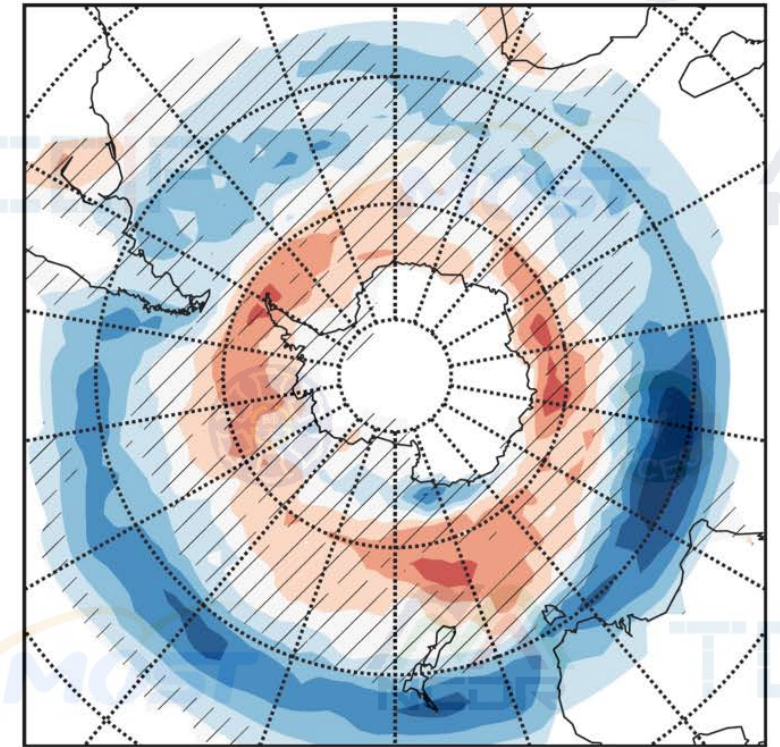


Figure 4.27

# 氣候系統的變化與未來氣候推估

## Recent and Future Changes in Ocean: Marine Heatwave

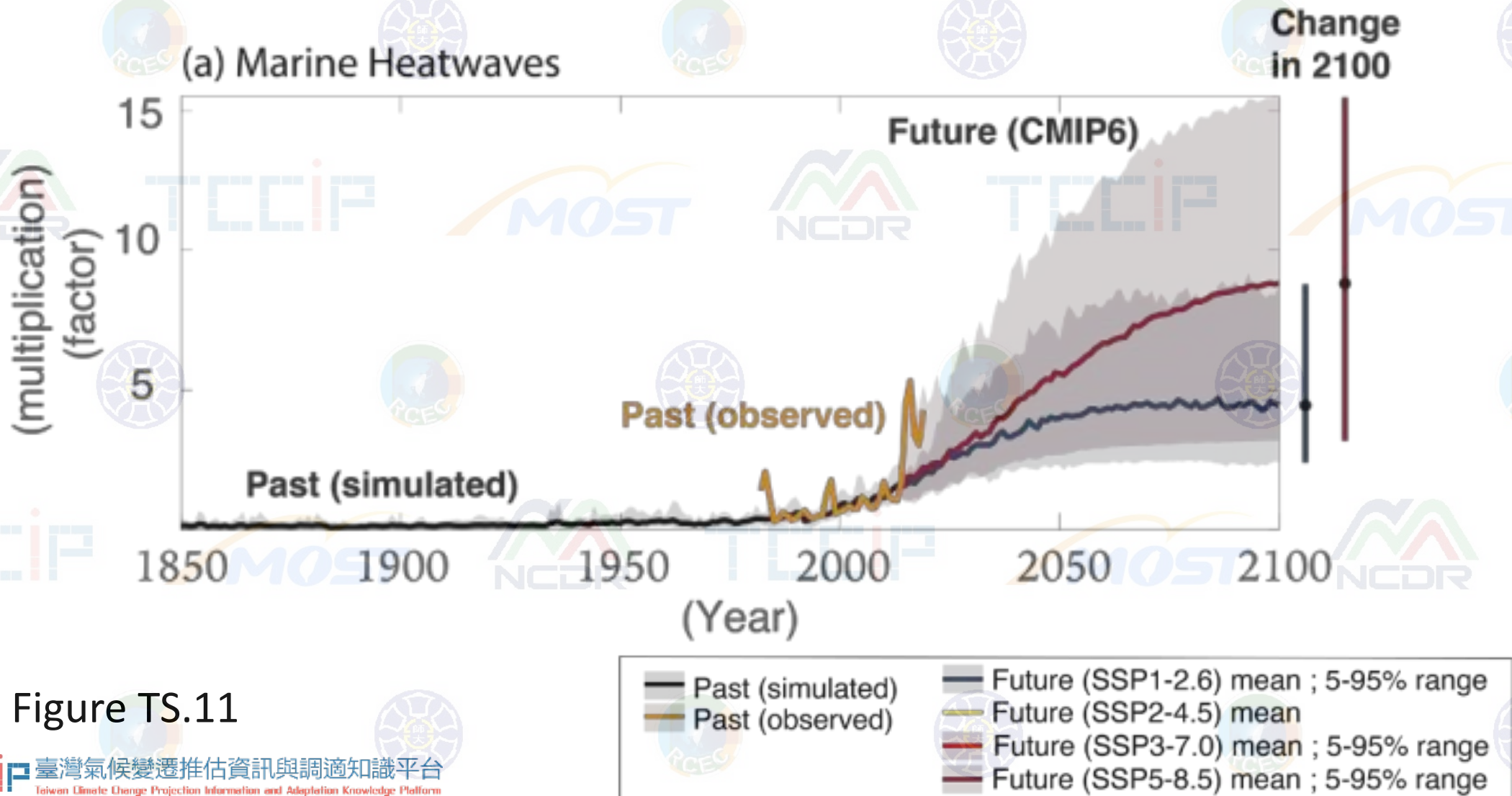


Figure TS.11

# 氣候系統的變化與未來氣候推估

## Recent and Future Changes in Ocean: Atlantic Meridional Overturning Circulation

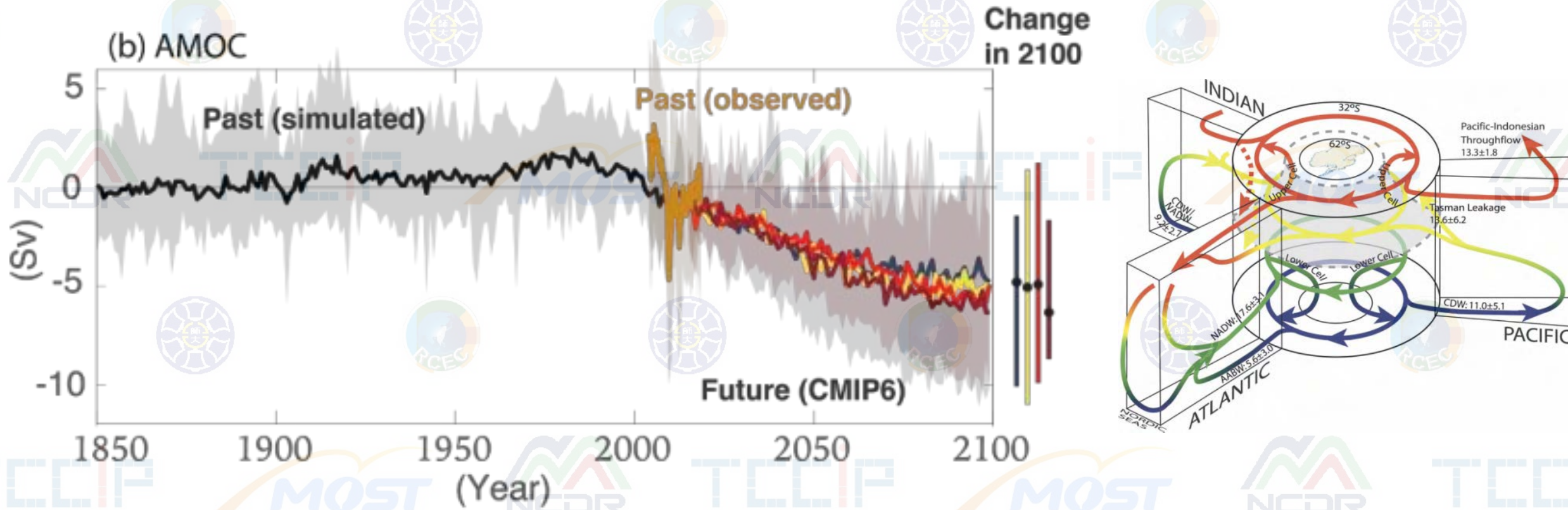


Figure TS.11

# 氣候系統的變化與未來氣候推估

## Recent and Future Changes in Ocean: Dissolved Oxygen

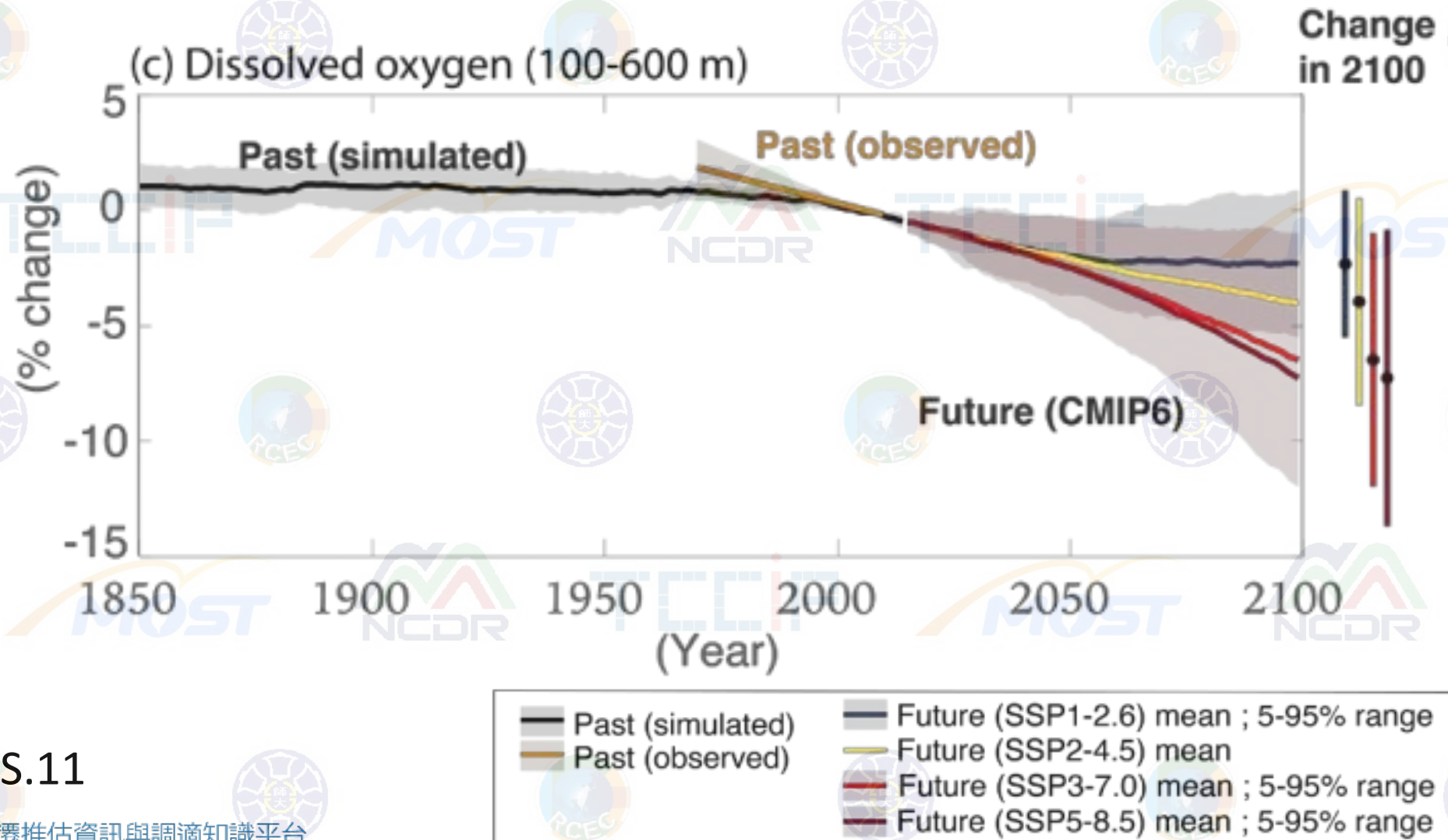


Figure TS.11

# 氣候系統的變化與未來氣候推估

## Recent and Future Changes in Ocean: Ocean Acidification

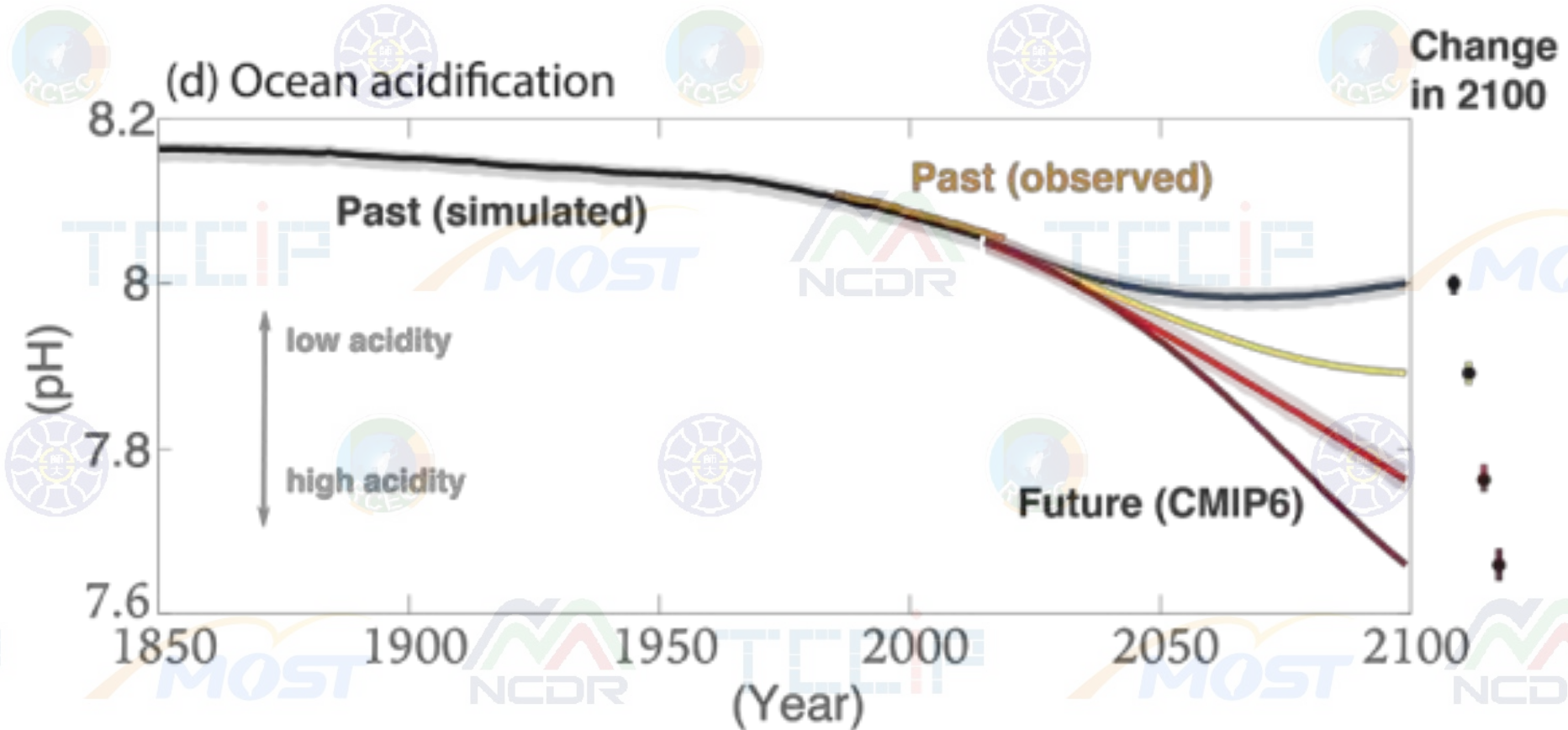


Figure TS.11



## Recent and Future Changes in ice sheets: Greenland and Antarctic

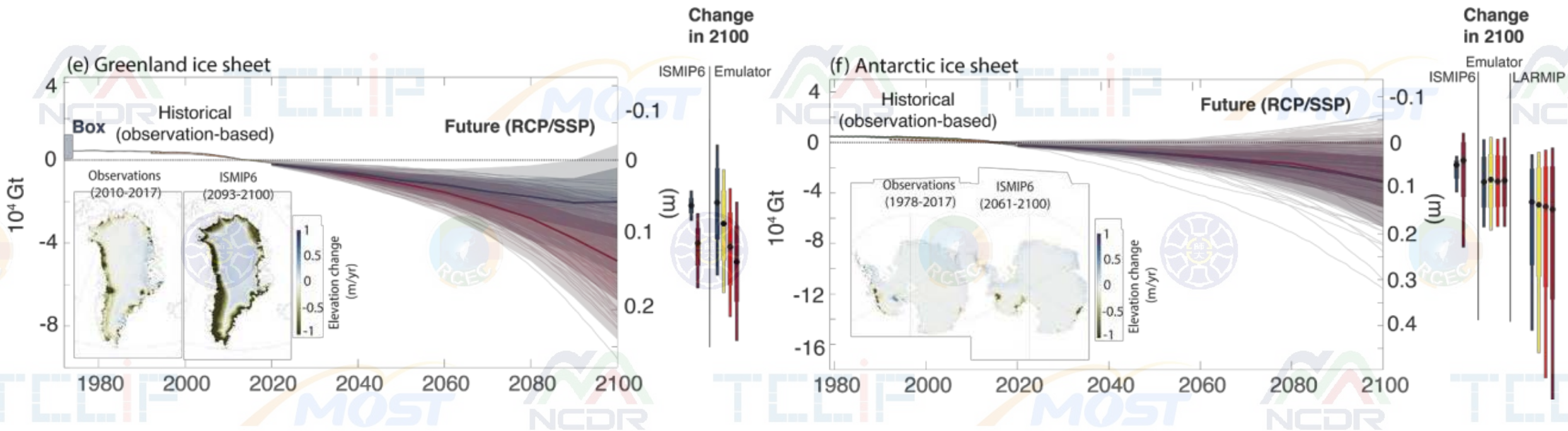
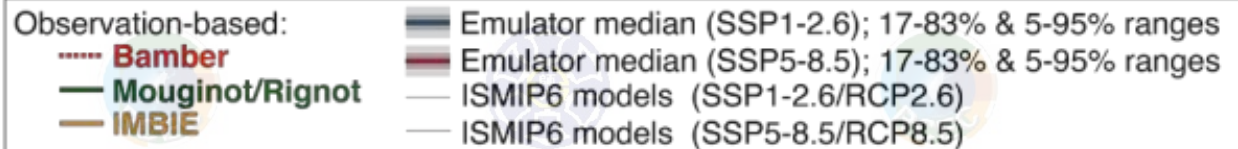
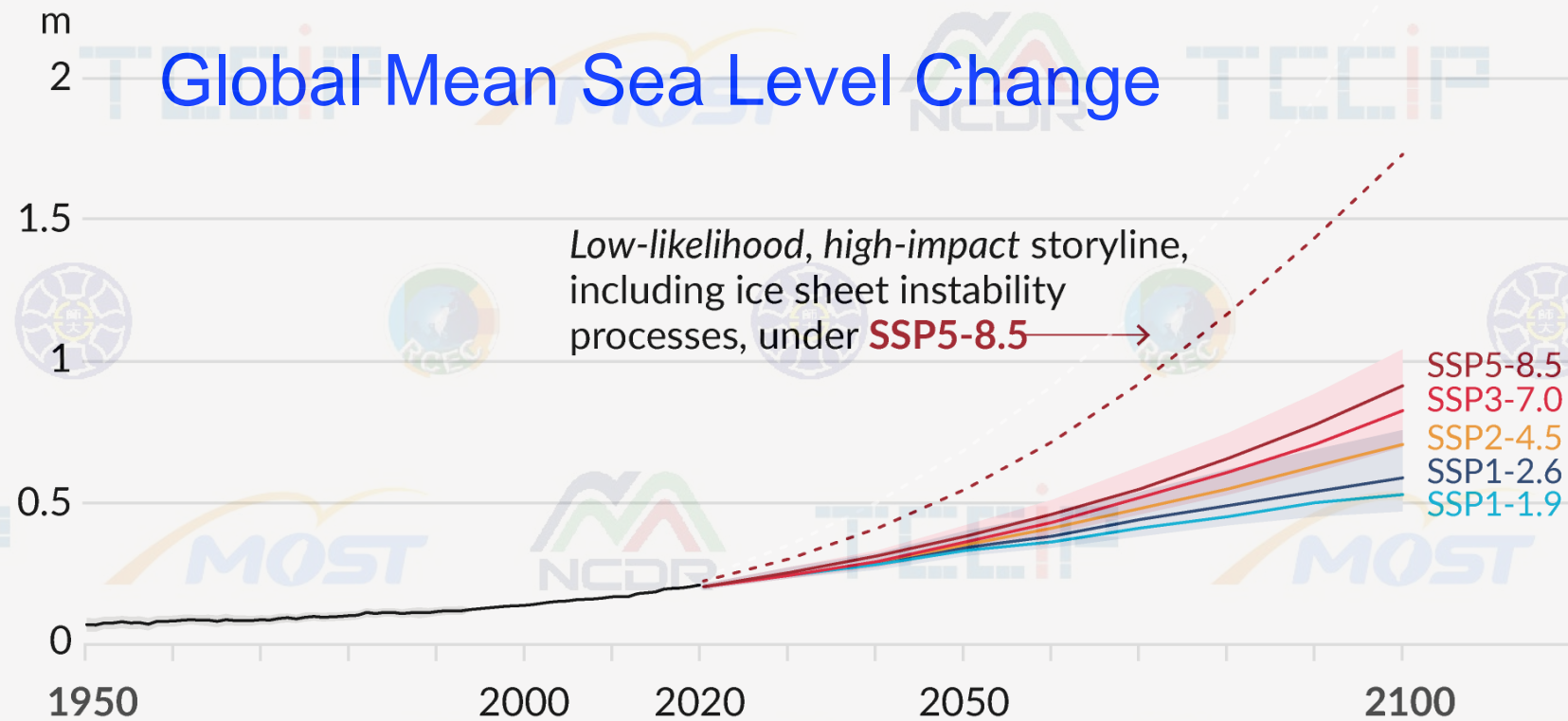


Figure TS.11



Human activities affect all the major climate system components with some responding over decades and others over centuries

d) Global mean sea level change relative to 1900





# 氣候系統的變化與未來氣候推估

Human activities affect all the major climate system components with some responding over decades and others over centuries

## Global Mean Sea Level Change

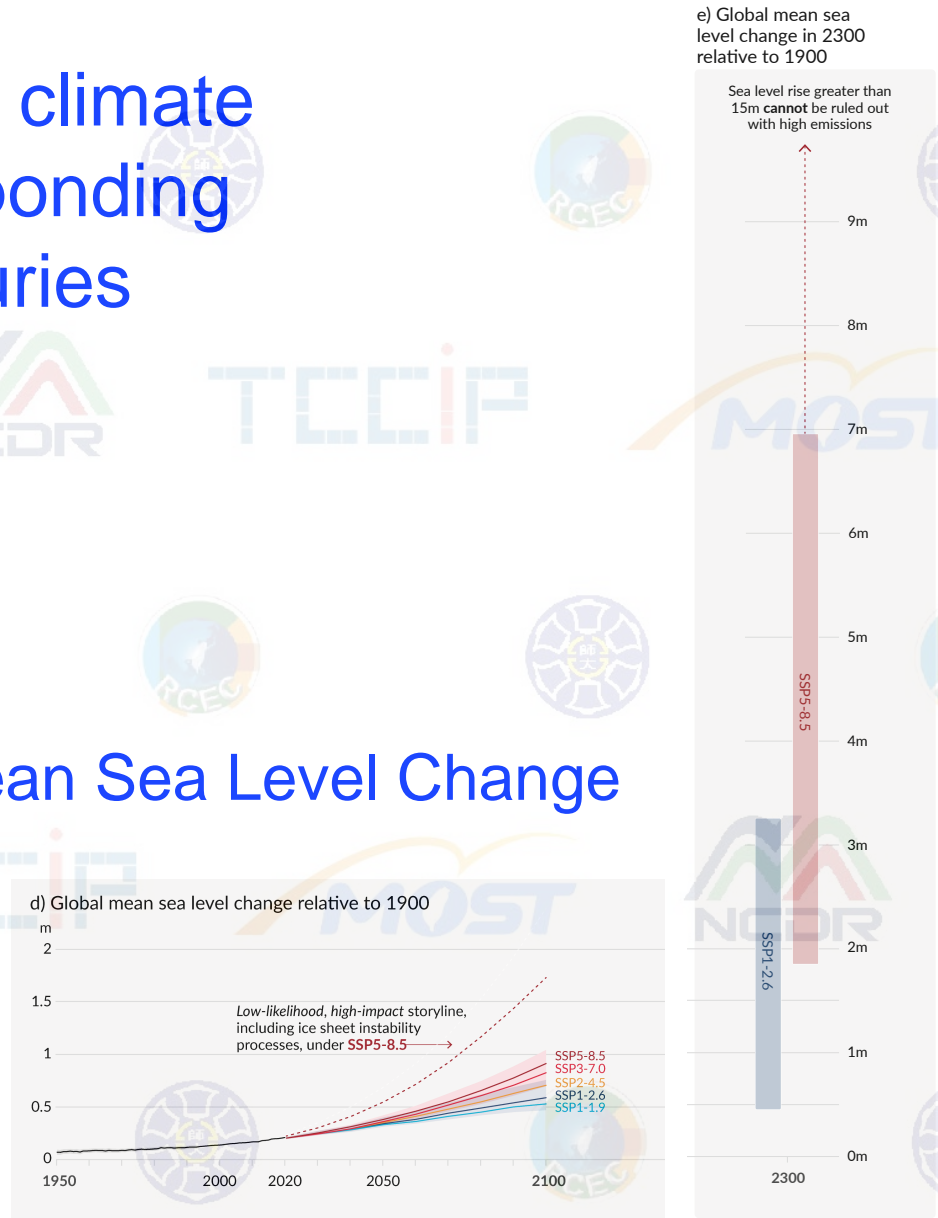
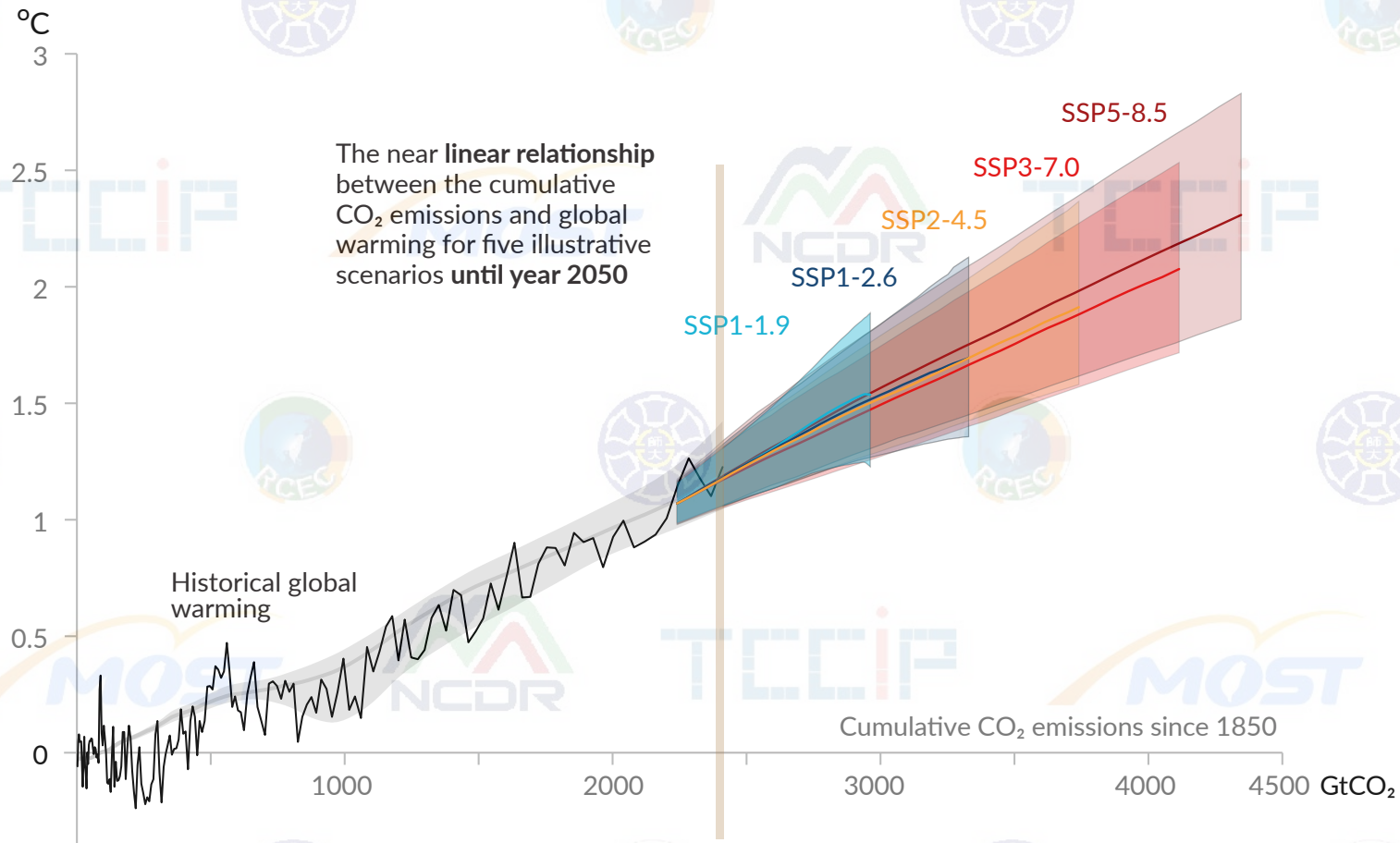


Figure SPM.8

# 未來全球氣候：不同情境下的長期推估與近期改變

## Every tonne of CO<sub>2</sub> emissions adds to global warming

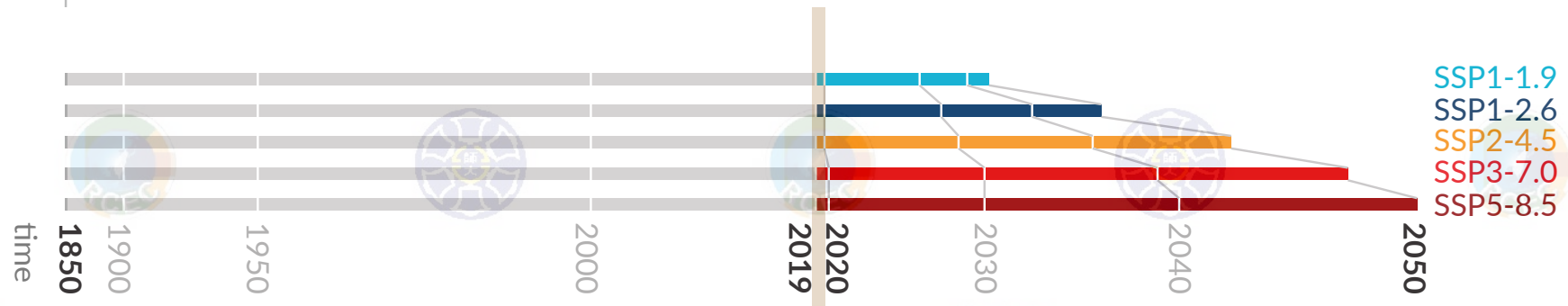
Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO<sub>2</sub> emissions (GtCO<sub>2</sub>)



2390 Gt CO<sub>2</sub>

Figure SPM.10

# 未來全球氣候：不同情境下的長期推估與近期改變



Future cumulative CO<sub>2</sub> emissions differ across scenarios, and determine how much warming we will experience

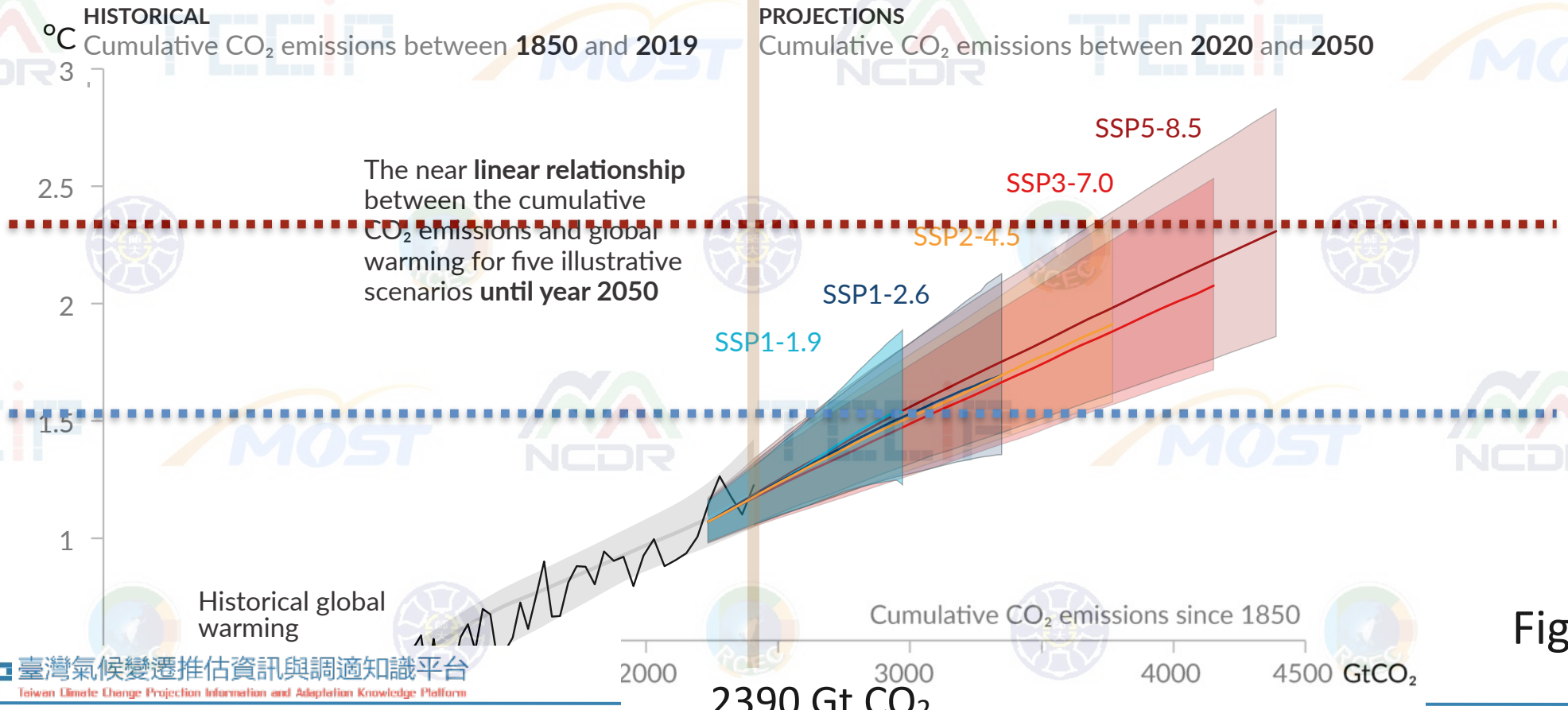


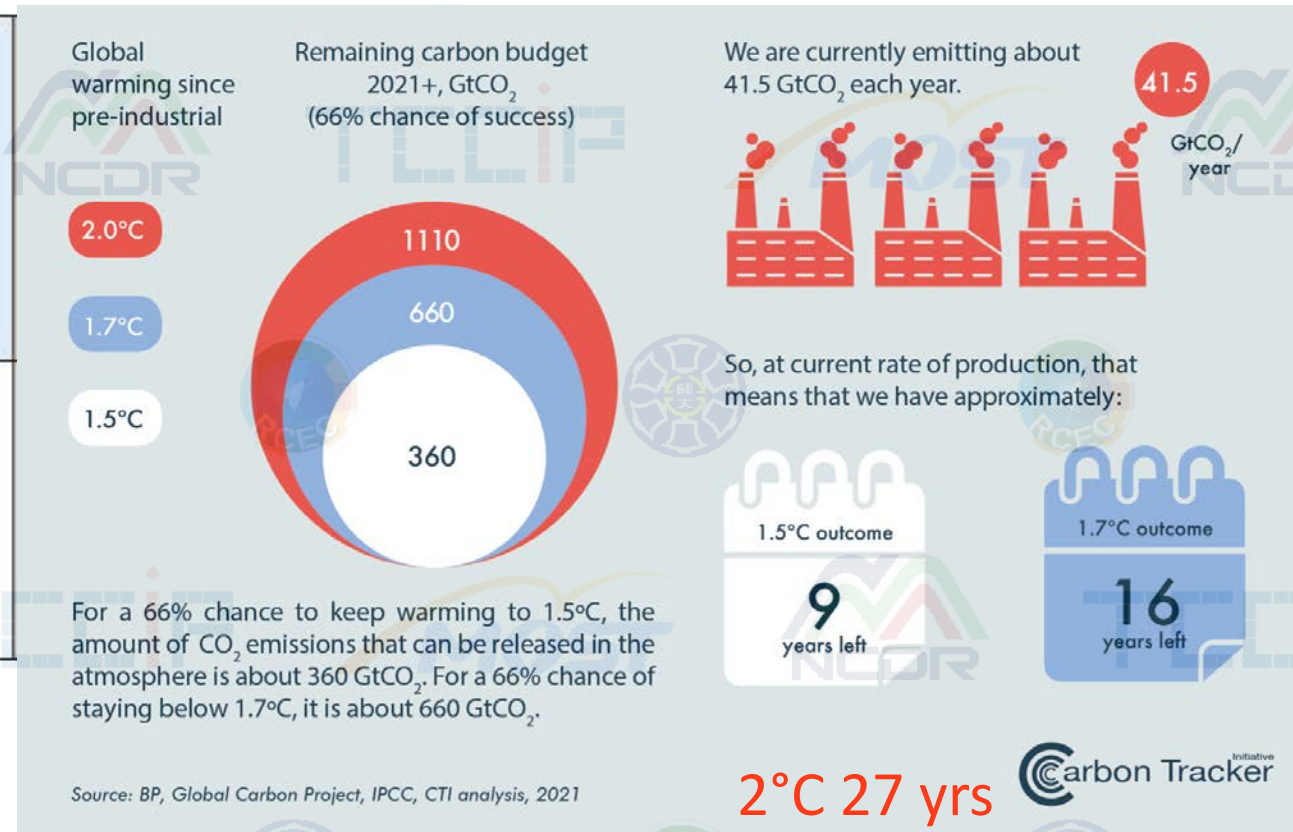
Figure SPM.10

# 未來全球氣候：不同情境下的長期推估與近期改變

Global warming between 1850–1900 and 2010–2019 (°C)	Historical cumulative CO <sub>2</sub> emissions from 1850 to 2019 (GtCO <sub>2</sub> )
1.07 (0.8–1.3; <i>likely range</i> )	2390 (± 240; <i>likely range</i> )

Approximate global warming relative to 1850–1900 until temperature limit (°C)*(1)	Additional global warming relative to 2010–2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 (GtCO <sub>2</sub> )				
		Likelihood of limiting global warming to temperature limit*(2)				
		17%	33%	50%	67%	83%
1.5	0.43	900	650	500	400	300
1.7	0.63	1450	1050	850	700	550
2.0	0.93	2300	1700	1350	1150	900

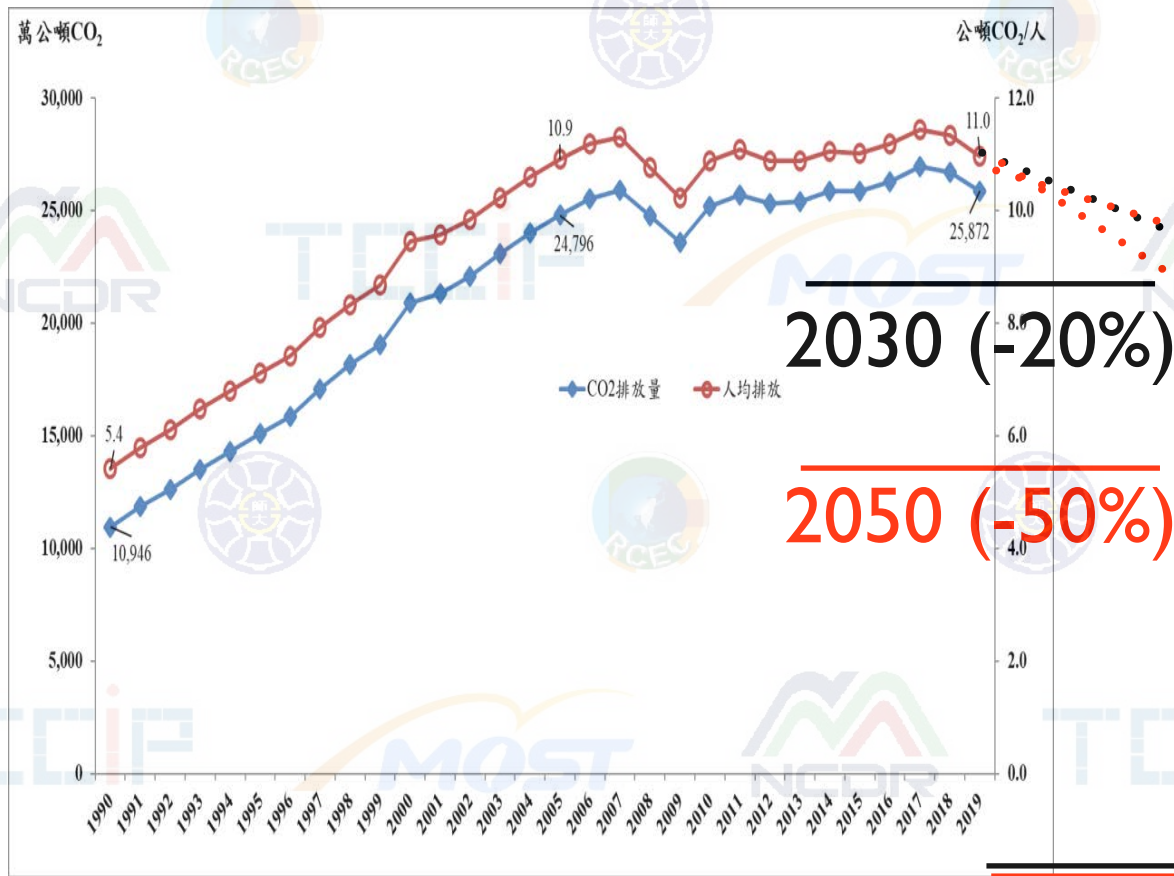
Table SPM.2



BP, Global Carbon Project, IPCC, CTI Analysis (2021 update)

# 未來全球氣候：不同情境下的長期推估與近期改變

國家溫室氣體長期減量目標為2050年溫室氣體排放量降為2005年排放量50%。但可參酌聯合國氣候變化綱要公約與其協議，適時調整。



資料來源：經濟部能源局，2020年7月。

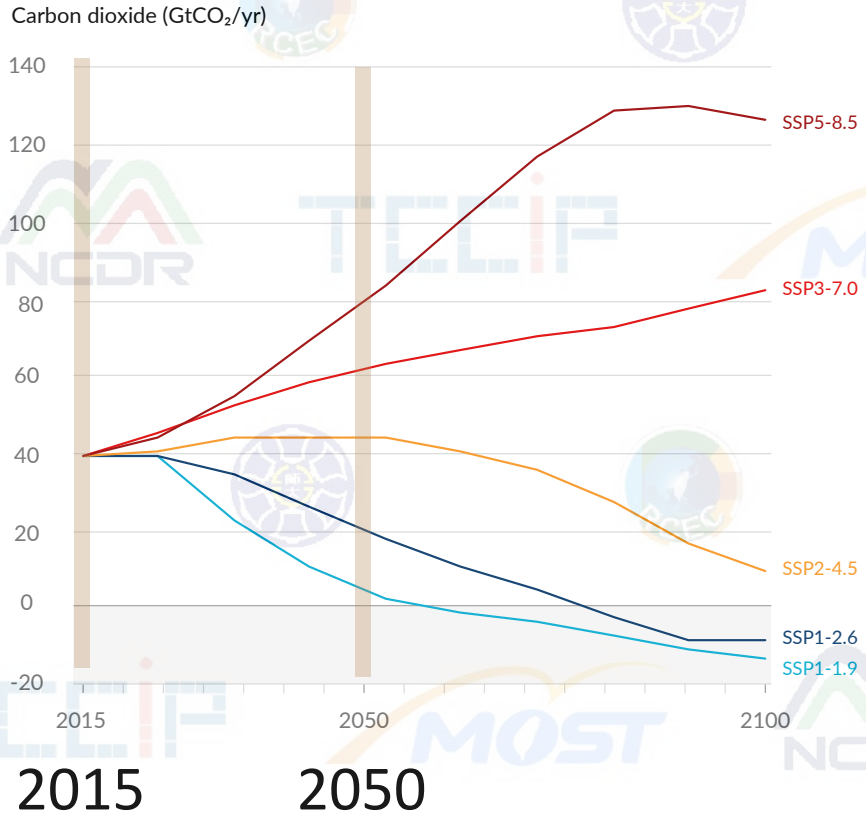
圖 1、歷年燃料燃燒 CO<sub>2</sub> 排放量與人均排放趨勢圖

2030

2050

# 全球的碳與其他生地化循環與反饋

## CO<sub>2</sub> 排放



## CO<sub>2</sub> 濃度

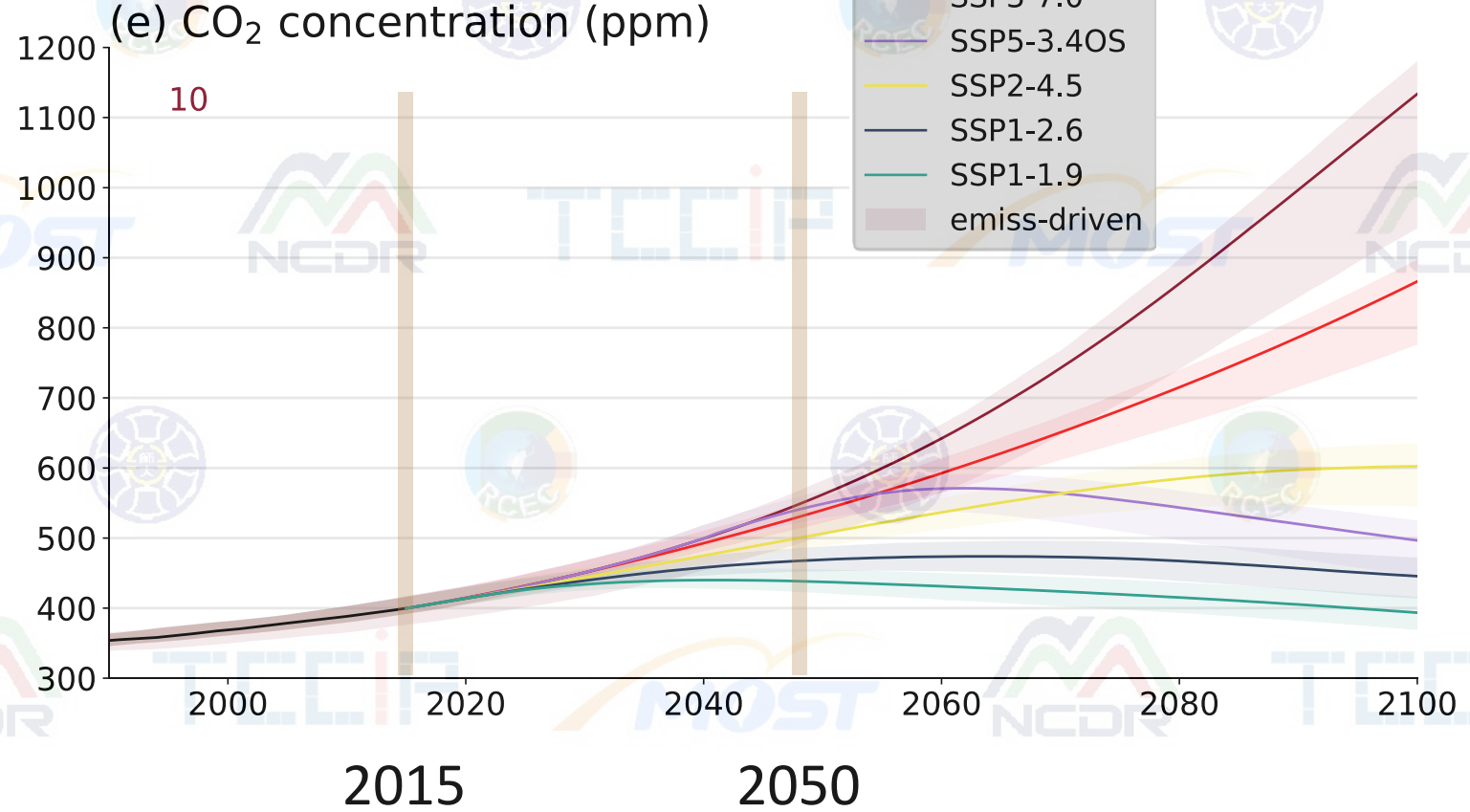


Figure SPM.4

Box TS.5 Figure 1

# 全球的碳與其他生地化循環與反饋

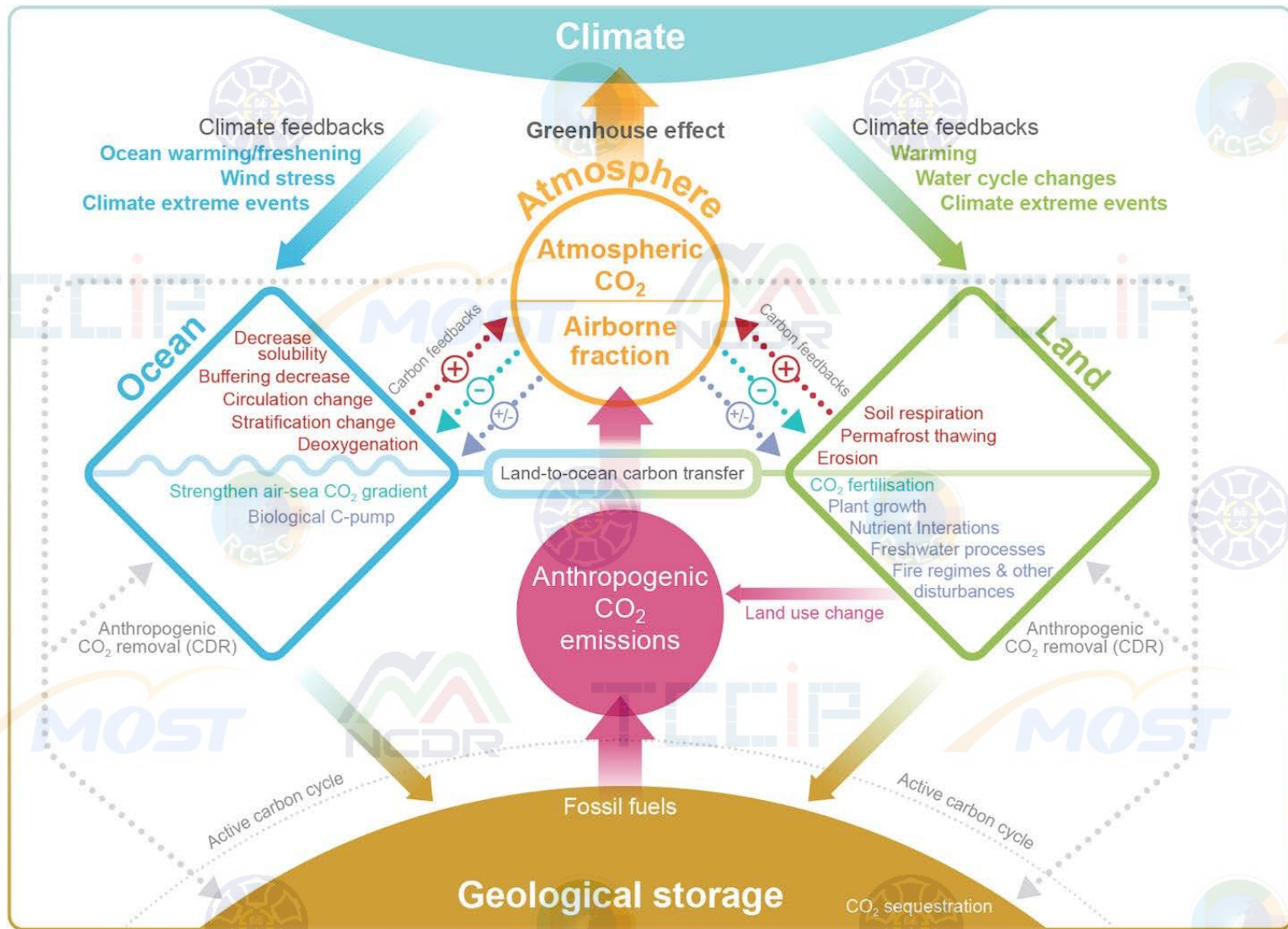
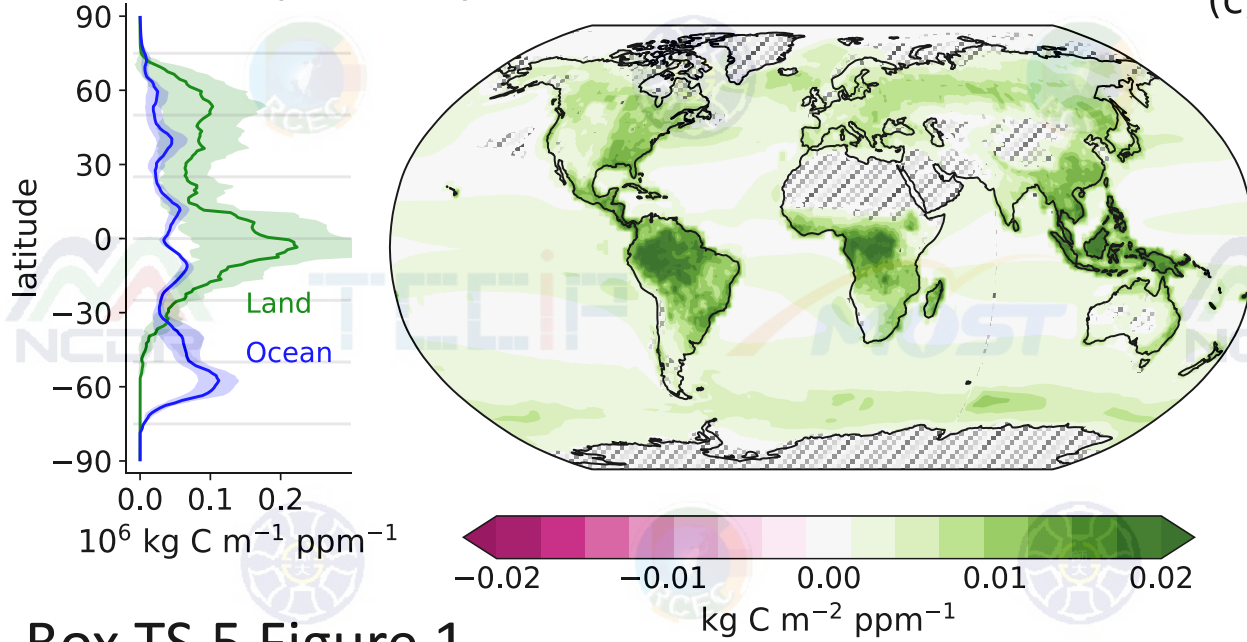


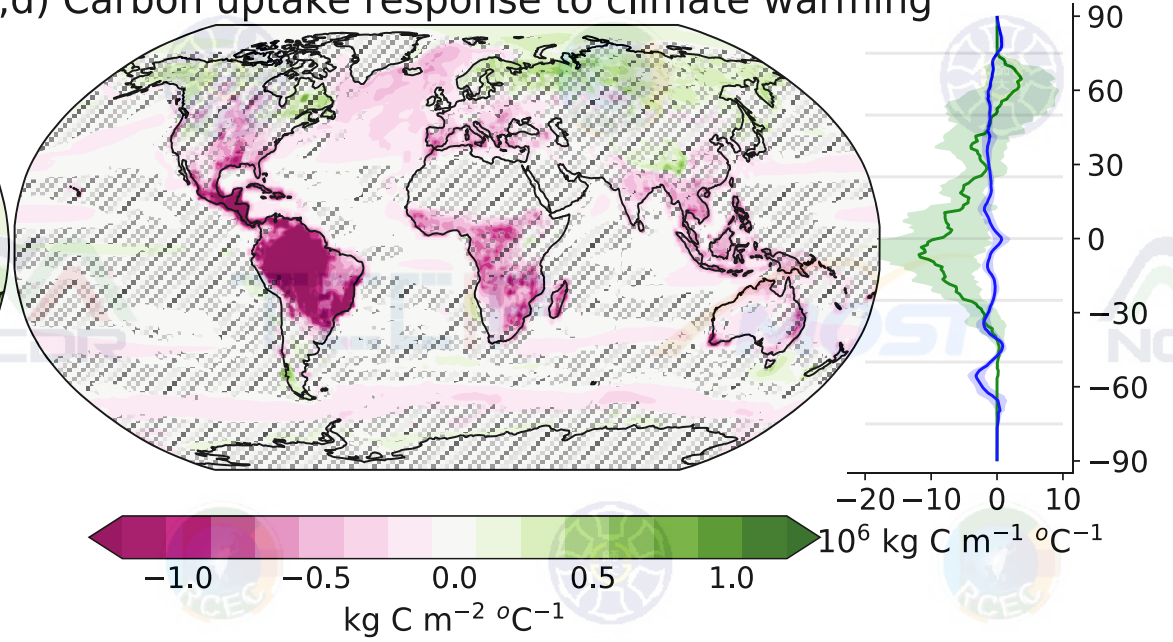
Figure 5.2

# 全球的碳與其他生地化循環與反饋

(a, b) Carbon uptake response to CO<sub>2</sub>



(c,d) Carbon uptake response to climate warming



Box TS.5 Figure 1

(c) Carbon-Cycle Climate Feedbacks

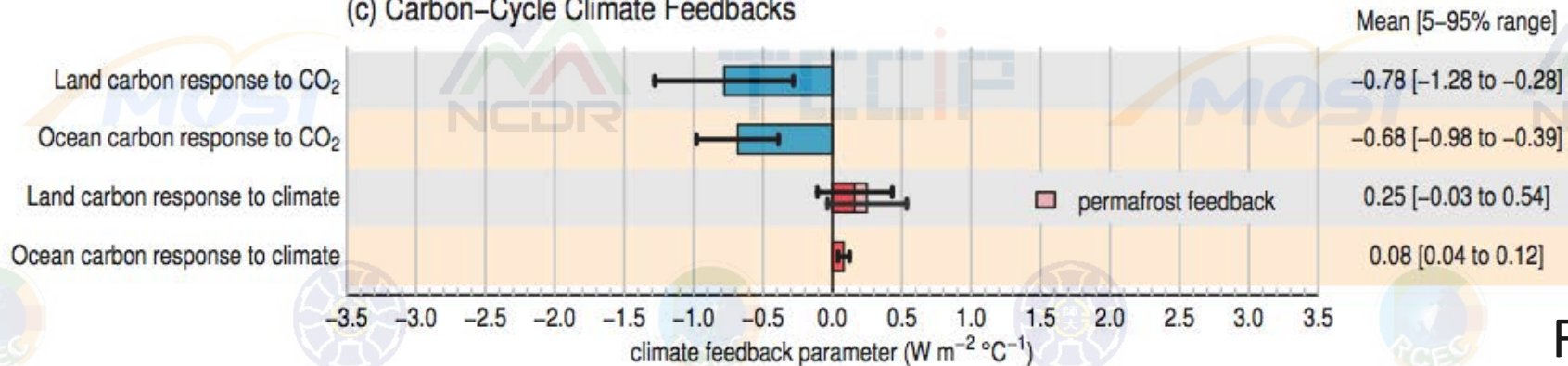


Figure TS.17



# 全球的碳與其他生地化循環與反饋

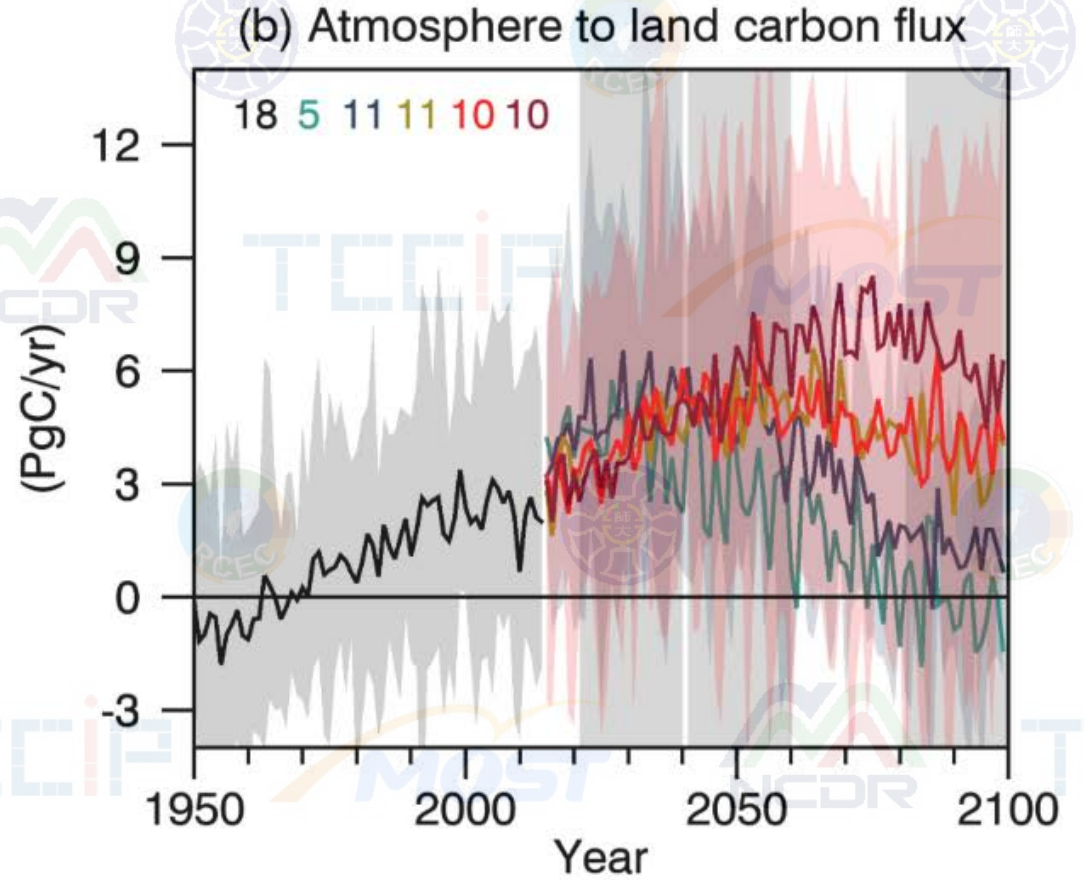
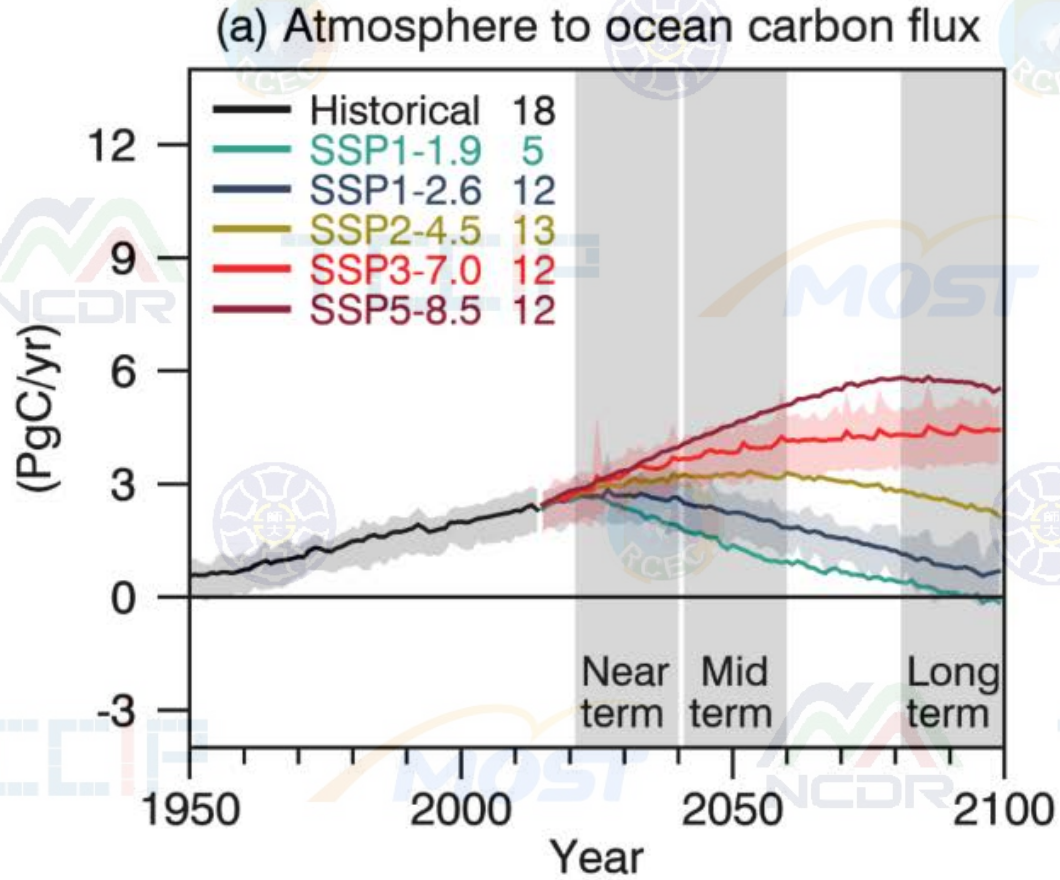


Figure 4.7

