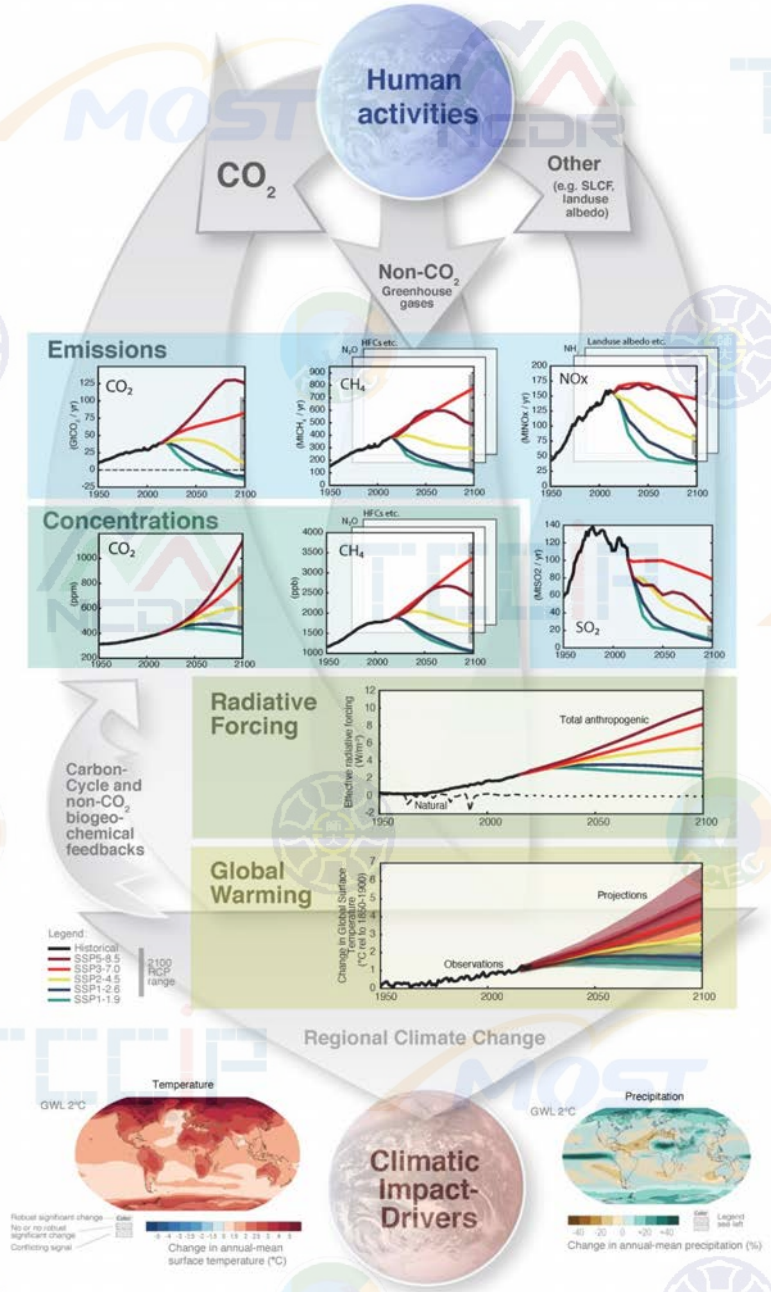
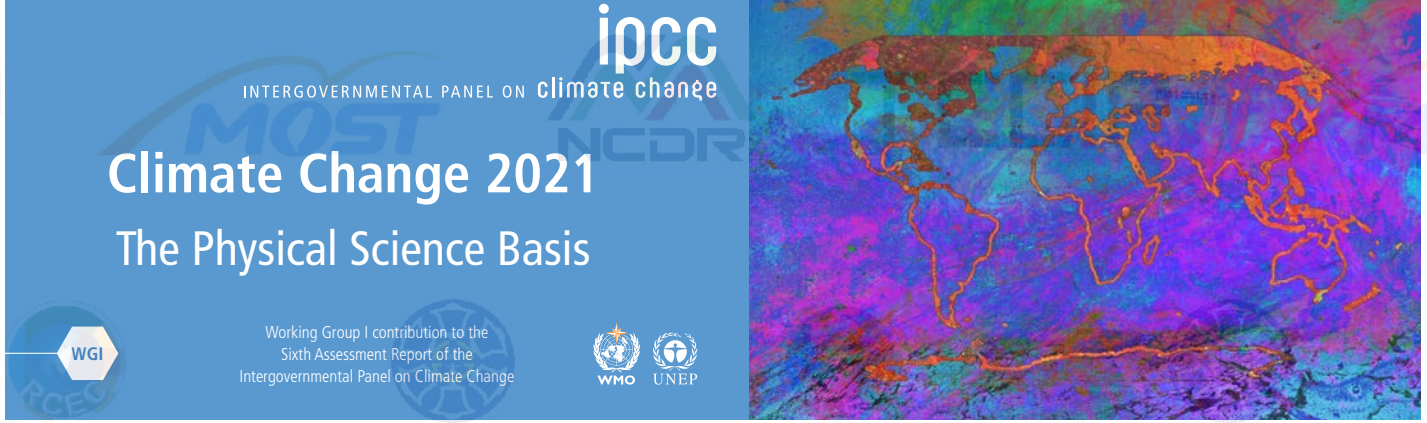




挖掘真相：氣候系統的變化

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

TCCIP 臺灣氣候變遷推估資訊與調適知識平台
Taiwan Climate Change Projection Information and Adaptation Knowledge Platform

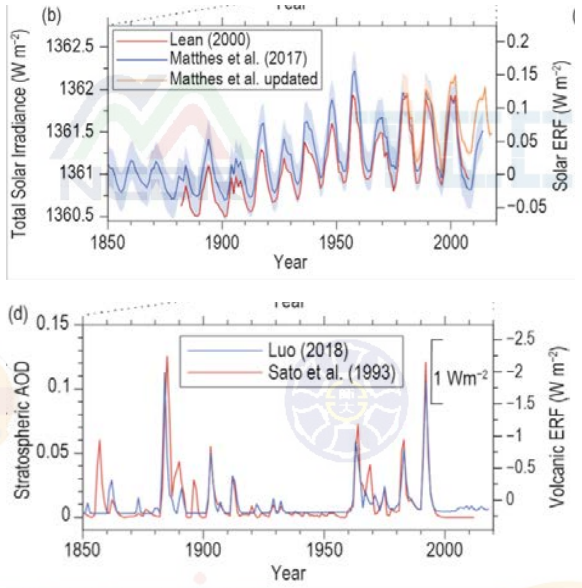
挖掘真相：氣候系統的變化

- 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

氣候系統的變化

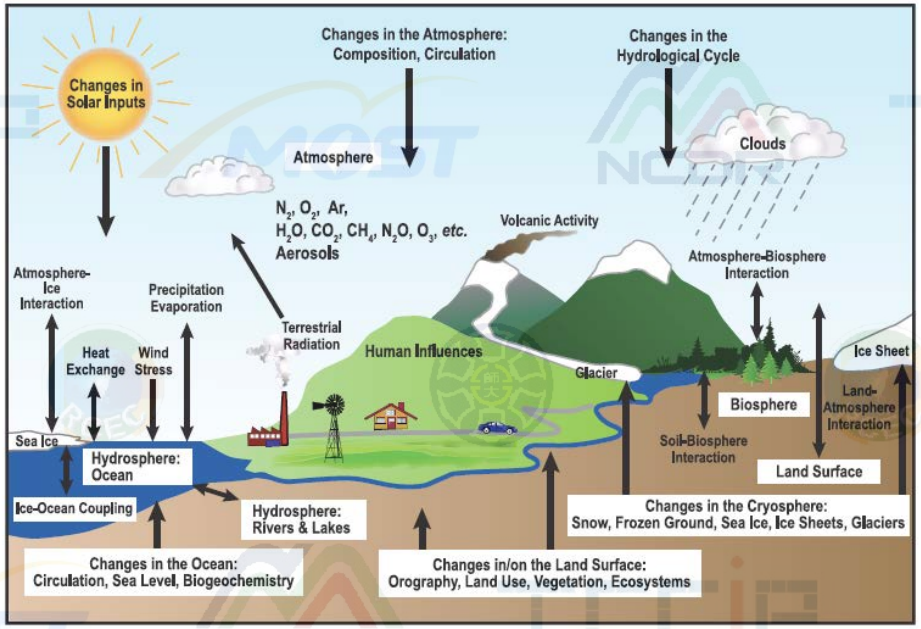
太陽輻射變動



火山爆發所產生的懸浮微粒

IPCC (2001, 2007, 2013, 2021)

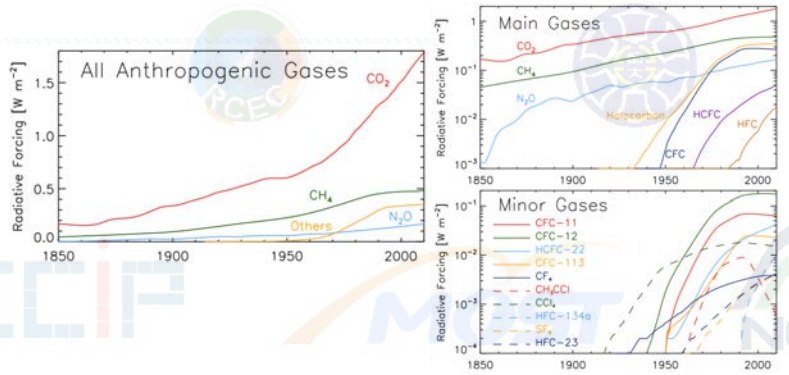
自然驅動力



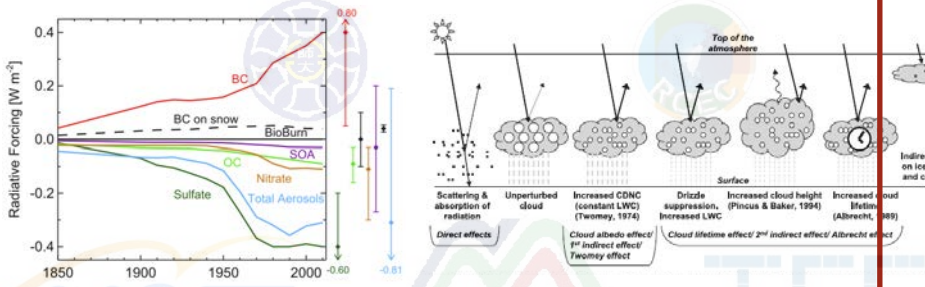
FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

人為驅動力

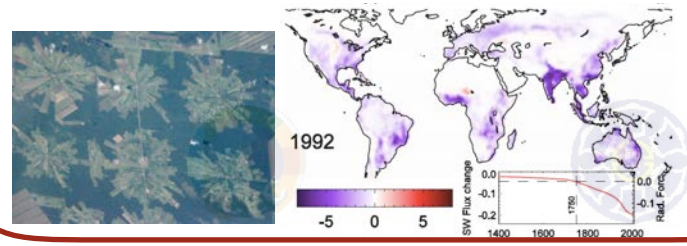
溫室氣體排放



人為造成大氣中的氣膠變化



人為造成地表特性改變

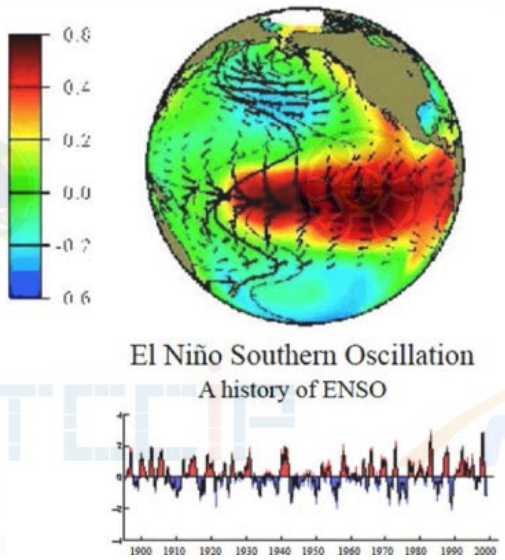


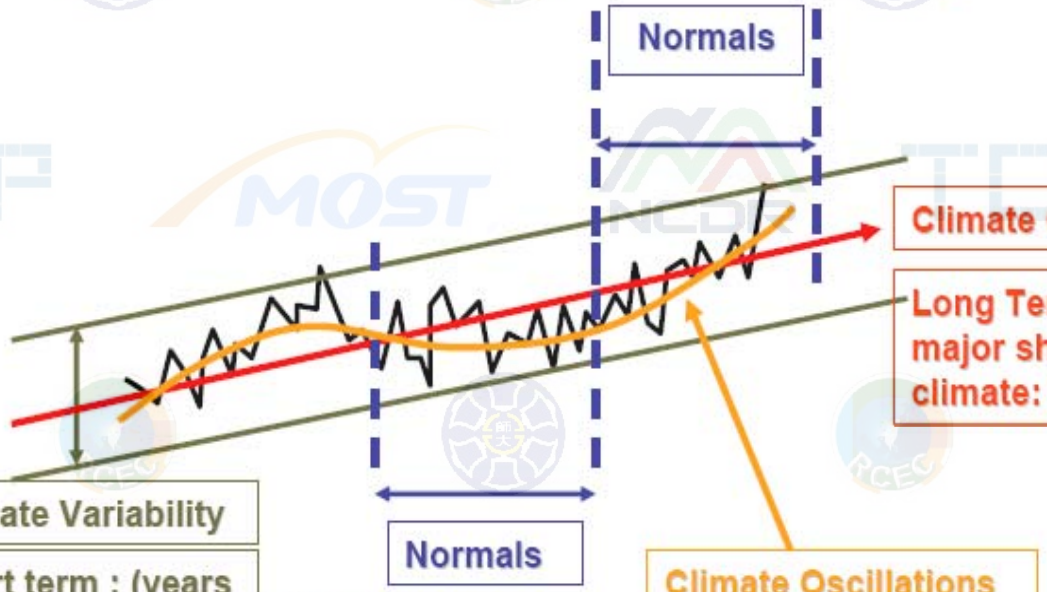
氣候系統的變化

氣候系統還有自然內部變動

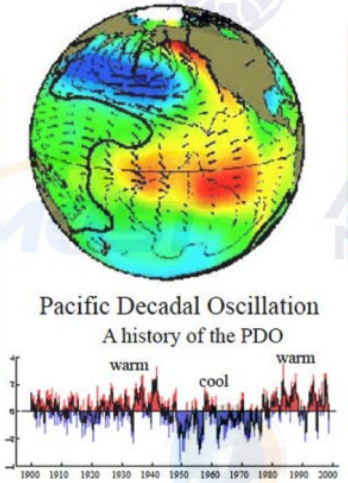
Climate Variability and Climate Change

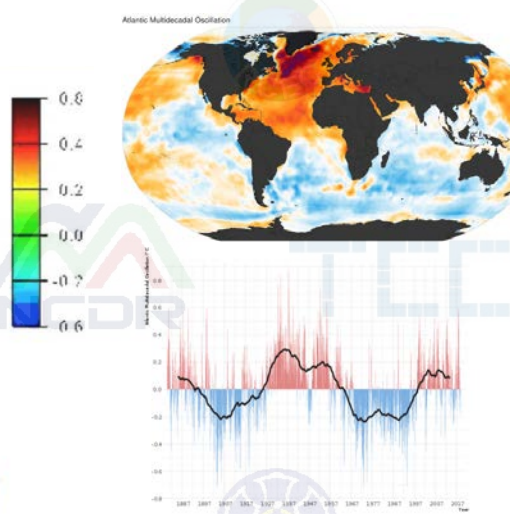
年際變化





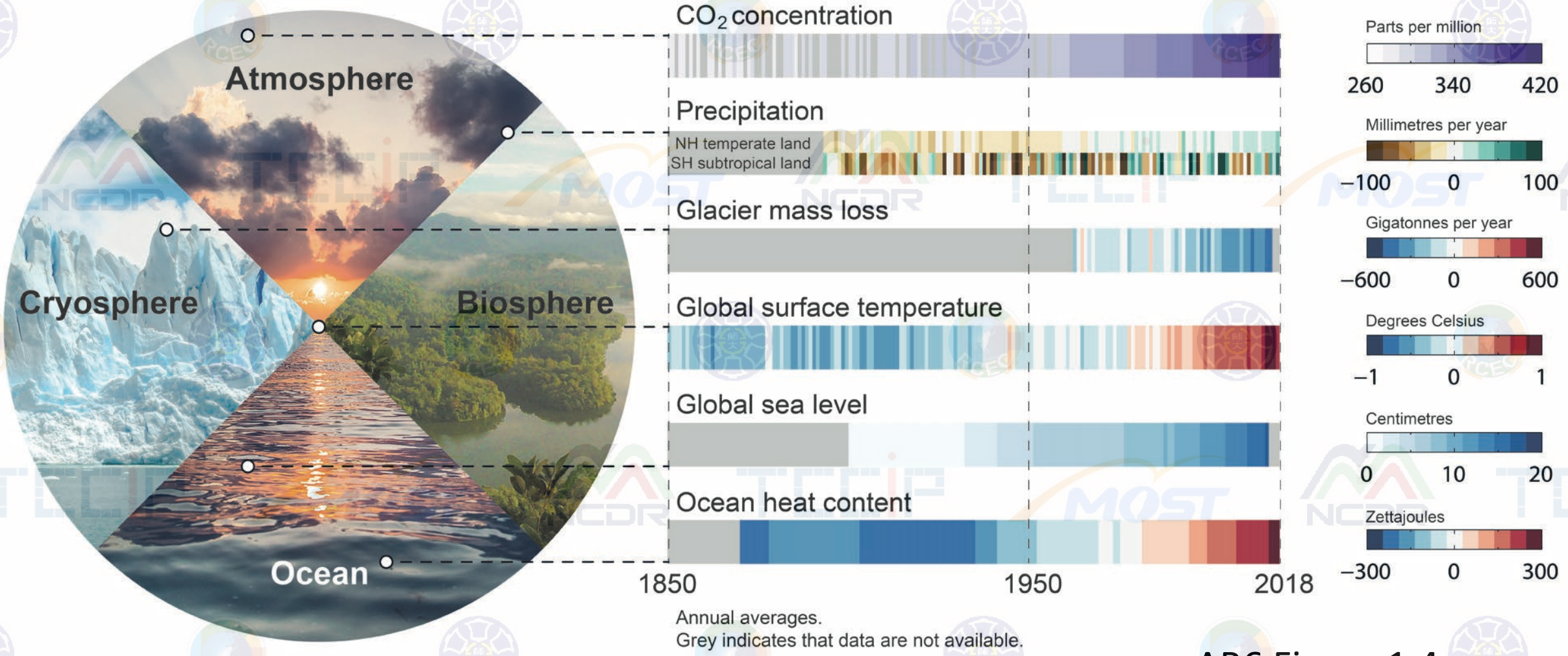
年代際變化





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



AR6 Figure 1.4

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

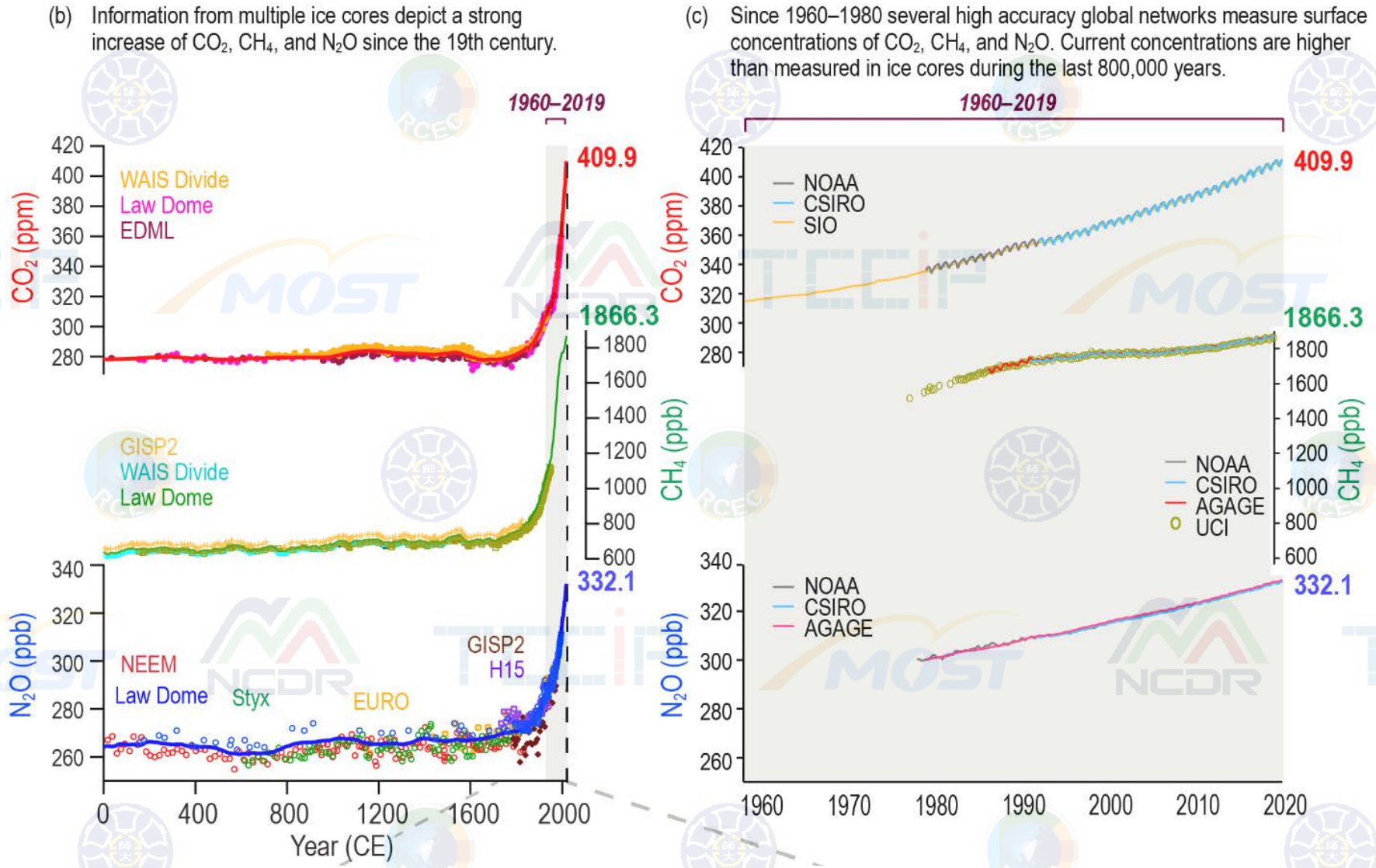
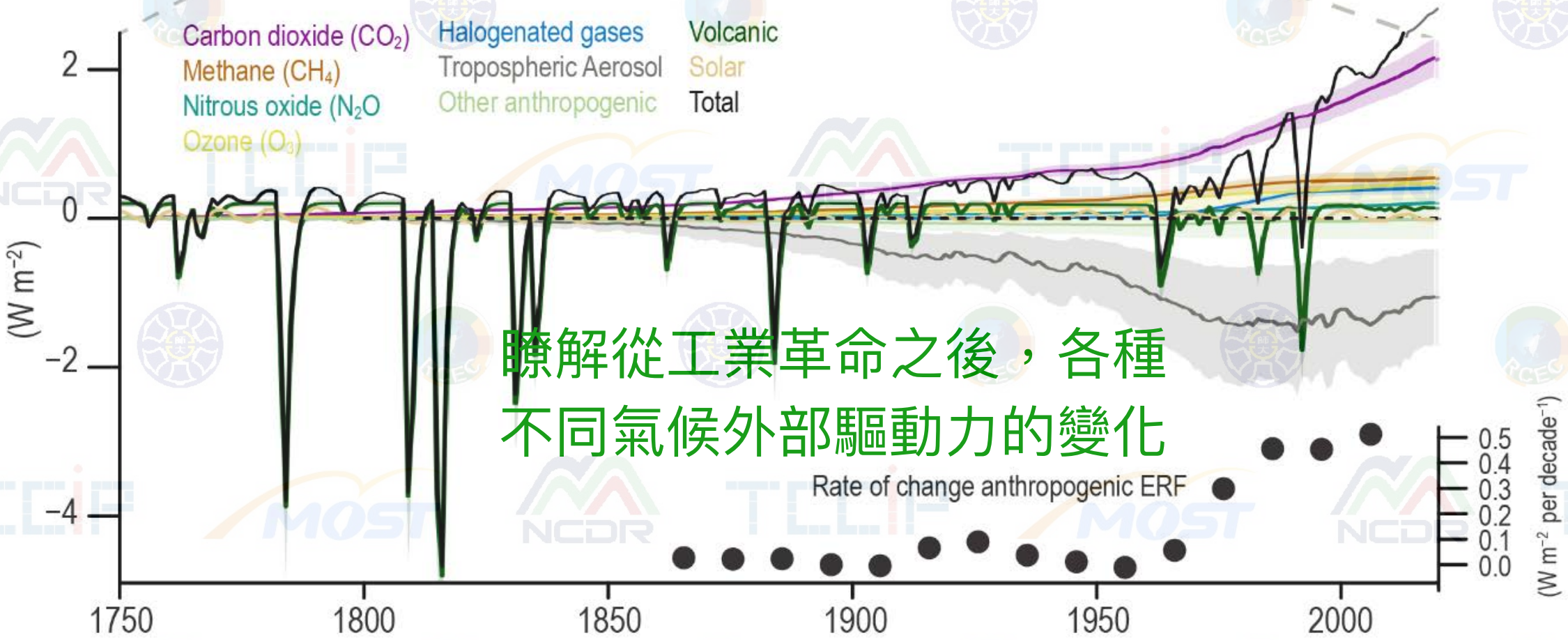


Figure TS.4

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.

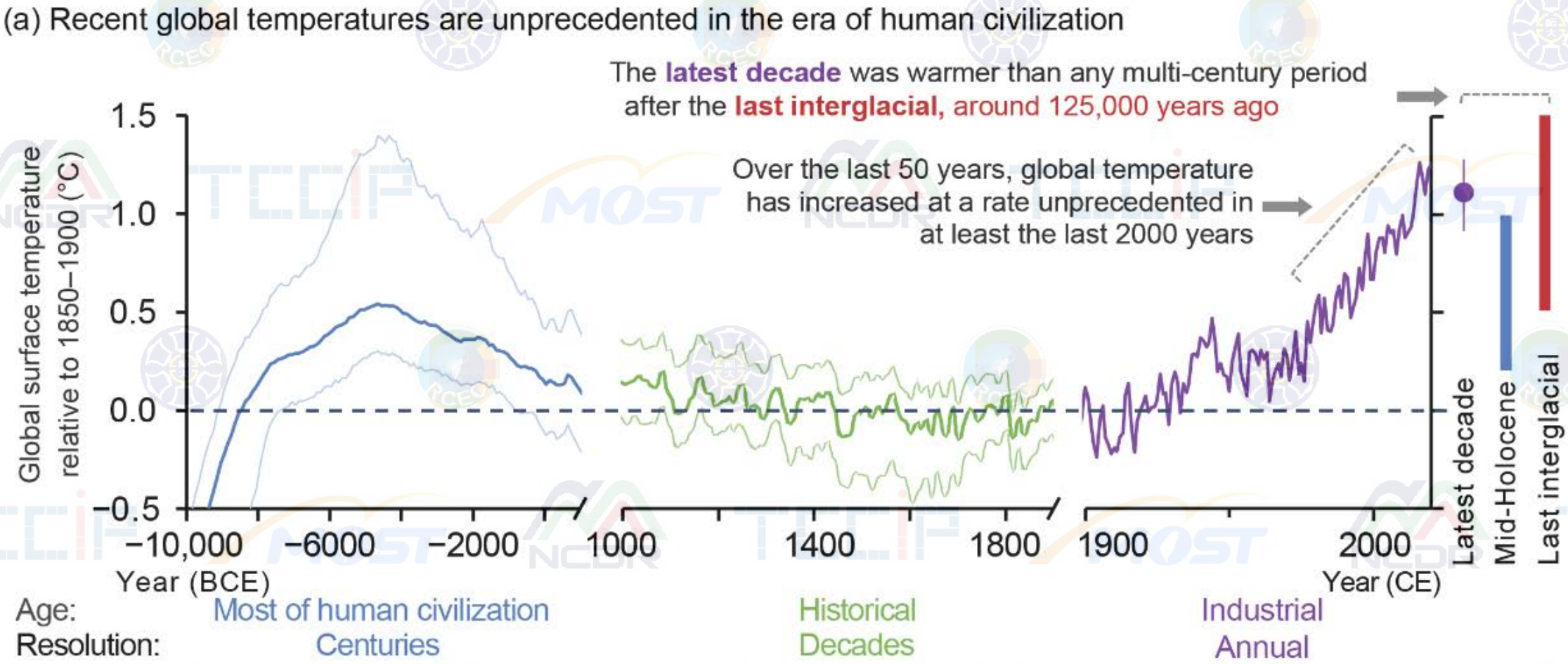


瞭解從工業革命之後，各種
不同氣候外部驅動力的變化

Figure TS.4

氣候系統的變化

全球氣溫在過去的改變



Cross-Section Box TS.1, Figure 1

氣候系統的變化

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

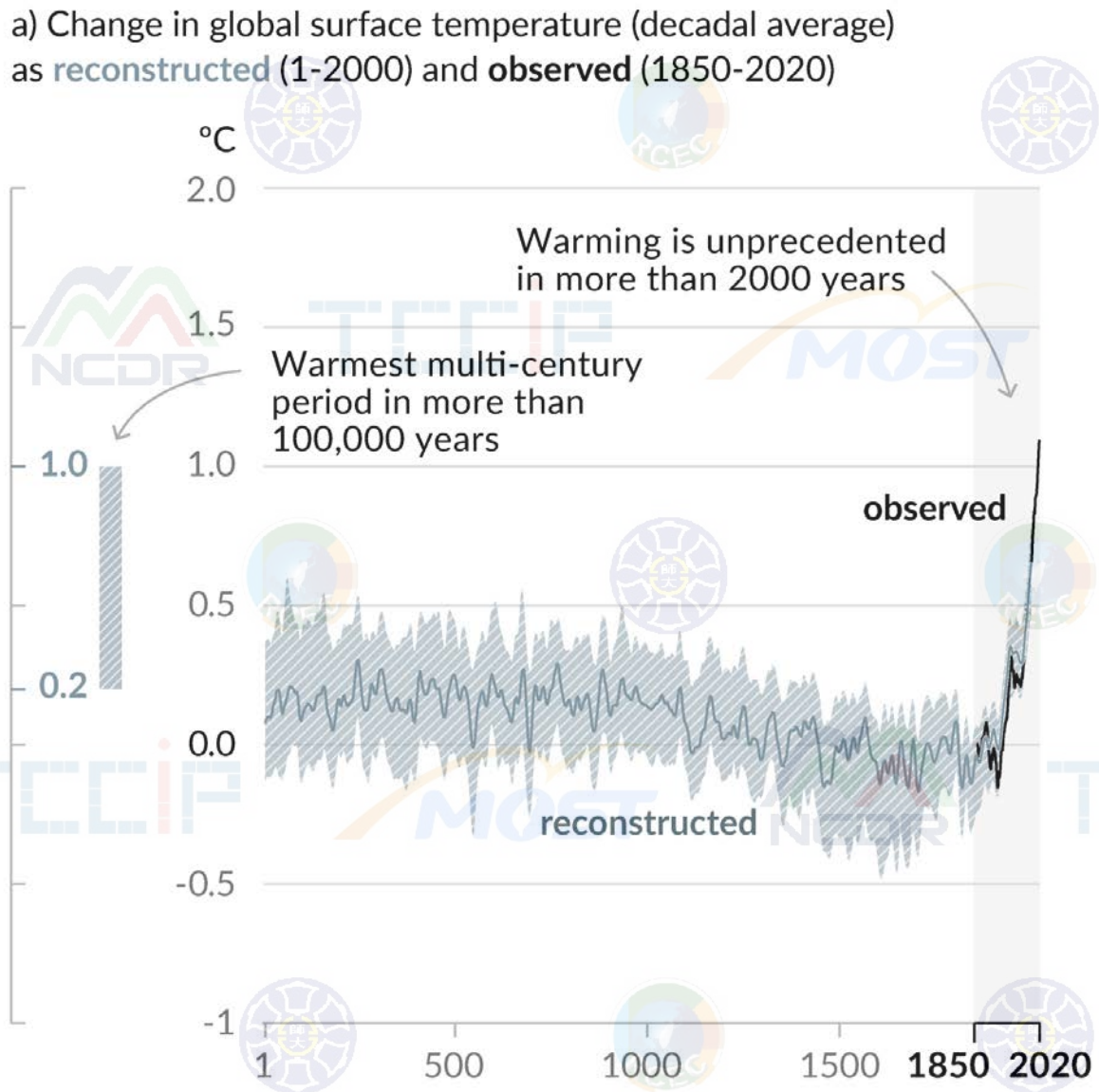


Figure SPM.1

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）

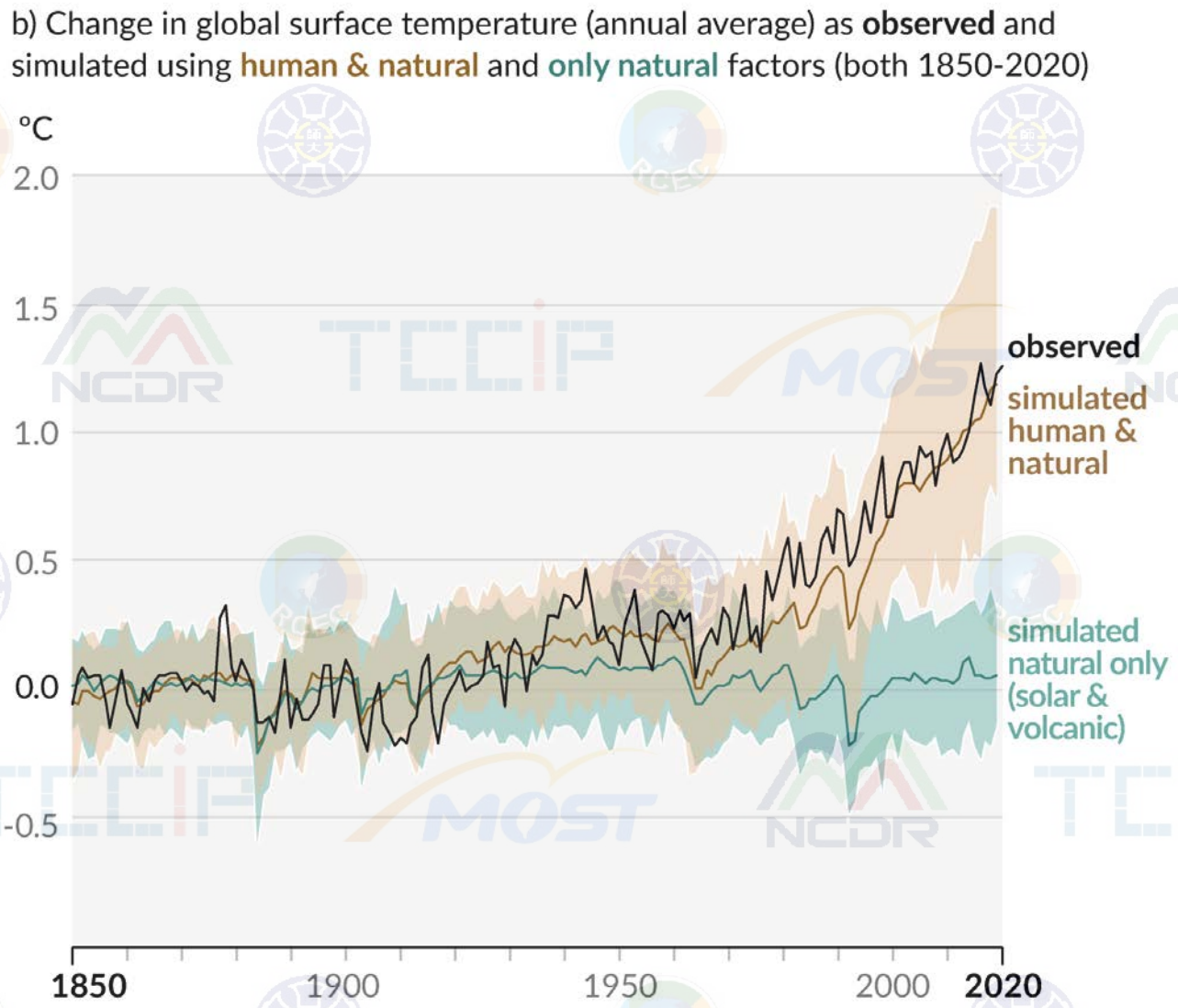


Figure SPM.1

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

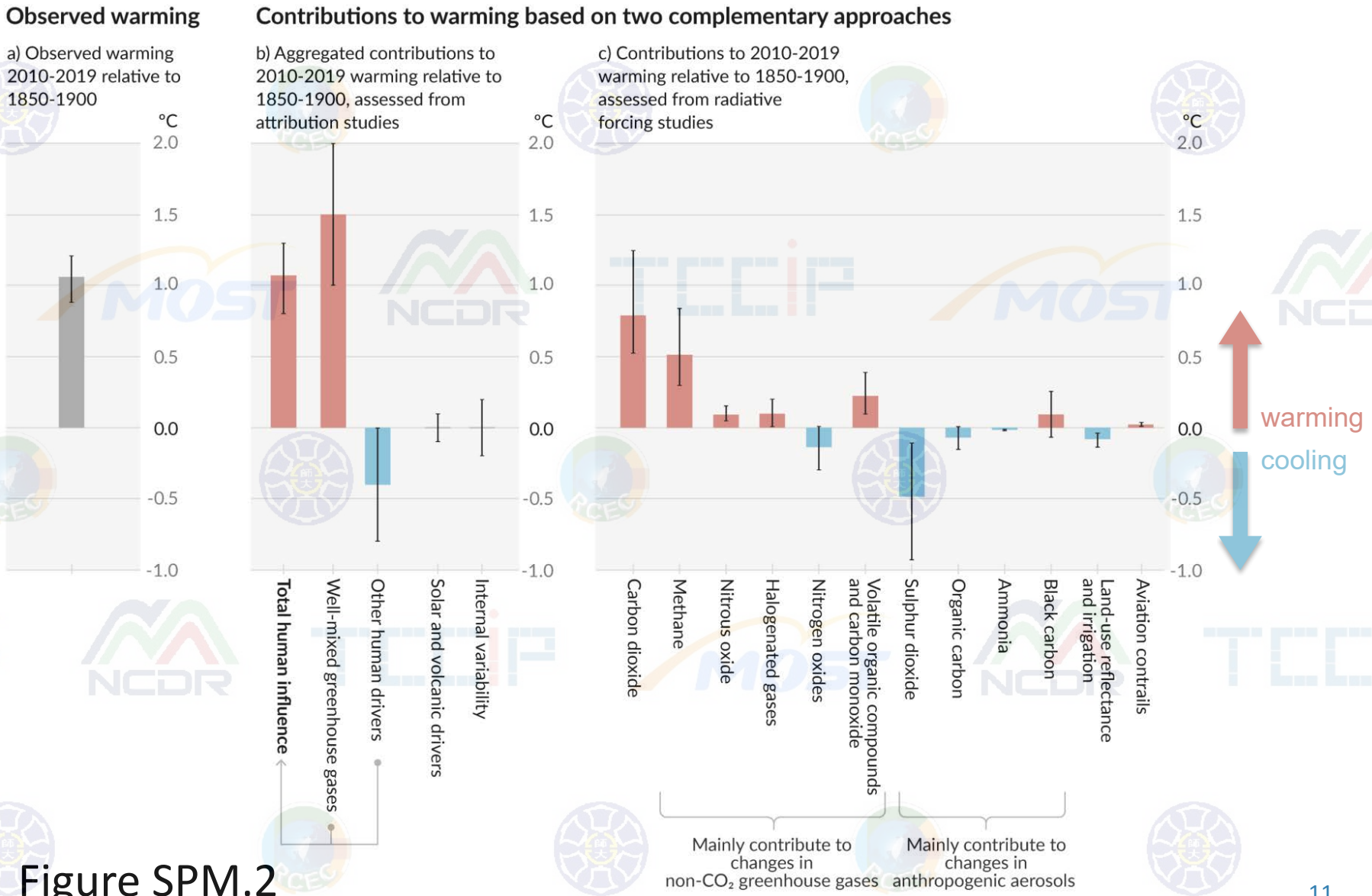
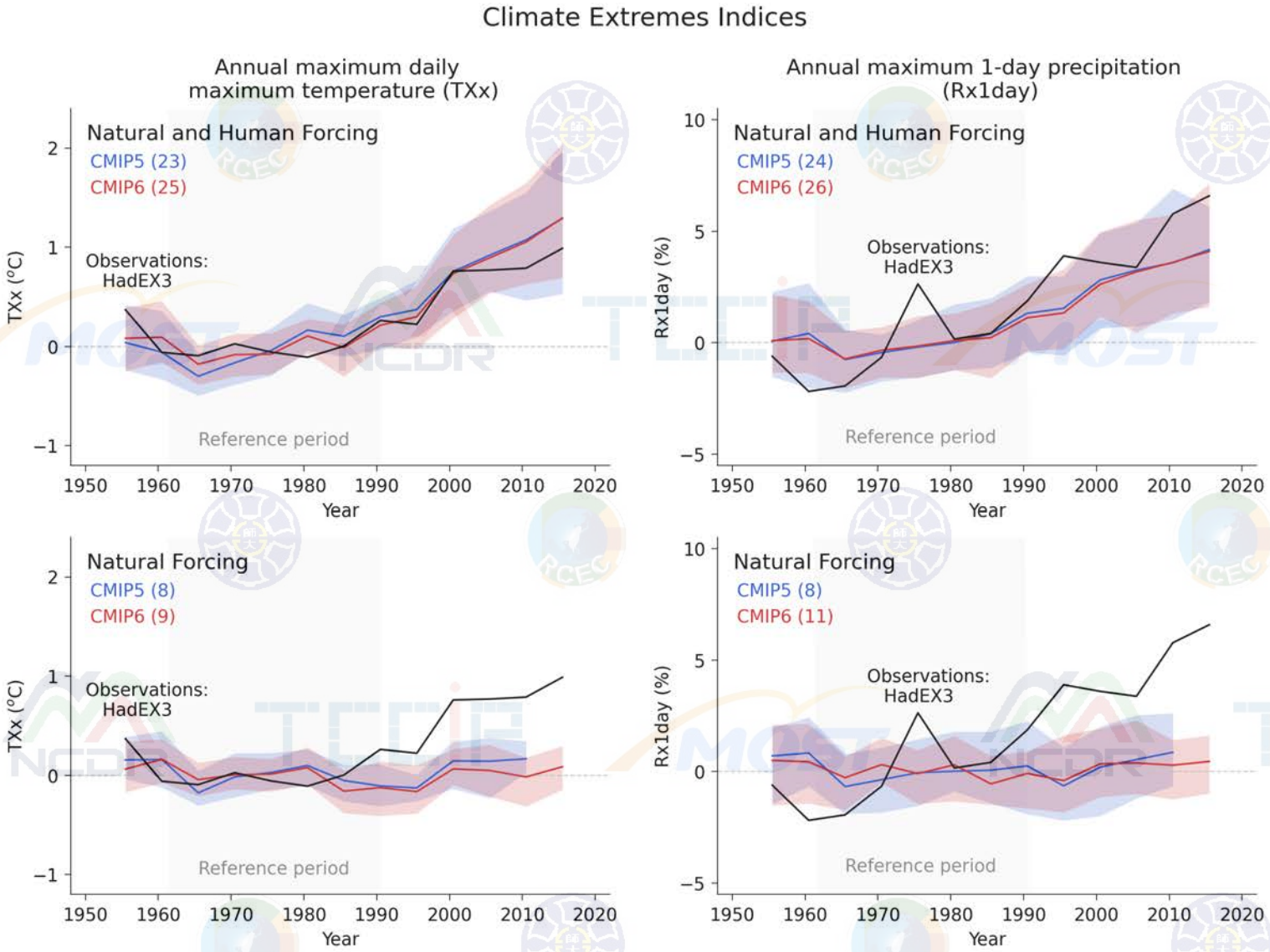


Figure SPM.2

人類對氣候系統的影響

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



Cross-Chapter Box 3.2, Figure 1

人類對氣候系統的影響

Temperature response (Attribution 歸因)

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)

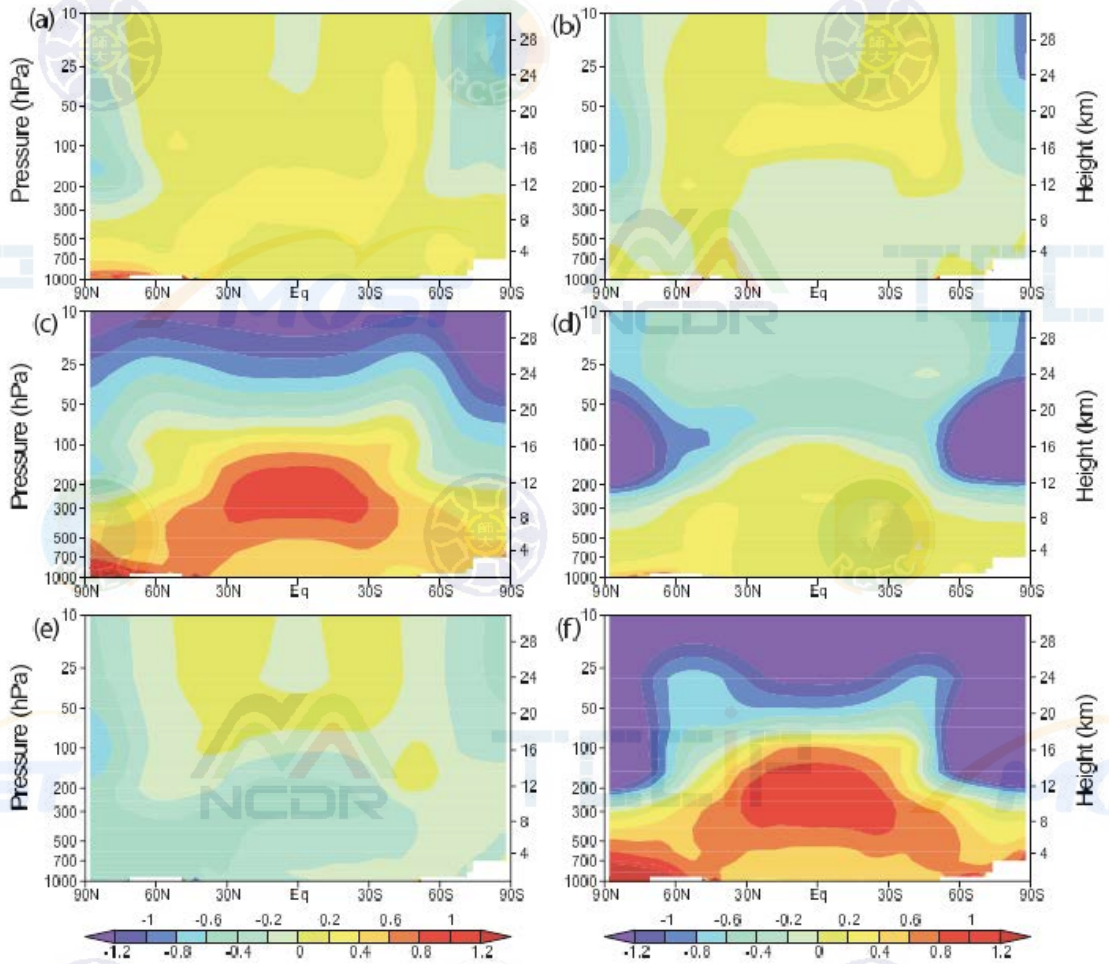


Figure 9.1. *Zonal mean atmospheric temperature change from 1890 to 1999 (°C per century) as simulated by the PCM model from (a) solar forcing, (b) volcanoes, (c) w mixed greenhouse gases, (d) tropospheric and stratospheric ozone changes, (e) direct sulphate aerosol forcing and (f) the sum of all forcings. 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).*

Volcanoes 火山爆發所產生的懸浮微粒

Ozone 臭氧

All forcings 所有驅動力

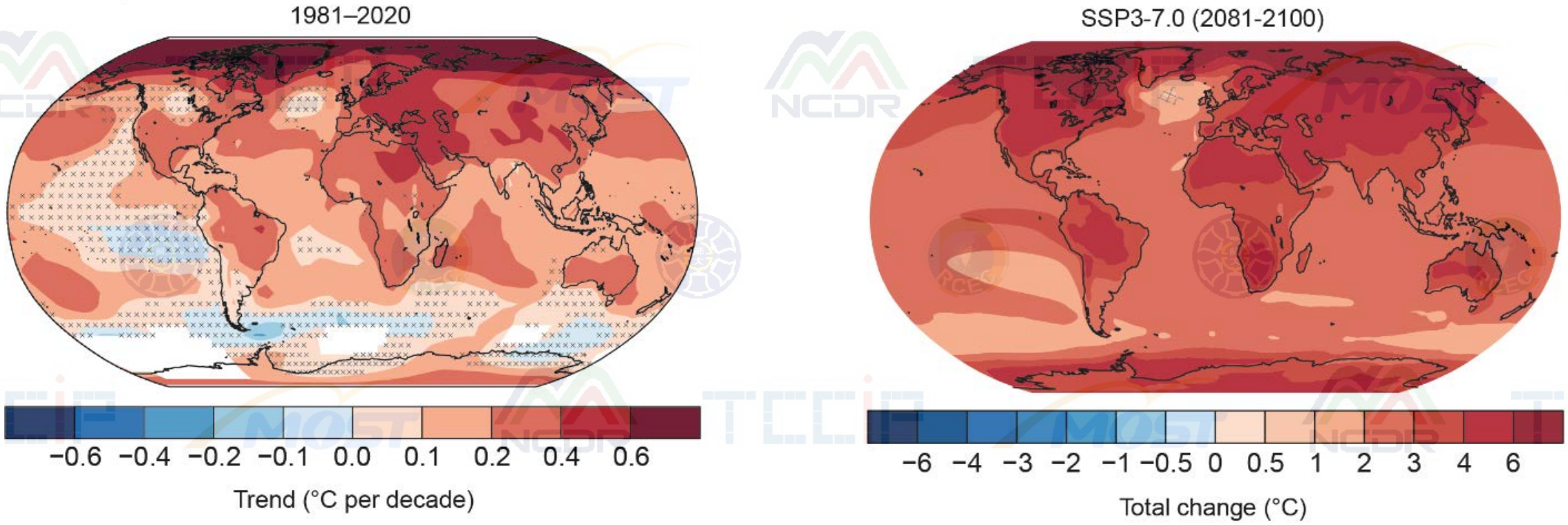
IPCC AR4

氣候系統的變化　與未來氣候推估

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



Cross-Section Box TS.1, Figure 1

氣候系統的變化與未來氣候推估

對流層增溫，平流層冷卻

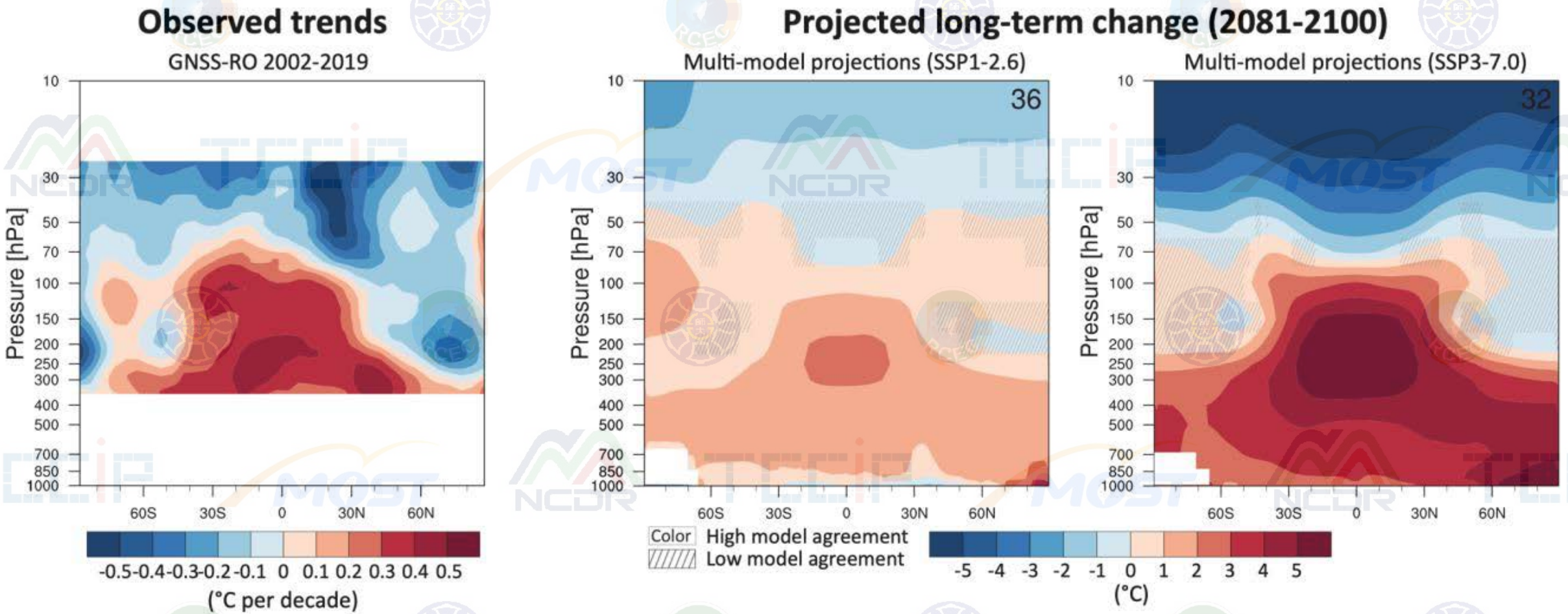
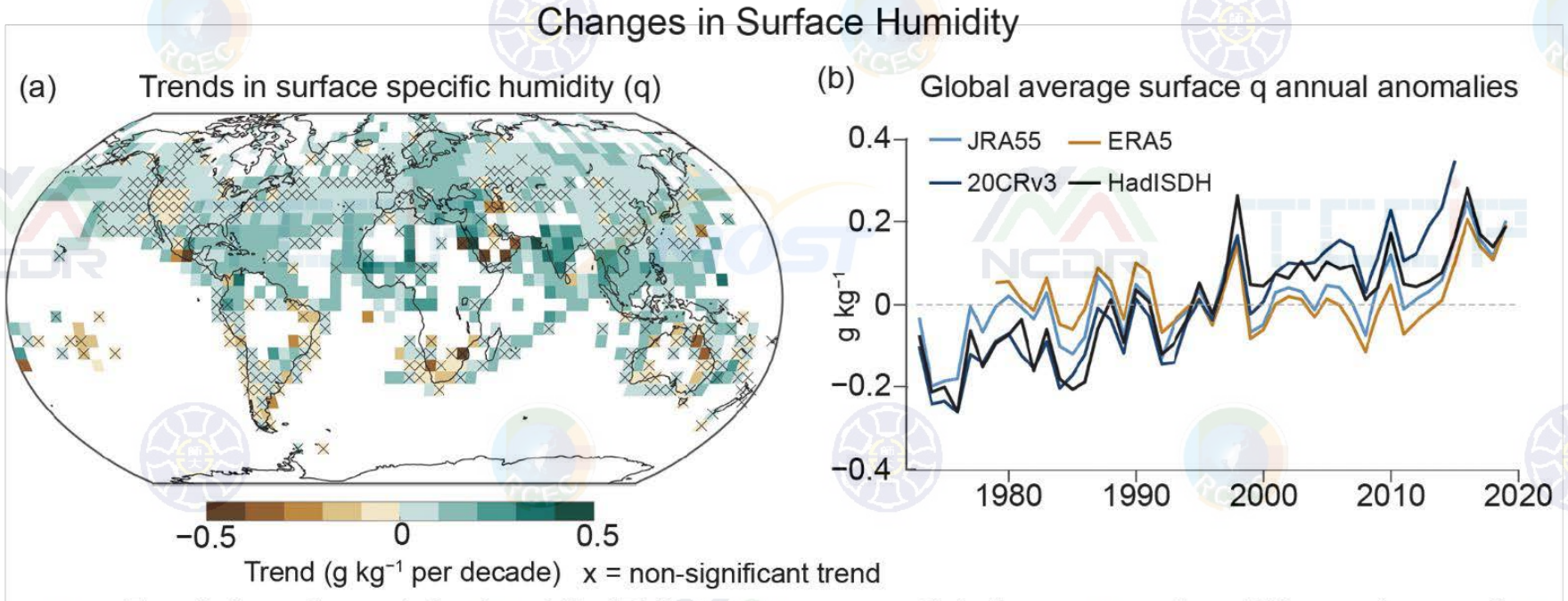


Figure TS.10

氣候系統的變化

近地面與整層的水氣含量都有長期增加的趨勢



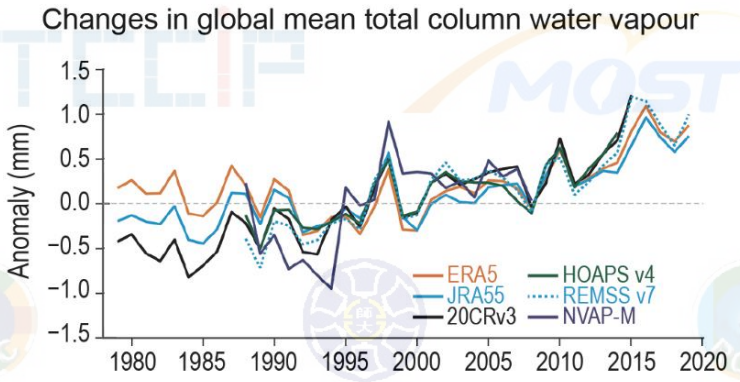
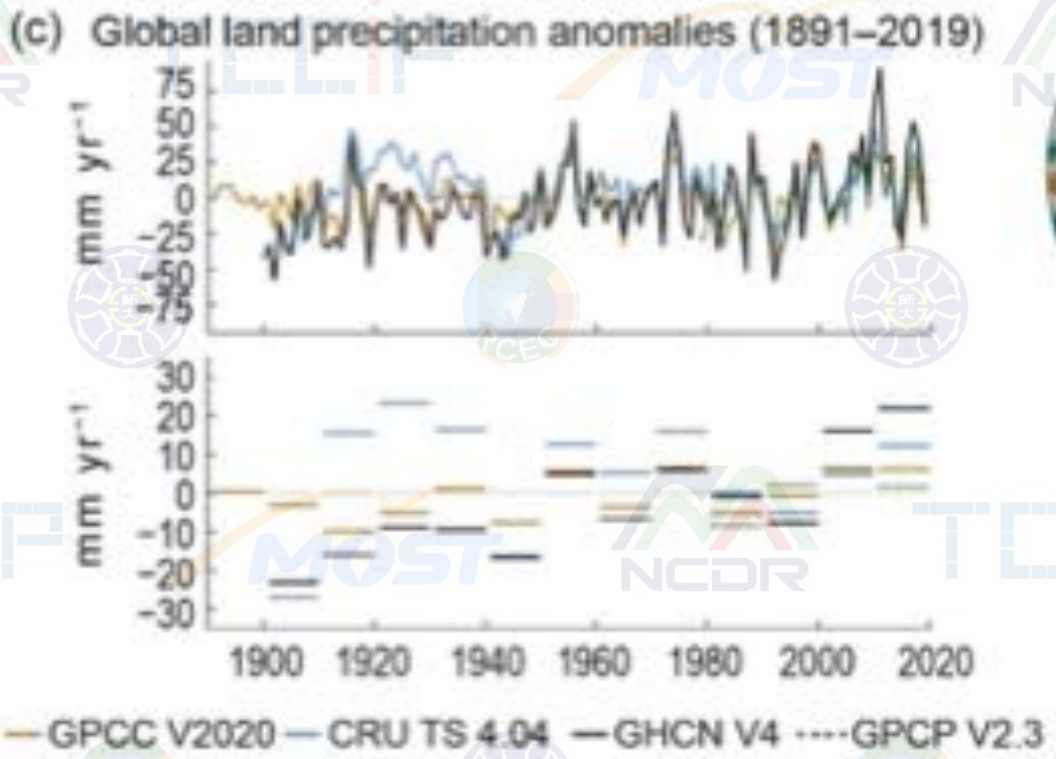


Figure 2.13, 2.14

氣候系統的變化

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



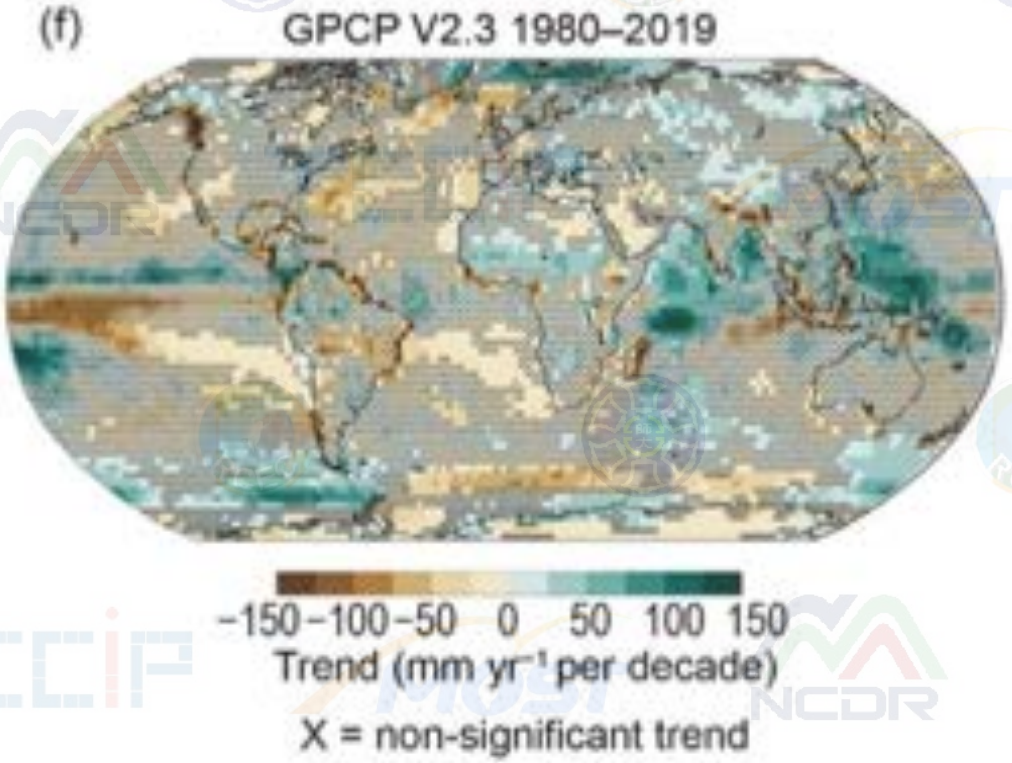
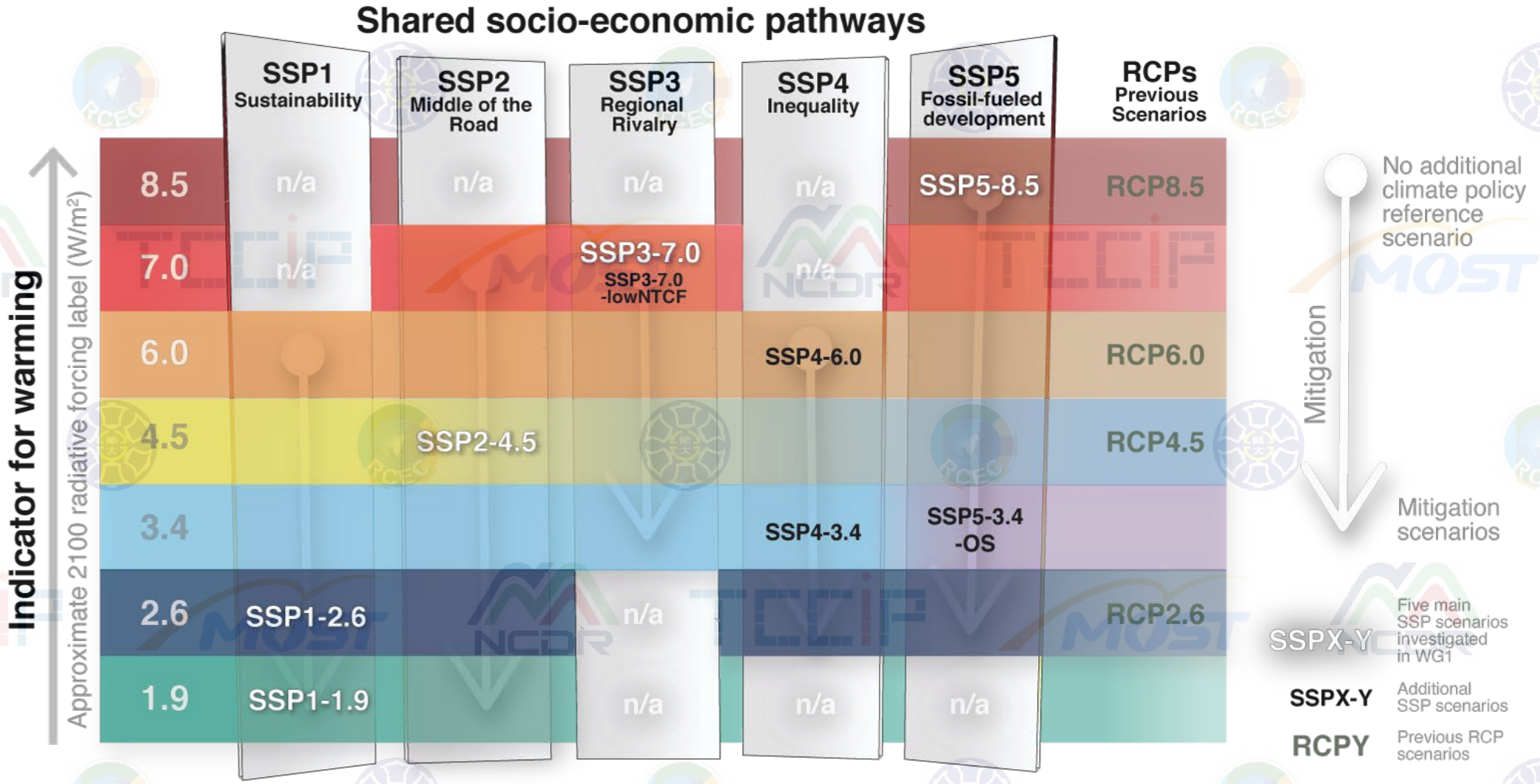


Figure 2.15

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

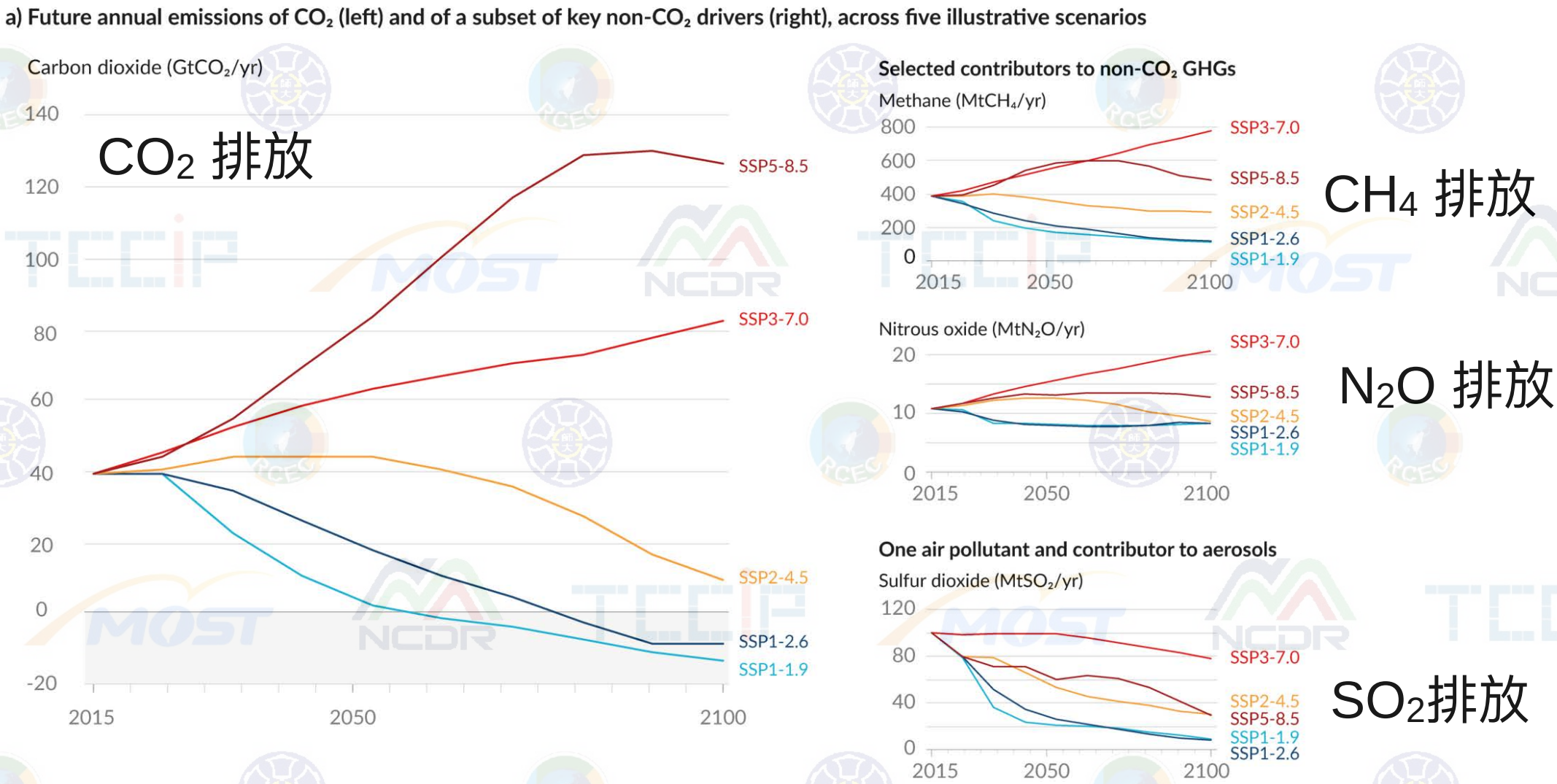


Figure SPM.4

未來全球氣候：不同情境下的長期推估與近期改變

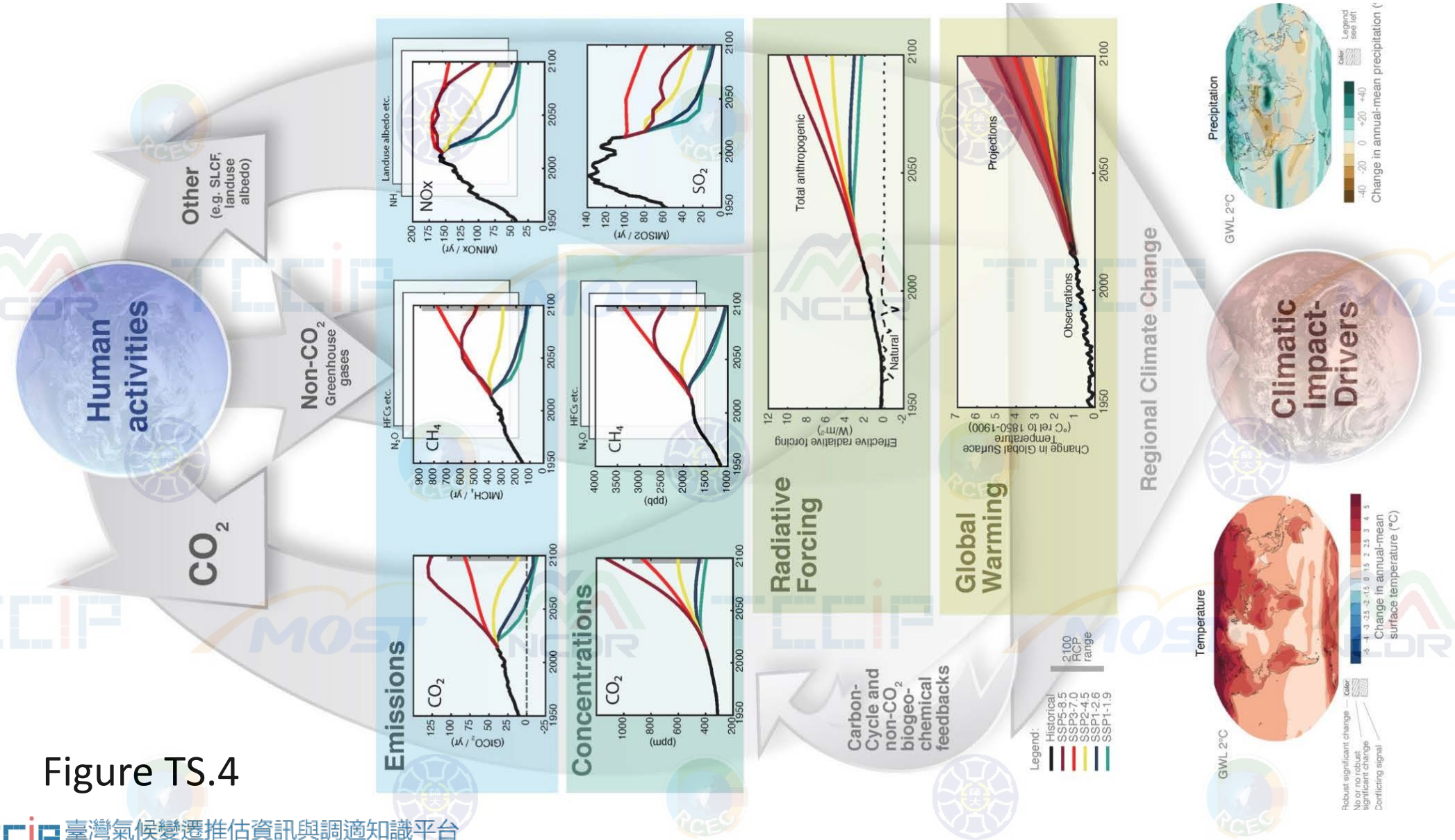
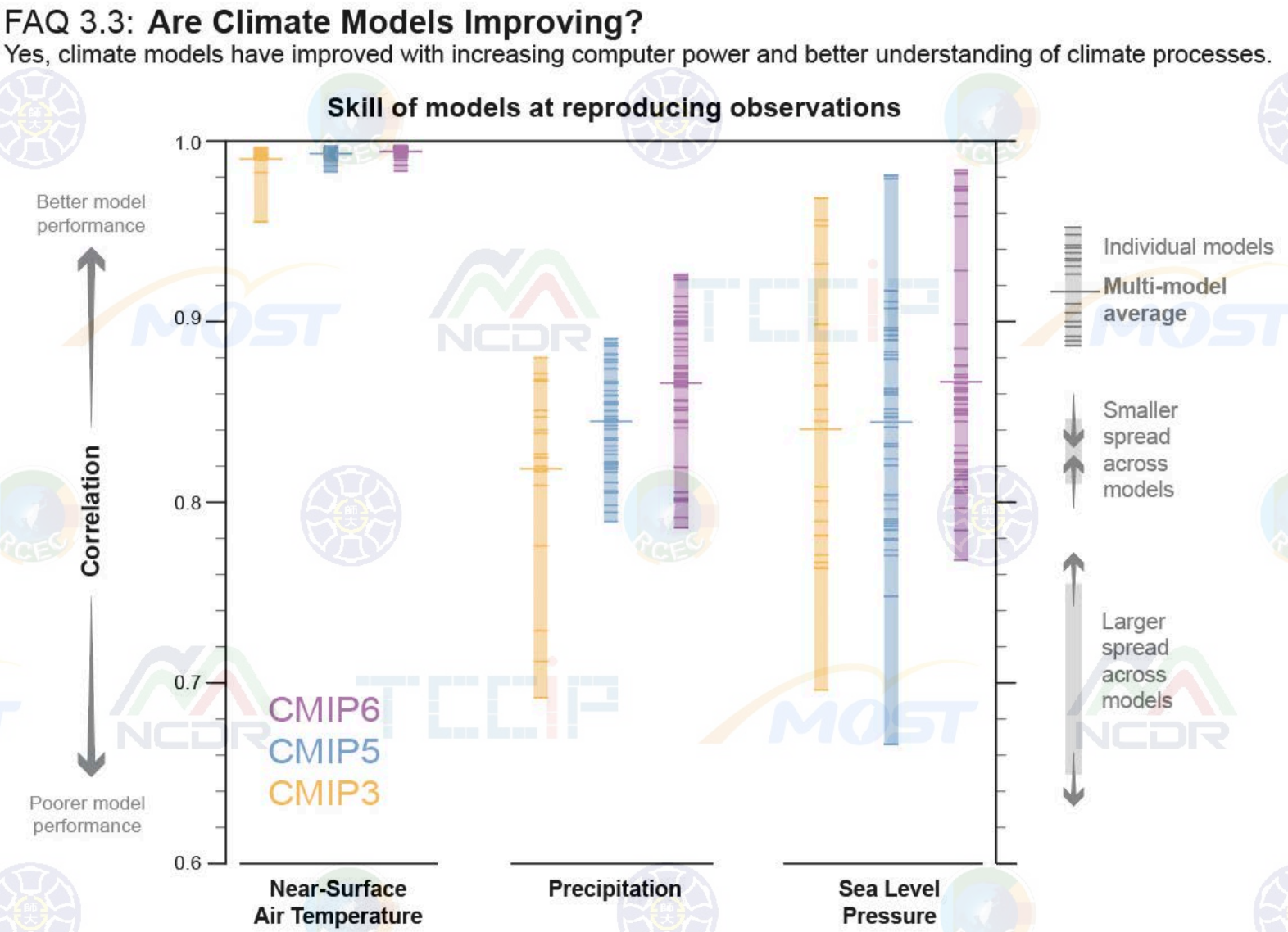


Figure TS.4

未來全球氣候：不同情境下的長期推估與近期改變

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

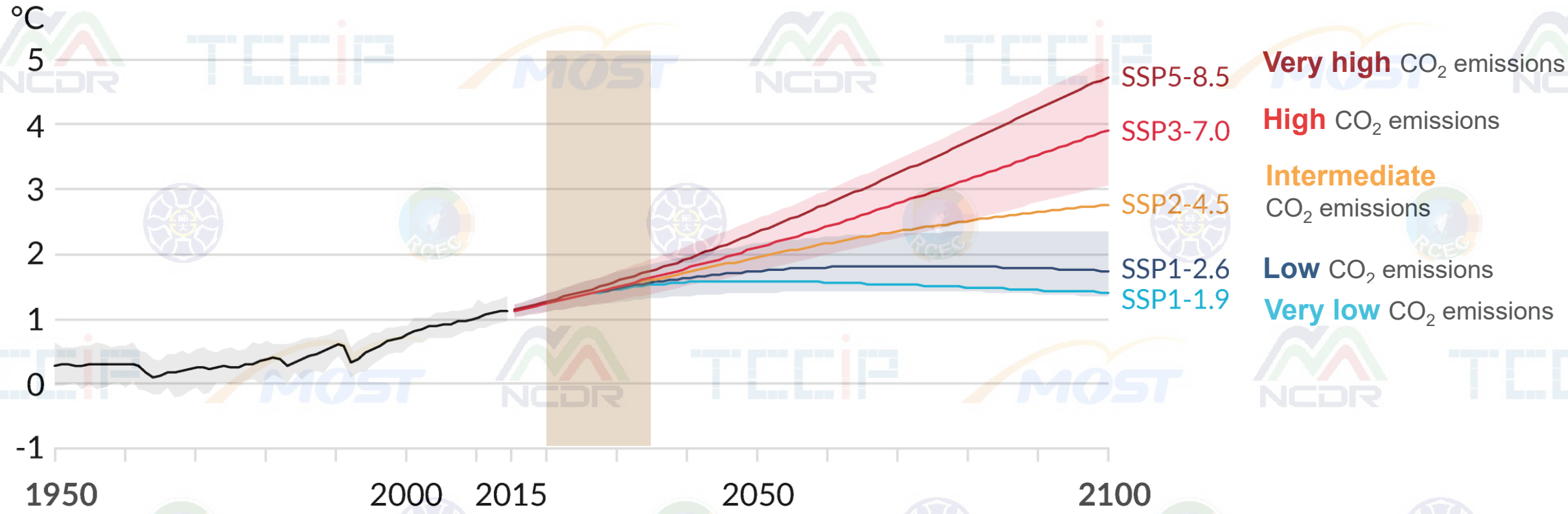


Figure SPM.8

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

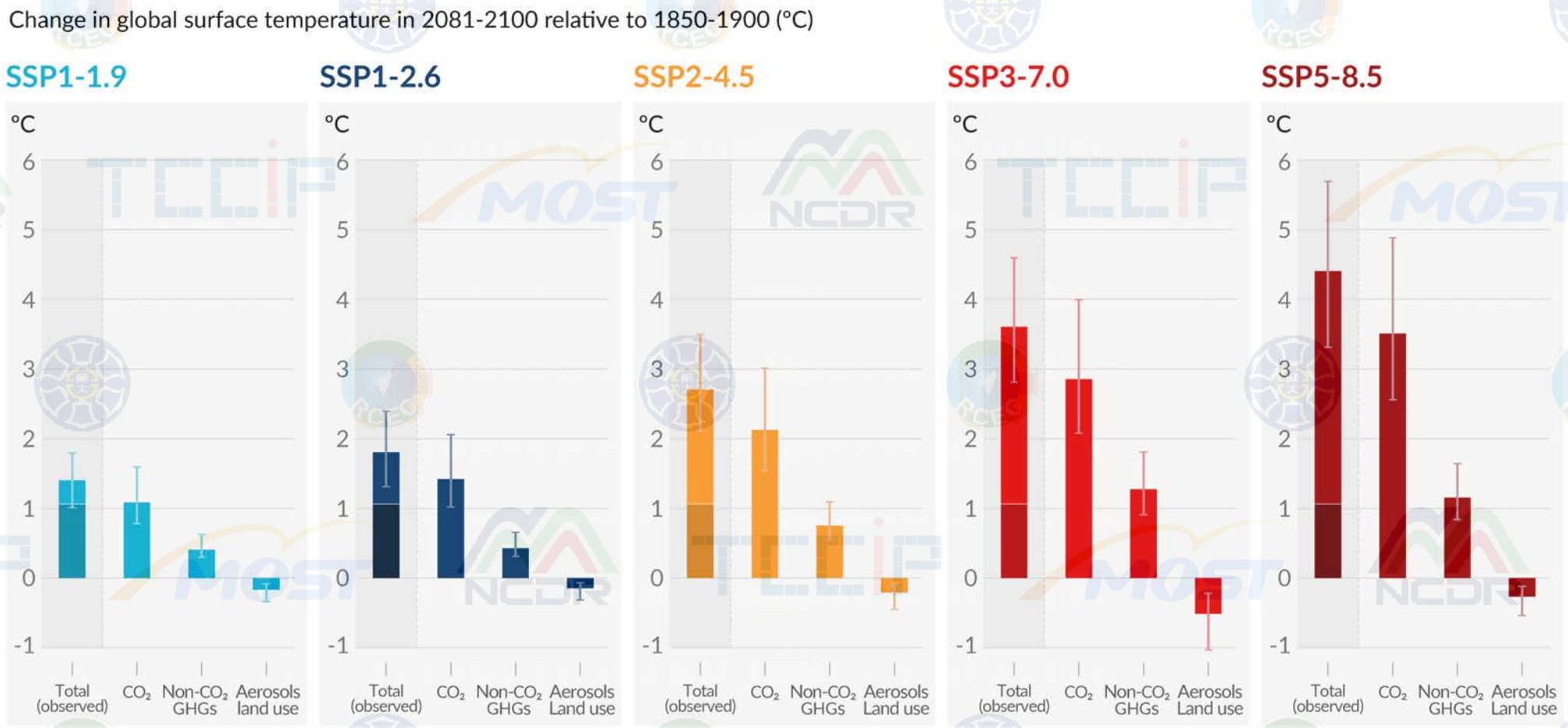


Figure SPM.4

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

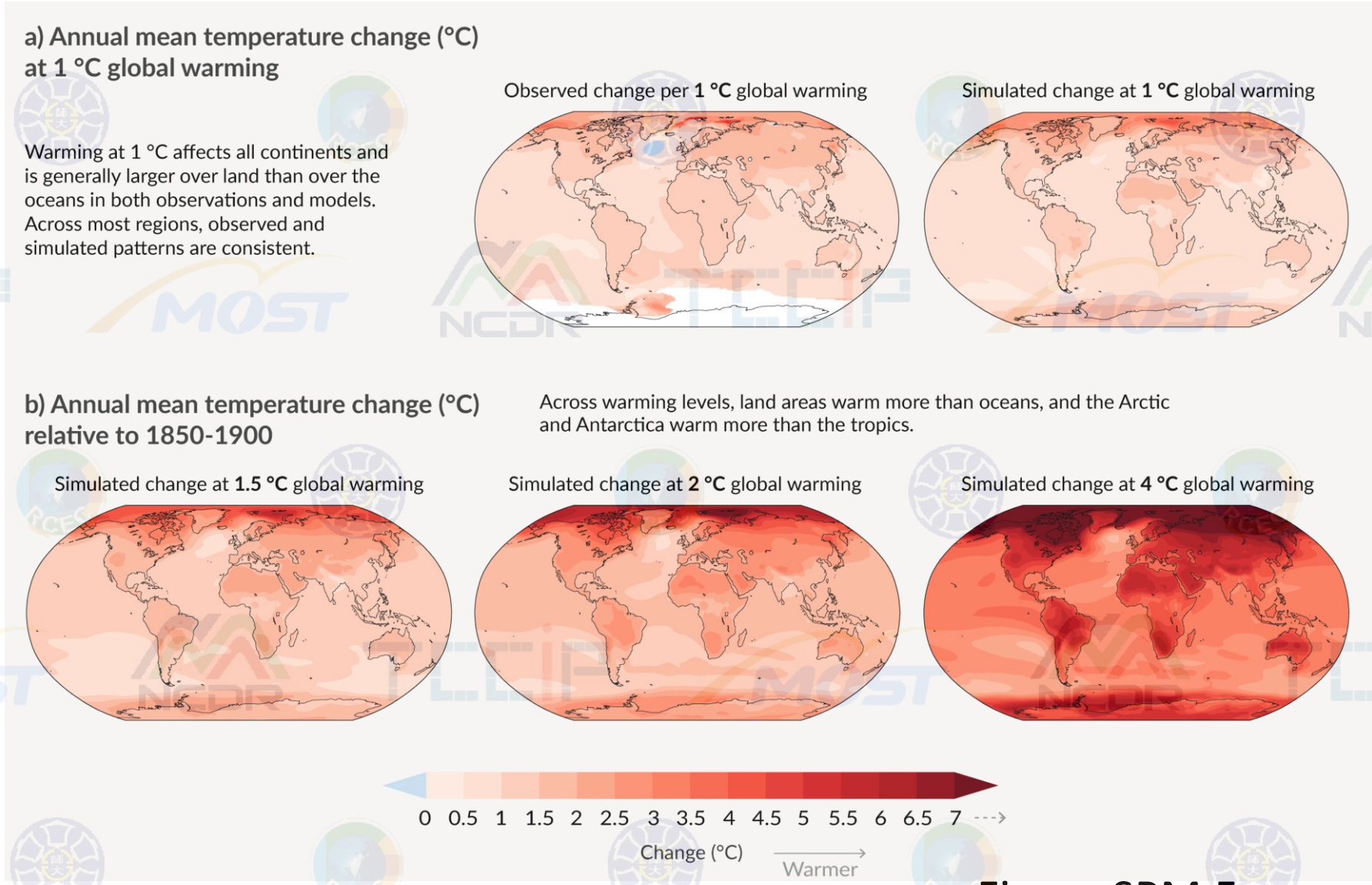


Figure SPM.5

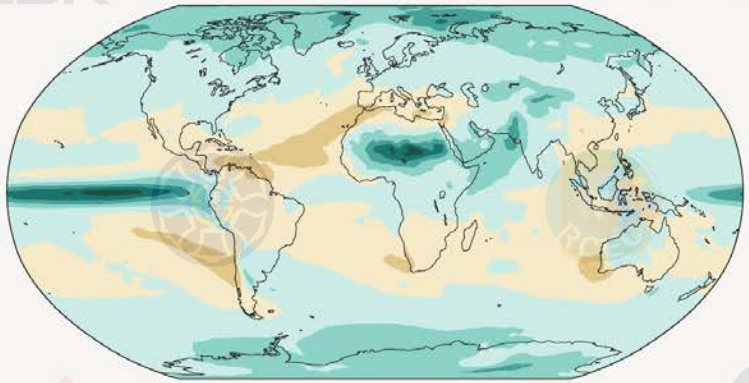
氣候系統的變化與未來氣候推估

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

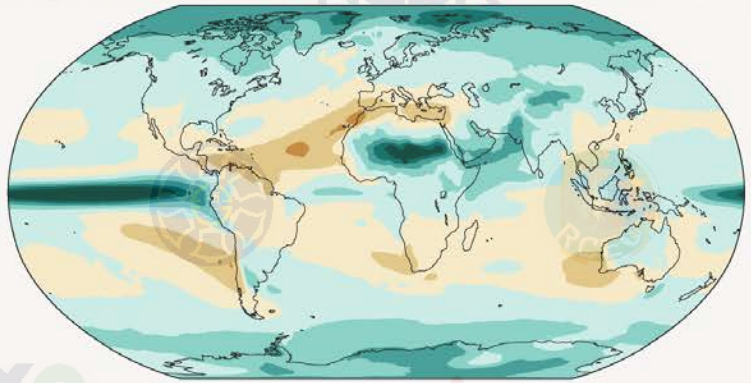
c) Annual mean precipitation change (%) relative to 1850-1900

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.

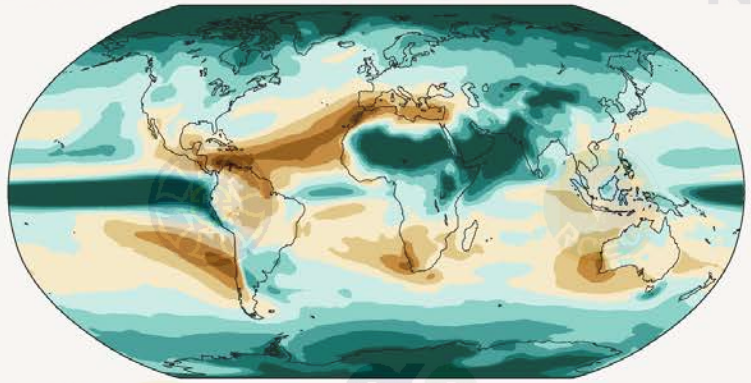
Simulated change at **1.5 °C** global warming



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

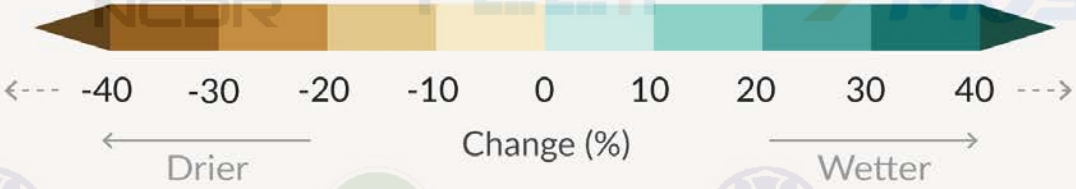


Figure SPM.5

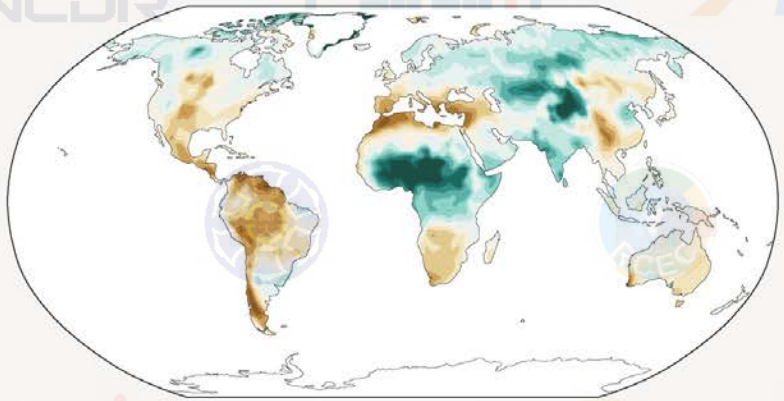
氣候系統的變化與未來氣候推估

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

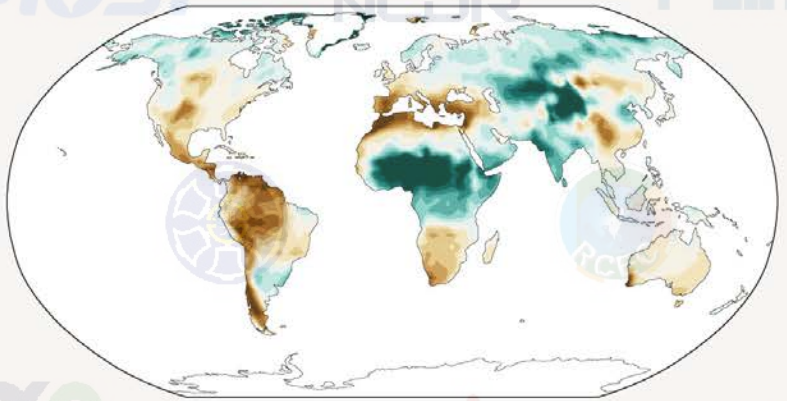
d) Annual mean total column soil moisture change (standard deviation)

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

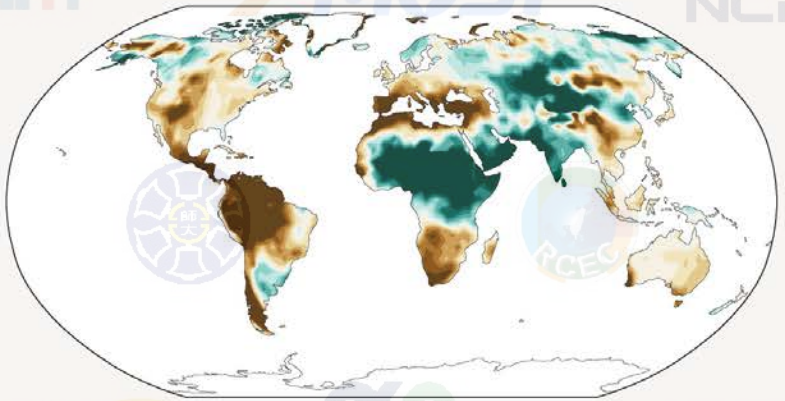
Simulated change at **1.5 °C** global warming



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

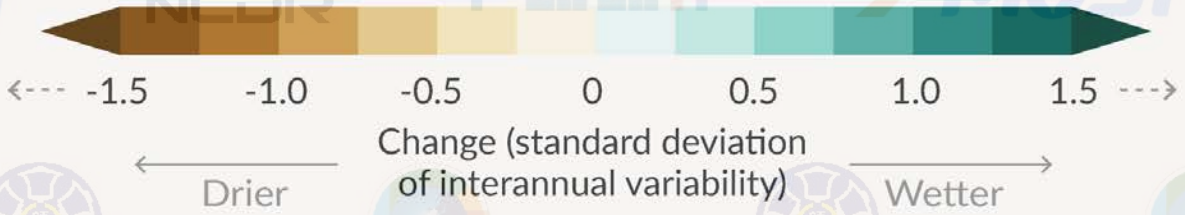


Figure SPM.5

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

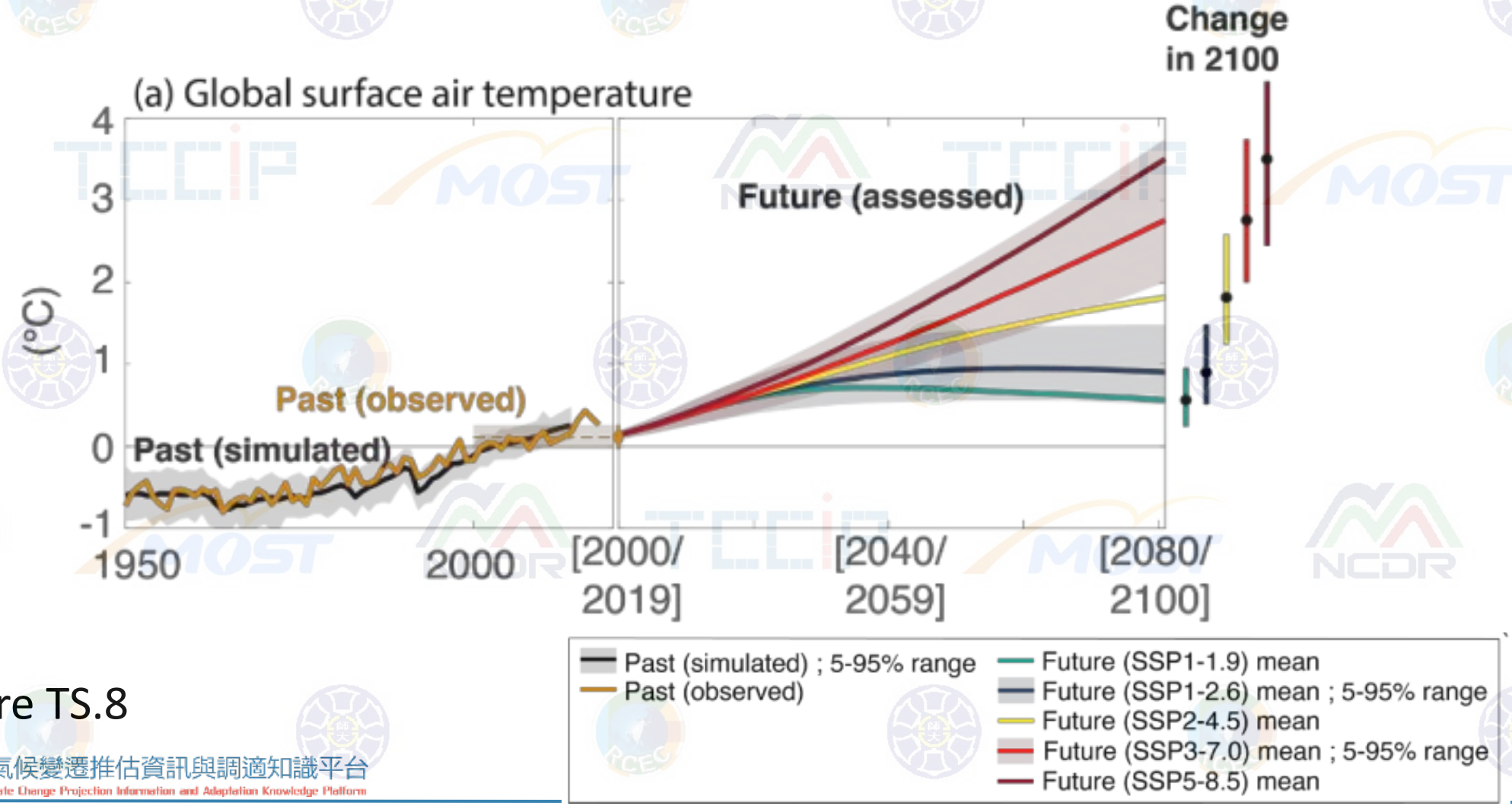


Figure TS.8

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

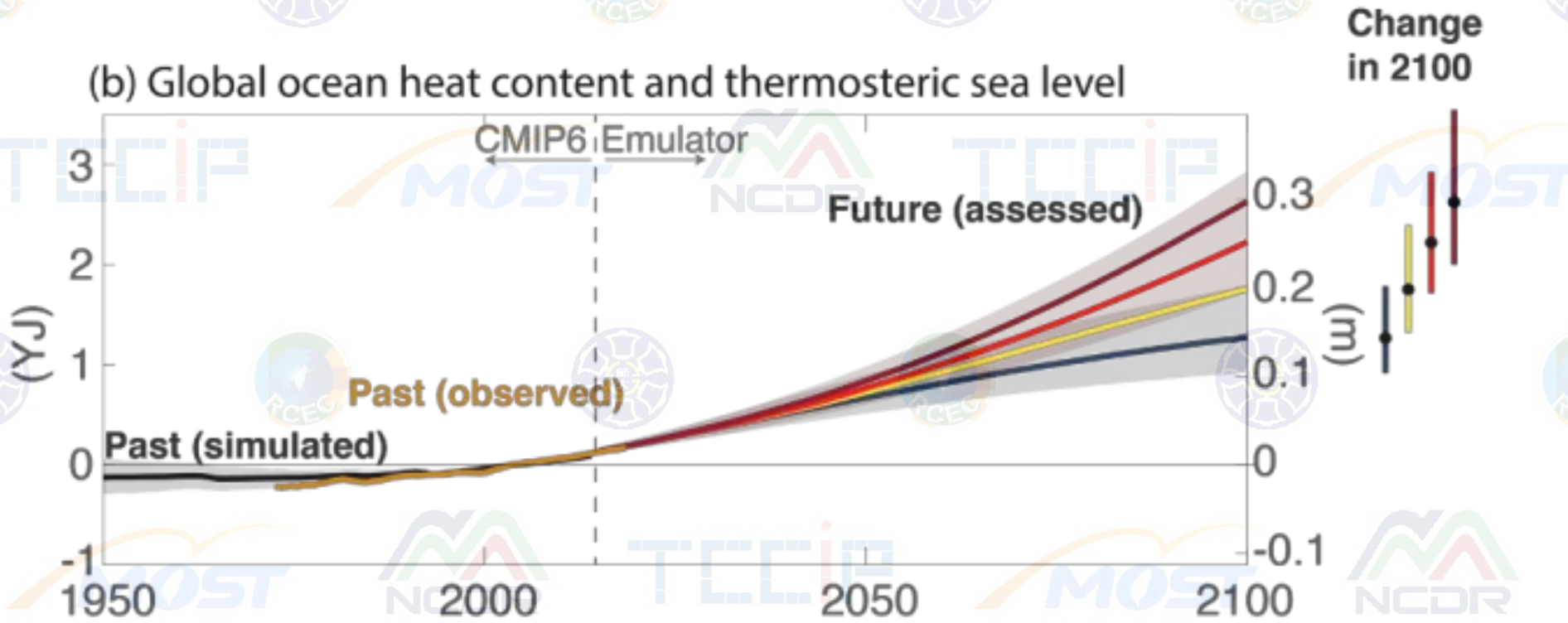


Figure TS.8

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

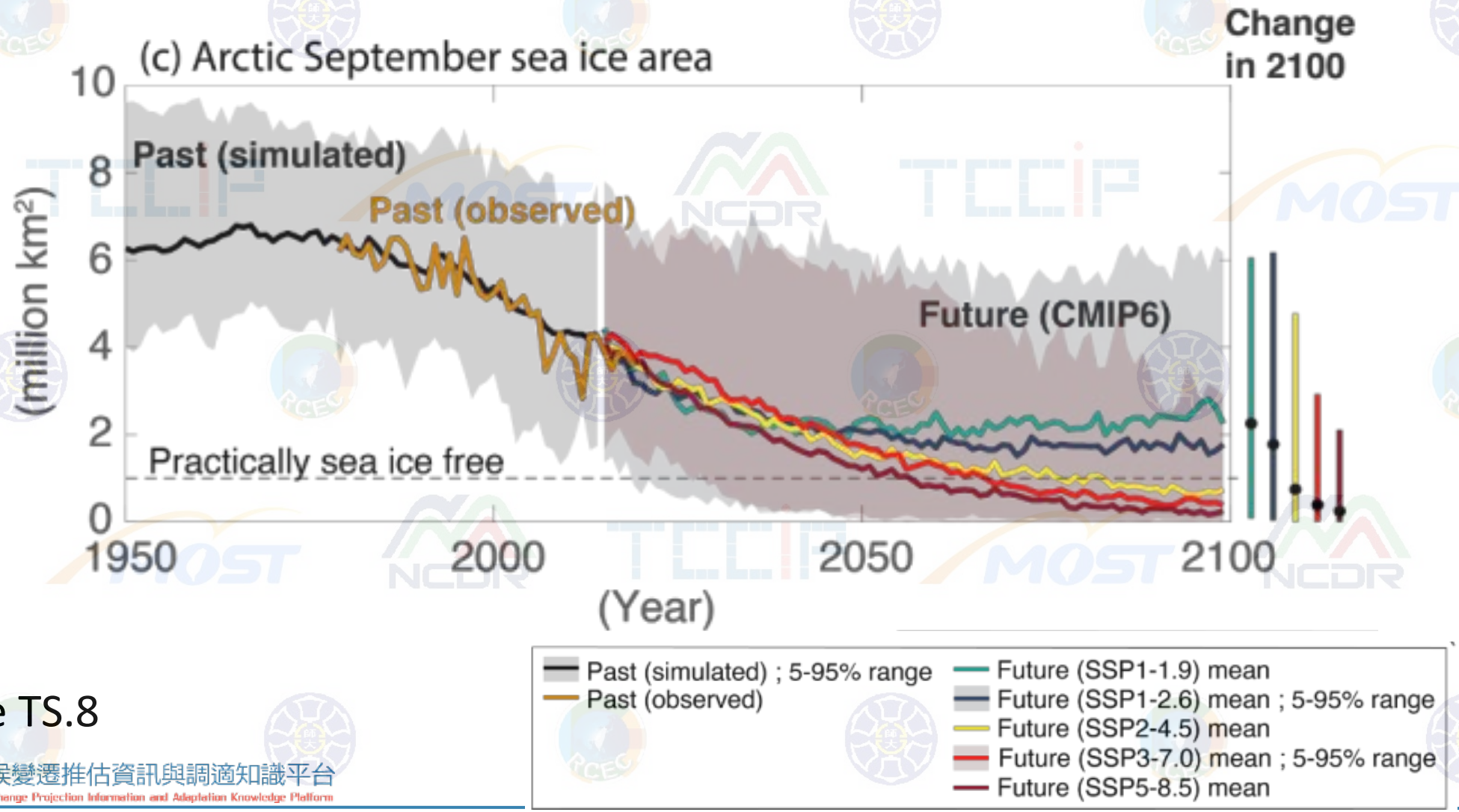


Figure TS.8

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

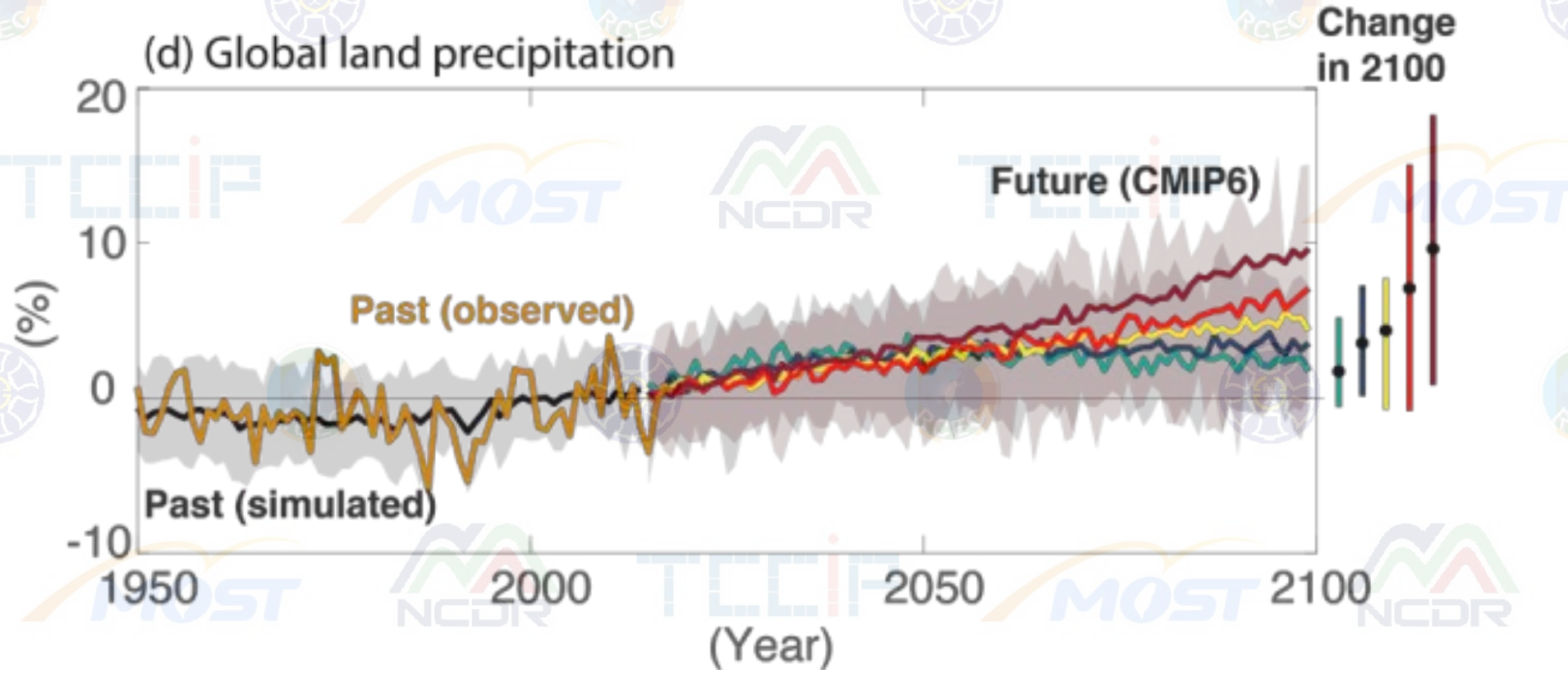
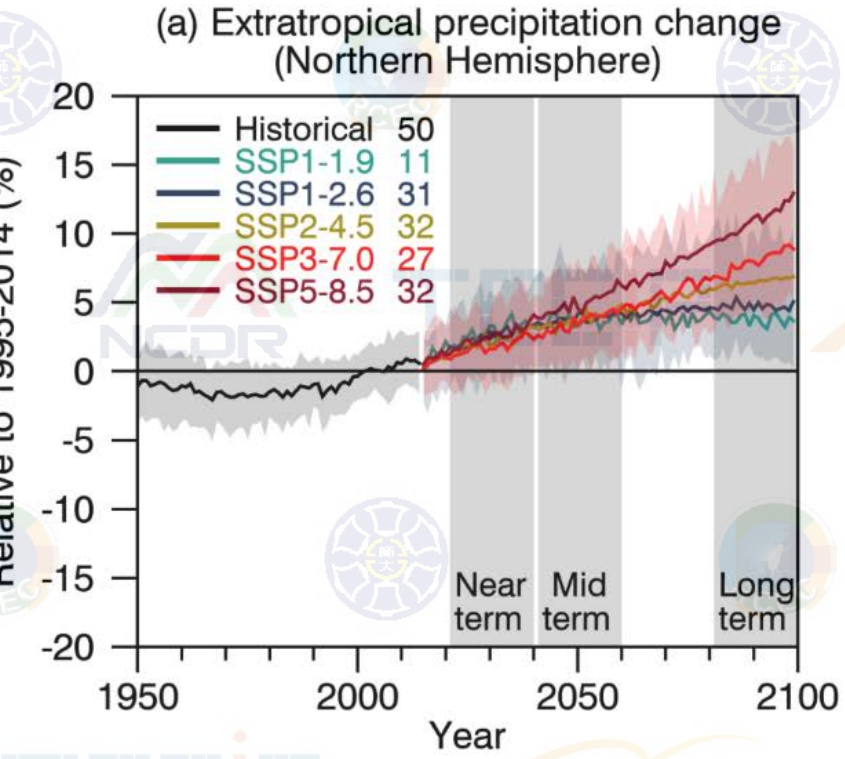


Figure TS.8

氣候系統的變化與未來氣候推估



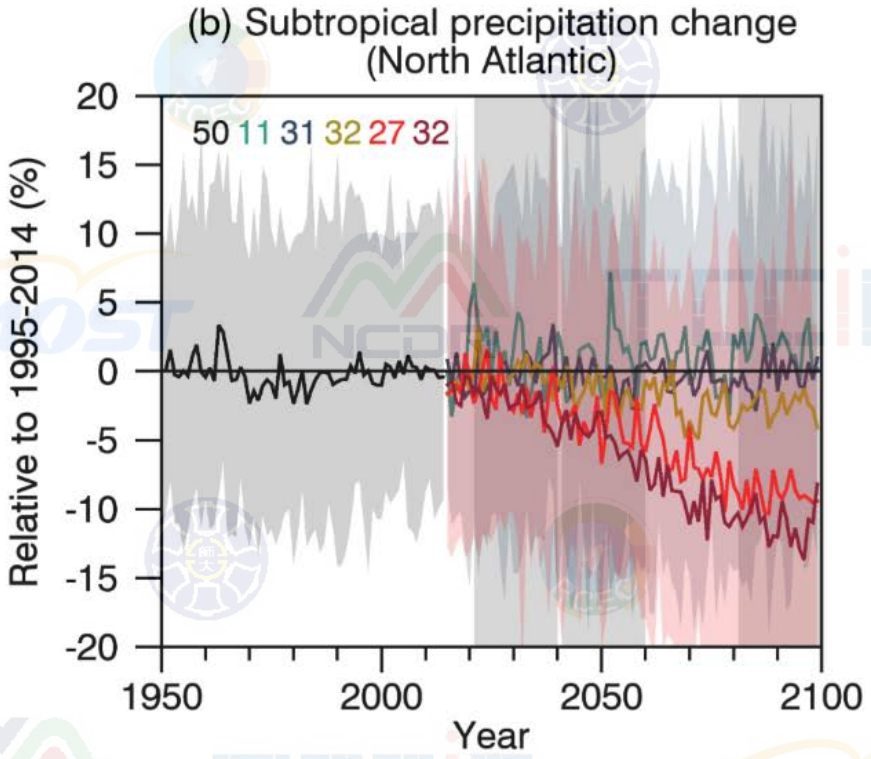
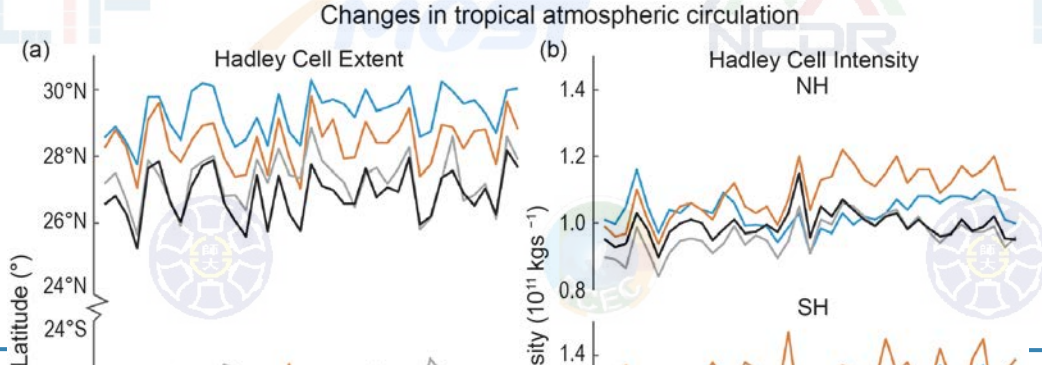


Figure 4.4

Figure 2.17



氣候系統的變化與未來氣候推估

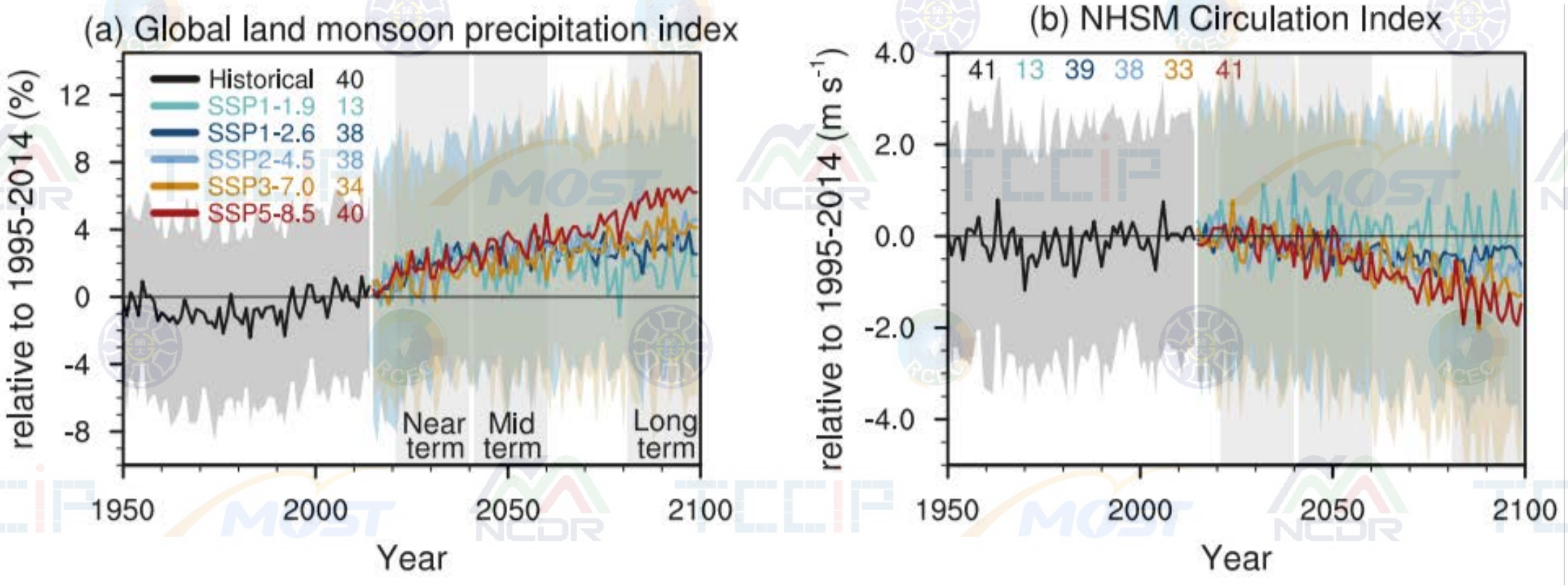
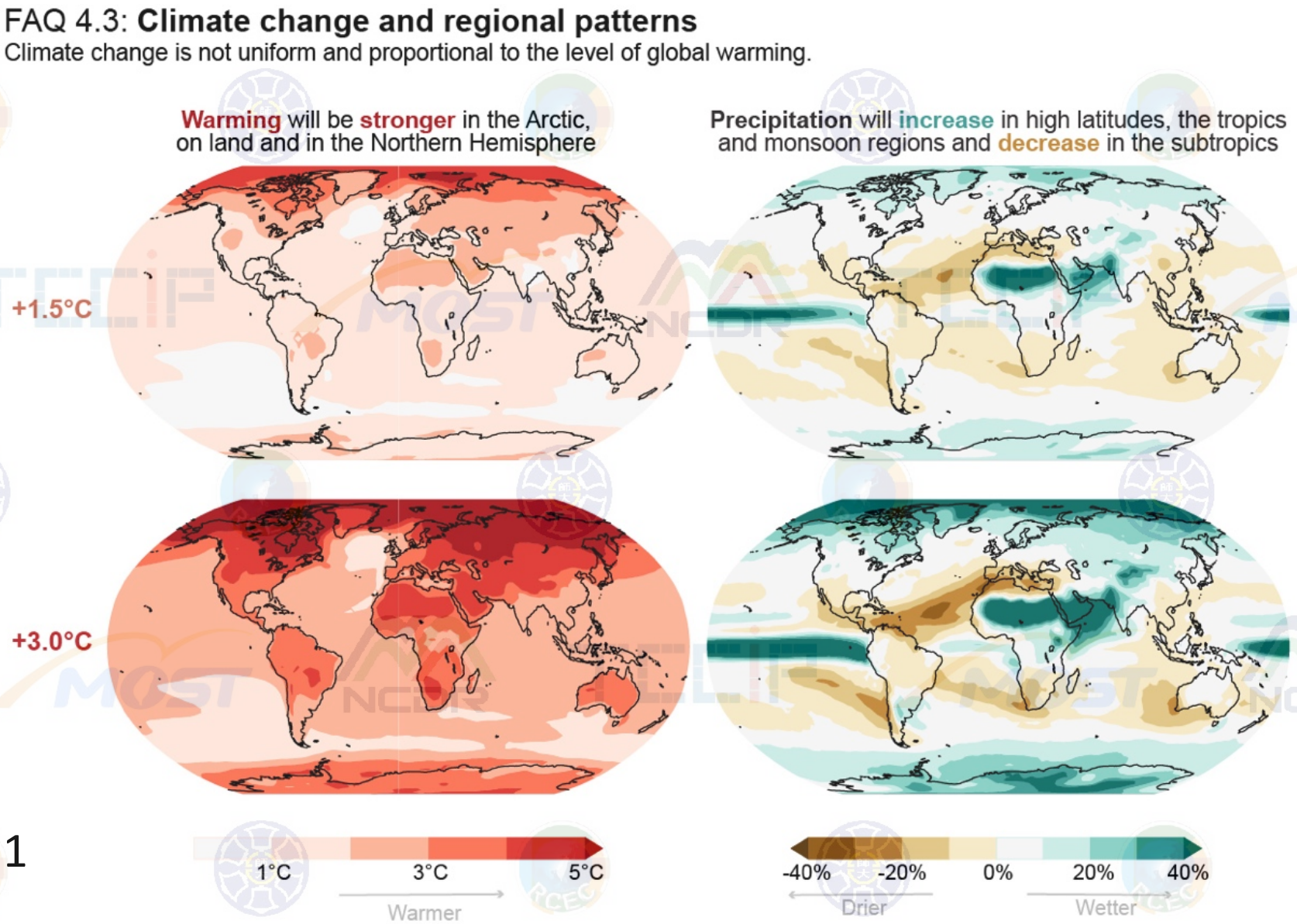


Figure 4.14

氣候系統的變化與未來氣候推估



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

氣候系統的變化與未來氣候推估

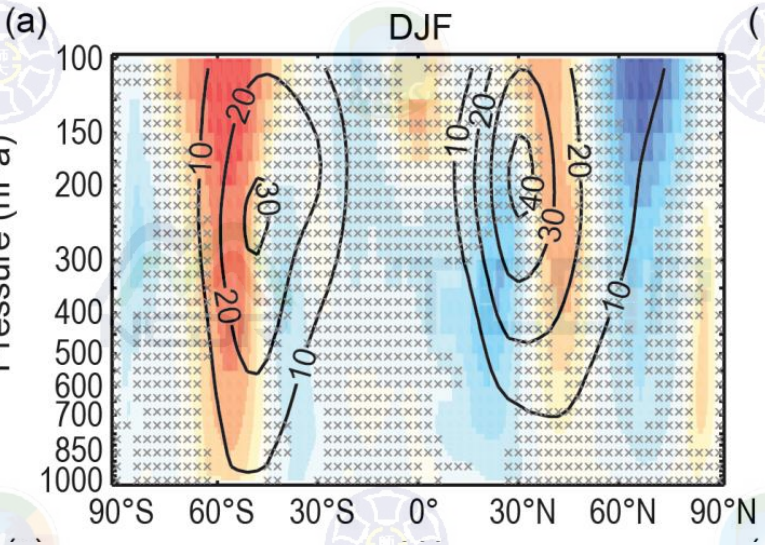


Figure 2.18

中緯度 Storm Tracks 往北偏移

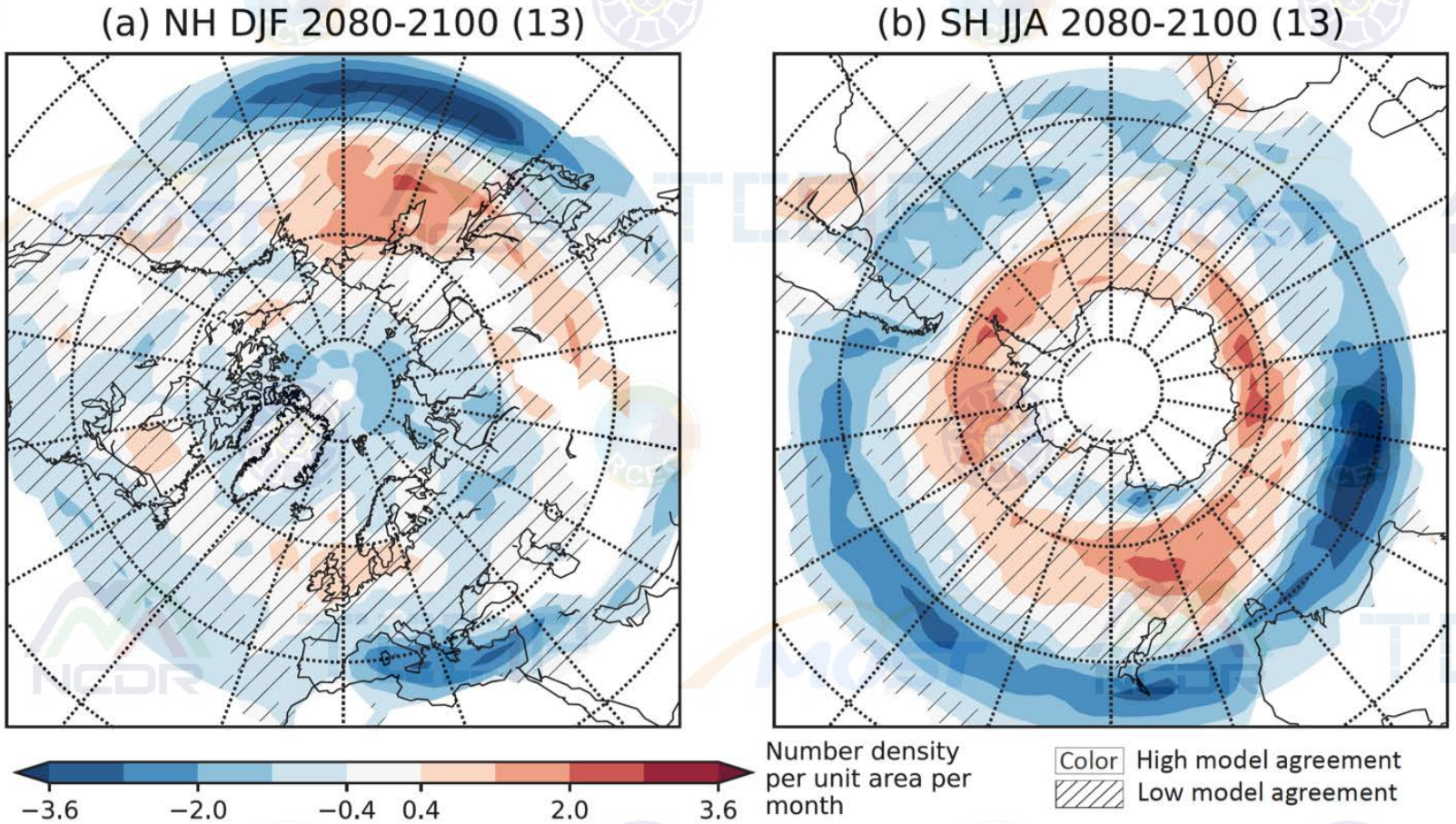


Figure 4.27

氣候系統的變化與未來氣候推估

Recent and Future Changes in Ocean: Marine Heatwave

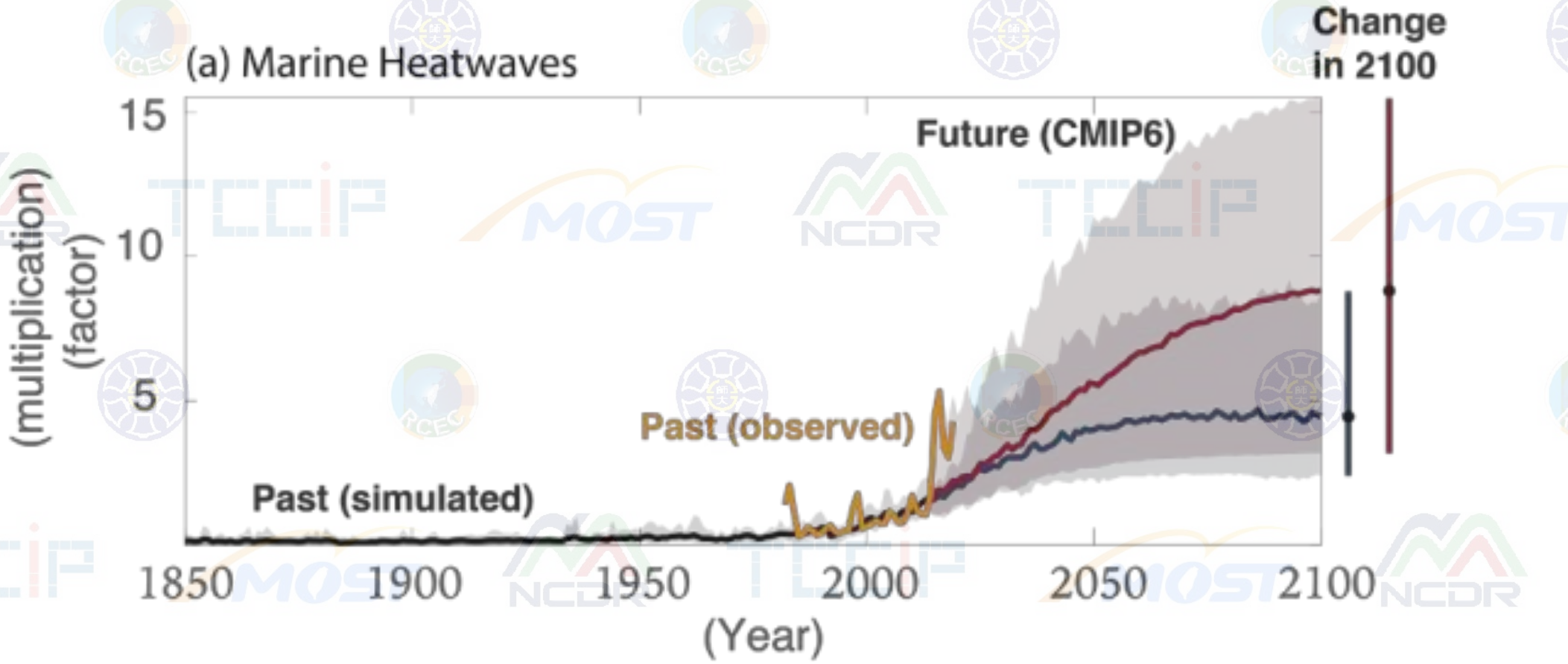
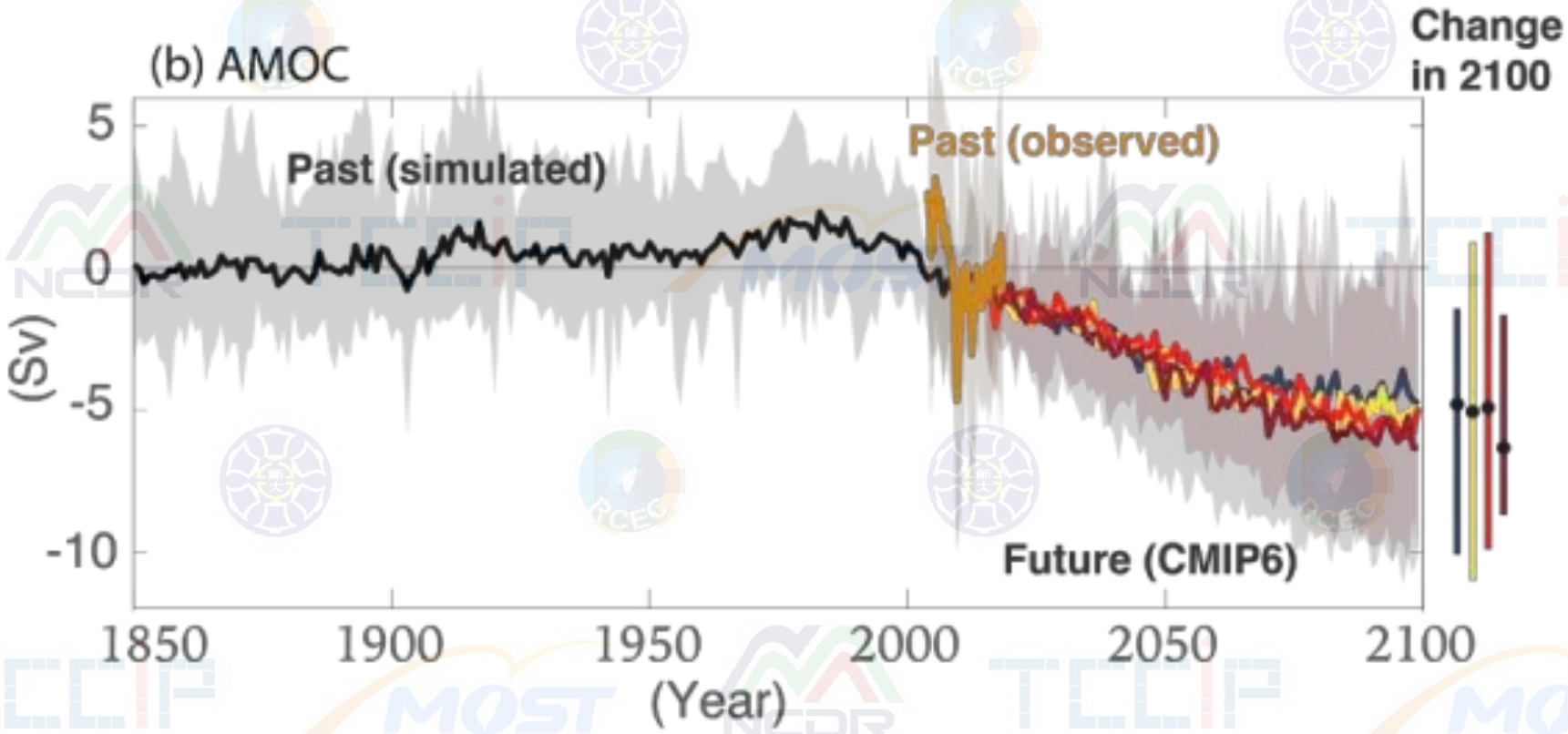


Figure TS.11

氣候系統的變化與未來氣候推估

Recent and Future Changes in Ocean: Atlantic Meridional Overturning Circulation



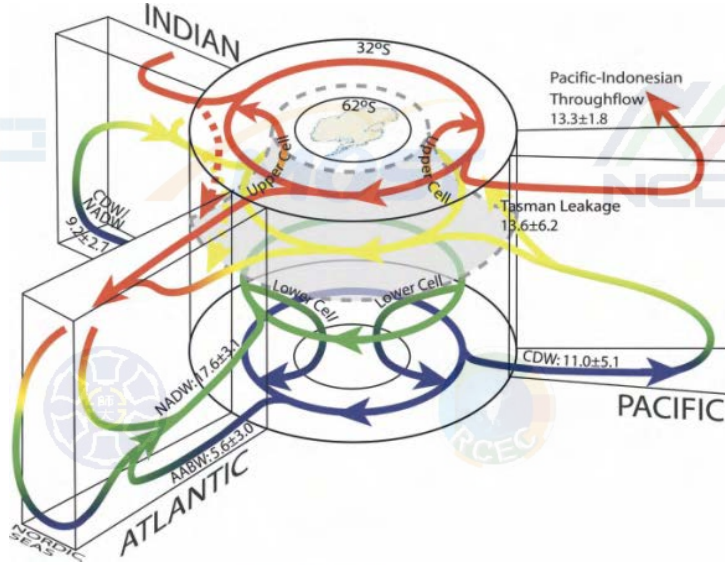


Figure TS.11

氣候系統的變化與未來氣候推估

Recent and Future Changes in Ocean: Dissolved Oxygen

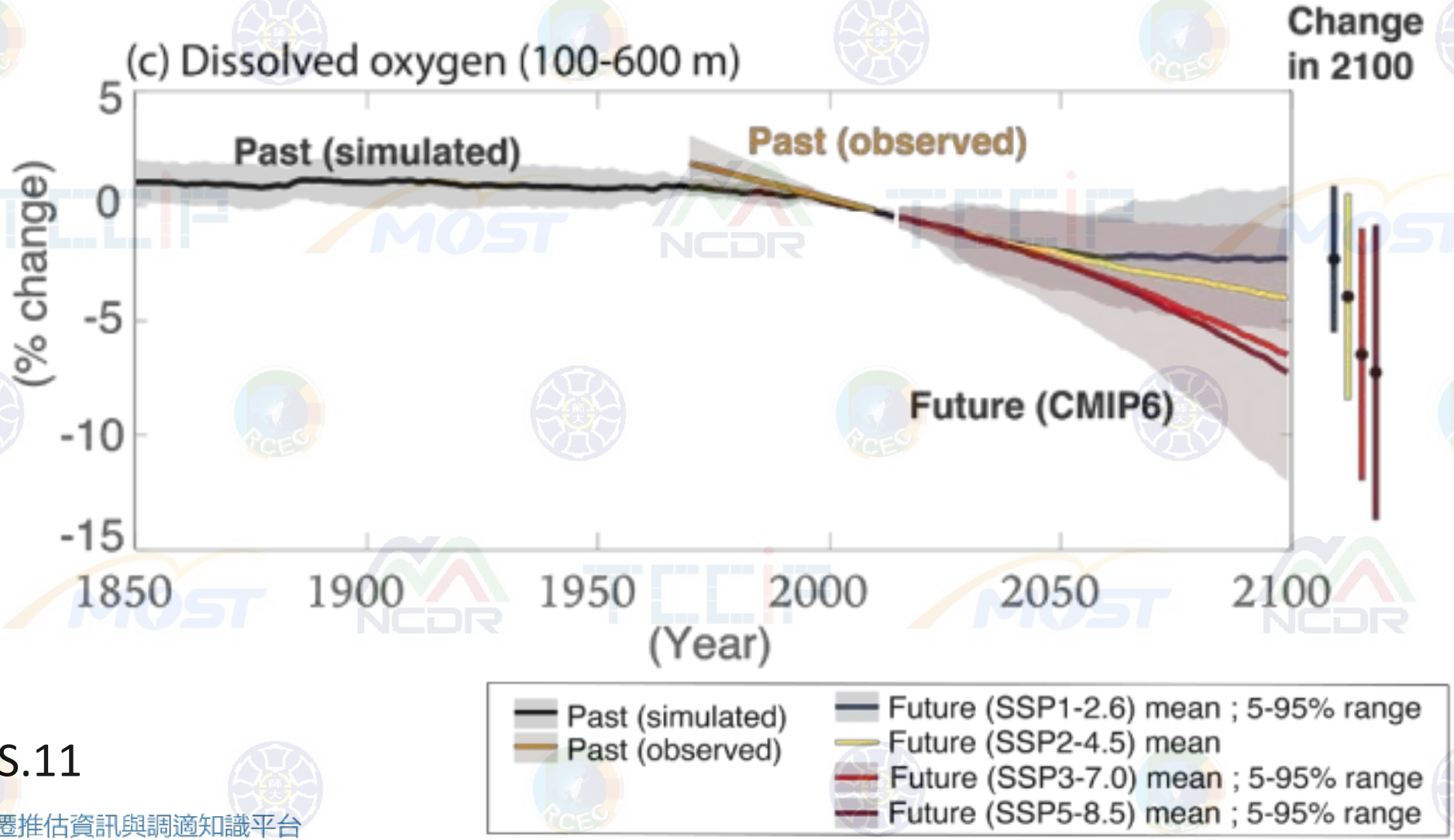


Figure TS.11

氣候系統的變化與未來氣候推估

Recent and Future Changes in Ocean: Ocean Acidification

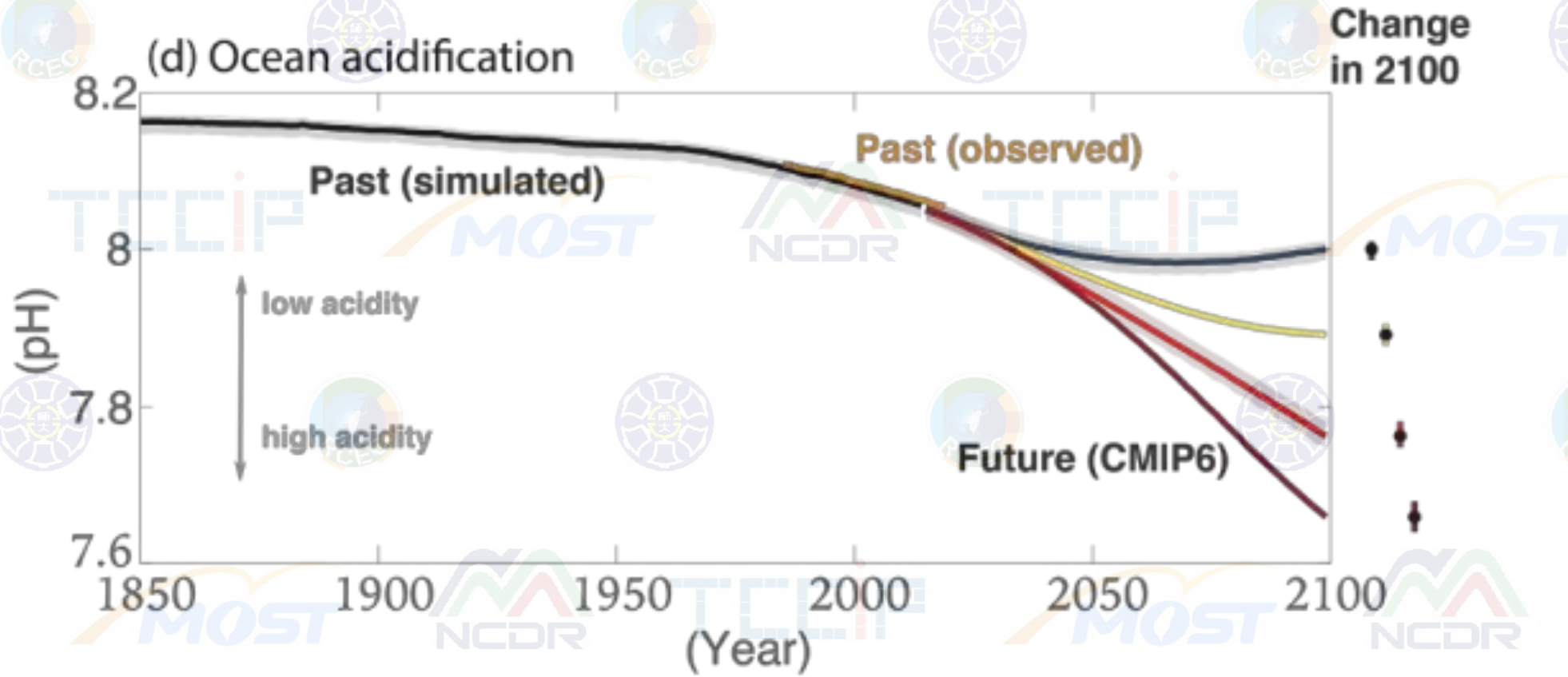


Figure TS.11

氣候系統的變化與未來氣候推估

Recent and Future Changes in ice sheets: Greenland and Antarctic

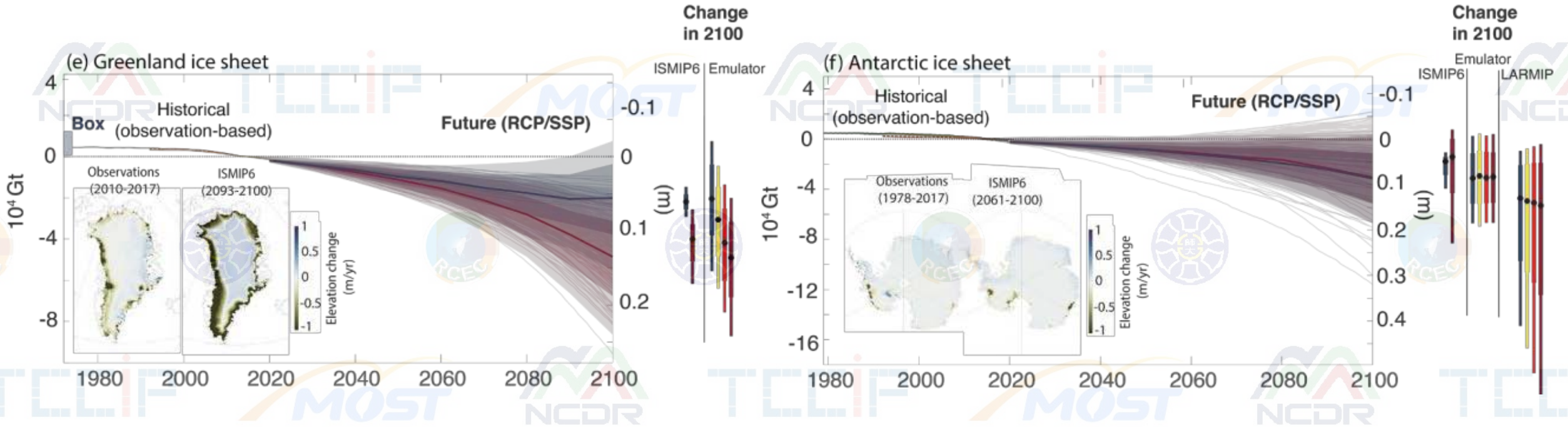


Figure TS.11

Observation-based:
Bamber
Mouginot/Rignot
IMBIE

Emulator median (SSP1-2.6); 17-83% & 5-95% ranges
Emulator median (SSP5-8.5); 17-83% & 5-95% ranges
ISMIP6 models (SSP1-2.6/RCP2.6)
ISMIP6 models (SSP5-8.5/RCP8.5)

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

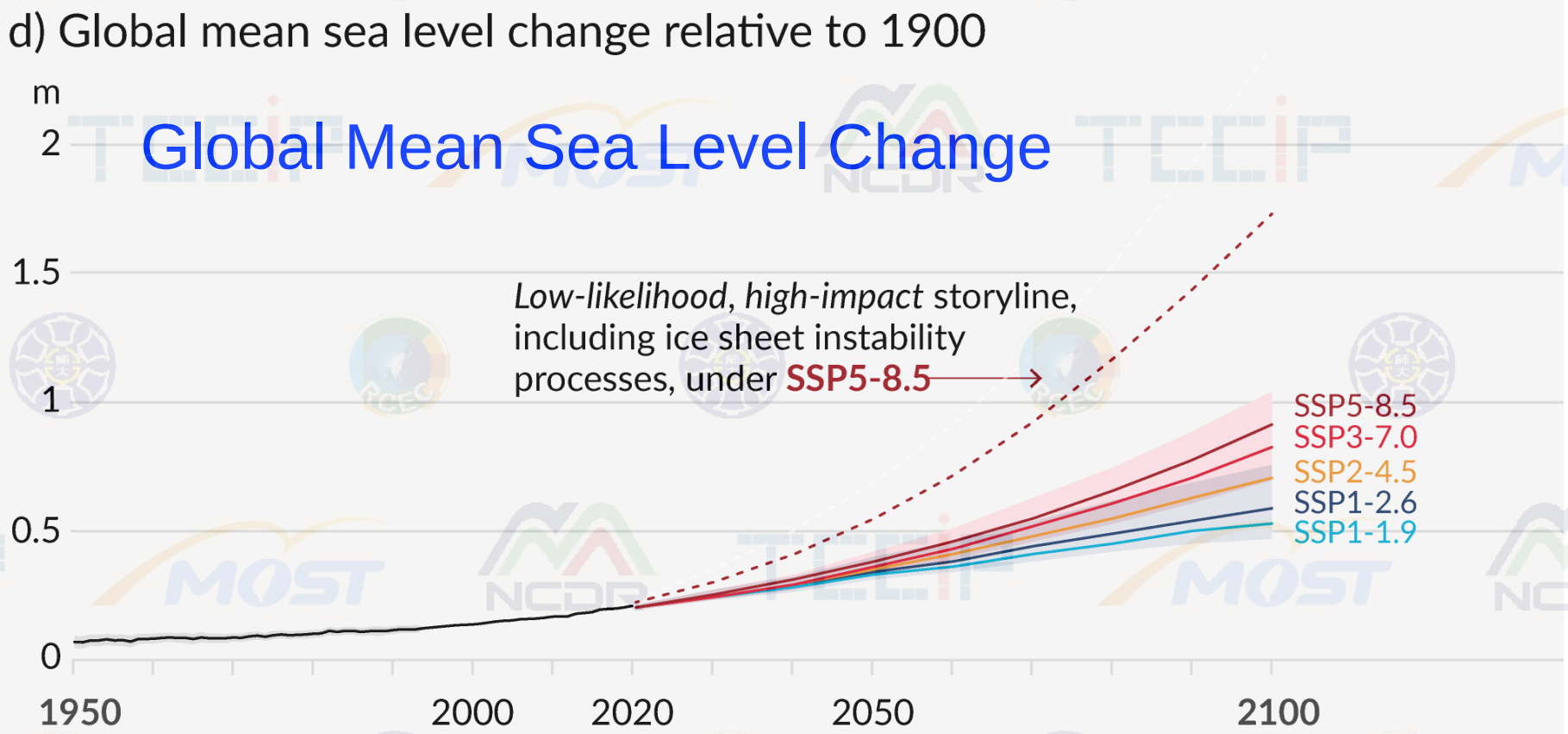
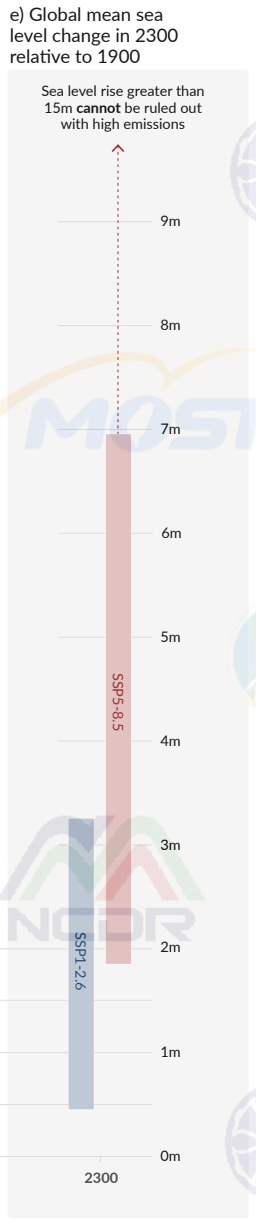


Figure SPM.8

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

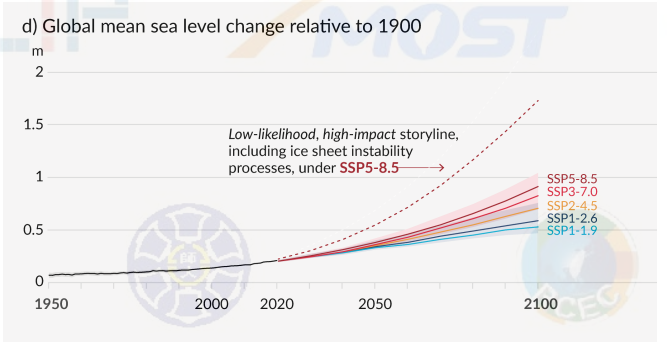
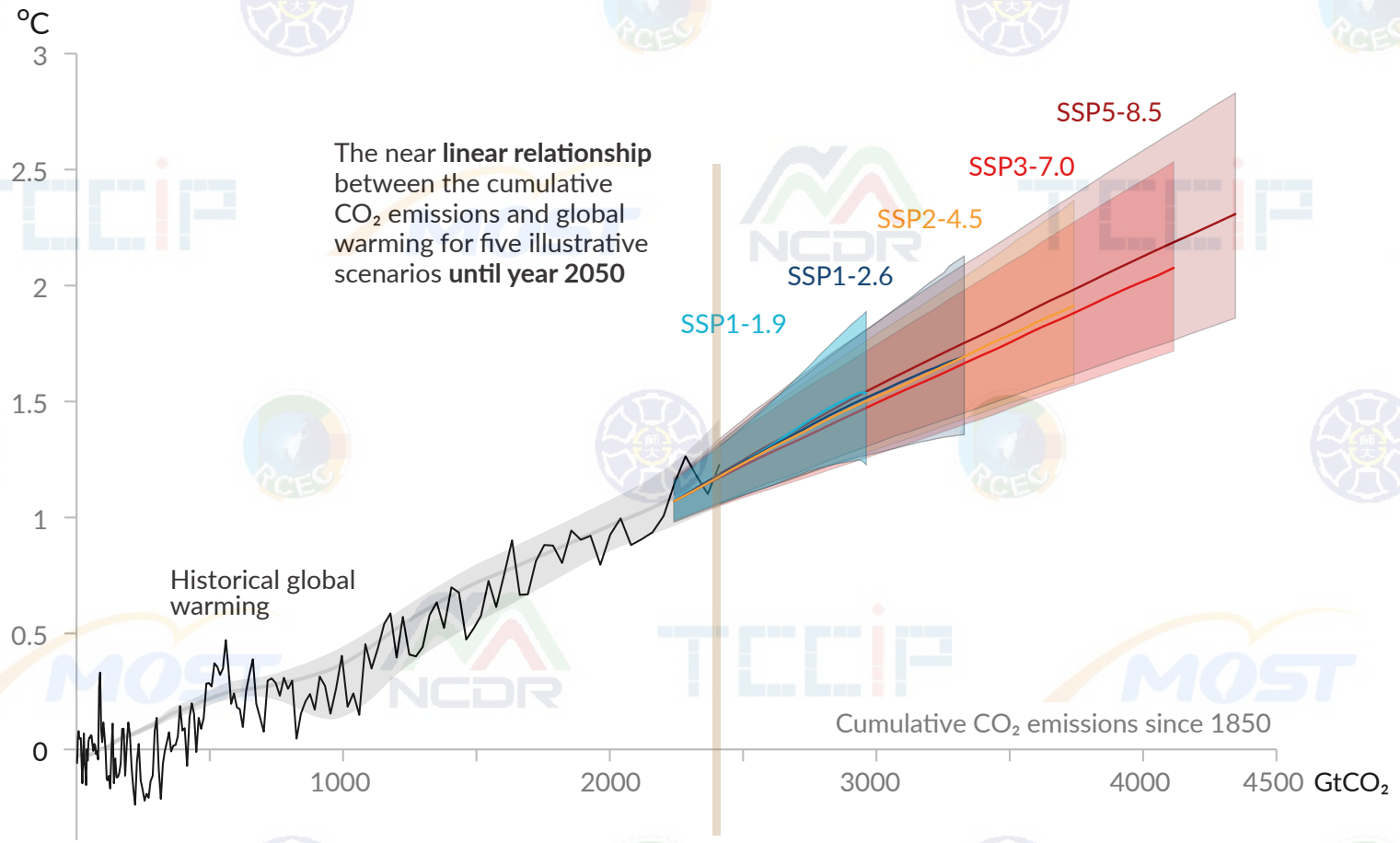


Figure SPM.8

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_2 emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



2390 Gt CO_2

Figure SPM.10

未來全球氣候：不同情境下的長期推估與近期改變

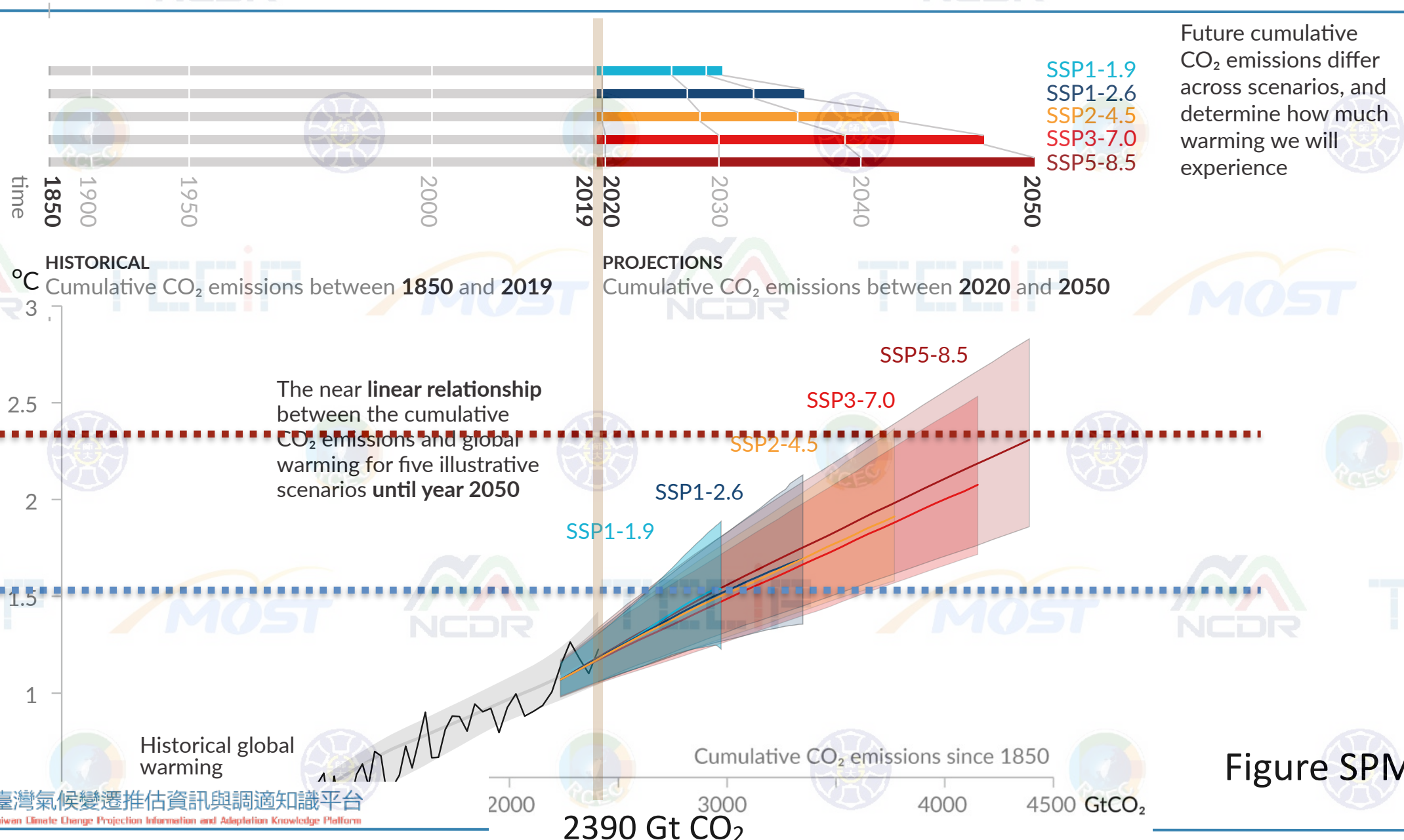


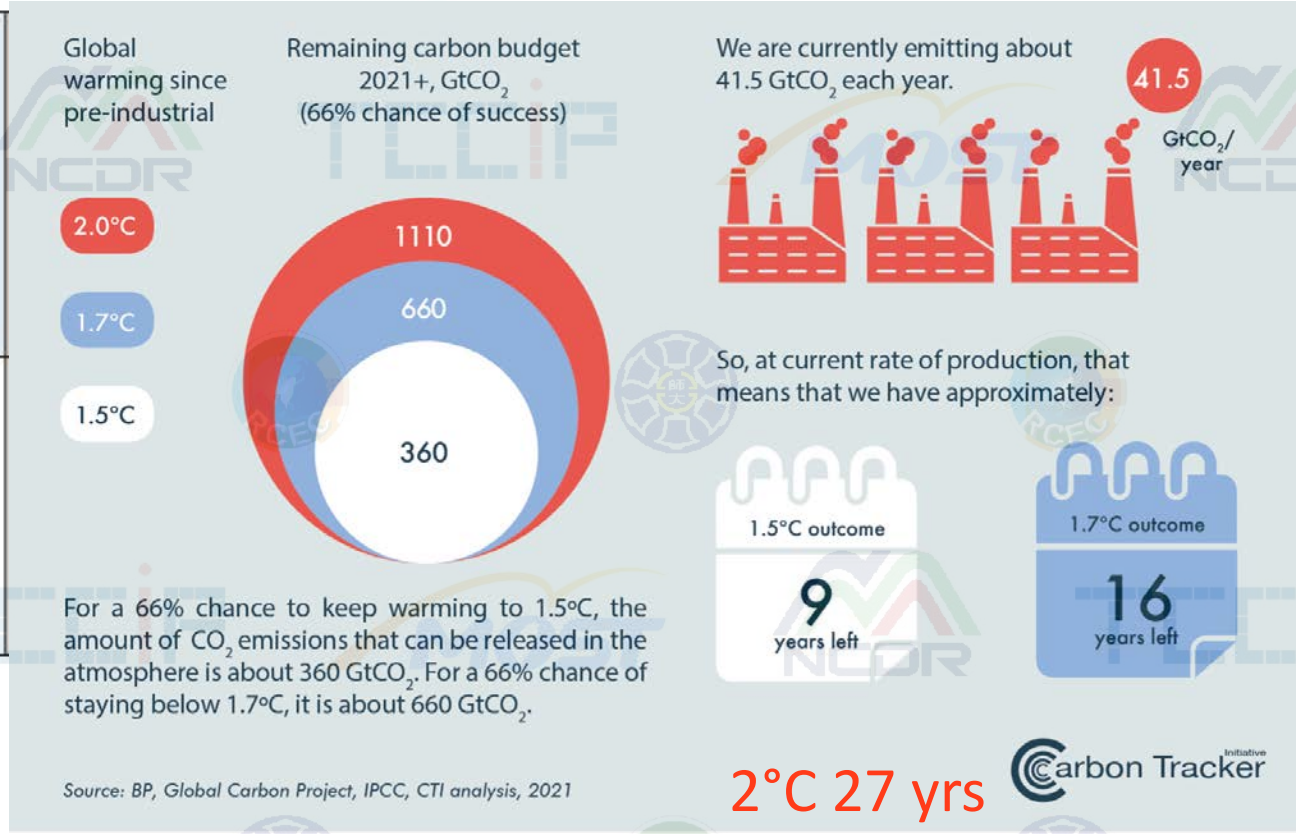
Figure SPM.10

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_2 emissions from 1850 to 2019 *($GtCO_2$)*
1.07 (0.8–1.3; *likely* range)	2390 (± 240; *likely* range)

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 *($GtCO_2$)*				
		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

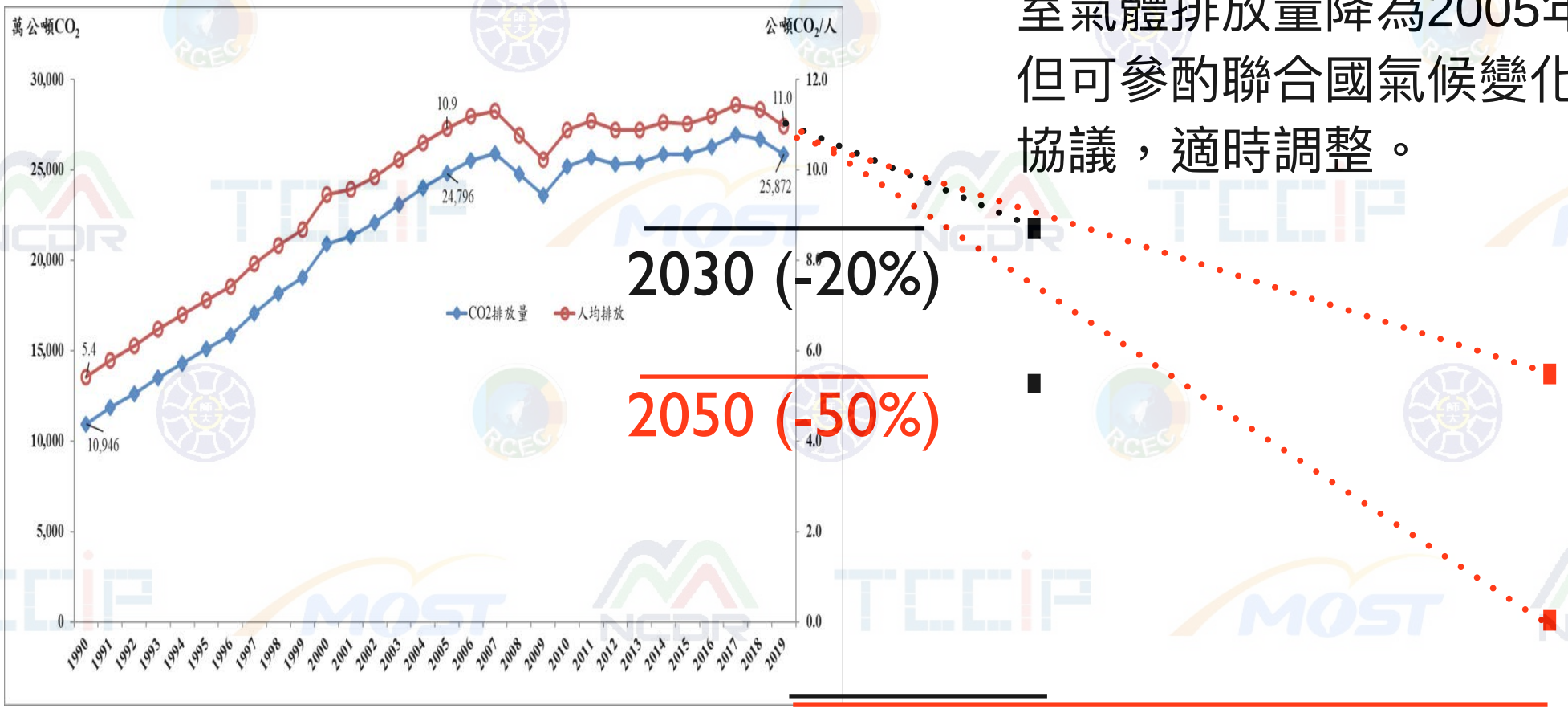
Table SPM.2



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。

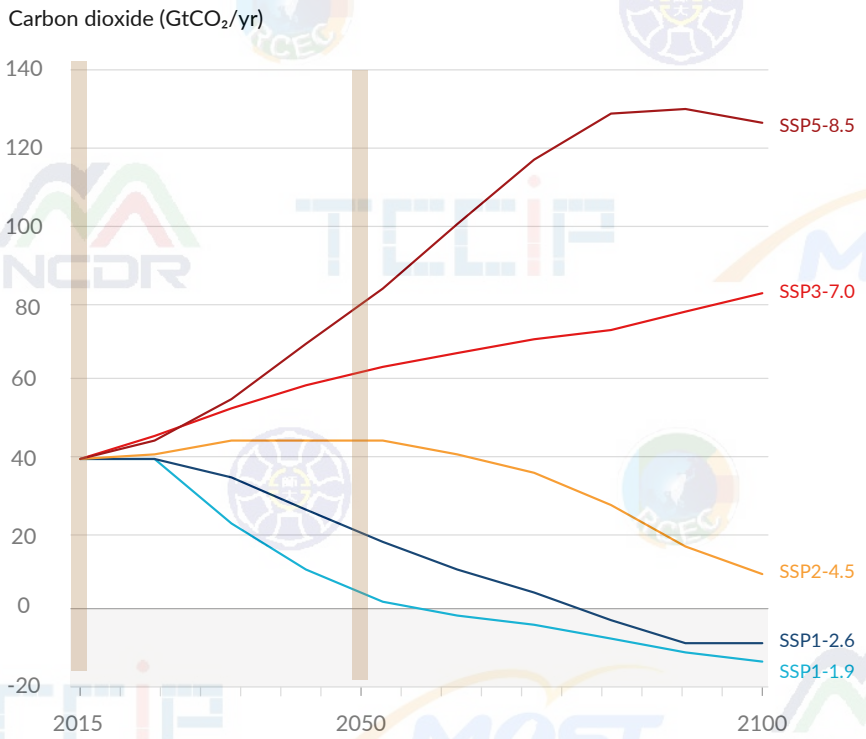


資料來源：經濟部能源局，2020 年 7 月。

圖 1、歷年燃料燃燒 CO_2 排放量與人均排放趨勢圖

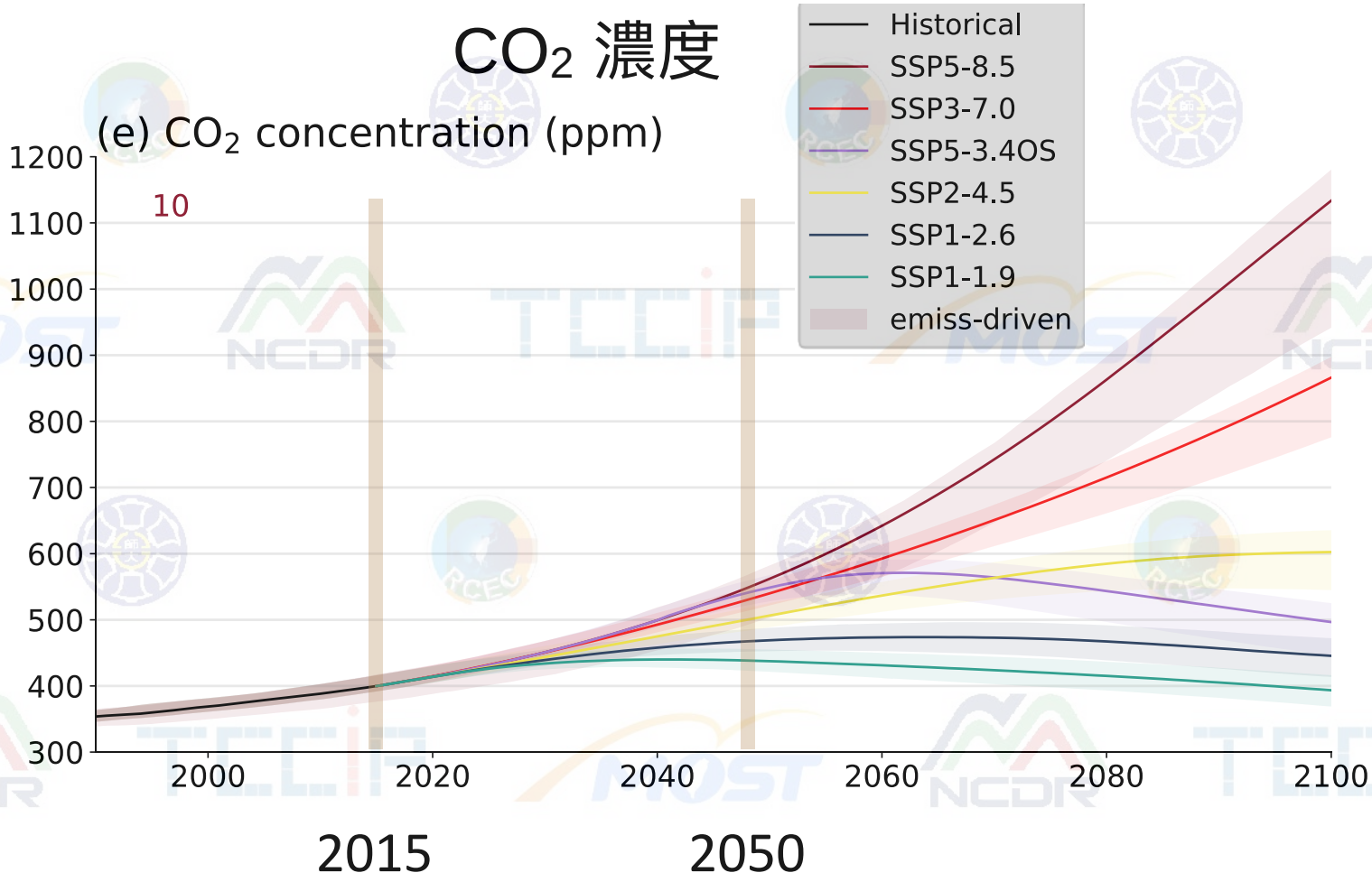
全球的碳與其他生地化循環與反饋

CO_2 排放



2015 2050

CO_2 濃度



2015 2050

Figure SPM.4

Box TS.5 Figure 1

全球的碳與其他生地化循環與反饋

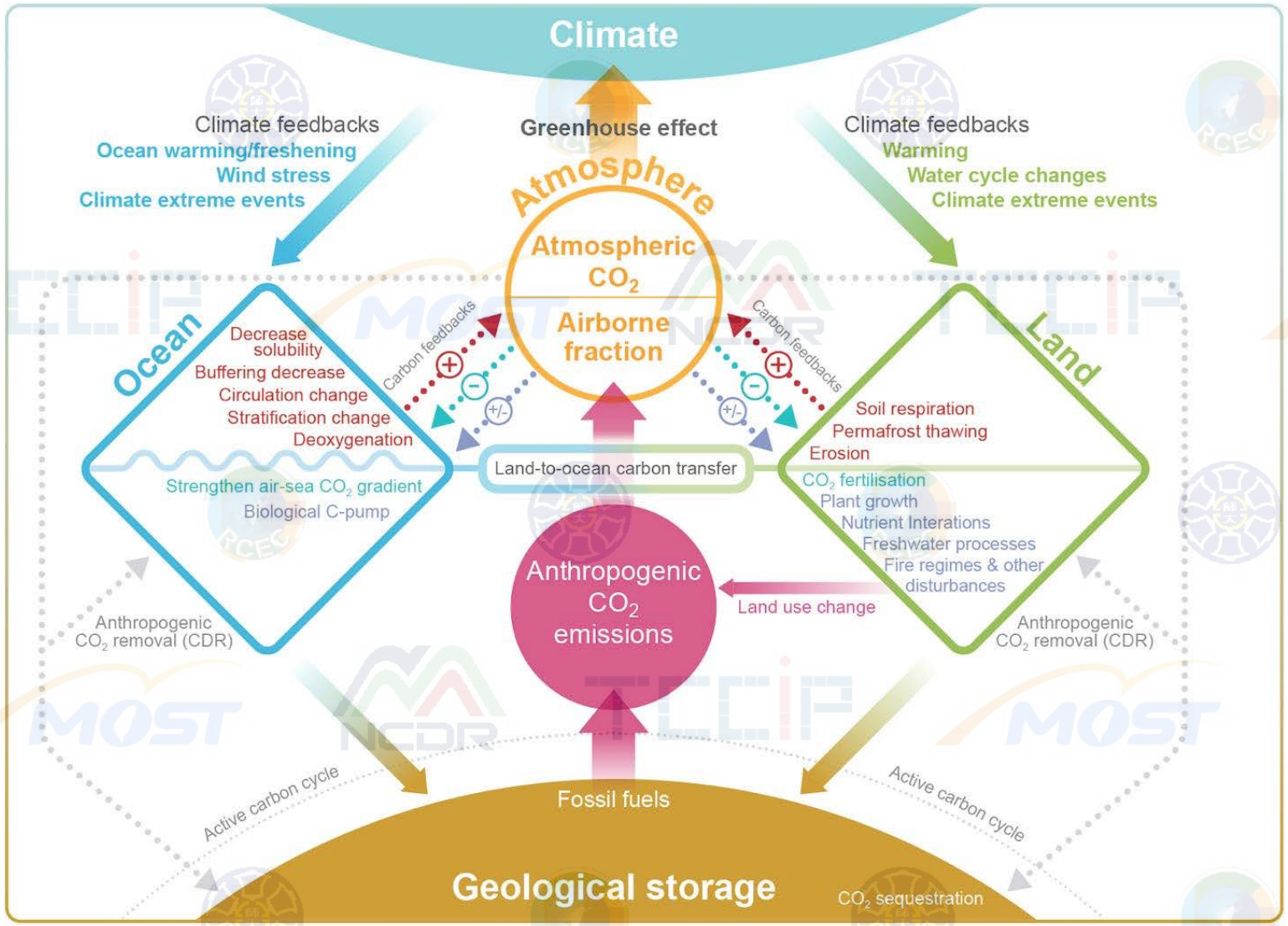
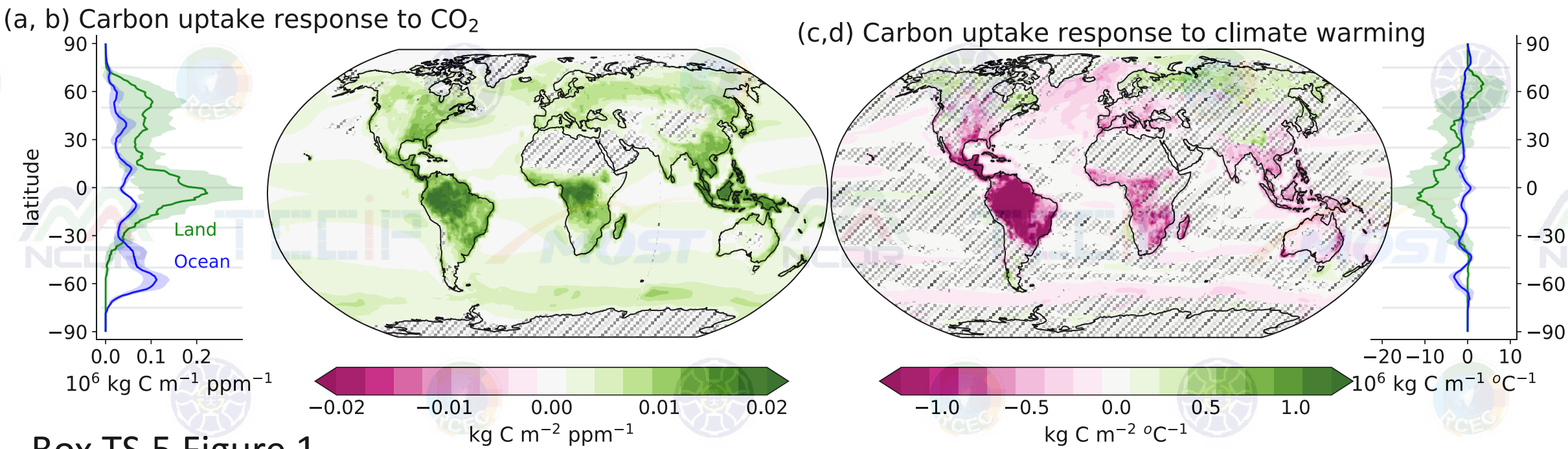


Figure 5.2

全球的碳與其他生地化循環與反饋



Box TS.5 Figure 1

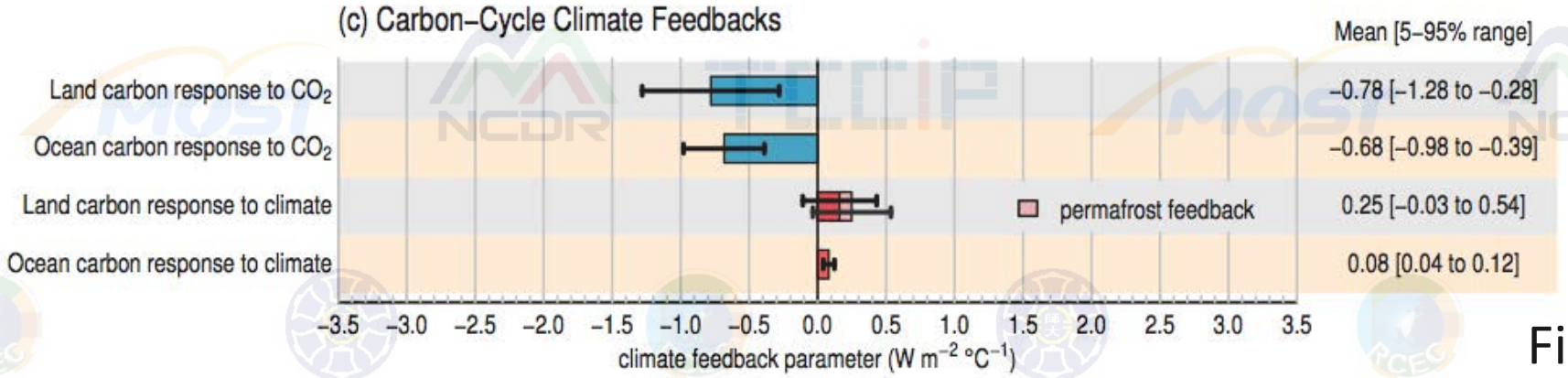


Figure TS.17

全球的碳與其他生地化循環與反饋

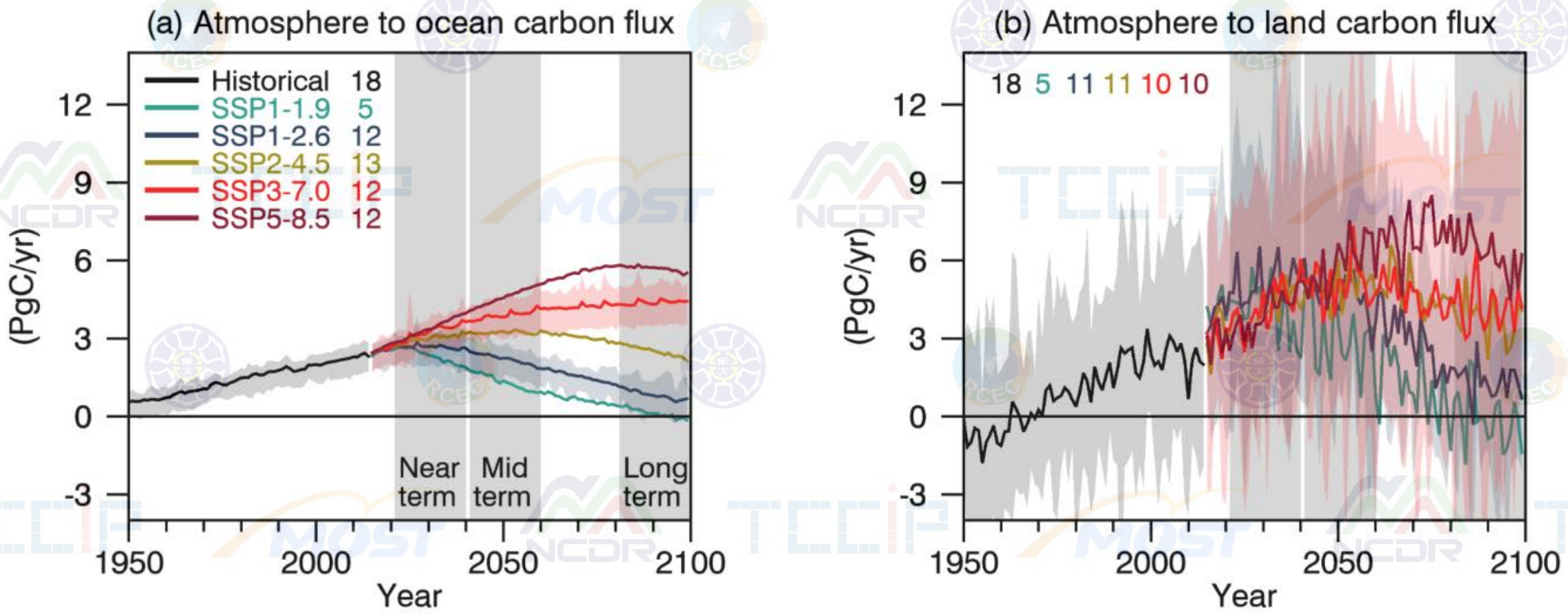
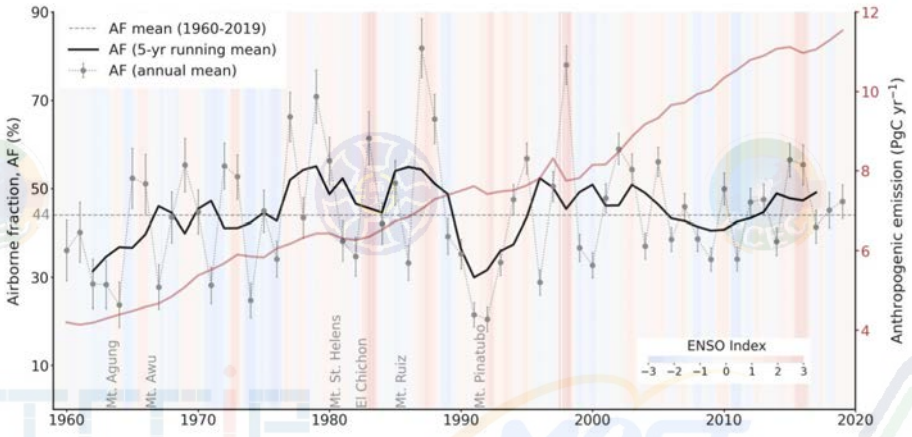


Figure 4.7

全球的碳與其他生地化循環與反饋

CO_2 排放後，
留在大氣中的比例
44%
(1960-2019 平均)



AR6 Figure 5.7

The proportion of CO_2 emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO_2 emissions

Total cumulative CO_2 emissions **taken up by land and oceans** (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100

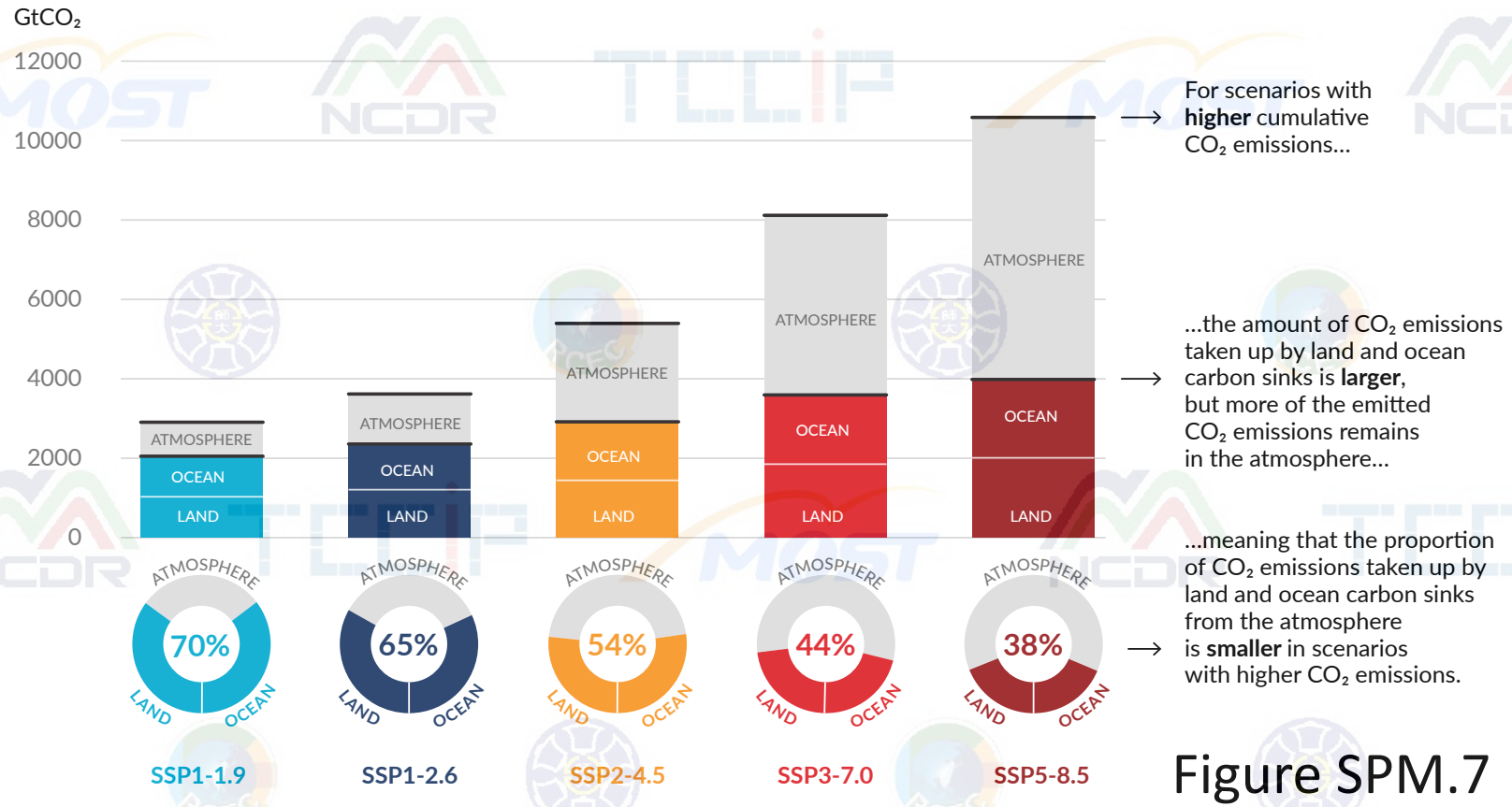


Figure SPM.7