Guide to the Science of Climate Change in the 21st Century

Chapter 18
AR5 - Impacts of Climate Change on Physical Systems

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Chapter 18.0 AR5 - Impacts of Climate Change on Physical Systems

18.1 Introduction

The observed impacts of climate change on physical systems motivated the development of climate models able to predict future global warming and climate changes resulting from sustained or increased greenhouse gas emissions and changes in land use. Climate science is sufficiently known that it is now possible to create and use climate models to predict climate change as a consequence of anthropogenic and natural causes. This capability has been demonstrated, at least as it has occurred since 1850. These models are the only tools available to guide society's adaptation and mitigation responses to impending impacts on natural and human environments.

The IPCC Fifth Assessment Report, AR5, was completed in 2013 and is the primary focus of this chapter. There are separate discussions on climate change tipping points and the impact of warming on the release of runoff from snow melt in mountainous regions. While snow is a very important element in discussions of the cryosphere, timing of runoff from mountain snow accumulation and melt is also very important. The impact of climate change on runoff volume (including snow melt) is discussed in section 18.3.2

The IPCC Sixth Assessment Report, AR6, is building on more recent information, model improvements and a different set of scenarios. The AR6 report, WGI, The Physical Science Basis, is expected to be published and available in the fall 2021.

While AR6 report, WG2: Impacts, Adaptation and Vulnerability is due to be published in 2022 draft versions of segments of this report are being leaked (June 22, 2021) which discuss the serious nature of climate change tipping points. It is the authors opinion that while this 'leaked' information is unofficial and confidential it is very valuable that some of the more serious issues be known at this time – well ahead of COP26 to be held in the fall of 2021. It will motivate the 'parties' to seriously deal with the urgency of the issues that need to resolved.

18.2 Scenarios AR5

Climate models have been used since AR1 (the first assessment report prepared in the 1990's). With every assessment report the ability to model climate has improved and so have the scenarios used by the climate models to predict future climate change impacts resulting from different patterns of GHG emissions. The patterns reported and used by the climate models are the result of the analysis of the physical circumstances and societal responses expected. This has continued with AR5.

The approach taken by the IPCC for AR5 is to use what they call representative concentration pathways or RPCs. Concentration is measured in terms of radiative forcing, Wm^{-2}, similar to that used in Figure 15.29 which reports global-average radiative forcing estimates and ranges for both anthropogenic forcings and natural forcings.

Integrated assessment models, IAMs, were used to select the RCPs. A description of complex IAMS is provided by Carbon Brief (02.10.2018): 'These models look at energy technologies, energy use choices, land-use changes and societal trends that cause – or prevent – greenhouse gas emissions.' (See Key websites, Carbon Brief.)

Four pathways were selected. Figure 18.1 illustrates the four RCPs identified and how the radiative forcing change annually to 2100. The names of the pathways refer to the radiative forcing from GHG concentration expected in year 2100. RCP8.5 pathway will result in GHG radiative forcing equal to 8.5 watts per square meter, RCP2.6 will result in a radiative forcing equal to 2.6 watts per square meter and so on. Table 18.1 discusses each of the four RCPs selected. They are not the only options but they are representative of the sort of emission patterns that will lead to a specific outcome. An overview of the representative concentration pathways used in AR5 and the climate models, CMIP5, may be found in https://link.springer.com/article/10.1007/s10584-011-0148-z and https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf pages 1045 – 1047.

Clearly, strategies for achieving the various RCPs place emphasis on reduction of GHGs (CO_2-equivalent) as this is the major cause for anthropogenic radiative forcing as shown in Figure 15.29.

The significance of following the different pathways on temperature or temperature change are shown in Figures 18.3 and 18.4.

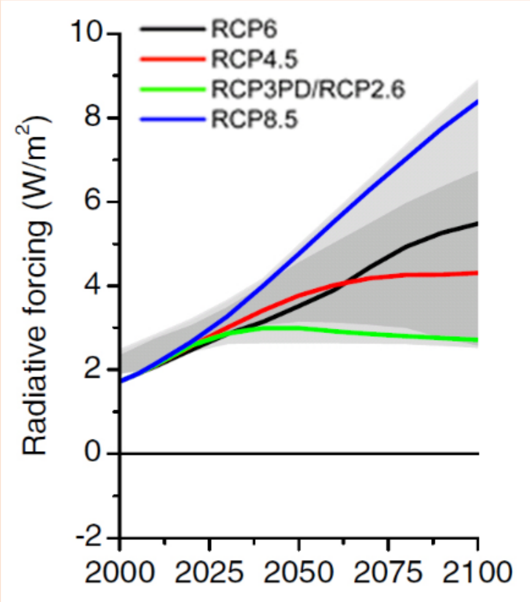

Figure 18.1 Representative concentration pathways or RPC's. Note that the name of the RPC; for example, RPC 8.5 refers to the radiative forcing in the year 2100. https://link.springer.com/article/10.1007/s10584-011-0148-z

RCP Description and Citations

	Description	IA Model	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m2 in 2100.	MESSAGE	Riahi et al. (2007) Rao & Riahi (2006)
RCP6	Stabilization without overshoot pathway to 6 W/m2 at stabilization after 2100	AIM	Fujino et al. (2006) Hijioka et al. (2008)
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100	GCAM (MiniCAM)	Smith and Wigley (2006) Clarke et al. (2007) Wise et al. (2009)
RCP2.6	Peak in radiative forcing at ~ 3 W/m2 before 2100 and decline	IMAGE	van Vuuren et al. (2006; 2007)

Table 18.1 Description of representative concentration pathways RCP along with associated integrated assessment model IAM

18.3 Projected physical impacts.

18.3.1 Temperature

The observed and projected global surface temperature changes from 1850 – 2300 are shown in Figure 18.3. (All of the CMIP5 models were used as indicated.) The shaded zones of the same colour as the RCP represents the range of temperature change. It is very large for RCP8.5 and much narrower for RCP2.6. The narrower the range, the more reliable the prediction. Projections past 2100 are of interest because only RCP2.6 indicates a stable or gradually decreasing temperature after 2100. The ONLY scenario that MIGHT limit global warming on land to 1.5 degrees centigrade in 2100 is RCP 2.6.

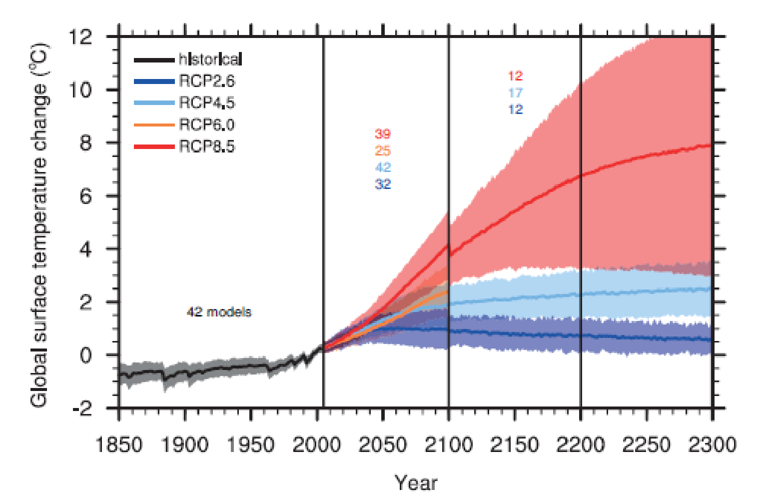

Figure 12.5 | Time series of global annual mean surface air temperature anomalies (relative to 1986–2005) from CMIP5 concentration-driven experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% range (±1.64 standard deviation) across the distribution of individual models (shading). Discontinuities at 2100 are due to different numbers of models performing the extension runs beyond the 21st century and have no physical meaning. Only one ensemble member is used from each model and numbers in the figure indicate the number of different models contributing to the different time periods. No ranges are given for the RCP6.0 projections beyond 2100 as only two models are available.

Figure 18.3 Observed and projected global surface temperature change 1850 – 2300.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

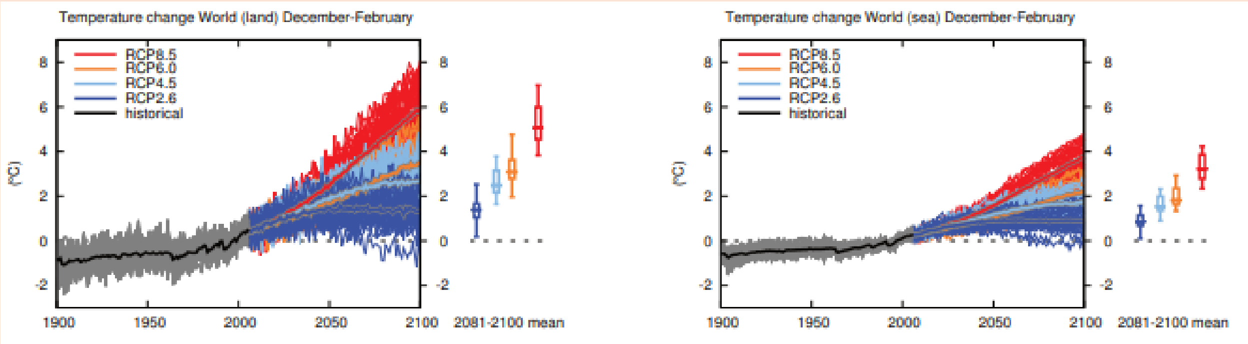

Figure 18.4 Observed and projected global surface and sea temperature change 1850 – 2100. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

Table 18.2 spells out the consequences of following the different RCPs in terms of reaching global target temperatures. The lower the probability of exceeding a certain temperature the more successful the RCP might be in limiting temperature increase. All of the RCPs appear to result in temperature increase greater than 1 degree by mid century (2046-2065). Only RCP2.6 might limit temperature increase below 1.5 degree by mid-century (2046-2065) – there is a 56% probability.

Scenario	Early (2016–2035)	Mid (2046–2065)
Temperature +1.0°C		
RCP 2.6	100% (84%)	100% (94%)
RCP 4.5	98% (93%)	100% (100%)
RCP 6.0	96% (80%)	100% (100%)
RCP 8.5	100% (100%)	100% (100%)
Temperature +1.5°C		
RCP 2.6	22% (0%)	56% (28%)
RCP 4.5	17% (0%)	95% (86%)
RCP 6.0	12% (0%)	92% (88%)
RCP 8.5	33% (5%)	100% (100%)
Temperature +2.0°C		
RCP 2.6	0% (0%)	16% (3%)
RCP 4.5	0% (0%)	43% (29%)
RCP 6.0	0% (0%)	32% (20%)
RCP 8.5	0% (0%)	95% (90%)
Temperature +3.0°C		
RCP 2.6	0% (0%)	0% (0%)
RCP 4.5	0% (0%)	0% (0%)
RCP 6.0	0% (0%)	0% (0%)
RCP 8.5	0% (0%)	21% (5%)

Table 18.2 AR5 Percentage of CMIP5 models for which the projected change in global mean surface air temperature, relative to 1850-1900, crosses the specified temperature levels, by the specified time periods and assuming the specified RCP scenarios. This table is taken the same as Table 11.3 in https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter11_FINAL.pdf

Table 18.3 is difficult to interpret but important. The mean (average) surface air temperature in degrees centigrade in the years 1986 to 2005 is the base from which temperature increase are measured. The objective is to limit the increase to 2 degrees by 2100. **The only RCP that might fulfill this objective is RCP2.6.**

Table 18.4 indicates that there is a 94% probability that RCP2.6 will result in a temperature change greater than 1 degree, a 56% probability that it will result in a temperature increase greater than 1.5 degrees and a 22% probability that it will result in a temperature increase greater than 2 degrees. **Again, RCP2.6 is the only RCP that might satisfy the objective of limiting temperature increase at or below 2 degrees by 2100.**

	RCP2.6 (ΔT in °C)	RCP4.5 (ΔT in °C)	RCP6.0 (ΔT in °C)	RCP8.5 (ΔT in °C)
Global: 2046–2065	1.0 ± 0.3 (0.4, 1.6)	1.4 ± 0.3 (0.9, 2.0)	1.3 ± 0.3 (0.8, 1.8)	2.0 ± 0.4 (1.4, 2.6)
2081–2100	1.0 ± 0.4 (0.3, 1.7)	1.8 ± 0.5 (1.1, 2.6)	2.2 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (2.6, 4.8)
2181–2200	0.7 ± 0.4 (0.1, 1.3)	2.3 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (-,-)	6.5 ± 2.0 (3.3, 9.8)
2281–2300	0.6 ± 0.3 (0.0, 1.2)	2.5 ± 0.6 (1.5, 3.5)	4.2 ± 1.0 (-,-)	7.8 ± 2.9 (3.0, 12.6)
Land: 2081–2100	1.2 ± 0.6 (0.3, 2.2)	2.4 ± 0.6 (1.3, 3.4)	3.0 ± 0.7 (1.8, 4.1)	4.8 ± 0.9 (3.4, 6.2)
Ocean: 2081–2100	0.8 ± 0.4 (0.2, 1.4)	1.5 ± 0.4 (0.9, 2.2)	1.9 ± 0.4 (1.1, 2.6)	3.1 ± 0.6 (2.1, 4.0)
Tropics: 2081–2100	0.9 ± 0.3 (0.3, 1.4)	1.6 ± 0.4 (0.9, 2.3)	2.0 ± 0.4 (1.3, 2.7)	3.3 ± 0.6 (2.2, 4.4)
Polar: Arctic: 2081–2100	2.2 ± 1.7 (-0.5, 5.0)	4.2 ± 1.6 (1.6, 6.9)	5.2 ± 1.9 (2.1, 8.3)	8.3 ± 1.9 (5.2, 11.4)
Polar: Antarctic: 2081–2100	0.8 ± 0.6 (-0.2, 1.8)	1.5 ± 0.7 (0.3, 2.7)	1.7 ± 0.9 (0.2, 3.2)	3.1 ± 1.2 (1.1, 5.1)

Table 18.3 CMIP5 annual mean surface air temperature anomalies (°C) from the 1986–2005 reference period for selected time periods, regions and RCPs. From Table 12.2 https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

	ΔT (°C) 2081–2100	ΔT > +1.0°C	ΔT > +1.5°C	ΔT > +2.0°C	ΔT > +3.0°C	ΔT > +4.0°C
RCP2.6	1.6 ± 0.4 (0.9, 2.3)	94%	56%	22%	0%	0%
RCP4.5	2.4 ± 0.5 (1.7, 3.2)	100%	100%	79%	12%	0%
RCP6.0	2.8 ± 0.5 (2.0, 3.7)	100%	100%	100%	36%	0%
RCP8.5	4.3 ± 0.7 (3.2, 5.4)	100%	100%	100%	100%	62%

Table 18.4 CMIP5 global annual mean temperature changes above 1850-1900 for the 2081–2100 period of each RCP scenario. From Table 12.3 https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

A clear illustration of how surface air temperature will change globally with the different RCPs is shown in Figure 18.5. The top line of maps show how temperatures will change for RCP2.6 for the years 2046 – 2065, 2081 – 22100, and 2181 – 2200. There is a row of maps for each of the RCPs. RCP8.5 predicts a very warm Earth.

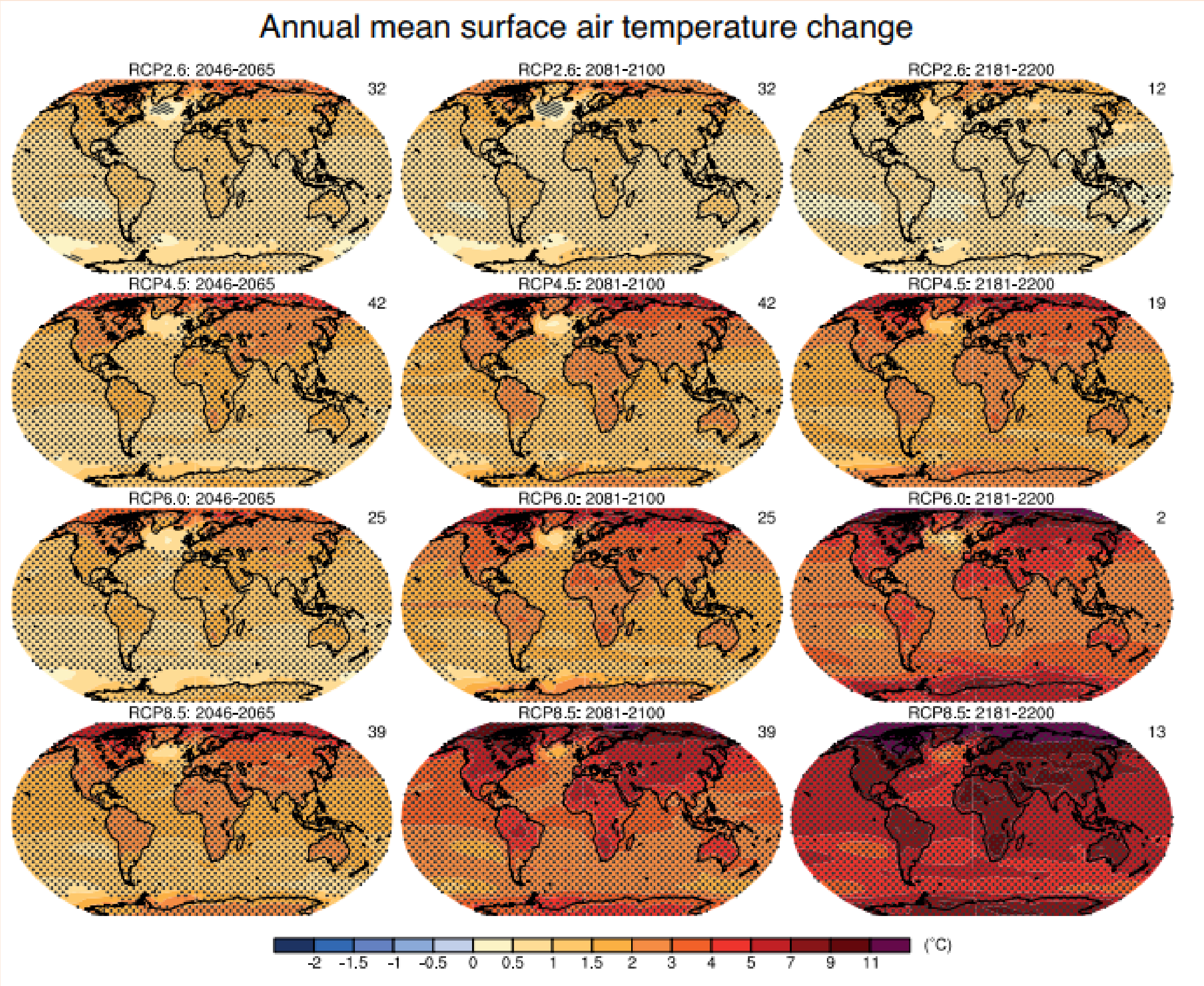

Figure 18.5 projected annual mean surface air temperature change from 1986-2005 average. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

The effects of global warming are more pronounced at the poles in what is called polar amplification, http://www.realclimate.org/index.php/archives/2006/01/polar-amplification/ .

Figure 18.6 illustrates how minimum and maximum temperatures; number of frost days and number of tropical nights are projected to change following RCP2.6, RCP4.5 and RCP8.5 to 2100. RCP2.6 is projected to stabilize around 2050.

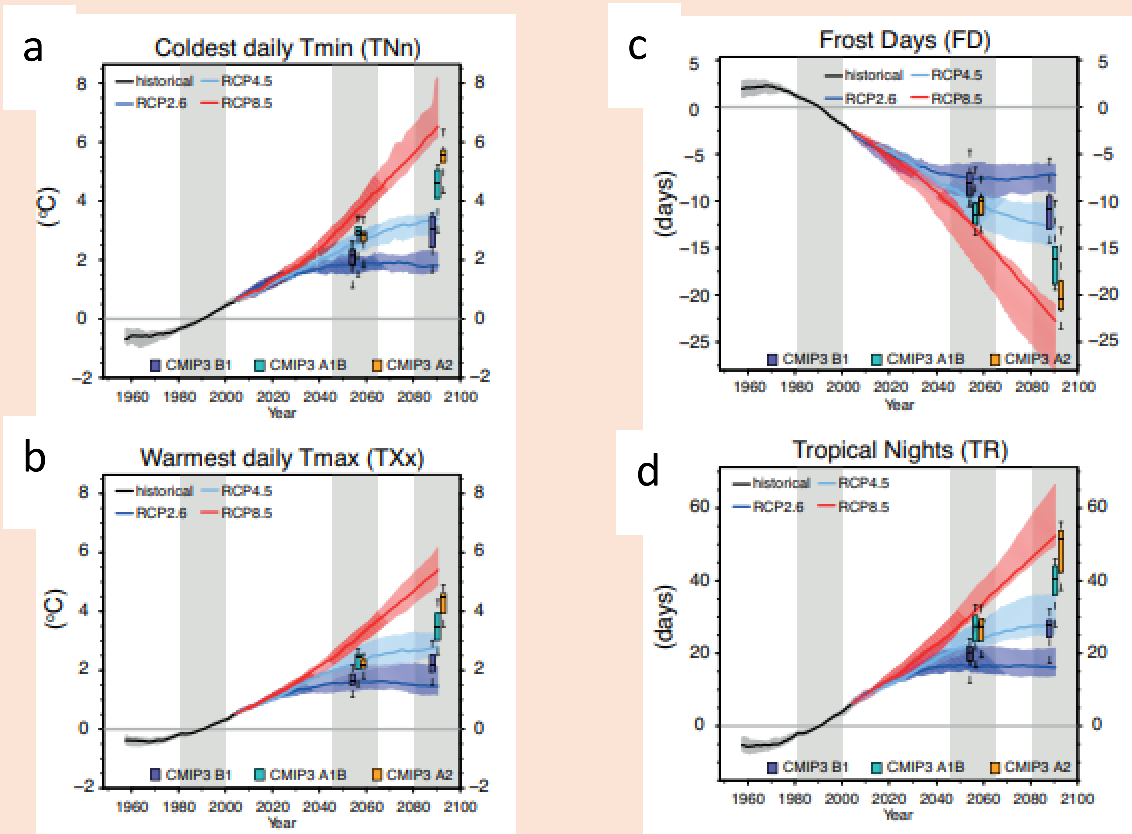

Figure 18.6 Historical and projected annual minimum of daily minimum, annual warmest daily of daily warmest, days of frost (below 0°C) and days of tropical nights (above 20°C). https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

18.3.2 Water

The projected annual near-surface soil moisture changes for all RCPs for 2018 – 2100 are shown In Figure 18.7. See surface temperature and precipitation. If surface temperature is high and precipitation is low, soil moisture will be low. Note sub-Sahara Africa and northern South America.

Projected annual runoff is shown in Figure 18.8. High soil moisture and high precipitation will result in increased runoff.

Observed and projected world surface and sea precipitation change 1850 – 2100 are shown in Figure 18.9.

Observed and projected global surface and sea evaporation change 2081-2100 are shown in Figure 18.10.

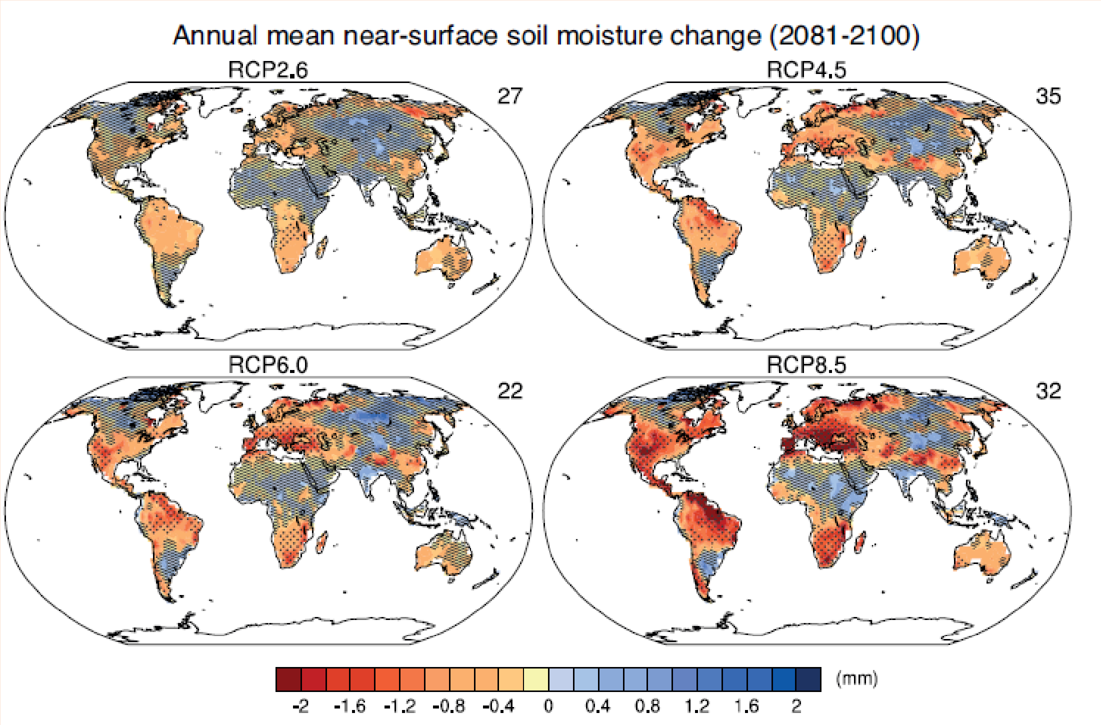

Figure 18.7 Projected annual mean near-surface soil moisture change (2018-2100)
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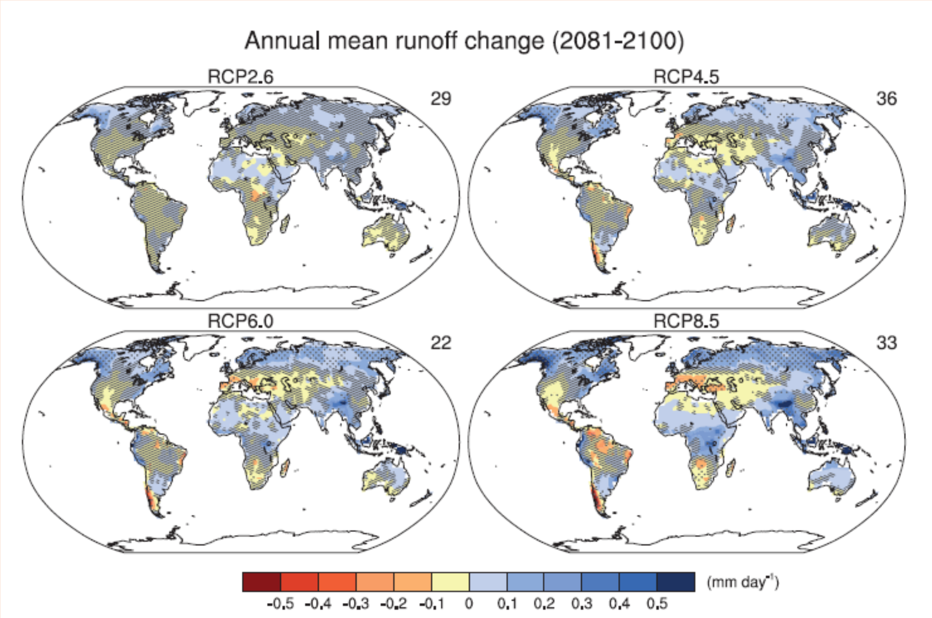

Figure 18.8 Projected annual mean runoff change (2018-2100).
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

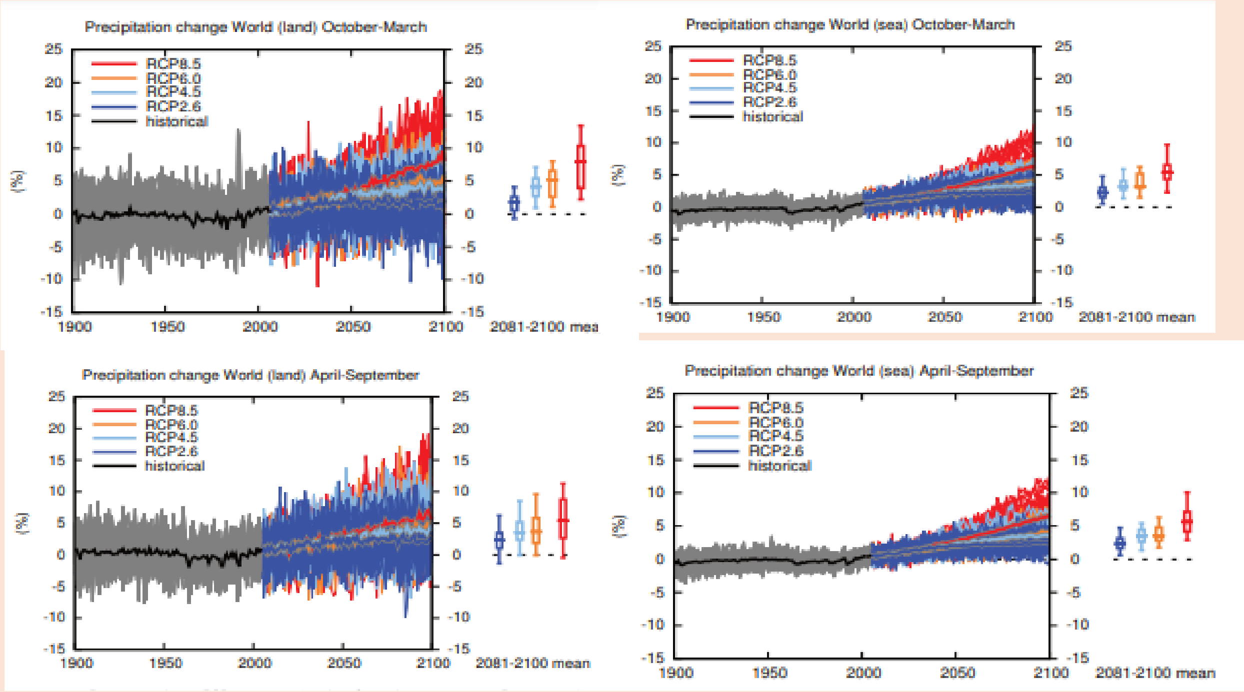

Figure 18.9 Observed and projected world surface and sea precipitation change 1850 – 2100.
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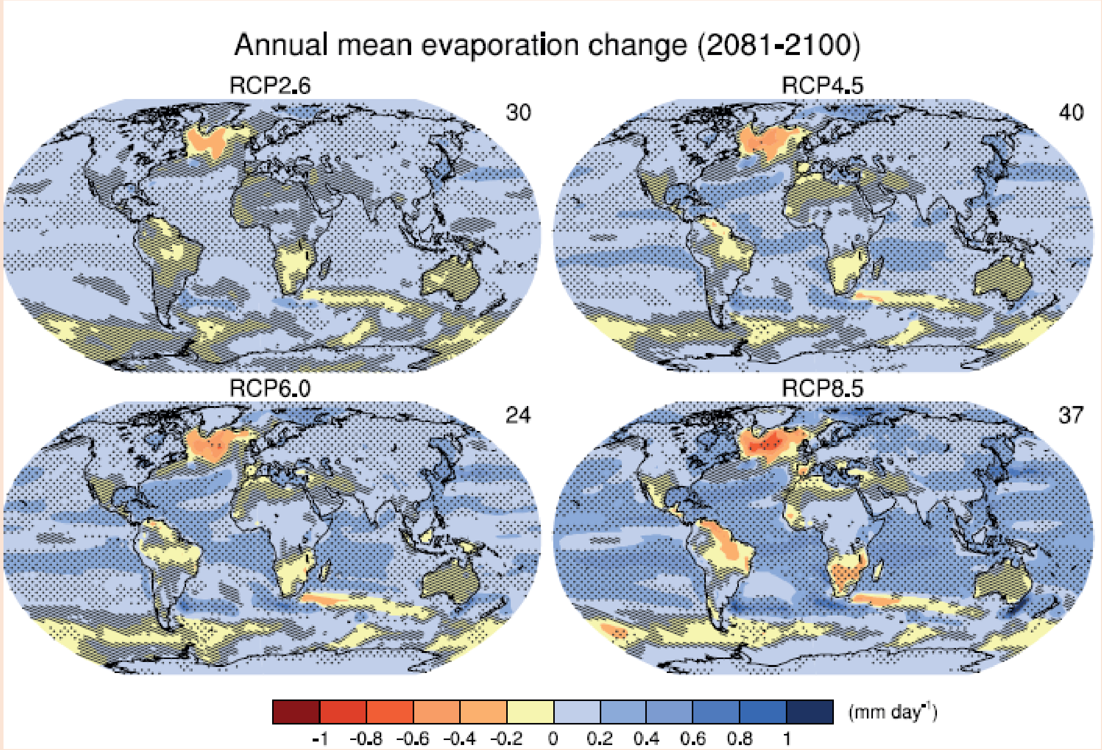


Figure 18.10 Observed and projected global surface and sea evaporation change 2081-2100.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

18.3.3 Cryosphere

Observed and projected sea ice extent in the northern and southern hemispheres to 2100 is shown in Figure 18.11. Figure 18.12 reflects these projections.

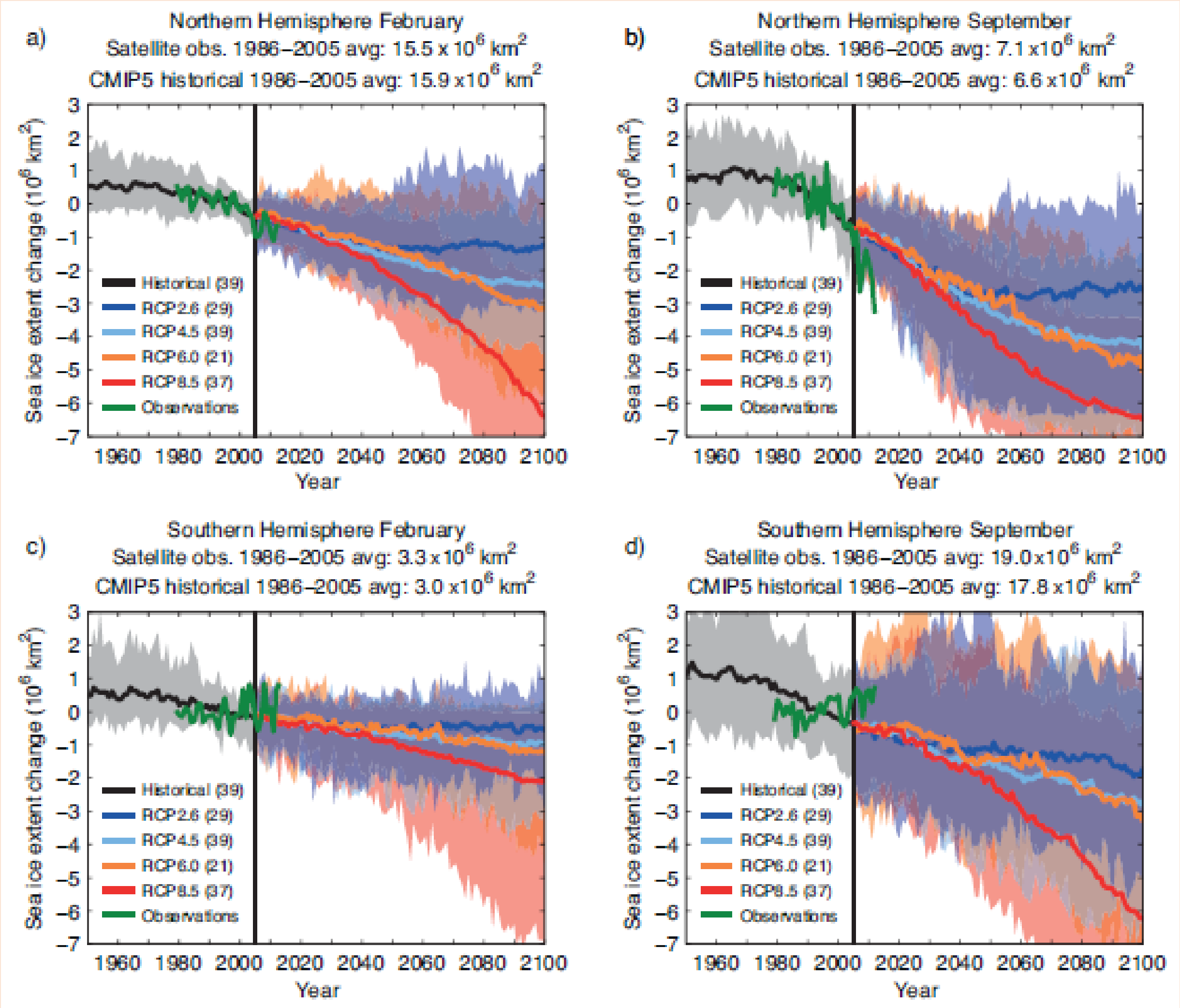


Figure 18.11 Sea ice extent northern hemisphere and southern hemisphere for February and September observed and projected.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

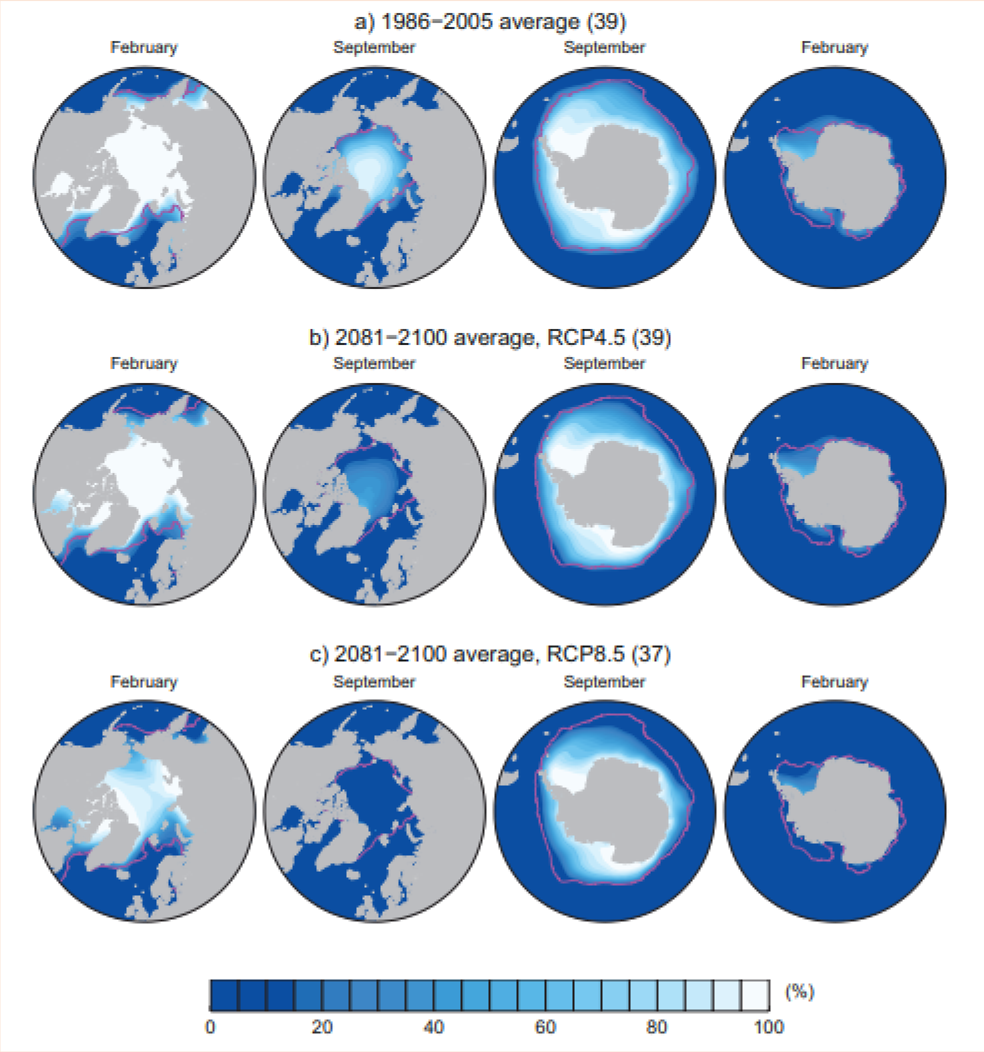


Figure 18.12 Sea ice concentrations for Arctic and Antarctic, 1986-2005 average, projected for February and September using RCP4.5 and 8.5.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

Snow cover extent change and near surface permafrost area change are shown in Figures 18.13 and 18.14.

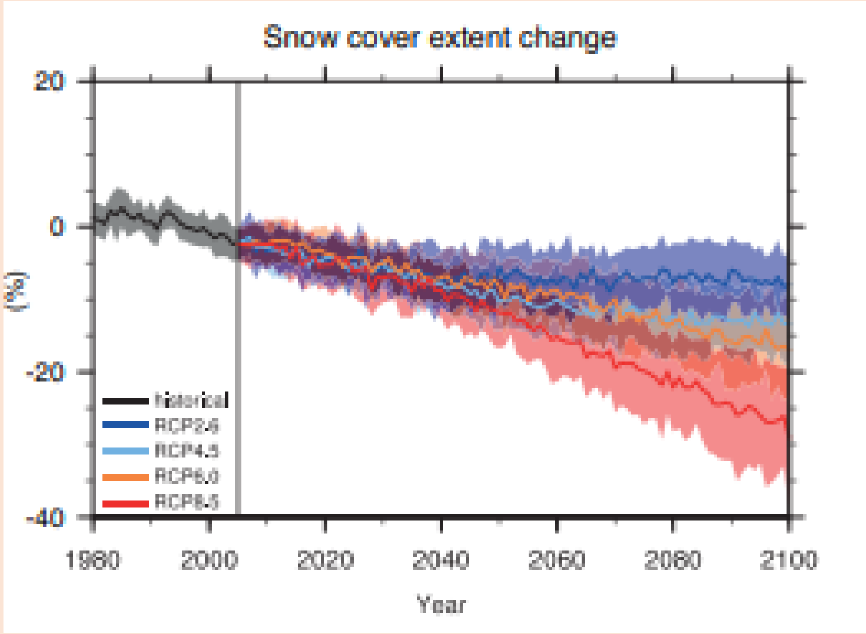


Figure 18.13 Snow cover extent range, historical and projected to 2100.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

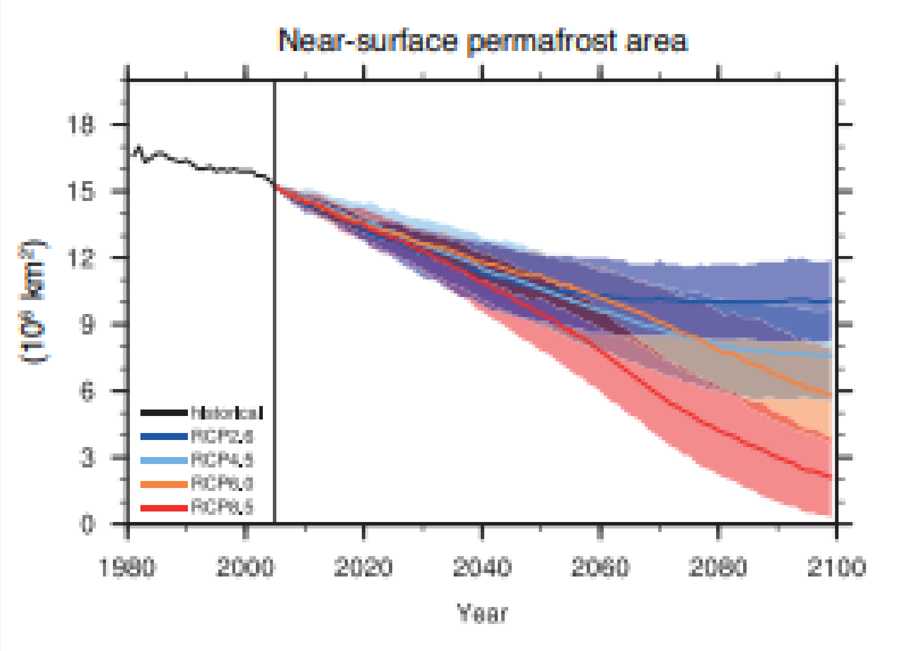


Figure 18.14 Near-surface permafrost area, historical and projected to 2100.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

18.3.4 Sea level

The projected global mean sea level rise as result of thermal expansion, glacier melt, Greenland ice sheet melt and Antarctic ice sheet melt for RCPS 2.6, 4.5, 6.0 and 8.5 are shown in Figure 18.15.

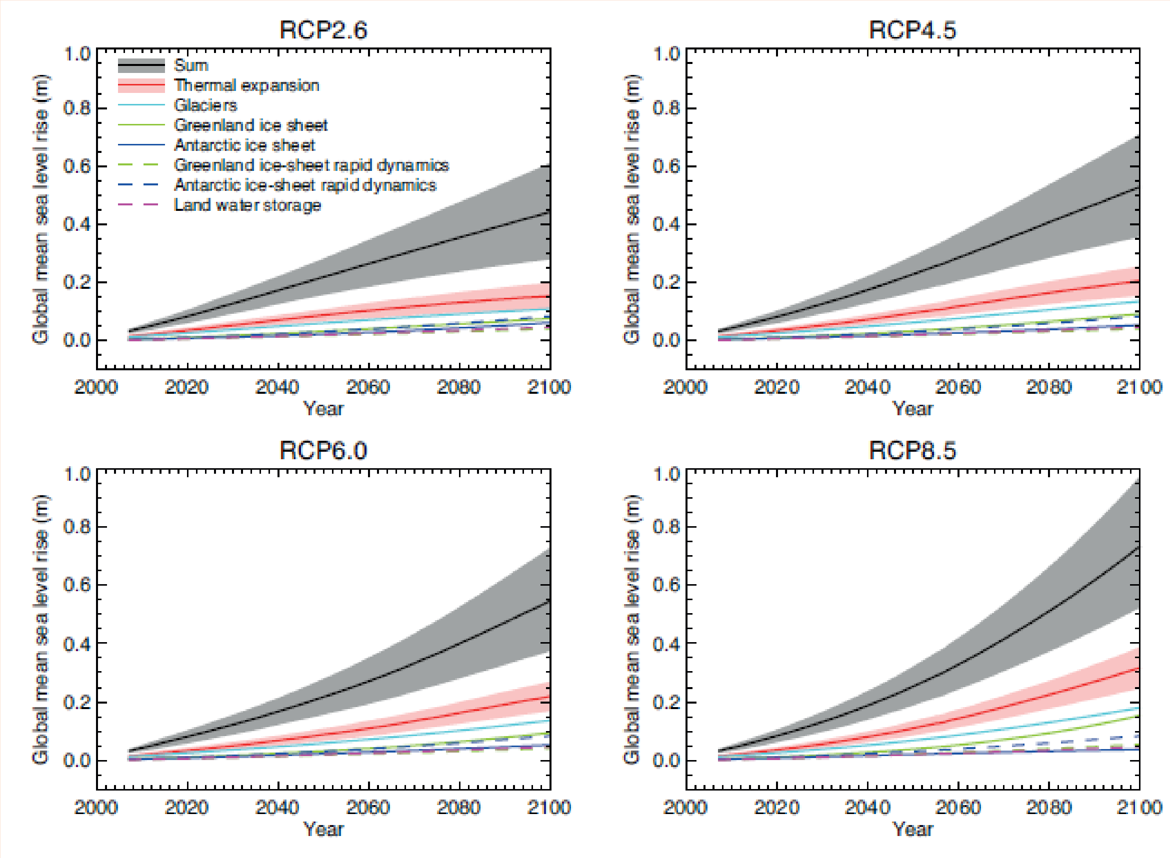


Figure 18.15 projected global sea level rise.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

18.3.5 Ocean chemistry

Observed and projected changes in per cent change in ocean oxygen content, changes in oxygen concentration (200-600m) from 1990s to 2090s for RCP 2.6 and 8.5 are shown in Figure 18.16.

Historical and projected ocean pH and dissolved carbon dioxide to 2100 is shown in Figure 18.17. RCP is not specified but likely RCP8.5.

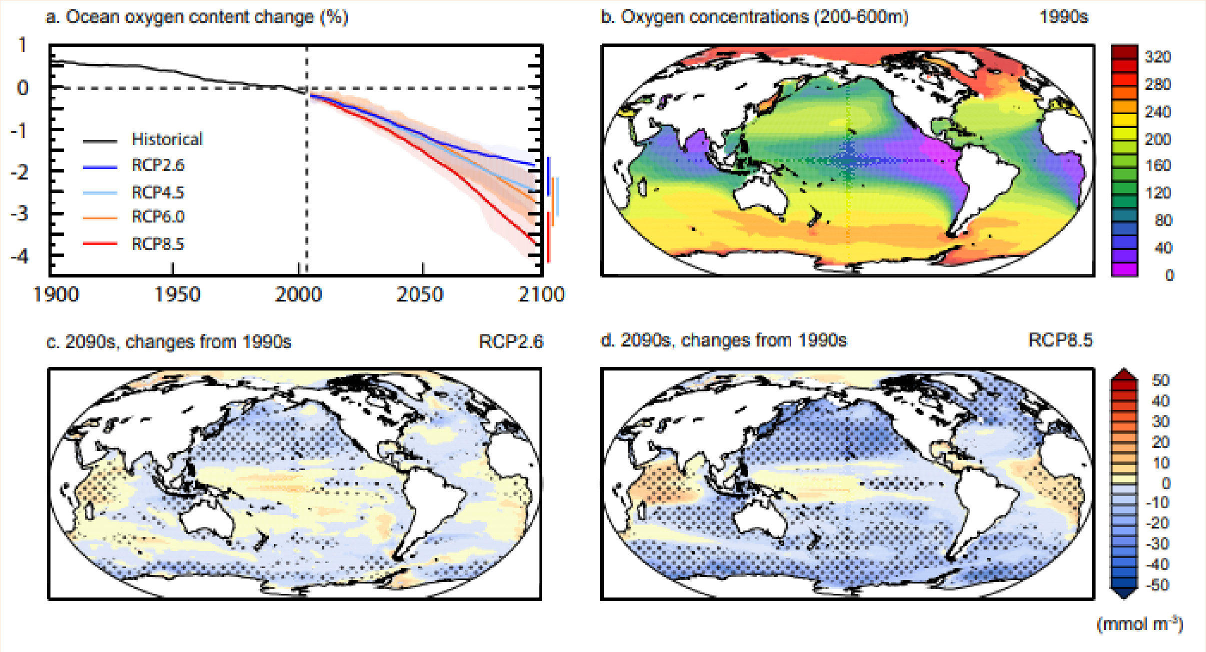


Figure 18.16 (a) Simulated changes in dissolved O2 (mean and model range as shading) relative to 1990s for RCP2.6, RCP4.5, RCP6.0 and RCP8.5. (b) Multi-model means dissolved O2 (µmol m–3) in the main thermocline (200 to 600 m depth average) for the 1990s, and changes in 2090s relative to 1990s for RCP2.6 (c) and RCP8.5 (d). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf

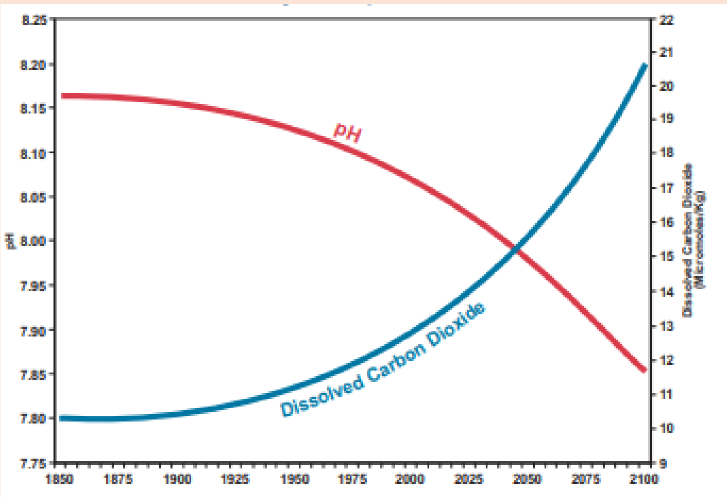


Figure 18.17 Historical and projected pH and dissolved CO_2.
https://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

18.3.6 Jet stream

The impact of climate change on the jet stream is illustrated in Figure 18.18.

"As the globe continues to warm, it is already having an effect on the jet stream and corresponding weather patterns, according to the latest U.N. IPCC climate report, which states: 'It is likely that circulation features have moved poleward since the 1970s, involving a widening of the tropical belt, a poleward shift of storm tracks and jet streams, and a contraction of the northern polar vortex. Evidence is more robust for the Northern Hemisphere.' The research that goes into this statement comes from multiple lines of evidence – from analyses of the expansion of the tropical Hadley Cell to satellite measured outgoing radiation, radiosonde observations, and weather pattern reanalyses. But just as certainty builds for a poleward shifting jet, there still remain questions about whether the jet is amplifying and promoting more blocking patterns." From Climate Central.

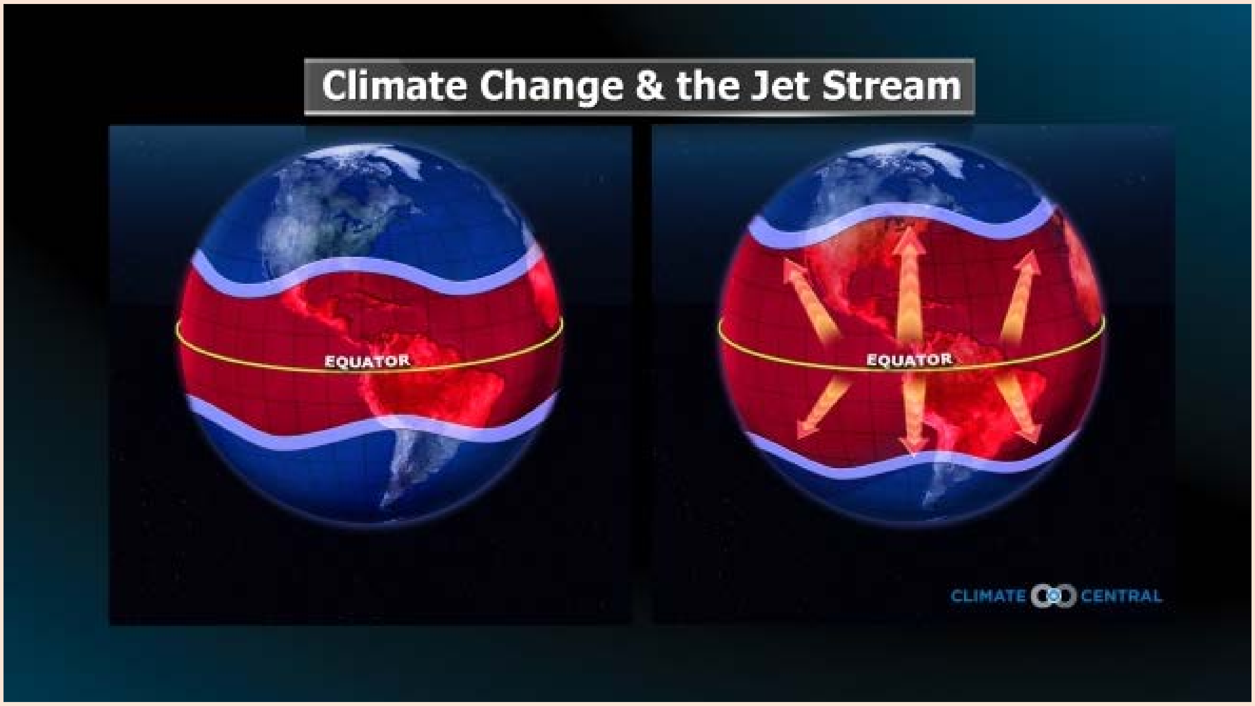
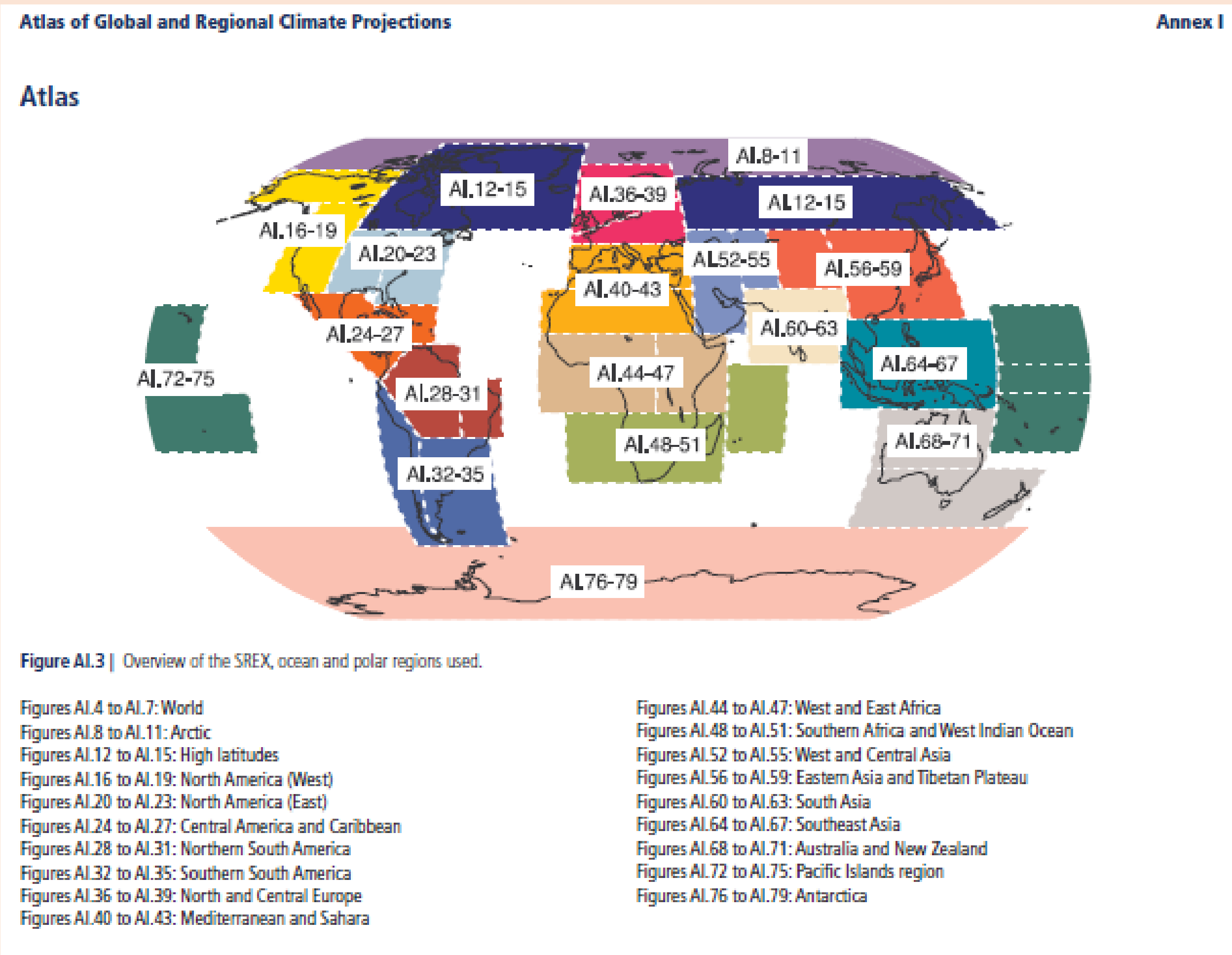


Figure 18.18 Climate change and the jet stream.
http://www.climatecentral.org/gallery/graphics/climate-change-the-jet-stream

18.3.7 Atlas of global and regional climate projections

The atlas of global and regional climate projections is shown in Figure 18.19. This atlas may be accessed by going to Annex 1 of IPCC AR5 WG1, https://www.ipcc.ch/report/ar5/wg1/.


Atlas of Global and Regional Climate Projections — Annex I

Atlas

Figure AI.3 | Overview of the SREX, ocean and polar regions used.

Figures AI.4 to AI.7: World
Figures AI.8 to AI.11: Arctic
Figures AI.12 to AI.15: High latitudes
Figures AI.16 to AI.19: North America (West)
Figures AI.20 to AI.23: North America (East)
Figures AI.24 to AI.27: Central America and Caribbean
Figures AI.28 to AI.31: Northern South America
Figures AI.32 to AI.35: Southern South America
Figures AI.36 to AI.39: North and Central Europe
Figures AI.40 to AI.43: Mediterranean and Sahara
Figures AI.44 to AI.47: West and East Africa
Figures AI.48 to AI.51: Southern Africa and West Indian Ocean
Figures AI.52 to AI.55: West and Central Asia
Figures AI.56 to AI.59: Eastern Asia and Tibetan Plateau
Figures AI.60 to AI.63: South Asia
Figures AI.64 to AI.67: Southeast Asia
Figures AI.68 to AI.71: Australia and New Zealand
Figures AI.72 to AI.75: Pacific Islands region
Figures AI.76 to AI.79: Antarctica

Figure 18.19 Annex 1 AR5 WG1 Atlas of global and regional climate projections. https://www.ipcc.ch/report/ar5/wg1/

18.4 Climate phenomena and regional climate change

The IPCC considers the full scope of regional climate variation in Chapter 14 of AR5 WG1. To say the least, this is an exceptional undertaking because of the number and diversity of phenomena that affect regional climate change.

Table 18.4, taken from IPCC AR5 WG1, lists climate phenomena, which are called modes of climate variability. These include a variety of well-known oscillations and other climate patterns and behaviour. The regional climate impact for each mode is provided. The approach to analysis of the effects of world climate change on the modes and how regional climate change phenomena such as monsoons, large-scale storm systems (tropical and subtropical cyclones) are presented. Table 18.5 provides a region-by-region summary of the significance of the impacts.

The modes are important in themselves (ENSO and the annular and dipolar modes) or they affect climate systems such as monsoons, tropical phenomena (convergence zones and Atlantic Ocean modes), tropical cyclones and extratropical cyclones. Other important phenomena such as blocking systems and teleconnections that are only vaguely understood complicate the ability to associate world climate change to regional climate.

Mode	Regional Climate Impacts
ENSO	Global impact on interannual variability in global mean temperature. Influences severe weather and tropical cyclone activity worldwide. The diverse El Niño flavours present different teleconnection patterns that induce large impacts in numerous regions from polar to tropical latitudes (Section 14.4).
PDO	Influences surface air temperature and precipitation over the entire North American continent and extratropical North Pacific. Modulates ENSO rainfall teleconnections, e.g., Australian climate (Section 14.7.3).
IPO	Modulates decadal variability in Australian rainfall, and ENSO teleconnections to rainfall, surface temperature, river flow and flood risk over Australia, New Zealand and the SPCZ (Section 14.7.3).
NAO	Influences the N. Atlantic jet stream, storm tracks and blocking and thereby affects winter climate in over the N. Atlantic and surrounding landmasses. The summer NAO (SNAO) influences Western Europe and Mediterranean basin climates in the season (Section 14.5.1).
NAM	Modulates the intensity of mid-latitude storms throughout the Northern Hemisphere and thereby influences North America and Eurasia climates as well as sea ice distribution across the Arctic sea (Section 14.5.1).
NPO	Influences winter air temperature and precipitation over much of western North America as well as Arctic sea ice in the Pacific sector (Section 14.5.1).
SAM	Influences temperature over Antarctica, Australia, Argentina, Tasmania and the south of New Zealand and precipitation over southern South America, New Zealand, Tasmania, Australia and South Africa (Section 14.5.2).
PNA	Influences the jet stream and storm tracks over the Pacific and North American sectors, exerting notable influences on the temperature and precipitation in these regions on intraseasonal and interannual time scales (Section 14.7.2).
PSA	Influences atmospheric circulation over South America and thereby has impacts on precipitation over the continent (Section 14.7.1).
AMO	Influences air temperatures and rainfall over much of the Northern Hemisphere, in particular, North America and Europe. It is associated with multidecadal variations in Indian, East Asian and West African monsoons, the North African Sahel and northeast Brazil rainfall, the frequency of North American droughts and Atlantic hurricanes (Section 14.7.6).
AMM	Influences seasonal hurricane activity in the tropical Atlantic on both decadal and interannual time scales. Its variability is influenced by other modes, particularly ENSO and NAO (Section 14.3.4).
AN	Affects the West African Monsoon, the oceanic forcing of Sahel rainfall on both decadal and interannual time-scales and the spatial extension of drought in South Africa (Section 14.3.4).
IOB	Associated with the intensity of Northwest Pacific monsoon, the tropical cyclone activity over the Northwest Pacific and anomalous rainfall over East Asia (Section 14.3.3).
IOD	Associated with droughts in Indonesia, reduced rainfall over Australia, intensified Indian summer monsoon, floods in East Africa, hot summers over Japan, and anomalous climate in the extratropical Southern Hemisphere (Section 14.3.3).
TBO	Modulates the strength of the Indian and West Pacific monsoons. Affects droughts and floods over large areas of south Asia and Australia (Section 14.7.4).
MJO	Modulates the intensity of monsoon systems around the globe and tropical cyclone activity in the Indian, Pacific and Atlantic Oceans. Associated with enhanced rainfall in Western North America, northeast Brazil, Southeast Africa and Indonesia during boreal winter and Central America/Mexico and Southeast Asia during boreal summer (Section 14.3.2).
QBO	Strongly affects the strength of the northern stratospheric polar vortex as well as the extratropical troposphere circulation, occurring preferentially in boreal winter (Section 14.7.5).
BLC	Associated with cold air outbreaks, heat-waves, floods and droughts in middle and high latitudes of both hemispheres (Box 14.2).

Notes:
AMM: Atlantic Meridional Mode
AMO: Atlantic Multi-decadal Oscillation
AN: Atlantic Niño pattern
BLC: Blocking events
ENSO: El Niño-Southern Oscillation
IOB: Indian Ocean Basin pattern
IOD: Indian Ocean Dipole pattern
IPO: Interdecadal Pacific Oscillation
MJO: Madden-Julian Oscillation
NAM: Northern Annular Mode
NAO: North Atlantic Oscillation
NPO: North Pacific Oscillation
PDO: Pacific Decadal Oscillation
PNA: Pacific North America pattern
PSA: Pacific South America pattern
QBO: Quasi-Biennial Oscillation
SAM: Southern Annular Mode
TBO: Tropospheric Biennial Oscillation

Table 18.4 Regional climate impacts. file:///H:/Documents/My%20Stuff%20Book%20GW%20and%20CC/Temp/WG1AR5_Chapter14_FINAL.pdf

Table 14.3 | Summary of the relevance of projected changes in major phenomena for mean change in future regional climate. The relevance is classified into high (red), medium (yellow), low (cyan), and 'no obvious relevance' (grey), based on confidence that there will be a change in the phenomena ('HP' for high, 'MP' for medium, 'LP' for low), and confidence in the impact of the phenomena on each region ('HI' for high, 'MI' for medium, 'LI' for low). More information on how these assessments have been constructed is given in the Supplementary Material (Section 14.SM.6.1).

Phenomena Regions	Section	Monsoon Systems *MP—see Section 14.2*	Tropical Phenomena[a] *HP/MP/LP/LP—See Section 14.3*	ENSO *LP—See Section 14.4*	Annular and Dipolar Modes *HP—See Section 14.5*	Tropical Cyclones *MP—See Section 14.6.1*	Extratropical Cyclones[b] *MP/HP—See Section 14.6.2*
Arctic	*14.8.2*				*HP/HI* The small projected increase in NAO is *likely* to contribute to wintertime changes in temperature and precipitation.		*MP/HI* Projected increase in precipitation in extratropical cyclones is *likely* to enhance mean precipitation.
North America	*14.8.3*	MP/HI It is *likely* the number of consecutive dry days will increase, and overall water availability will be reduced.	HP/LI Projected ITCZ shifts unrelated to ENSO changes will impact temperature and precipitation, especially in winter.	LP/HI *Likely* changes in N. American precipitation if ENSO changes.	HP/MI The small projected increase in the NAO index is *likely* to contribute to wintertime temperature and precipitation changes in NE America.	MP/HI Projected increases in extreme precipitation near the centres of tropical cyclones making landfall along the western coast of the USA and Mexico, the Gulf Mexico, and the eastern coast of the USA and Canada.	MP/HI Projected increases in precipitation in extratropical cyclones will lead to large increases in wintertime precipitation over the northern third of the continent.
Central America and Caribbean	*14.8.4*	*MP/HI* Projected reduction in mean precipitation .	*HP/MI* Reduced mean precipitation in southern Central America if there is a southward displacement of the East Pacific ITCZ.	*LP/HI* Reduced mean precipitation if El Niño events become more frequent and/or intense.		*MP/HI* More extreme precipitation near the centres of tropical cyclones making landfall along the eastern and western coasts.	
South America	*14.8.5*	*MP/HI* Projected increase in extreme precipitation and in the extension of monsoon area.	*HP/HI* Projected increase in the mean precipitation in the southeast due to the projected southward displacement of the SACZ.	*LP/HI* Reduced mean precipitation in eastern Amazonia and increased precipitation in the La Plata Basin.	*HP/HI* Poleward shift of storm tracks due to projected positive trend in SAMS phase leads to less precipitation in central Chile and increased precipitation in the southern tip of South America.		*HP/HI* Southward displacement of cyclogenesis activity increases the precipitation in the extreme south.
Europe and Mediterranean	*14.8.6*				*HP/HI* Projected increase in the NAO will lead to enhanced winter warming and precipitation over NW Europe.		*MP/HI* Enhanced extremes of storm-related precipitation and decreased frequency of storm-related precipitation over the E. Mediterranean.
Africa	*14.8.7*	*MP/HI* Projected enhancement of summer precipitation in West Africa.	*HP/LI* Enhanced precipitation in parts of East Africa due to projected shifts in ITCZ. Modified precipitation in West or East Africa according to variations in Atlantic or Indian Ocean SSTs.	*LP/HI* Increased precipitation in East Africa and decreased precipitation and enhanced warming in southern Africa if El Niño events become more frequent and/or intense.	*HP/HI* Enhanced winter warming over southern Africa due to projected increase in SAM.	*MP/HI* Projected increase in extreme precipitation near the centres of tropical cyclones making landfall along the eastern coast (including Madagascar).	*HP/HI* Enhanced extremes of storm-related precipitation and decreased frequency of storm-related precipitation over southwestern Africa.
Central and North Asia	*14.8.8*	*MP/MI* Projected enhancement in summer mean precipitation.			*HP/LI* Projected enhancement in winter warming over North Asia.		
East Asia	*14.8.9*	*MP/MI* Enhanced summer precipitation due to intensification of East Asian summer monsoon circulation.		*LP/HI* Enhanced warming if El Niño events become more frequent and/or intense.		*MP/HI* Projected increase in extreme precipitation near the centres of tropical cyclones making landfall in Japan, along coasts of east China Sea and Sea of Japan.	*MP/MI* Projected reduction in midwinter precipitation.

Table 18.5 Summary of the relevance of projected changes in major phenomena for mean change in regional climate.

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter14_FINAL.pdf

Phenomena Regions	Section	Monsoon Systems MP—see Section 14.2	Tropical Phenomena[a] HP/MP/LP/LP—See Section 14.3	ENSO LP—See Section 14.4	Annular and Dipolar Modes HP—See Section 14.5	Tropical Cyclones MP—See Section 14.6.1	Extratropical Cyclones[b] MP/HP—See Section 14.6.2
West Asia	14.8.10		*HP/LI* Enhanced precipitation in southern parts of West Asia due to projected northward shift in ITCZ.			*MP/HI* Projected increase in extreme precipitation near the centres of tropical cyclones making landfall on the Arabian Peninsula.	*MP/LI* Projected decrease in mean precipitation due to northward shift of storm tracks.
South Asia	14.8.11	*MP/MI* Enhanced summer precipitation associated with Indian Monsoon.	*LP/MI* Strengthened break monsoon precipitation anomalies associated with MJO.	*LP/HI* Enhanced warming and increased summer season rainfall variability due to ENSO.		*MP/HI* Projected increase in extreme precipitation near the centres of tropical cyclones making landfall along coasts of Bay of Bengal and Arabian Sea.	
Southeast Asia	14.8.12	*LP/MI* Decrease in precipitation over Maritime continent.	*HP/MI* Projected changes in IOD-like warming pattern will reduce mean precipitation in Indonesia during Jul-Oct.	*LP/HI* Reduction in mean precipitation and enhanced warming if El Niño events become more frequent and/or intense.		*MP/HI* Projected increase in extreme precipitation near the centres of tropical cyclones making landfall along coasts of South China Sea, Gulf of Thailand, and Andaman Sea.	
Australia and New Zealand	14.8.13	*MP/LI* Mean monsoon precipitation may increase over northern Australia.	*HP/LI* More frequent zonal SPCZ episodes may reduce precipitation in NE Australia.	*LP/HI* Reduced precipitation in North and East Australia and NZ if El Niño events become more frequent and/or intense.	*HP/MI* Increased warming and reduced precipitation in NZ and South Aust. due to projected positive trend in SAM.	*MP/HI* More extreme precipitation near the centres of tropical cyclones making landfall along the eastern, western, and northern coasts of Australia.	*HP/HI* Projected increase in extremes of storm-related precipitation.
Pacific Islands Region	14.8.14		*HP/LI* Increased mean precipitation along equator with ITCZ intensification. More frequent zonal SPCZ episodes leading to reduced precipitation in southwest and increases in east.	*HP/LI* Increased mean precipitation in central/east Pacific if El Niño events become more frequent and/or intense.		*HP/HI* More extreme precipitation near the centres of tropical cyclones passing over or near Pacific islands.	
Antarctica	14.8.15			*LP/MI* Increased warming over Antarctic Peninsula and reduced across central Pacific if El Niño events become more frequent and/or intense.	*HP/HI* Increased warming over Antarctic Peninsula and west Antarctic related to positive trend projected in SAM.		*HP/MI* Increased precipitation in coastal areas due to projected poleward shift of storm track.

Table 18.5 Summary of the relevance of projected changes in major phenomena for mean change in regional climate.

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter14_FINAL.pdf

18.5 Tipping points

'Tipping point' is a metaphor that identifies a process where an otherwise small change in an input, that would normally have little effect on an outcome, results in a disproportionate response. A familiar example is 'the straw that broke the camel's back'. All straws loaded on the camel were accommodated but the last straw resulted in catastrophic consequences for the camel (broken back). The phrase, 'this is the last straw' is derived from the 'camel's back' metaphor. Consequences of an input were minor until a point was reached where significant consequences resulted from similar minor inputs. The social statement, 'one bad behavior too many results in the loss of significant privileges' is another good example of 'tipping point'. Phrases such 'one time too many' and 'crossed the line' come to mind. A tipping point is the condition where a small change in a factor that historically had seemingly minor influences results in a much larger important response. It is very important to identify tipping points so as to avoid the critical input that results the disproportionate response.

'Knock on' consequences are similar to the 'domino effect', when one significant change results in the significant change in another phenomena or process. This is particularly important when the significant response results from a tipping point being exceeded. An example is greenhouse gases in the atmosphere causing climate change that results in lower rainfall which in turn causes drought conditions that in turn cause increased potential for wildfires. Another important example is loss of habitat caused by temperature increases, such as change in vegetation. Animals depending on the vegetation might disappear which might possibly result in the disappearance the predators depending on the presence of the plant eating animals.

'Knock on' effects can result in an additional increase to the input that originally caused the tipping point to be exceeded in the first place. The apparently amplified input can result in even greater consequences further strengthening the magnitude of the input. The phrase, 'out of control' comes to mind. This phenomenon is 'out of control' until it is constrained by other critical inputs or conditions that might not be available or the process simply breaks down. An example is global warming caused by greenhouse gases resulting in the accelerated thawing of the permafrost which then releases methane, a greenhouse gas that has twenty times the effect of carbon dioxide, that results in increased warming and so on.

In the context of climate change the critical input is typically the increase in greenhouse gas concentration in the atmosphere that results in the temperature change.
The discussion provided by Wikipedia is particularly relevant, https://en.wikipedia.org/wiki/Tipping_points_in_the_climate_system#Cascading_tipping_points .
There are several important examples identified in the paper titled, tipping elements in the Earth's climate system, https://www.pnas.org/content/105/6/1786 including where the authors propose methodology for identifying tipping points. The specifically consider:

1. Loss of Arctic Sea ice.

2. Depletion/ loss of Greenland ice sheet.
3. Loss of Antarctic ice sheet.
4. Alteration of the Atlantic thermohaline circulation.
5. Alteration of the El Nino-Southern Oscillation (ENSO).
6. Indian Summer Monsoon (ISM).
7. Sahara/ Sahel and West African Monsoon (WSM).
8. Environment over the Amazon Rainforest.
9. Environment over the boreal forest.
10. Loss of permafrost.

Other phenomenon of relevance which are not specifically addressed include:

11. Warming of the sea water and fresh water.
12. Change in the acidity of oceans.
13. Loss of glaciers.
14. Alteration of any of the other ocean and atmospheric oscillations that might be impacted by global warming.

and, pretty well all of the physical impacts caused by global warming discussed in this chapter.

The ability to identify tipping points is important from the perspective of mitigating climate change to the extent that these tipping points are not reached.

18.6 Snowmelt from mountainous regions

The volume of snow melt and the manner with which it occurs (timing of the melt) has been predictable – particularly from mountainous regions. For this reason, humans have developed a dependency on the mountain snow melt for domestic and agricultural use. In some regions of the world mountain snow melt is captured using dams and reservoirs so that it can be gradually used for irrigation purposes or in times when the available snow melt in rivers and streams would be insufficient for domestic, municipal and industrial use. Melt water is often stored for generation of electricity.

The impact of global warming and climate change on runoff from snow accumulations is a decrease in volume of snow melt and also the earlier melting of snow resulting in historically lower flows and water shortages later in the year. See discussion paper https://www.carbonbrief.org/climate-change-has-driven-16-drop-in-snow-meltwater-from-asias-high-mountains?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210625&utm_medium=email&utm_source=Revue%20Daily.

18.7 Atmospheric rivers

Atmospheric rivers are discussed in Chapter 7.

A NASA-led study, https://climate.nasa.gov/news/2740/climate-change-may-lead-to-bigger-atmospheric-rivers/, 'shows that climate change is likely to intensify extreme weather events known as atmospheric rivers across most of the globe by the end of this century, while slightly reducing their number.'

The relationship between climate change and the characteristics of atmospheric rivers is not well established.

18.8 Information support

Key web sites:

1. IPCC Climate change 2013, the physical science basis. https://www.ipcc.ch/report/ar5/wg1/

2. IPCC Climate change 2013, the physical science basis, Chapter 14. file:///H:/Documents/My%20Stuff%20Book%20GW%20and%20CC/Temp/WG1AR5_Chapter14_FINAL.pdf

3. Mitigation. https://climatescenarios.org/primer/mitigation/

4. Representative concentration pathway. https://en.wikipedia.org/wiki/Representative_Concentration_Pathway

5. The representative pathways: an overview. https://link.springer.com/article/10.1007/s10584-011-0148-z

6. Carbon brief. https://www.carbonbrief.org/

7. Integrated assessment models. https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change#:~:text=Integrated%20assessment%20models%20(IAMs)%20are,parts%20of%20the%20Earth%20system.

8. Jet stream and climate change. https://www.climatecentral.org/gallery/graphics/climate-change-the-jet-stream

9. Polar amplification. http://www.realclimate.org/index.php/archives/2006/01/polar-amplification/

10. Carbon dioxide 2100, changing chemistry of the ocean. https://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

11. Tipping points. Wikipedia. https://en.wikipedia.org/wiki/Tipping_points_in_the_climate_system#Cascading_tipping_points.

12. Tipping elements in the Earth's climate system, Lenton, T, Held, H, Kriegler, E., Hall, J. W., Lucht, W. and Rahmst, S. in the Proceedings of the National Academy of Sciences in the United States of America, https://www.pnas.org/content/105/6/1786 .

13. Snow melt water – effect of climate change on volume and time of melt, discussion paper by Ayesha Tandon in Carbon Brief, 2021-06-24, https://www.carbonbrief.org/climate-change-has-driven-16-drop-in-snow-meltwater-from-asias-high-mountains?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210625&utm_medium=email&utm_source=Revue%20Daily.

14. Atmospheric rivers and climate change, NASA, Global Climate Change, Climate change may lead to bigger atmospheric rivers, May 24, 2018. https://climate.nasa.gov/news/2740/climate-change-may-lead-to-bigger-atmospheric-rivers/.