1SM

Framing and Context of the Report
Supplementary Material

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SM1.1 Supplementary Material Supporting the Text in Section 1.4

Table SM1.1 | Development of assessments of climate, ocean and cryosphere change across past IPCC working group 1 assessment reports. This table supports the text in Section 1.4. The material is derived from the Summary for Policy Makers (SPM) sections of the Working Group I reports of the First Assessment Report (IPCC, 1990), the Second Assessment Report (IPCC, 1995), the Third Assessment Report (IPCC, 2001), the Fourth Assessment Report (IPCC, 2007), and the Fifth Assessment Report (AR5) (IPCC, 2013).

Report	Global Context	Cryosphere	Ocean	Sea Level
First Assessment Report SPM (1990): observed change	Global mean surface temperature has increased by 0.3°C–0.6°C over the last 100 years. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.	Retreat of most mountain glaciers since the end of the 19th century.		Global sea level has increased by 0.1–0.2 m (over the last 100 years).
First Assessment Report SPM (1990): projected change[a]	Likely increase in global mean temperature of about 3°C above the present (about 4°C above pre-industrial) before the end of the next century, under a business-as-usual scenario.	The West Antarctic ice sheet is of special concern. Within the next century it is not likely that there will be a major outflow of ice from West Antarctica due directly to global warming.	Key areas of scientific uncertainty include the exchange of energy between the oceans and the atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean.	Predicted rise is about 0.2 m in global mean sea level by 2030, and 0.65 m by the end of the next century. Over the next 100 years the effect of the Antarctic and Greenland ice sheets is expected to be small. Grounds for believing that future warming will lead to an acceleration in sea level rise.
Second Assessment Report SPM (1995): observed change	Global mean surface air temperature has increased by between about 0.3°C–0.6°C since the late 19th century. The balance of evidence suggests a discernible human influence on global climate.			Global sea level has risen by between 0.1–0.25 m over the past 100 years and much of the rise may be related to the increase in global mean temperature.
Second Assessment Report SPM (1995): projected change[b]	The lowest emission scenario with a low value of climate sensitivity leads to a projected temperature increase of about 1°C by 2100. The highest emission scenario with a high value of climate sensitivity gives warming of about 3.5°C (by 2100, relative to 1990).	Models project that between one-third and one-half of existing mountain glacier mass could disappear over the next 100 years. Little change in the extent of the Greenland and Antarctic ice sheets is expected over the next 50–100 years.	Most simulations show a reduction in the strength of the north Atlantic thermohaline circulation [AMOC].	The lowest emission scenario with low climate and ice-melt sensitivities gives a projected sea level rise of about 0.15 m from the present to 2100. The highest emission scenario combined with high climate and ice-melt sensitivities gives a sea level rise of about 0.95 m from present to 2100.
Third Assessment Report SPM (2001): observed change	The global average surface temperature has increased over the 20th century by about 0.6°C (±0.2°C). There is new and stronger evidence that most of the warming observed over the last 50 years is attributed to human activities.	Snow cover and ice extent have decreased. There are very likely to have been decreases of about 10% in the extent of snow cover since the late 1960s. There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. Northern Hemisphere spring and summer sea ice extent has decreased by about 10–15% since the 1950s.	Global ocean heat content has increased since the last 1950s. Warm episodes of the El Niño-Southern Oscillation phenomenon have been more frequent, persistent and intense since the mid-1970s compared with the previous 100 years.	Global average sea level rose between 0.1–0.2 m during the 20th century. It is very likely that the 20th century warming has contributed significantly to the observed sea level rise, through thermal expansion of sea water and widespread loss of land ice. Within present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea level rise during the 20th century.

Report	Global Context	Cryosphere	Ocean	Sea Level
Third Assessment Report SPM (2001): projected change[c]	Global average temperature and sea level are projected to rise under all IPCC Special Report on Emissions Scenarios (SRES). The globally average surface temperature is projected to increase by between 1.4°C and 5.8°C over the period 1990–2100.	Northern Hemisphere snow cover and sea ice extent are projected to decrease further. Glaciers and ice caps are projected to continue their widespread retreat during the 21st century. The Greenland ice sheet is likely to lose mass. The Antarctic ice sheet is likely to gain mass because of greater precipitation. Concerns have been expressed about the stability of the West Antarctic ice sheet, however loss of grounded ice leading to substantial sea level rise from this source is now widely agreed to be very unlikely during the 21st century.	Most models show weakening of the ocean thermohaline circulation, but do not exhibit complete shut-down of the thermohaline circulation by 2100. Beyond 2100 the thermohaline circulation could completely, and possibly irreversibly, shut down in either hemisphere. Increases in tropical cyclone peak wind intensities and in mean and peak precipitation intensities are likely over some areas.	Global mean sea level is projected to rise by between 0.09 and 0.88 m between 1990 and 2100.
Fourth Assessment Report SPM (2007): observed change	Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Temperature increase from 1850–1899 to 2001–2005 is 0.76 (0.57–0.95) °C. Arctic temperatures increased at almost twice the global average rate in the past 100 years.	Mountain glaciers and snow cover have declined on average in both hemispheres. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic. Seasonally frozen ground has decreased by around 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%. Data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 (2.1–3.3) % per decade, with larger decreases in summer of 7.4 (5.0–9.8) % per decade. New data show that losses from the ice sheets of Greenland and Antarctic have *very likely* contributed to sea level rise over 1993–2003.	Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3,000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970 (*likely*), [but] there is no clear trend in the numbers of tropical cyclones.	Total 20th century global mean sea level rise is estimated to be 0.17 (0.12–0.22) m. There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century. It is *very likely* that anthropogenic activity contributed to a rise in average sea level. There has *likely* been an increased incidence of extreme high sea level.
Fourth Assessment Report SPM (2007): projected change[c]	Best estimates and *likely* ranges for globally average surface air warming at the end of the 21st century (2090–2099, relative to 1980–1999) for the low scenario is 1.8 (1.1–2.9) °C and for the high scenario is 4.0 (2.4 to 6.4) °C. Since IPCCs first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15°C–0.3°C per decade for 1990–2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections.	Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late summer sea ice disappears almost entirely by the latter part of the 21st century. Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming.	Projections give reductions in average global surface ocean pH of between 0.14–0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times. It is *likely* that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SST. It is *very likely* that the Atlantic Meridional Overturning Circulation (AMOC) will slow down during the 21st century. It is *very unlikely* that the AMOC will undergo a large abrupt transition during the 21st century. Longer-term changes in AMOC cannot be assessed with confidence.	Model-based *likely* ranges for global mean sea level rise at the end of the 21st century (2090–2099, relative to 1980–1999) for the low scenario are 0.18–0.38 m and for the high scenario are 0.26–0.59 m. Models used to date do not include the full effects of changes in ice sheet flow.

Report	Global Context	Cryosphere	Ocean	Sea Level
Fifth Assessment Report SPM (2013): observed change	Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. The total increase (in global mean surface temperature) between the average of the 1850–1900 period and the 2003–2012 period is 0.78 (0.72–0.85) °C.	Over the last two decades the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent, and permafrost temperatures have increased in most regions (high confidence). See IPCC (2013) AR5 SPM for extensive quantification of observed cryosphere changes.	Ocean warming accounts for more than 90% of the energy accumulated between 1971–2010 (high confidence). It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between 1987–1971. There is no observational evidence of a trend in the AMOC. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*), corresponding to a 26% increase in hydrogen ion concentration.	Over the period 1901–2010, global mean sea level rose by 0.19 (0.17–0.21) m. The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia.
Fifth Assessment Report SPM (2013): projected change[d]	Increase in global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to *likely* be in the range of 0.3°C–1.7°C for a low emission future (RCP2.6) or 2.6°C–4.8°C for a high emission future (RCP8.5). The observed warming from 1850–1900 (pre-industrial) to 1986–2005 is 0.61 (0.55–0.67) °C.	Reductions in Arctic sea ice extent projected by the end of the 21st century range from 43% (RCP2.6) to 94% (RCP8.5) in September. A nearly ice-free Arctic Ocean in September before mid-century is *likely* for RCP8.5. A decrease in Antarctic sea ice extent and volume is projected with low confidence for the end of the 21st century. By the end of the 21st century: global glacier volume is projected to decrease by 15–55% for RCP2.6 and by 35–85% for RCP8.5 (*medium confidence*), Northern Hemisphere spring snow cover is projected to decrease by 7% for RCP2.6 and 25% in RCP8.5, and the area of permafrost near the surface (upper 3.5m) is projected to decrease by between 37% (RCP2.6) to 81% (RCP8.5).	Best estimates of ocean warming in the top 100 m are about 0.6°C (RCP2.6) to 2.0°C (RCP8.5), and about 0.3°C (RCP2.6) to 6°C (RCP8.5) at a depth of about 1,000 m by the end of the 21st century. It is *very likely* that the AMOC will weaken over the 21st century by 11 (1–24) % in RCP2.6, and 34 (12–54) % in RCP8.5. It is *very unlikely* that the AMOC will undergo an abrupt transition of collapse in the 21st century, however a collapse beyond the 21st century for large sustained warming cannot be excluded. A decrease in surface ocean pH by the end of the 21st century is in the range of 0.06–0.07 for RCP2.6 and 0.30–0.32 for RCP8.5.	Global mean sea level rise for 2081–2100 relative to 1986–2005 will *likely* be in the ranges of 0.26–0.55 m for a low emission future (RCP2.6), and 0.45–0.82 m for a high emission future (RCP8.5). For RCP8.5, the rise by the year 2100 is 0.52–0.98 m, relative to 1986–2005. It is *virtually certain* that global mean sea level rise will continue beyond 2100.

Notes:

(a) Business-as-usual scenario used in the First Assessment Report assumes few or no steps are taken to limit greenhouse gas emissions, and has an atmospheric CO_2 concentration of around 830 ppm by 2100.

(b) Second Assessment Report uses the IS92 emission scenarios. The lowest emission scenario is IS92c, and the highest emission scenario is IS92e.

(c) The Third and Fourth Assessment Reports use the SRES emission scenarios, which have a range of atmospheric carbon dioxide concentrations at 2100 of between 540–970 ppm (see SM1.2).

(d) AR5 uses the Representative Concentration Pathways (RCP) emission scenarios (Cross-Chapter Box 1 in Chapter 1; SM1.2).

SM1.2 Supplementary Material Supporting the Text in Cross-Chapter Box 1 in Chapter 1

Additional details are provided below on the Representative Concentration Pathways (RCPs), the Shared Socioeconomic Pathways (SSPs) and the Special Report on Emission Scenarios (SRES), supporting the Cross-Chapter Box 1 in Chapter 1.

Five SSP narratives describe alternative pathways for future society (Figure SM1.1). Each SSP looks at how the different RCPs could be achieved within the context of the underlying socioeconomic characteristics and shared policy assumptions of that world. The SSPs five alternative socio-economic futures compromise: sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4) and fossil-fuelled development (SSP5) (Kriegler et al., 2016; Riahi et al., 2017). Across these five SSP narratives there are a total of 23 'Marker' SSP scenarios. Appendix 1.A, Figure 2 shows some specific SSP Markers compared with the RCPs, according to (O'Neill et al., 2016). SSP5–8.5 represents the high end of the range of future pathways, corresponding to RCP8.5. SSP3–7.0 lies between RCP6.0 and RCP8.5, and represents the medium to high end of the range of future forcing pathways. SSP4–6.0 corresponds to RCP6.0, fills in the range of medium forcing pathways. SSP2–4.5 represents the medium part

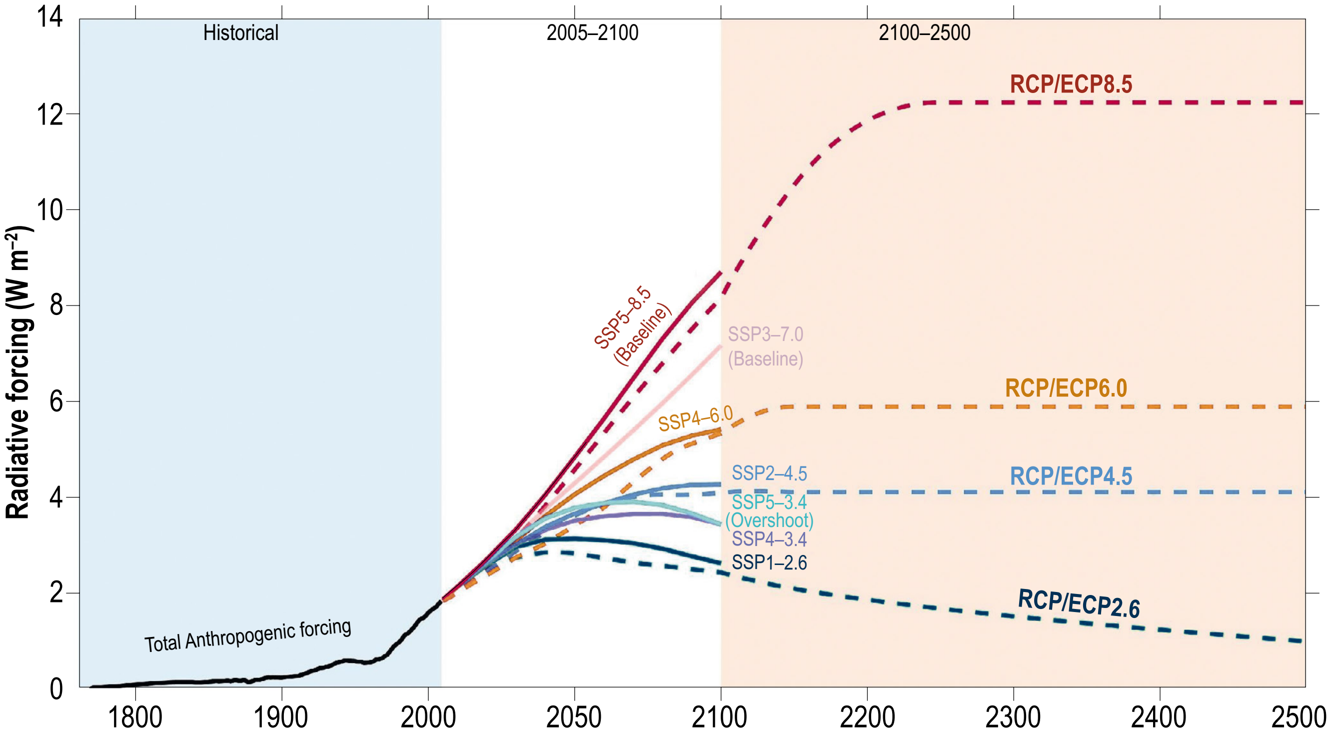

Figure SM1.1 | Radiative forcing (W m^{-2}) time series for historical data (1765–2004), and for future scenarios from the Representative Concentration Pathways (RCP; 2005–2100) and their continuation as the extended RCPs (2100–2500), and the Shared Socioeconomic Pathways (SSP; 2005–2100). The RCP scenarios are shown as dashed curves, and SSPs are shown as solid curves ('Marker' scenarios are used). Note the change in x-axis scale for the 2005–2100 interval to give an improved illustration of radiative forcing scenarios during the 21st century.

of the range of future forcing pathways and updates RCP4.5. SSP5–3.4 (Overshoot) fills a gap in existing climate simulations by investigating the implications of a substantial 21st century overshoot in radiative forcing relative to a longer-term target. SSP4–3.4 fills in the range of low forcing pathways, and there is substantial mitigation policy interest in this scenario that reaches 3.4 W m^{-2} by 2100. SSP1–2.6 is similar to RCP2.6. It is anticipated that it will produce a multi-model mean of less than 2°C warming by 2100.

Table CB1.1 provides projections for near-term and end-of-century changes in climate and ocean parameters under different RCP scenarios. Table SM1.2 (below) provides information on the models and ensemble members used for these calculating the data presented in Table CB1.1.

Prior to the RCPs, the coupled model intercomparison project used the SRES (Nakicenovic and Swart, 2000; Table SM1.3). SRES includes four qualitative storylines, yielding four sets of scenarios called 'families': A1, A2, B1, and B2. The A1 family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 family develops into three groups distinguished by their technological emphasis: fossil-fuel intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B1 family describes a convergent world with a global population that peaks in mid-century and declines thereafter (as in the A1 storyline), but with rapid changes in economic structures toward a service and information economy, reductions in material intensity and the introduction of clean and resource-efficient technologies. The B2 family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. With respect to radiative forcing, RCP4.5 is close to SRES B1, RCP6.0 is close to SRES A1B, and RCP8.5 is somewhat higher than A2 and close to the SRES A1FI scenario. RCP2.6 is lower than any of the SRES (Cubasch et al., 2013; Stocker et al., 2013). Table SM1.3 gives SRES projections for global mean surface air temperature for the near-term and end-of-century, and Table SM1.4 gives details of the models used in calculating these projections.

Table SM1.2 | List of the Coupled Model Intercomparison Project Phase 5 (CMIP5) General Circulation Model (GCM) runs used for Table CB1.1. Ensemble members used are “r1i1p1” except otherwise indicated.

CMIP5 model name	Global Mean Surface Air Temperature				Global Mean Sea Surface Temperature		Surface pH		Dissolved Oxygen (100–600 m)	
	RCP2.6	RCP4.5	RCP6.0	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
ACCESS1–0		X		X						
ACCESS1.3		X		X						
bcc-csm1–1	X	X	X	X	X	X				
bcc-csm1–1-m	X	X	X	X		X				
BNU-ESM	X	X		X						
CanESM2	X	X		X	X	X	X	X		
CCSM4	X	X	X	X	X	X				
CESM1-BGC		X		X						
CESM1-CAM5	X	X	X	X	X	X				
CMCC-CESM				X						
CMCC-CM		X		X						
CMCC-CMS		X		X						
CNRM-CM5	X	X		X	X	X				
CSIRO-Mk3–6-0	X	X	X	X						
CSIRO-Mk3L-1–2		r1i2p1								
EC-EARTH	r8i1p1	X		X						
FGOALS_g2	X	X		X						
FIO-ESM	X	X	X	X						
GFDL-CM3	X	X	X	X	X	X				
GFDL-ESM2G	X	X	X	X	X	X	X	X	X	X
GFDL-ESM2M	X	X	X	X	X	X	X	X		
GISS-E2-H	X	X	X	X	X	X				
GISS-E2-H-CC		X		X						
GISS-E2-R	X	X	X	X	X	X				
GISS-E2-R-CC		X		X						
HadGEM2-AO	X	X	X	X						
HadGEM2-CC		X		X						
HadGEM2-ES	X	X	r2i1p1	X						
inmcm4		X		X						
IPSL-CM5A-LR	X	X	X	X	X	X	X	X	X	X
IPSL-CM5A-MR	X	X	X	X	X	X	X	X	X	X
IPSL-CM5B-LR		X		X				X		X
MIROC-ESM	X	X	X	X	X	X				
MIROC-ESM-CHEM	X	X	X	X						
MIROC5	X	X	X	X						
MPI-ESM-LR	X	X		X			X	X	X	X
MPI-ESM-MR	X	X		X	X	X	X	X	X	X
MRI-CGCM3	X	X	X	X						
MRI-ESM1				X						
NorESM1-M	X	X	X	X						
NorESM1-ME	X	X	X	X	X	X				

Table SM1.3 | Special Report on Emissions Scenarios (SRES) global mean surface air temperature changes, relative to the recent past (1986–2005), and approximate Representative Concentration Pathways (RCP) equivalent. The IPCC 5th Assessment Report (AR5) assessed that observed warming from the pre-industrial to the 1986–2005 reference period was 0.61°C (*likely* range of 0.55°C–0.67°C).

	2031–2050		2080–2099		Approximate RCP Equivalent
Scenario	Mean	5–95% range	Mean	5–95% range	
B1	0.8°C	0.4°C –1.1°C	1.6°C	1.0°C –2.2°C	RCP4.5
A1B	1.1°C	0.6°C –1.6°C	2.4°C	1.7°C –3.2°C	RCP6.0
A2	1.0°C	0.6°C –1.5°C	3.0°C	2.2°C –3.7°C	RCP8.5

Table SM1.4 | List of the Coupled Model Intercomparison Project Phase 3 (CMIP3) General Circulation Model (GCM) runs used for Table SM1.3.

Global Mean Surface Air Temperature in Special Report on Emissions Scenarios (SRES) Experiments			
CMIP5 model name	B1	A1B	A2
BCCR-BCM2–0	run1	run1	run1
CCCMA-CGCM3–1	run1	run1	run1
CCCMA-CGCM3–1-T63	run1	run1	
CNRM-CM3	run1	run1	run1
CSIRO-Mk3–0	run1	run1	run1
GFDL-CM2–0	run1	run1	run1
GFDL-CM2–1	run1	run1	run1
GISS-AOM	run1	run1	
GISS-MODEL-E-H		run1	
IAP-FGOALS1–0-G	run1	run1	
INGV-ECHAM4		run1	run1
inmcm3–0	run1	run1	run1
IPSL-CM4	run1	run1	run1
MIROC3–2-MEDRES	run1	run1	run1
MIUB-ECHO-G	run1	run1	run1
MPI-ECHAM5	run1	run1	run1
MRI-CGCM2–3-2A	run1	run1	run1
NCAR-CCSM3–0	run1	run1	run1
NCAR-PCM1	run2	run2	run1
UKMO-HadCM3	run1	run1	run1
UKMO-HadGEM1		run1	

SM1.3 Supplementary Material Supporting Figure 1.2

Additional details are provided below on the main responses to observed and expected changes in the ocean and cryosphere in a changing climate including mitigation and adaptation measures. These details expand on the summary provided in Figure 1.2.

Supporting biological and ecological adaptation (including ecosystem-based management)

- **Pollution reduction**: Reduce pollution from land, rivers and atmosphere
- **Conservation**: Protect habitats and ecosystems through spatial measures including terrestrial and marine protected areas
- **Assisted evolution**: Assisted evolution (active intervention to accelerate the rate of naturally occurring evolutionary processes) and genetic modifications
- **Restoration and enhancement**: of habitats, ecosystems and ecosystem services; ecological engineering; assisted migration

Addressing the causes of climate change

- **Reduce atmospheric pollution**, including emissions from shipping and black carbon
- **Renewable energy**: Energy substitution for fossil energy
- **Increase energy efficiency**
- **Carbon capture and storage**: Sequestration of CO_2 underground on land and under sea floor
- **Direct air capture and storage**

- **Bioenergy with carbon capture and storage**: Crops are burnt in power plants to generate energy and resulting CO_2 is captured and stored
- **Biochar and soil carbon**: Carbon, including from partly burnt biomass added to soil
- **Afforestation and reforestation**: Including blue carbon from marine and coastal vegetation to enhance CO_2 uptake and avoid further emissions
- **Enhance open-ocean productivity** by adding nutrients and cultivating marine plants
- **Enhanced weathering and alkalinisation**: Addition of natural or man-made alkalinity to enhance CO_2 removal and/or carbon storage

Enhancing societal adaptation

- **Community-based adaptation**: Enhance local social capital, gender equity, indigenous knowledge, local knowledge
- **Infrastructure-based adaptation**: Building standards, hard defences
- **Relocate and diversify economics activities**
- **Relocate people**: Coastal retreat and migration
- **Change practices and policies**: Resource use, consumption modes, urban planning, regulation

SM1.4 Supplementary Material for Figure 1.3

The lower panel of Figure 1.3 gives examples of available data/output for the ocean and cryosphere (Section 1.8.1). Heights depict the number of observations, parameters or simulations available through time expressed relative to the maximum data availability, and colour scale depicts spatial coverage of data across the relevant domain. Details and data sources are:

Physical Ocean (temperature and salinity) observations are from the World Ocean Database (Boyer et al., 2013). The data in Figure 1.3 shows the number of observations in the database through time for three depth layers, relative to maximum annual values of 1,102,401 for the 0–800 m layer, 382,619 for the 800–2,000 m layer and 12,875 for observations deeper than 2,000 m. Spatial coverage is calculated as the percentage of 3° x 3° ocean grid cells that have observations. Additional detail of the spatial coverage of ocean temperature and salinity observations by depth is given in Figure SM1.2. Database: www.nodc.noaa.gov/OC5/WOD/pr_wod.html

Ocean biogeochemistry (dissolved inorganic carbon; DIC) observations data stem from the Global Ocean Data Analysis Project version 2 (GLODAPv2) product (Olsen et al., 2016), in which the vast majority of all available DIC data since the early 1970s were assembled. It is composed of data from 724 scientific cruises covering the global ocean. The data plotted represent the number of distinct samples measured as a function of time from the surface down to the bottom of the ocean. The bi-modal distribution is a result of the two large survey campaigns that underlie these data, that is, the JGOFS/WOCE survey in the 1980s and 1990s (Wallace, 2001) and the ongoing Repeat Hydrography/GOSHIP survey after 2000 (Talley et al., 2016). The spatial coverage in any given year is relatively low owing to the decadal survey character of the programs. Along any survey line, the spatial coverage tends to be high, as a full profile is typically taken at every 1° of latitude/longitude.

Ocean biology (Continuous Plankton Recorder; CPR) observations are from the Global Alliance of Continuous Plankton Recorder Surveys (GACS), an international collaboration which encompasses the original CPR Survey and twelve other regional CPR Surveys. Data plotted represent the number of processed CPR samples (subset from the total number of archived samples) from 1936–2013. Until 1991, surveys only covered the North Atlantic, then extended into the Southern Ocean and in 2000 into the North Pacific, so that for two decades there has been sampling in both hemispheres and three ocean basins (McQuatters-Gollop et al., 2015). For conversion to spatial area, each sample was considered to cover 10 square nautical miles. Data may be requested at: www.cprsurvey.org/data/data-request-form/

Sea level observations are from tide gauge data archived in the Permanent Service for Mean Sea Level (PSMSL) (PSMSL, 2016). There are a total of 1,508 tide gauge sites in the PSMSL database and these are located around the world's coastal and island regions. The maximum number of tide gauges giving measurements in a single year in the PSMSL database is 776. Data coverage is calculated as the percentage of 3° x 3° ocean grid cells that have observations, and the low level (<10%) of ocean coverage is due to tide gauges being located primarily on coasts, rather than across the open ocean. Database: www.psmsl.org/data/obtaining/

Glacier length observations are from the World Glacier Monitoring Service (WGMS) (WGMS, 2017). This database is used as an illustrative example, but other glacier databases include the National Snow and Ice Data Center and the Randolph Glacier Inventory (containing data for 216,000 glaciers worldwide). The illustrative data from the WGMS database amalgamate the glacier front variation and glacier reconstructed front variation databases, and show the number of glacier length observations through time relative to a maximum annual value of 837. The percentage coverage is based on the number of glaciers with length observations relative to the total number of glacier identification codes in the WGMS database (8490). Database doi: 10.5904/wgms-fog-2017–10.

Remote sensing (surface ocean) shows the availability through time of systematic and sustained satellite monitoring of six surface ocean parameters: sea surface temperature, sea surface salinity, ocean colour, ocean wind, ocean height and ocean mass change. **Remote sensing (cryosphere)** shows the availability through time of systematic and sustained satellite monitoring of: sea ice extent, snow cover, glacier and ice sheet area, and glacier and ice sheet mass change (Dowell et al., 2013; Raup et al., 2015).

Palaeoclimate data uses an example from the PAGES2k version 2.0.0 database (PAGES2K Consortium, 2017) of temperature sensitive records, which include temperature proxies over ice sheets (from ice cores) and in the ocean (from corals and marine sediments).

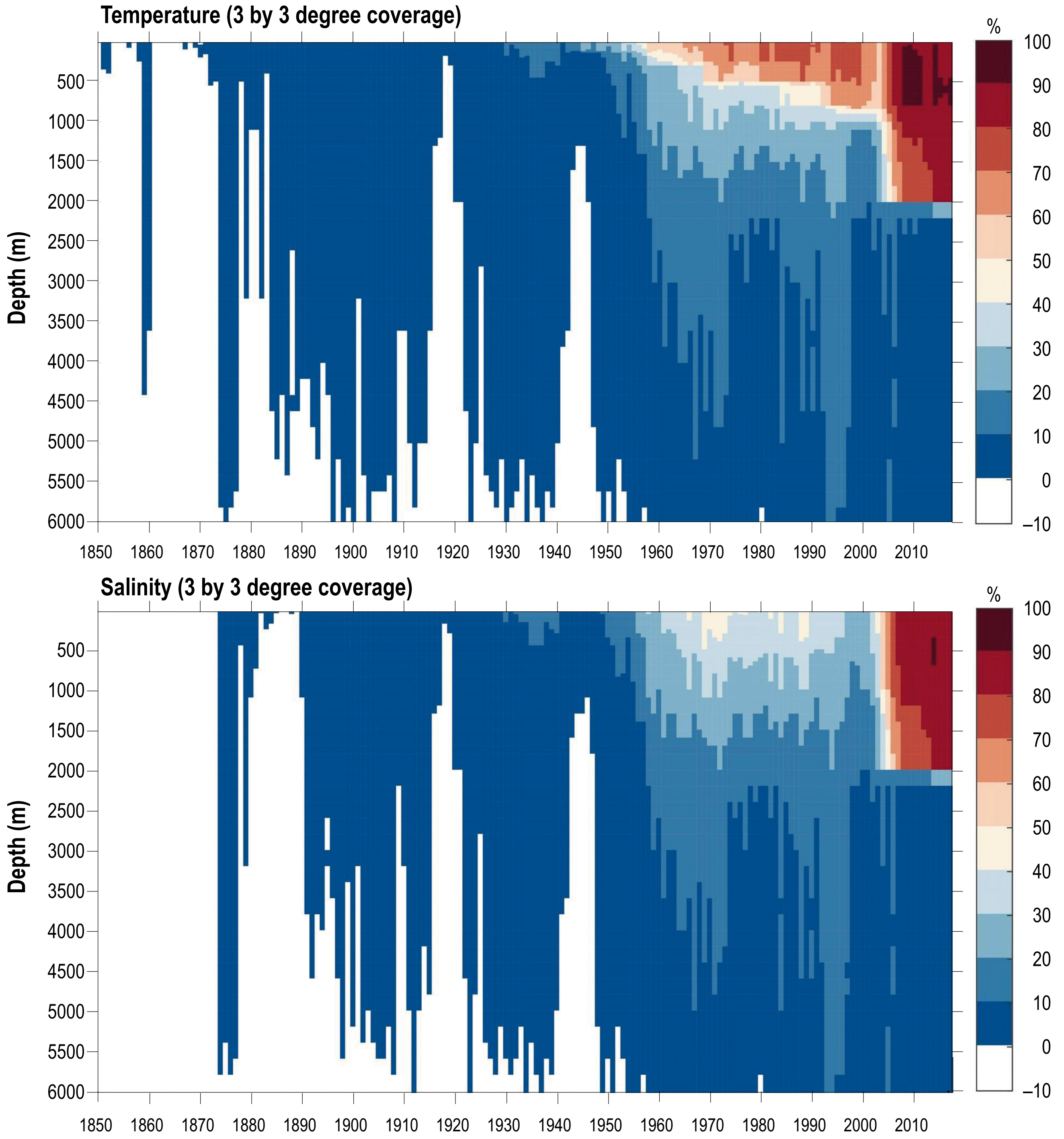

Figure SM1.2 | Further detail on the spatial coverage of ocean *in situ* temperature (upper) and salinity (lower) observations from the sea surface to 6,000 m depth in the World Ocean Database (Boyer et al., 2013). Coverage is calculated as the percentage of 3° x 3° ocean grid cells that have observations. Coverage calculations at each depth layer take into account the changing lateral extent of the ocean at different depth levels. The figure is adapted and extended based on Rhein et al. (2013) and Meyssignac et al. (2019).

Figure 1.3 shows the number of palaeoclimate records available through time, relative to an annual maximum of 649. Spatial coverage is calculated as the percentage of 3° x 3° surface grid cells across the globe that have palaeoclimate data. Database doi: 10.6084/m9.figshare.c.3285353.

Model simulation outputs in Figure 1.3 are based on search results for CMIP5 simulations (Taylor et al., 2012) in the Earth System Grid Federation database (http://esgf.llnl.gov/), using the search criteria of last millennium (p1000; 850–1850 CE), historical (1851–2005 CE), RCP (2005–2100 CE), and RCP-extended (2100 CE onwards) experiments with monthly resolution output for the ocean. Data availability is shown relative to the maximum number of datasets meeting these search criteria (508 for RCP experiments).

References

Boyer, T.P. et al., 2013: World Ocean Database 2013. [Levitus, S. and A. Mishonov (eds.)]. Silver Spring, MD, NOAA Atlas, 209 pp.

Cubasch, U. et al., 2013: Introduction. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 119–158.

Dowell, M. et al., 2013: *Strategy towards an architecture for climate monitoring from space*. Committee on Earth Observation Satellites, 39 pp. [Available at: www.wmo.int/pages/prog/sat/.../ARCH_strategy-climate-architecture-space.pdf].

IPCC, 1990: Policymakers Summary. In: Climate Change: The IPCC Scientific Assessment [Houghton, J.T., G.J. Jenkins and J.J. Ephraums (eds.)]. Cambridge University Press, Cambridge, United Kingdom.

IPCC, 1995: Summary for Policymakers. In: Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1–8.

IPCC, 2001: Summary for Policymakers. In: Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Platter, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kriegler, E. et al., 2016: Fossil-fueled development (SSP5): an energy and resource intensive scenario for the 21st century. *Global Environ. Change*, **42**, 297–315, doi:10.1016/j.gloenvcha.2016.05.015.

McQuatters-Gollop, A. et al., 2015: The Continuous Plankton Recorder survey: How can long-term phytoplankton datasets contribute to the assessment of Good Environmental Status? *Estuar. Coast. Shelf Sci.*, **162**, 88–97, doi:10.1016/j.ecss.2015.05.010.

Meyssignac, B. et al., Accepted: Measuring Global Ocean Heat Content to estimate the Earth Energy Imbalance. *Front. Mar. Sci.* doi: 10.3389/fmars.2019.00432.

Nakicenovic, N. and R. Swart, 2000: *Special Report on Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, 608 pp. ISBN: 0521804930.

O'Neill, B.C. et al., 2016: The scenario model intercomparison project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.*, **9**(9), 3461–3482, doi:10.5194/gmd-9-3461-2016.

Olsen, A. et al., 2016: The Global Ocean Data Analysis Project version 2 (GLODAPv2) – an internally consistent data product for the world ocean. *Earth Sys. Sci. Data*, **8**(2), 297–323, doi:10.5194/essd-8-297-2016.

PAGES2K Consortium, 2017: A global multiproxy database for temperature reconstructions of the Common Era. *Sci. Data*, **4**, 170088, doi:10.1038/sdata.2017.88.

PSMSL. Permanent Service for Mean Sea Level. [Available at: www.psmsl.org.]

Raup, B.H., L.M. Andreassen, T. Bolch and S. Bevan, 2015: Remote Sensing of Glaciers. In: *Remote Sensing of the Cryosphere* [Tedesco, M. (ed.)]. Wiley Blackwell, pp. 123–156. ISBN: 9781118368855.

Rhein, M. et al., 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V.B. And and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 255–315.

Riahi, K. et al., 2017: The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environ. Change*, **42**, 153–168, doi:10.1016/j.gloenvcha.2016.05.009.

Stocker, T.F. et al., 2013: Technical summary. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 33–115.

Talley, L.D. et al., 2016: Changes in ocean heat, carbon content and ventilation: A review of the first decade of GO-SHIP global repeat hydrography. *Annu. Rev. Mar. Sci.*, **8**(1), 185–215, doi:10.1146/annurev-marine-052915-100829.

Taylor, K.E., R.J. Stouffer and G.A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bull. Am. Meteor. Soc.* **93**(4), 485–498, doi:10.1175/BAMS-D-11-00094.1.

Wallace, D.W.R., 2001: Storage and transport of excess CO_2 in the oceans: the JGOFS/WOCE Global CO_2 Survey. In: *Ocean Circulation and Climate* [Siedler, G., J. Church and J. Gould (eds.)]. Academic Press, San Diego, pp. 489–524. ISBN: 9780126413519.

WGMS, 2017: *Fluctuations of Glaciers Database*. World Glacier Monitoring Service, Zurich, Switzerland [Available at: http://dx.doi.org/10.5904/wgms-fog-2017-10].