IPCC Special Report on
The Ocean and Cryosphere in a Changing Climate

Changing ocean properties, circulation and sea ice in the polar regions: causes and consequences

M.P. Meredith, M. Sommerkorn, S. Cassotta, C. Derksen, A. Ekaykin, A. Hollowed, G. Kofinas, A. Mackintosh, J. Melbourne-Thomas, M. Muelbert, G. Ottersen, H. Pritchard, E. Schuur, S. He, V. Peck, R. Hallberg, A. Tagliabue, A. Meijers, J. Oliver, A. Hogg.

Climate change in the Arctic and Antarctic is exerting a profound influence both within the polar regions themselves, and over all of our planet. Physical changes influence ecosystems, societies, cultures and economies. The IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) assesses past, ongoing and future changes in the polar regions, the impacts of those changes, and possible options for mitigation and adaptation under different climate change scenarios.

Observed changes in the Arctic and Southern Ocean assessed in SROCC include:-

Arctic sea ice extent continues to decline in all months of the year; the strongest reductions in September are unprecedented in at least 1000 years (Figure 1). Since 1979, the areal proportion of thick ice at least 5 years old has declined by approximately 90%. Approximately half the observed sea ice loss is attributable to increased atmospheric greenhouse gas concentrations. Changes in Arctic sea ice can influence mid-latitude weather on timescales of weeks to months.

The polar oceans have continued to warm in recent years, with the Southern Ocean especially important in global ocean heat increase. Over large sectors of the seasonally ice-free Arctic, summer upper-ocean temperatures increased at ~0.5ºC per decade during 1982–2017. During 1970–2017, the Southern Ocean accounted for 35–43% of the global ocean heat gain in the upper 2000 m; in recent years (2005–2017), it was responsible for an increased proportion (45–62%)

The Arctic and Southern Oceans continue to remove CO_2 from the atmosphere and to acidify. The amount of CO_2 drawn into the Southern Ocean has varied decadally since the 1980s. Rates of calcification, by which marine organisms form hard skeletons and shells, declined in the Southern Ocean between 1998 and 2014. In the Arctic Ocean, the area corrosive to organisms that form shells and skeletons using aragonite expanded between the 1990s and 2010, with instances of extreme aragonite undersaturation.

Sea level rise has accelerated due to the increased ice loss from the Greenland and Antarctic ice sheets. Mass loss from Antarctica over the period 2007–2016 tripled relative to 1997–2006. For Greenland, mass loss doubled over the same period. Oceanic change is strongly implicated as a driver, for Antarctic change especially.

Southern Ocean circulation is responding to climatic changes in forcing in complex ways, with global-scale implications via changing water mass production and export to lower latitudes (Figure 2).

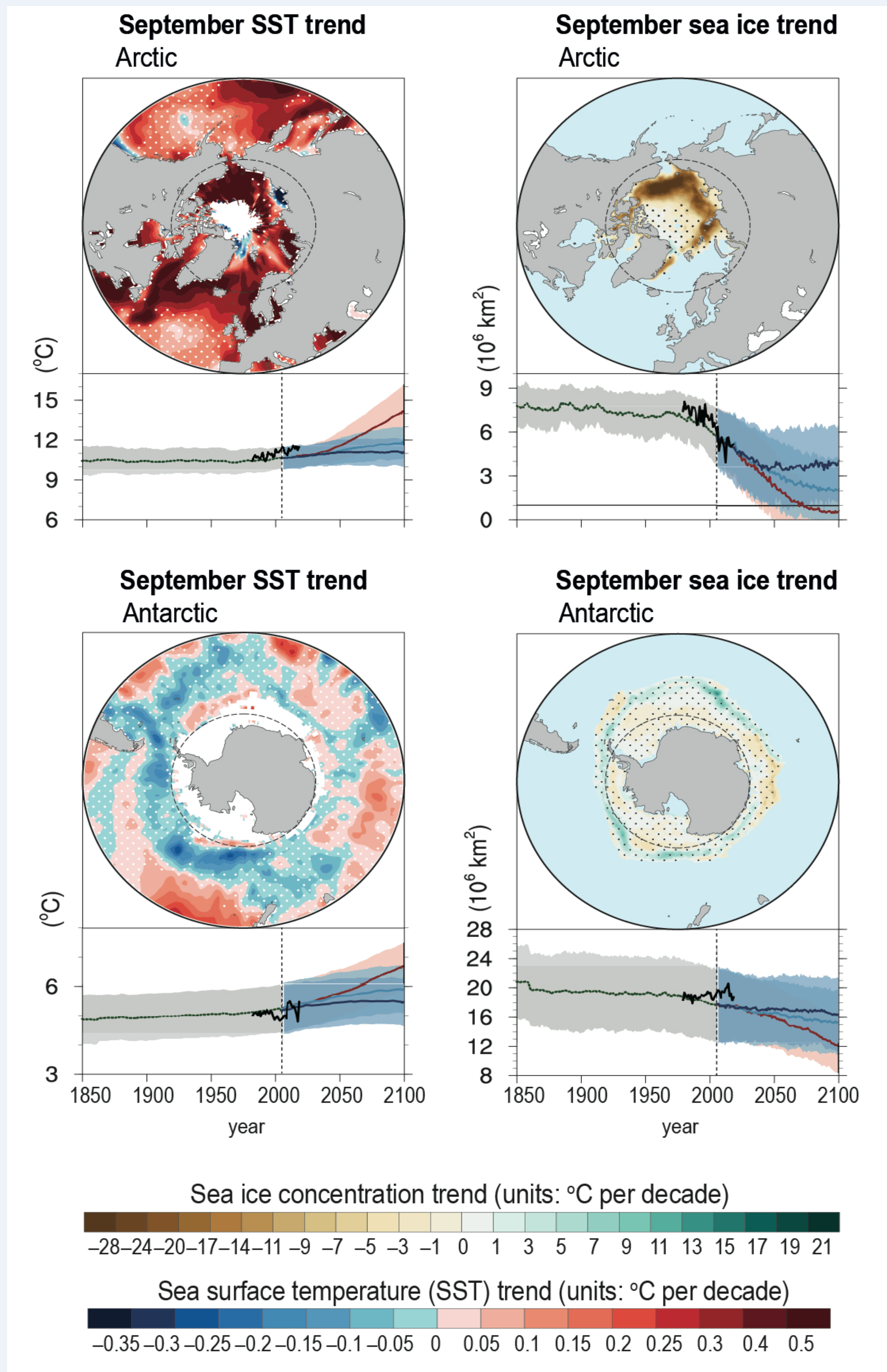

Figure 1. Observed trends in sea ice concentration and sea surface temperature for the Arctic and Southern Ocean (maps), plus historical and future trajectories under different greenhouse gas concentration scenarios (time series)

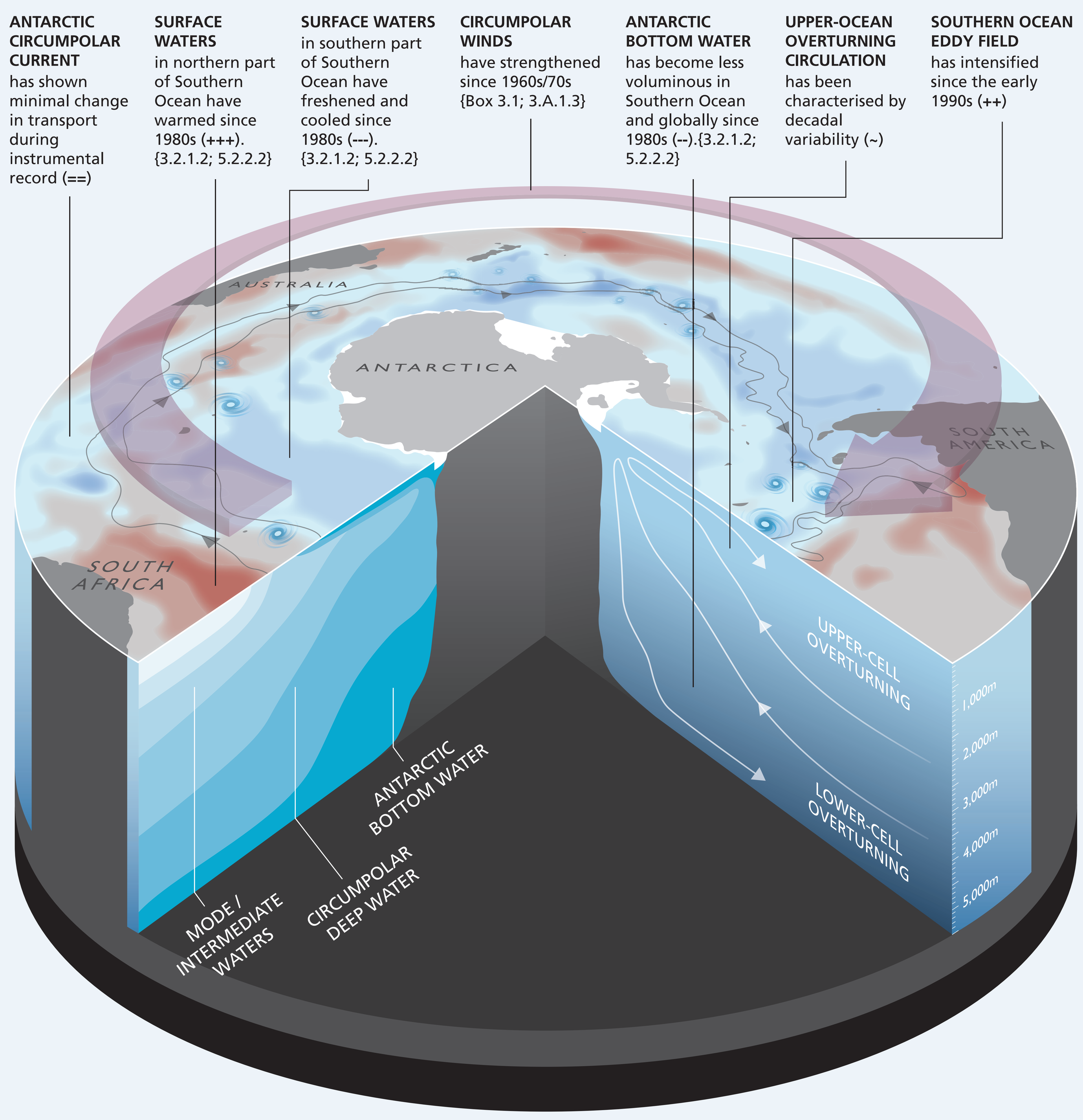

Figure 2. Observed changes in Southern Ocean circulation, as assessed in SROCC.

Projected changes in the Arctic and Southern Ocean assessed in SROCC include:-

Arctic warming will result in continued loss of sea ice and snow, and reductions in the mass of glaciers. For stabilised global warming of 1.5°C, an ~1% chance of a given September being sea ice free in 2100 is projected; for stabilised warming at a 2°C increase, this rises to 10–35%. Projected mass reductions for polar glaciers between 2015 and 2100 range from 16% to 33% depending on the level to which greenhouse gas concentrations are limited.

The polar oceans will be increasingly affected by CO_2 uptake, causing conditions corrosive for calcium carbonate shell-producing organisms (Figure 3). This will have associated impacts on marine organisms and ecosystems. It is very likely that both the Southern Ocean and the Arctic will experience year-round conditions of surface water undersaturation for mineral forms of calcium carbonate by 2100 if anthropogenic CO_2 emissions are not strongly reduced.

The polar ice sheets will make increasing contributions to global sea level rise by 2100, with the amount dependent on future climate change. Antarctica is projected to contribute ~0.04 m for a low greenhouse gas scenario, up to ~0.12 m for a high greenhouse gas scenario. Greenland's contribution in 2100 is projected to be ~0.07 m to ~0.15 m, dependent on scenario. Whilst Greenland is currently contributing more to sea level rise than Antarctica, the latter could become a larger contributor by the end of the century as a consequence of potential rapid retreat.

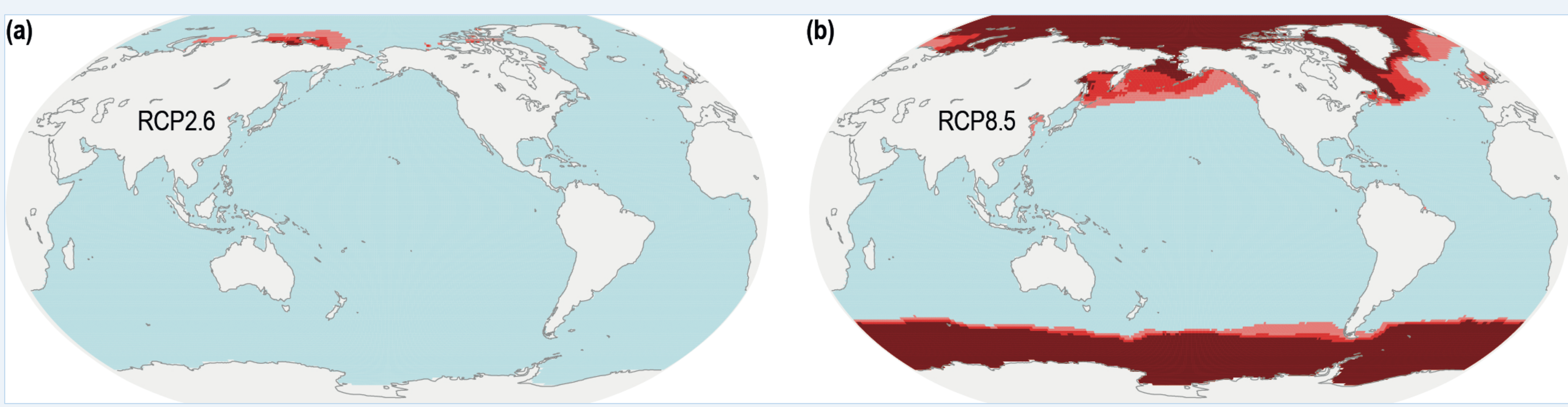

Figure 3. Regions of the surface ocean characterized by year-round aragonite undersaturation in 2100 for a low greenhouse gas scenario (left) and a high greenhouse gas scenario (right).

Take home messages:-

1) The polar oceans are changing rapidly and losing ice. The consequences of this polar transition extend to the whole planet, and are affecting ecosystems and people in multiple ways.

2) The polar oceans will be profoundly different in future compared with today, and the degree and nature of that difference will depend strongly on the rate and magnitude of global climatic change. This will challenge adaptation responses regionally and worldwide.

3) Response options exist that can ameliorate the impacts of polar change, build resilience and allow time for effective mitigation measures, including major reductions in emissions of greenhouse gases.

Contact:
tsu@ipcc-wg2.awi.de
Working Group II Technical Support Unit
Intergovernmental Panel on Climate Change
c/o Alfred-Wegener-Institute

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IPCC Special Report on
The Ocean and Cryosphere in a Changing Climate

Causes and consequences of changing ocean properties on polar ecosystems: the SROCC assessment

Anne B Hollowed[1], Michael P. Meredith[2*] , Martin Sommerkorn[3*], Sandra Cassotta[4], Chris Derksen[5], Alexey Ekaykin[6], Gary Kofinas[7], Andrew Mackintosh[8], Jess Melbourne-Thomas[9], Mônica Muelbert[10], Geir Ottersen[11], Hamish D Pritchard[2], Edward Schuur[12], Shengping He[13], and Victoria L Peck[2]

* Coordinating Lead Author

1. NOAA Fisheries, Alaska Fisheries Science Center, USA; 2. British Antarctic Survey, UK; 3. World Wildlife Foundation, Norway; 4. Aalborg University, Denmark; 5. Environment and Climate Change Canada; 6. Arctic and Antarctic Research Institute, Russia; 7. University of Alaska Fairbanks, USA; 8. Monash University, Australia; 9. CSIRO, Australia; 10. Federal University of São Paulo- UNIFESP, Brazil; 11. Institute of Marine Research, Norway; 12. Northern Arizona University, USA; 13. Bjerknes Center for Climate Research, Norway

Overview: the polar regions chapter assessed the consequences of climate change in the polar regions. Physical and biogeochemical impacts are presented in the companion poster (Meredith et al.). Here we present results from a systems approach that was taken to assess individual and interacting changes within and between these elements to consider consequences, impacts and risks for marine ecosystems and for people. Mapping on to those observed and projected impacts, we assessed human responses to climate change in the polar regions.

Observed Impacts:

Climate change in the Arctic and Antarctic is already influencing polar region ecosystems with cascading impacts on marine resource dependent communities with global implications for food provisioning.

Evidence of regional heterogeneity in the response of marine species and humans to changing ocean conditions.

Some ice dependent marine mammals are particularly vulnerable to changing climate due to the direct linkage between sea ice thickness and extent on the suitability of foraging and breeding habitat.

Impacts and risks for polar biodiversity from range shifts and species invasions related to climate change: In polar regions climate-induced environmental change has expanded the range of some temperate species and contracted the range of some polar fish and ice-associated species (Figure 1, *high confidence* for detection, *medium confidence* for attribution). These changes have the potential to alter biodiversity in polar marine ecosystems (*medium confidence*).

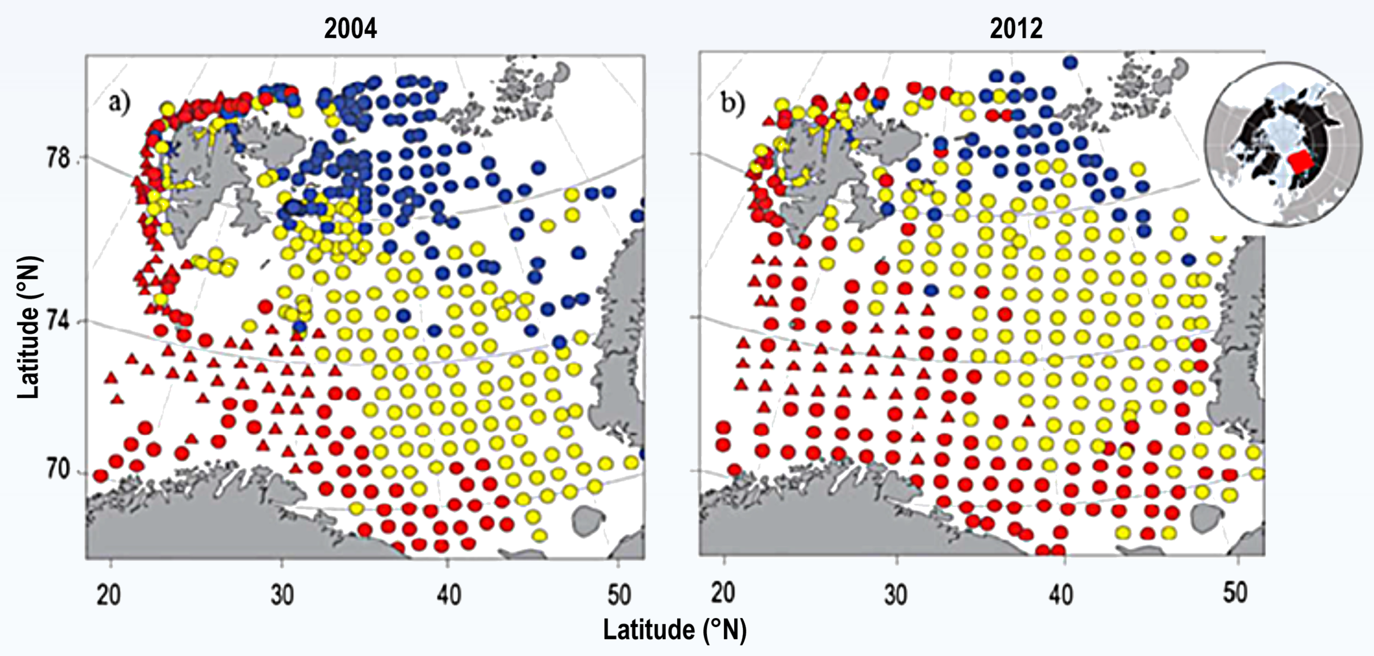

Figure 1 | Spatial distribution of fish communities identified at bottom trawl stations in the Barents Sea (north of northern Norway and Russia, position indicated by red box in small globe) in (a) 2004 and (b) 2012. Atlantic (red), Arctic (blue) and Central communities (yellow). Circles: shallow sub-communities, triangles: deep sub-communities. Modified from Fossheim et al. (2015).

Societal Impacts

Changes in the ocean have impacted polar marine ecosystems and ecosystem services with regionally diverse outcomes, challenging their governance (high confidence). Warming-induced changes in the spatial distribution and abundance of some fish and shellfish stocks have had positive and negative impacts on catches, economic benefits, livelihoods, and local culture (*high confidence*). Loss of sea ice, thawing permafrost and glacial melt creates challenges to the marine environment arising from changes in transportation pathways (shipping), tourism and access to non-renewable resources. These new environmental stressors challenge regional governments to develop ecosystem approaches to fisheries management that incorporate the positive and negative implications of changing climate at various life stages.

Projected Impacts on marine ecosystems:

While some marine species have exhibited resilience to the highly variable environmental conditions of the polar regions, under the high emission scenarios, the scope for adaptation will be reduced with implications on subsistence, recreational and commercial harvesting of fish, shellfish and marine mammals (Figures 2 & 3).

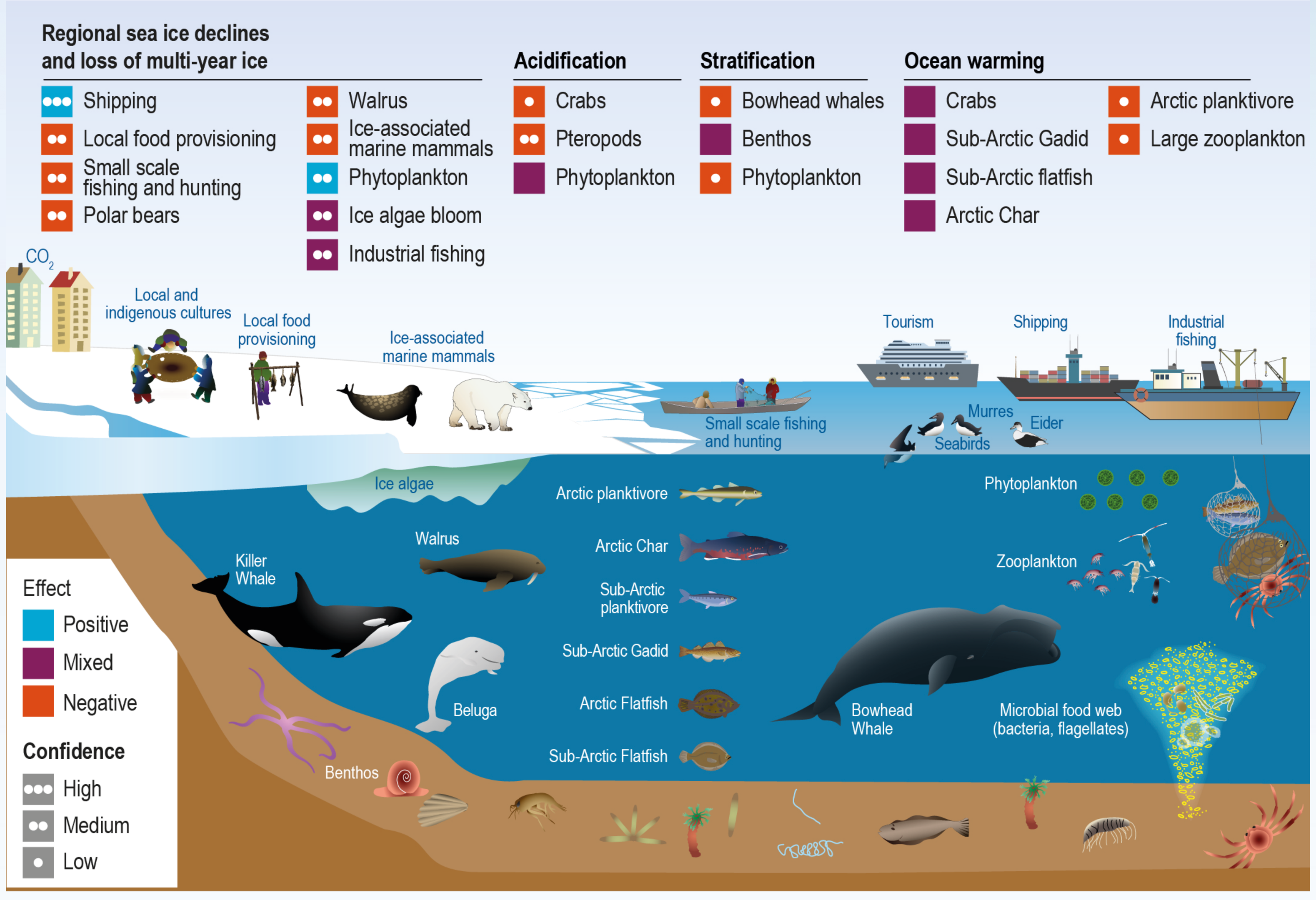

Figure 2 | Schematic summary of key drivers that are causing, or are projected to cause, direct effects on Arctic marine ecosystems. Projected effects are conceptual representations based on high emission scenarios. The cross-sectional view of the Arctic ecosystem shows the association of key functional groups (marine mammals, birds, fish, zooplankton, phytoplankton and benthic assemblages) with Arctic marine habitats.

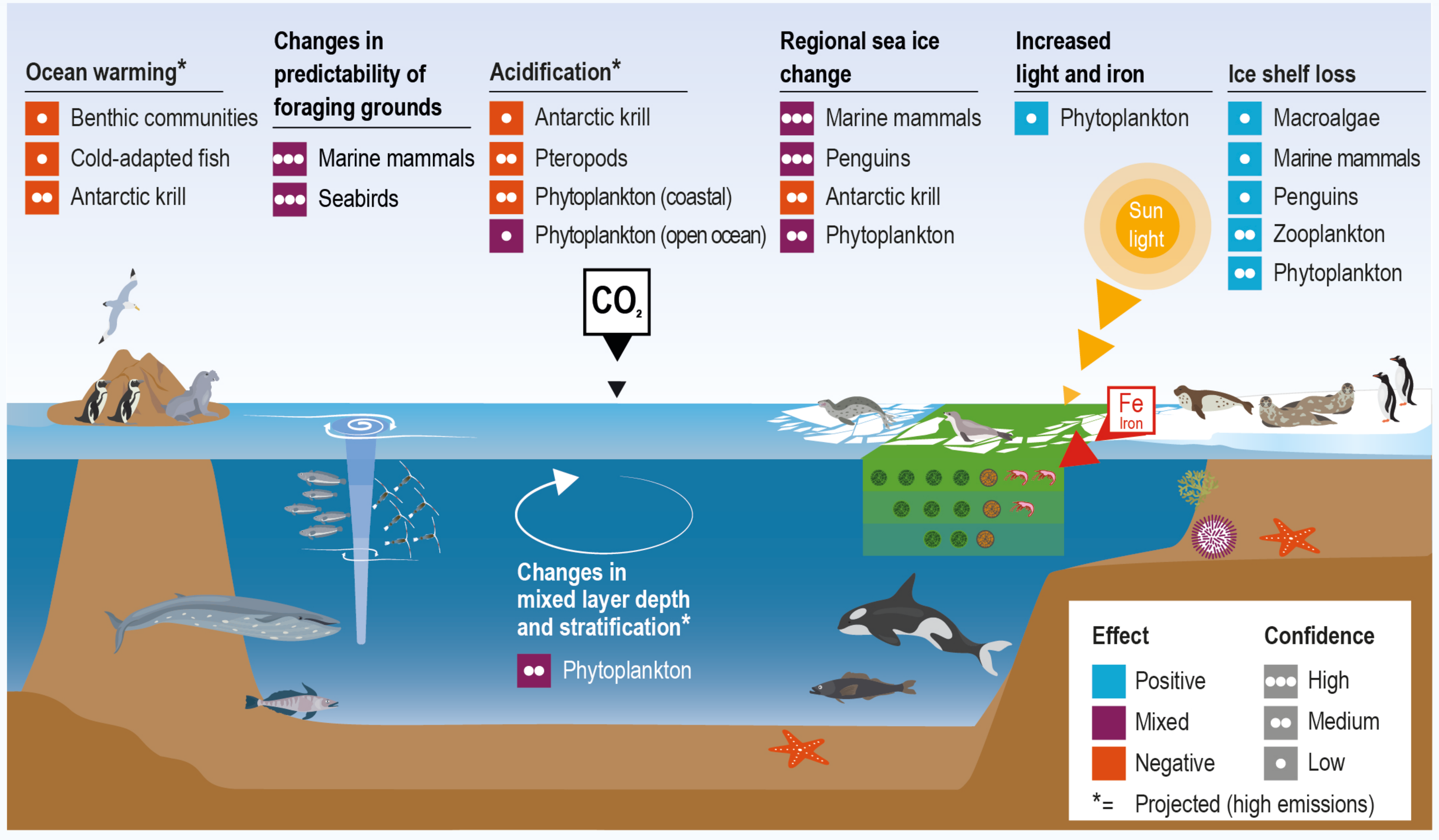

Figure 3 | Schematic summary of key drivers that are causing or are projected to cause direct effects on Southern Ocean marine ecosystems. Projected changes (indicated by an asterisk) are for high emissions scenarios. The cross-sectional view of the Southern Ocean ecosystem shows the association of key functional groups (marine mammals, birds, fish, zooplankton, phytoplankton and benthic assemblages) with Southern Ocean habitats.

TAKE HOME MESSAGE: *The polar regions are losing ice, and their oceans are changing rapidly. The consequences of this polar transition extend to the whole planet, and are affecting people in multiple ways.*

Contact:
tsu@ipcc-wg2.awi.de
Working Group II Technical Support Unit
Intergovernmental Panel on Climate Change
c/o Alfred-Wegener-Institute

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