Climate Change Impacts

Synopsis of the 2019 Report by IPCC :

The Ocean and Cryosphere in a Changing Climate

Tom Warren, M.S.

Presentation Outline

- The IPCC
- Review of climate science
- Findings of the IPCC Report
- Local examples

IPCC - *The Intergovernmental Panel on Climate Change*

- Established by the World Meteorological Society and the United Nations Environment Programme in 1988, the IPCC's mandate is "to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts."
- *"The unique power of this UN climate body lies in the breadth and depth of its climate assessment reports: Thousands of experts from around the world synthesize the latest scientific findings on the impacts of and the potential responses to climate change with the IPCC's comprehensive Assessment Reports released every five to seven years. There is nothing else like it"*.

IPCC - Recent Reports

- Oct 2018: *Special Report: Global Warming of 1.5 degrees C.*

In order to prevent reaching more than 1.5 degrees, will need to reach net emissions of zero by 2050.

- May 2019: *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
- Aug 2019: *Climate Change and Land*
- **Sept 2019: *The Ocean and Cryosphere in a Changing Climate***

Climate Science Background (not in IPCC report)

The Global Climate System – Complex Interactions

- Atmosphere
- Ocean
- Land

The Global exchange of water, energy and carbon

Climate affects the fundamentals

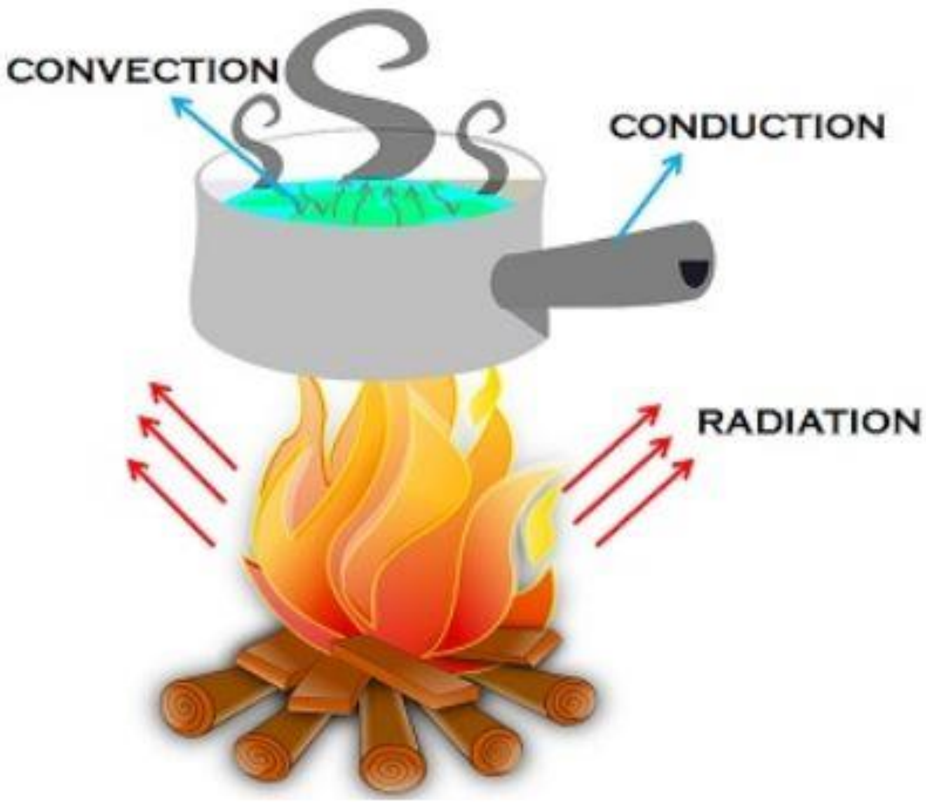
- **The climate drives the ecological processes and 'services' that life depends upon:**

- Water cycle (*nearly all rain that falls over land originates in the ocean)*
- Carbon and Nutrient cycle → Food
- Suitable temperature conditions

The Earth's Climate – underlying science

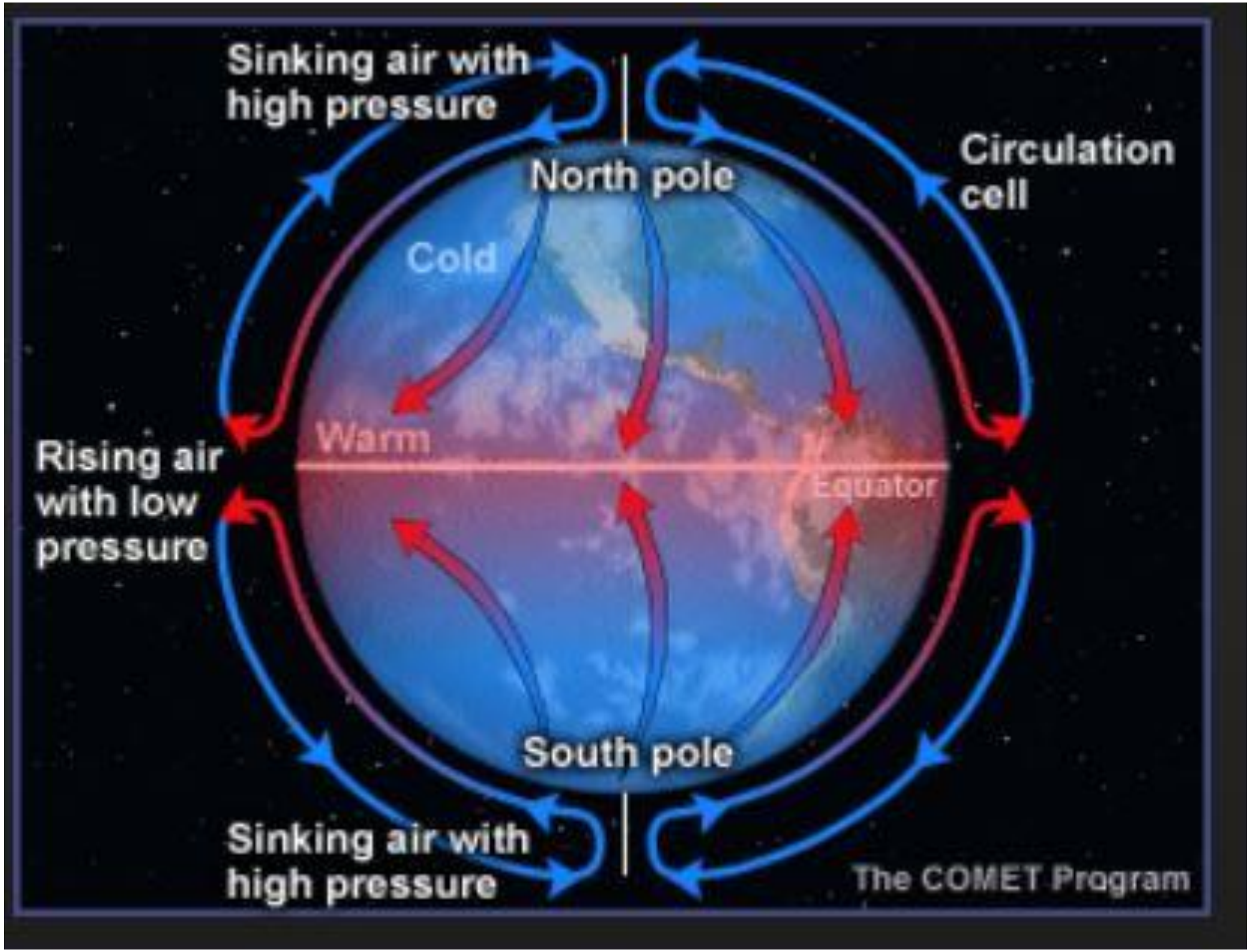
- The climate is driven by the absorption of **solar radiation** and subsequent **redistribution of energy** through wind, ocean currents and the water cycle (evaporation and rain)

Methods of Heat Transfer



While **conduction** is the transfer of heat energy by direct contact, **convection** is the movement of heat by actual motion of matter; **radiation** is the transfer of energy with the help of electromagnetic waves.

Warming and cooling causes air movement



Waterspouts

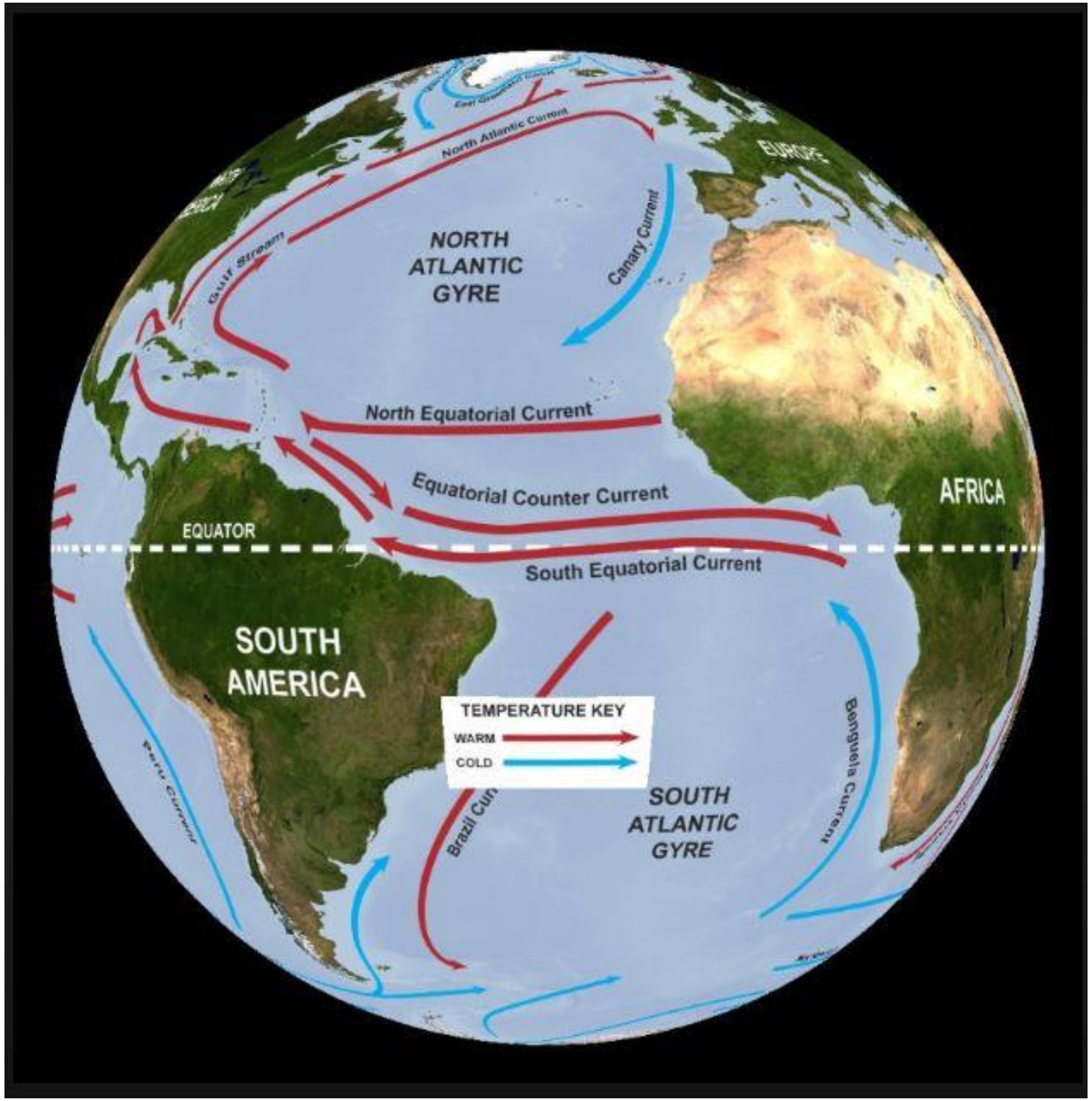
Off Grand Isle, Louisiana

Warm temperatures and high humidity, especially in a localized area, can cause air to rise with enough strength that water is drawn up with it into a funnel.

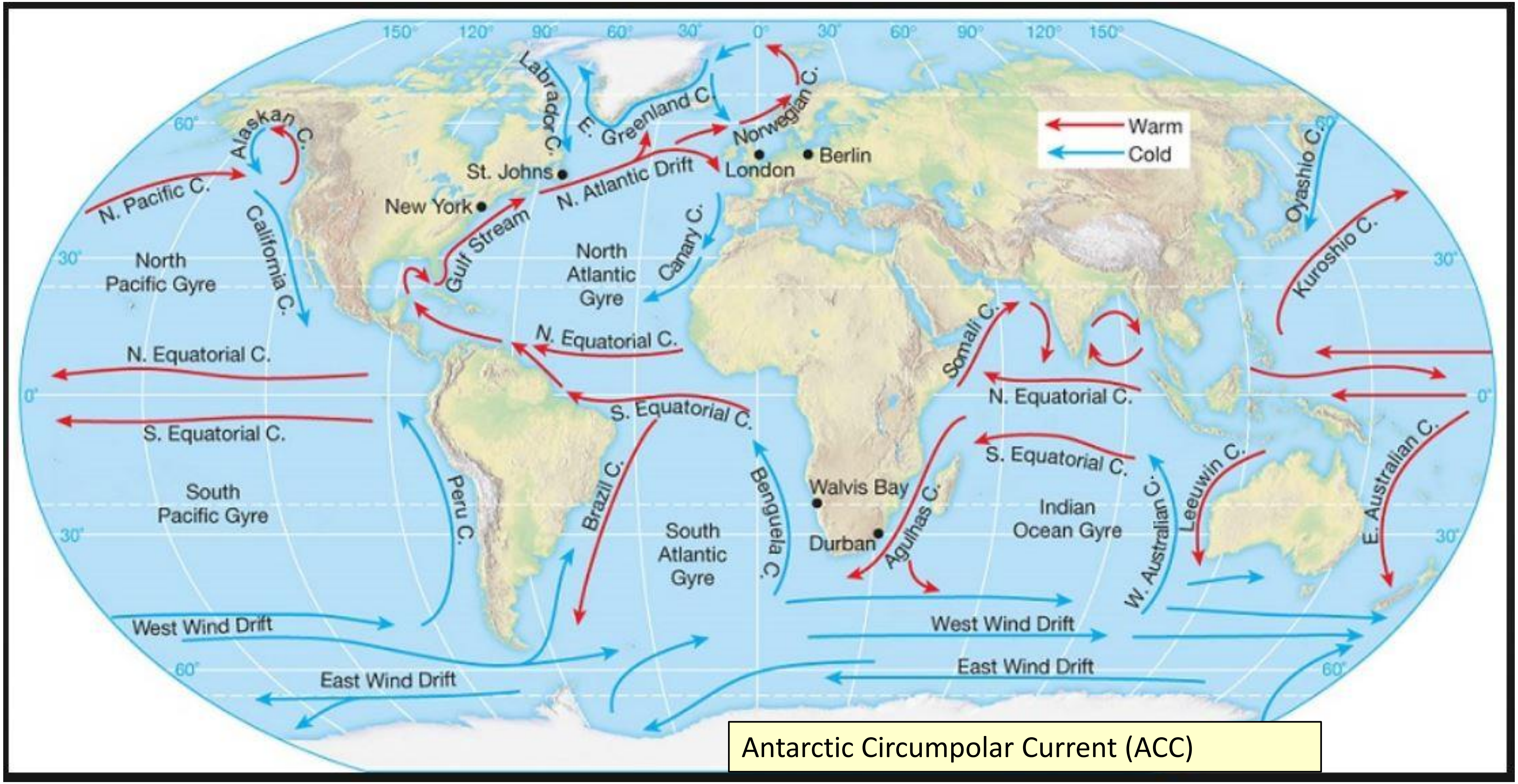
Transfer of energy

National Weather Service photo; Tim Osborn

Warming and cooling causes water movement



Global currents



Antarctic Circumpolar Current (ACC)

Climate Change – underlying science

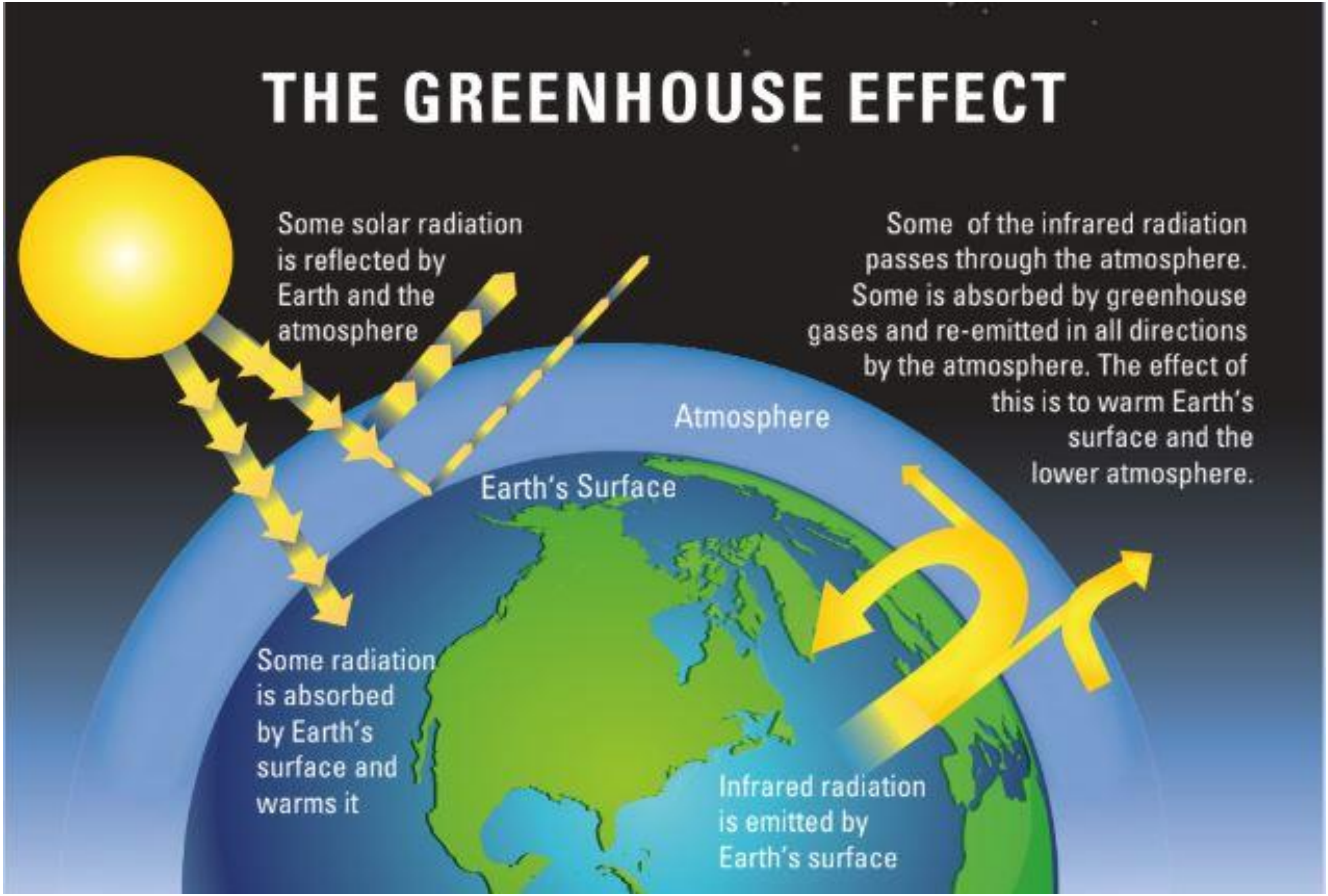
- Ocean currents drive global weather patterns
- Greenhouse gases* such as carbon dioxide (CO_2) absorb heat emitted from the earth's surfaces.
- Without these greenhouse gases, life would not exist; they trap the sun's heat and keep the planet warm.
- However, increases in the atmospheric concentration of these gases cause earth to warm by trapping more of this heat.

*Other greenhouse gases: methane (CH_2), nitrous oxide (N_2O), water vapor (H_2O)

The Physics of Climate Change

- The relationships between the atmospheric concentration of greenhouse gases and their radiative effects are well quantified (i.e., they absorb heat and then radiate heat energy in all directions)
- Unlike other greenhouse gases, CO_2 is not destroyed in the atmosphere but instead cycles between the atmosphere, terrestrial biosphere, and oceans.
- Energy use is the primary source of greenhouse gases. The main factors that drive energy use are economic growth and population growth.

https://www.aps.org/policy/reports/popa-reports/energy/climate.cfm
American Physical Society


THE GREENHOUSE EFFECT
Some solar radiation is reflected by Earth and the atmosphere
Some of the infrared radiation passes through the atmosphere. Some is absorbed by greenhouse gases and re-emitted in all directions by the atmosphere. The effect of this is to warm Earth's surface and the lower atmosphere.
Atmosphere
Earth's Surface
Some radiation is absorbed by Earth's surface and warms it
Infrared radiation is emitted by Earth's surface

Atmospheric CO2 – late 1950's to present

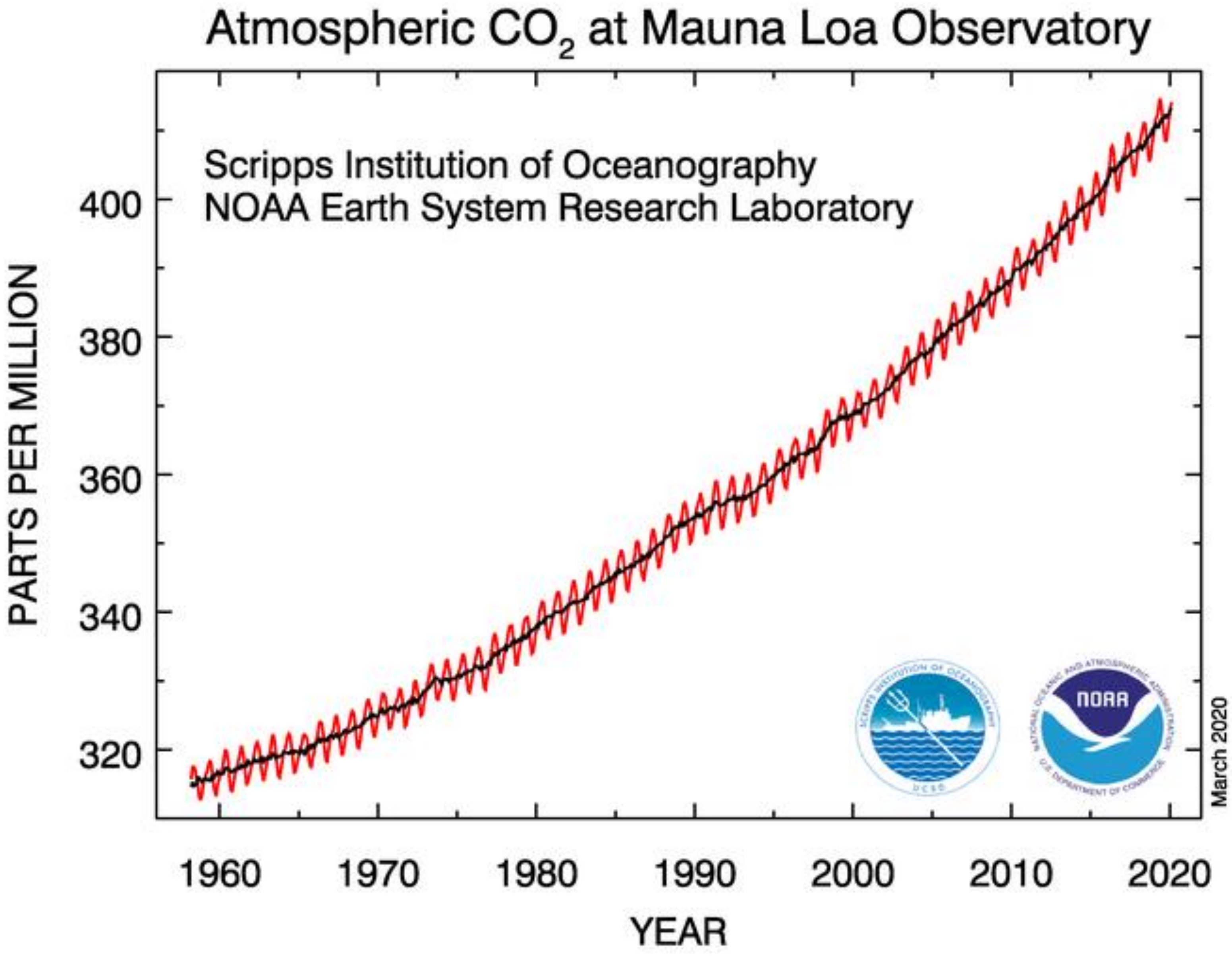
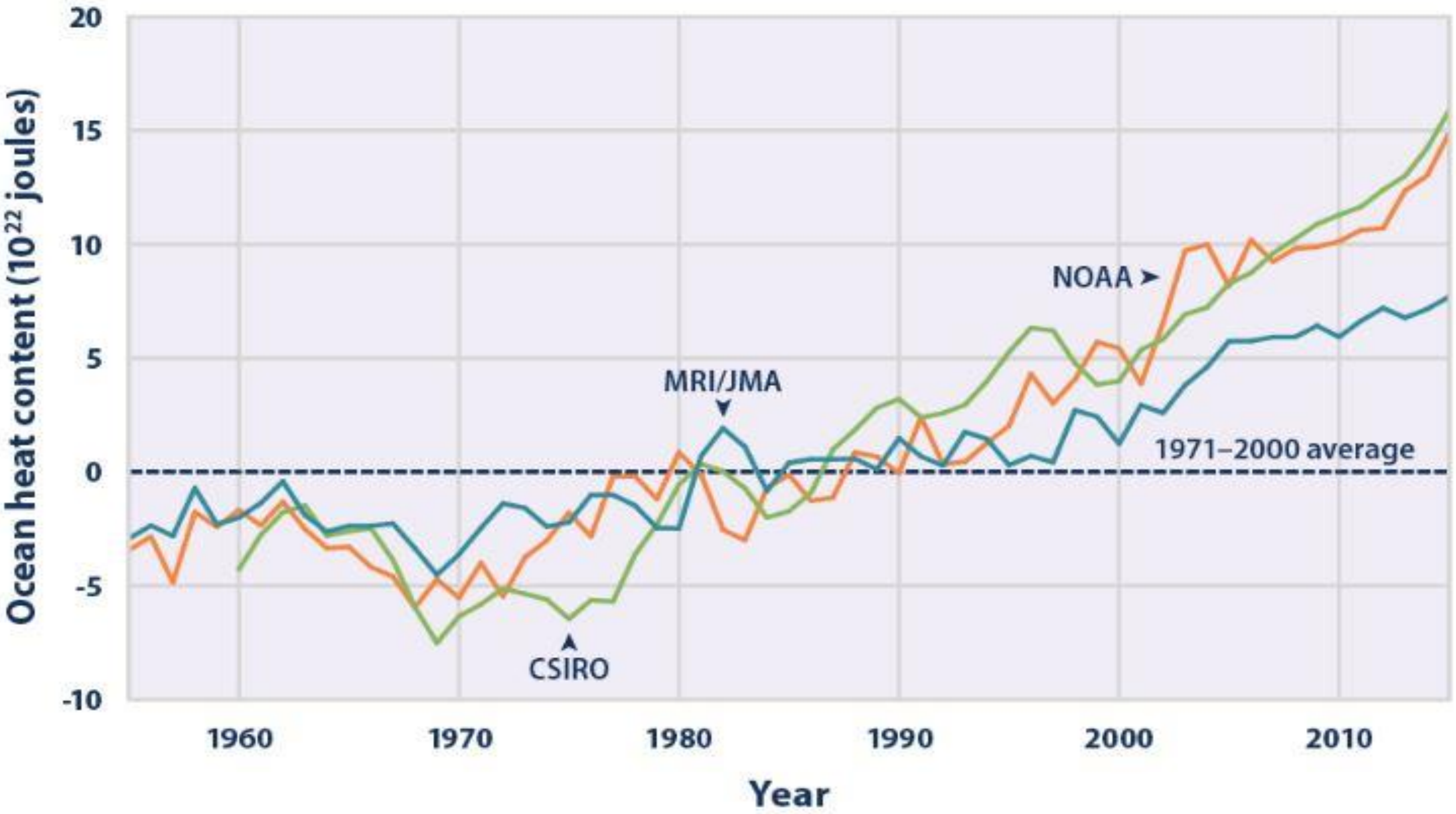


Figure 1. Ocean Heat Content, 1955–2015



Graph: US EPA

1 notable trend; Data from 3 countries

Harpoon vessel pursuing a school of bluefin tuna in Cape Cod Bay

Impacts of increased ocean heat content on bluefin unknown

INTERGOVERNMENTAL PANEL ON climate change

The Ocean and Cryosphere in a Changing Climate

This Summary for Policymakers was formally approved at the Second Joint Session of Working Groups I and II of the IPCC and accepted by the 51th Session of the IPCC, Principality of Monaco, 24th September 2019

Summary for Policymakers

Drafting Authors:

Nerilie Abram (Australia), Carolina Adler (Switzerland/Australia), Nathaniel L. Bindoff (Australia), Lijing Cheng (China), So-Min Cheong (Republic of Korea), William W. L. Cheung (Canada), Matthew Collins (UK), Chris Derksen (Canada), Alexey Ekaykin (Russian Federation), Thomas Frölicher (Switzerland), Matthias Garschagen (Germany), Jean-Pierre Gattuso (France), Bruce Glavovic (New Zealand), Stephan Gruber (Canada/Germany), Valeria Guinder (Argentina), Robert Hallberg (USA), Sherilee Harper (Canada), Nathalie Hilmi (Monaco/France), Jochen Hinkel (Germany), Yukiko Hirabayashi (Japan), Regine Hock (USA), Anne Hollowed (USA), Helene Jacot Des Combes (Fiji), James Kairo (Kenya), Alexandre K. Magnan (France), Valérie Masson-Delmotte (France), J.B. Robin Matthews (UK), Kathleen McInnes (Australia), Michael Meredith (UK), Katja Mintenbeck (Germany), Samuel Morin (France), Andrew Okem (South Africa/Nigeria), Michael Oppenheimer (USA), Ben Orlove (USA), Jan Petzold (Germany), Anna Pirani (Italy), Elvira Poloczanska (UK/Australia), Hans-Otto Pörtner (Germany), Anjal Prakash (Nepal/India), Golam Rasul (Nepal), Evelia Rivera-Arriaga (Mexico), Debra C. Roberts (South Africa), Edward A.G. Schuur (USA), Zita Sebesvari (Hungary/Germany), Martin Sommerkorn (Norway/Germany), Michael Sutherland (Trinidad and Tobago), Alessandro Tagliabue (UK), Roderik Van De Wal (Netherlands), Phil Williamson (UK), Rong Yu (China), Panmao Zhai (China)

Draft Contributing Authors: Andrés Alegria (Honduras), Robert M. DeConto (USA), Andreas Fischlin (Switzerland), Shengping He (Norway/China), Miriam Jackson (Norway), Martin Künsting (Germany), Erwin Lambert (Netherlands), Pierre-Marie Lefeuvre (Norway/France), Alexander Milner (UK), Jess Melbourne-Thomas (Australia), Benoit Meyssignac (France), Maike Nicolai (Germany), Hamish Pritchard (UK), Heidi Steltzer (USA), Nora M. Weyer (Germany)

DATE: 24 September 2019

Methods

“Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., medium confidence. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%”.

Scope of Report

- Ocean -
- Cryosphere - components of the Earth System at and below the land and ocean surface that are frozen - including snow cover, glaciers, ice sheets, ice shelves, icebergs, sea ice, lake ice, river ice, permafrost, and seasonally frozen ground
- High Mountain areas include all mountain regions where glaciers, snow and permafrost are prominent features of the landscape

- Ocean currents are an important component of the earth's climate system
- Oceans are a carbon 'sink'; absorb CO_2 and heat
- Arctic and Antarctic regions play important role in regulating earth's temperature.

Report Organization: Observed Impacts

- Physical Changes
- Impacts on Ecosystems
- Impacts on Ecosystem Services (anthropocentric)

10% of the earth’ s land surface is covered by glaciers or ice sheets;
The global ocean covers 71% of the earth’s surface

Physical Changes

- Increased surface air temperature
- Increased sea surface temperature
- Increased ocean heat content

Oceans have absorbed more than 90 % of the increased heat over the last 50 years

Physical Changes - Example of a finding

A2. It is *virtually certain* that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system (*high confidence*). Since 1993, the rate of ocean warming has more than doubled (*likely*). Marine heatwaves have *very likely* doubled in frequency since 1982 and are increasing in intensity (*very high confidence*). By absorbing more CO_2, the ocean has undergone increasing surface acidification (*virtually certain*). A loss of oxygen has occurred from the surface to 1000 m (*medium confidence*). {1.4, 3.2, 5.2, 6.4, 6.7, Figures SPM.1, SPM.2}

Physical Changes- Cryosphere

- Reductions in Arctic snow cover (June) (temperature rise in the arctic more than double the average global rate -during past 2 decades)
- Greenland Ice Sheet loss
- Glaciers mass loss
- Antarctic ice sheet loss
- Arctic sea ice thickness & extent (Sept)
- Decreased near-surface permafrost area (frozen soil and rocks) – release of methane and CO_2

Melting Permafrost

Release of methane and CO2

Photo: LA Times

Physical Changes - Cryosphere

- Reductions in Snow Cover
- Loss in Ice Sheets and Glaciers
- Reduction in Arctic sea ice thickness & extent
- Increased permafrost temp

Shrinking Cryosphere

Physical Changes – Cryosphere
Arctic Sea-Ice Feedback Loop

- Warmer surface air temp
- Reduced sea-ice
- Decreased sea ice reflective surface to reflect solar radiation
- Increase in surface area of ocean exposed to sun
- Additional warming of the ocean

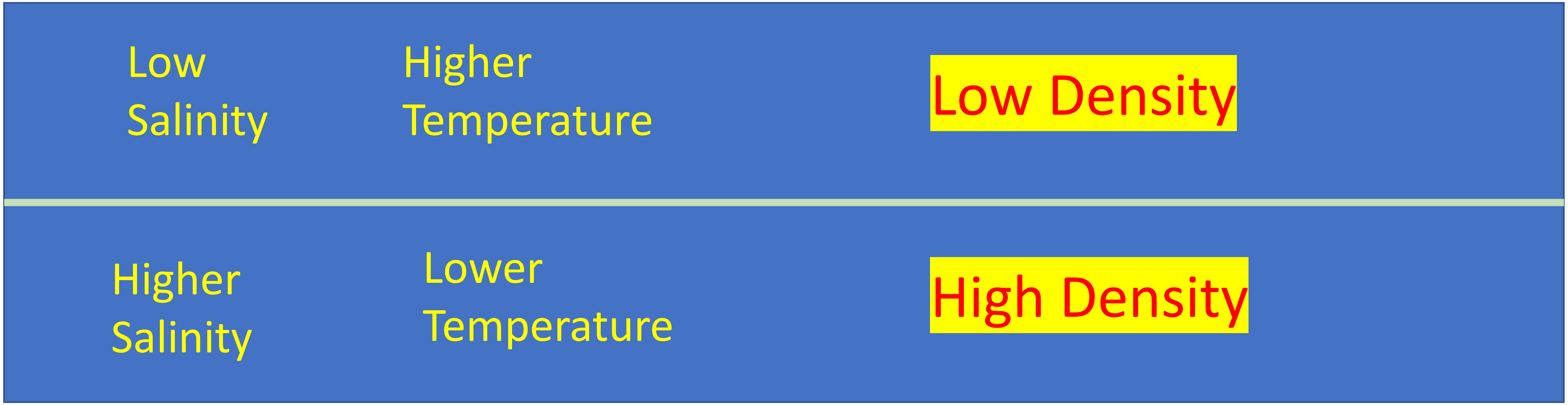
Physical Changes – High Mountain and Polar Land

- Water availability
- Floods
- Landslides
- Avalanches
- Ground subsidence

Physical Changes - Ocean

- Increased Ocean Temperature +
- Freshwater runoff from shrinking cryosphere (*melting ice*)

- **Increased density stratification (layering) in upper 200 m. of portions of ocean**



Physical Changes - Ocean

- **Increased stratification (layering) of portions of ocean**

↓

- Decreased mixing /water exchange from bottom to surface

↓

- Decreased oxygen in surface (warmer water retains less oxygen)
- Reduced nutrient availability in surface layer (nutrients sink to bottom of ocean over time)

Physical Changes - Ocean

- Ocean heat content (thermal expansion)
- Arctic sea ice extent
- Antarctic snow cover
- Near-surface permafrost area

Global mean sea level rise

Physical Changes - Ocean

- **Increased CO_2 in atmosphere**

↓

- **Increased CO_2 absorbed by ocean**

↓

- Declining pH of surface seawater

Additional Physical Changes – Ocean

- Increased precipitation (increased evaporation, higher atmospheric moisture and energy, esp. in Atlantic)
- Increased wave heights
- Increase in extreme sea level events

- Coastal erosion and flooding, salinization

Summary: Principal Physical Changes – Ocean

- Temperature
- Oxygen
- Ocean pH
- Sea-Ice extent
- Sea level

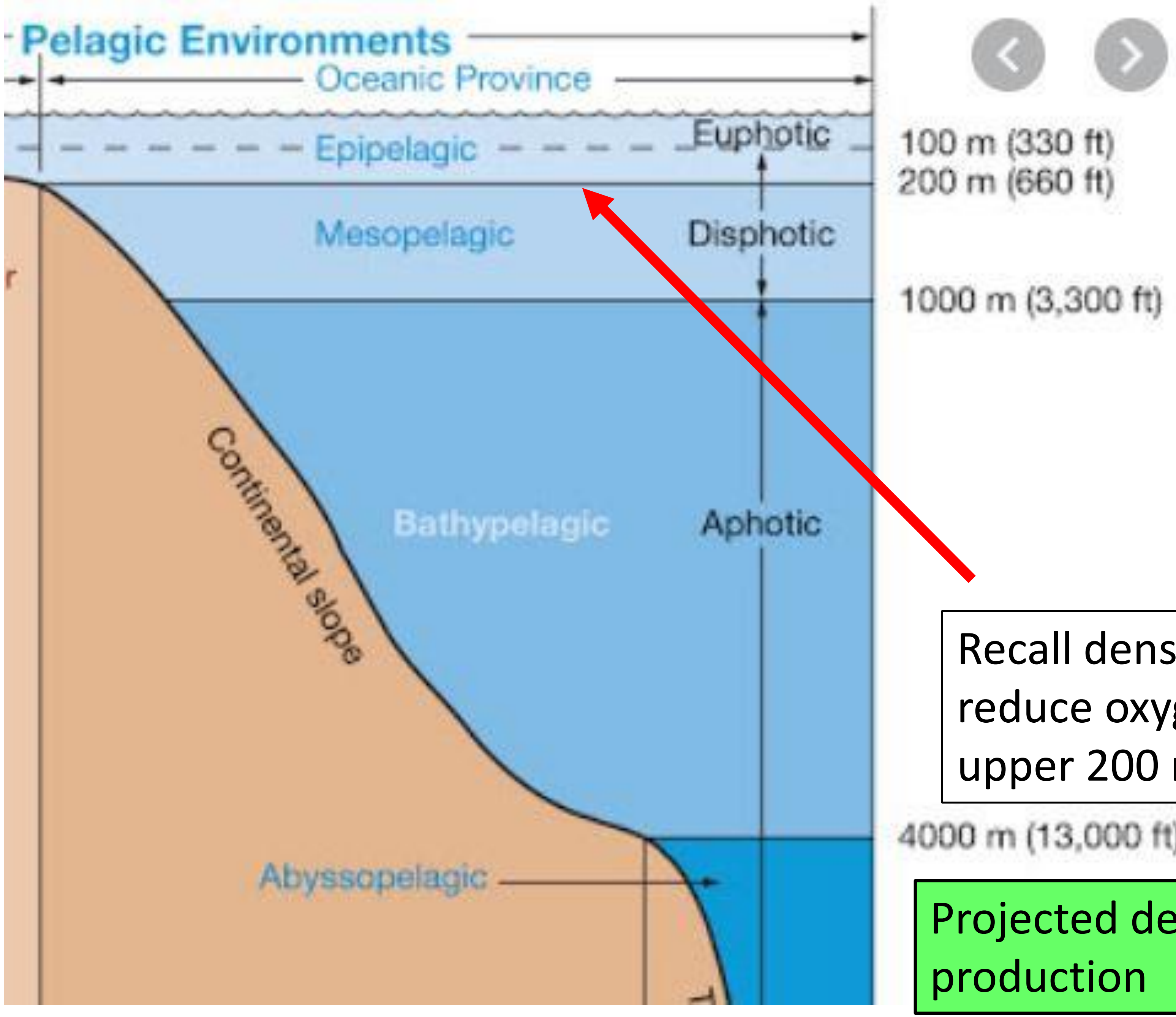
Ecosystems Impacted - Ocean

- Upper water column
- Coral
- Coastal wetlands
- Kelp forest
- Rocky shores
- Deep sea
- Polar benthos
- Sea-ice associated

Ecosystems Impacted - Ocean

Upper water column –

- **Species distribution shifts**, esp. poleward shifts (surface and bottom)(e.g. cod, lobster, etc.). Increasing catches of warm water species on shelves. Fish are poikilotherms ('cold blooded' – body temp varies over wide range, but narrow optimal range)
- **Primary Productivity - Variable impact to date but future negative impact projected** due to combined affects of warming, stratification, light, and nutrients
- **Change in ecosystem structure and function**
  - Increase in arctic net primary productivity (phytoplankton and zooplankton)
  - Spring phytoplankton bloom occurring earlier – timing issues
  - Prey distribution → Changes in forages success for seabirds and marine mammals
  - Negative impacts on two major upwelling systems: California current and Humbolt current Due to acidification and oxygen depletion
- **Outbreaks of diseases affecting marine organisms**



Euphotic zone receives enough light for photosynthesis

Disphotic zone Sunlight insufficient for photosynthesis

Recall density stratification may reduce oxygen and nutrients to upper 200 meters; euphotic zone

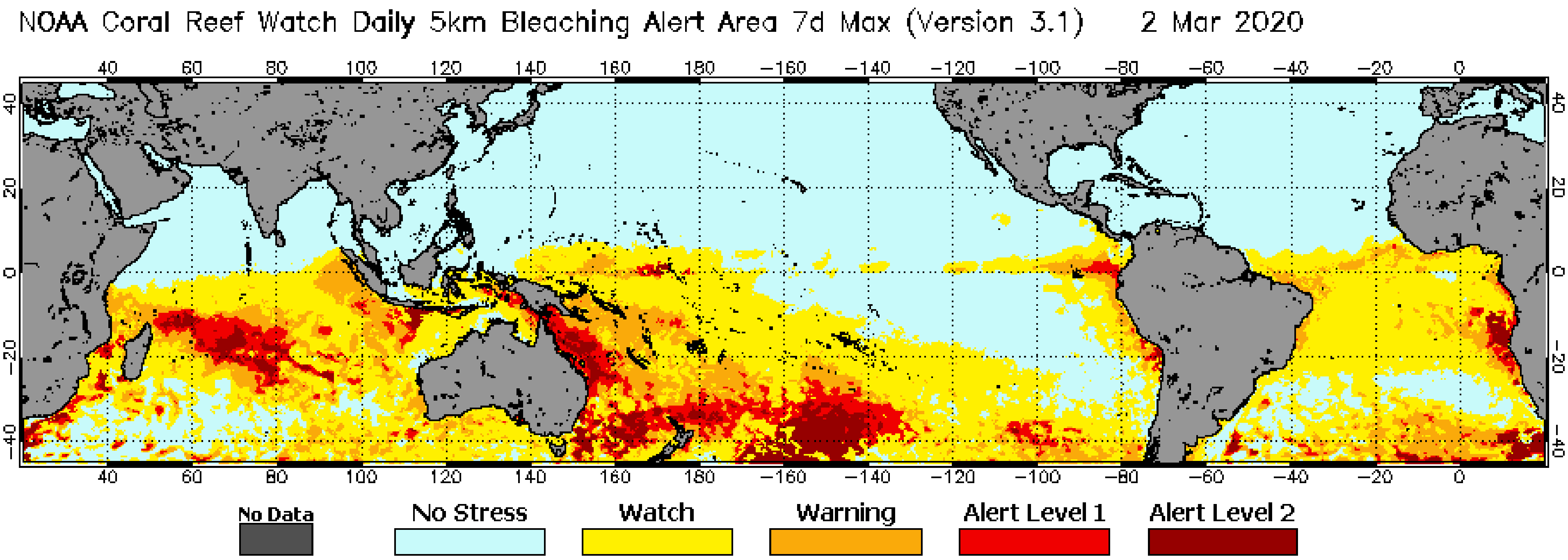
Projected decline in net primary production

Ecosystems Impacted - Ocean

Coral

- Warm water coral reef loss due to warmth and acidification
- Almost all coral reefs are projected to degrade from their current state

Analysis of Current Thermal Conditions: Regions currently experiencing high levels of heat stress that can cause coral bleaching and mortality.



Coralreefwatch.NOAA.gov

Ecosystems Impacted - Ocean

Benthic (bottom):

As a result of the reduction in Ph, and calcium carbonate undersaturation in surface waters, with warming and decreasing oxygen levels, projected

- impacts on shellfish larvae, benthic invertebrates and demersal (bottom) fishes
- related fisheries and aquaculture

Ecosystem Impacts - Ocean

- Primary drivers of marine ecosystem change:
  - Surface warming
  - Acidification
  - Oxygen loss
  - Nitrate content
  - Primary productivity change (phytoplankton & zooplankton, the base of the marine food web)

Ecosystems Impacted - Coastal

- **Degraded coastal ecosystems** (e.g., saltmarshes & mangroves) – species shift, decrease biodiversity; expansion of topical species
- **Loss of coastal wetlands** due to combined impacts of development, warming, sea level rise, and storms (50% loss of coastal wetlands in the last 100 yrs)
- **Saltwater intrusion into estuaries-** redistribution of species, and reduction of marine habitat, and decreased O_2
- **Rocky shore ecosystems** dominated by immobile calcifying organisms (mussels, barnacles) at risk

Synergistic effects with other human impacts:
habitat loss, nutrient load in estuaries

Ecosystems Impacted by Cyrosphere Changes

High Mountain and Polar ecosystem changes:

- Land uncovered
- Changes in abundance, distribution and activities and plants and animals
- Ecosystem function changes (tundra, forest, lakes/ponds, rivers/streams)
- Increased ecosystem disturbances (e.g., wildfires, and permafrost thaws)

Human Systems & Ecosystem Services - Ocean

- Food -Fisheries (cod; lobster; salmon; Apalachicola, Fla oysters, etc); projected reduction in global animal biomass (very likely), with regional differences

- Tourism (e.g., snorkeling on coral reefs; fishing; visiting the beach - harmful algal blooms, red tide and neurotoxins, Gulf of Mexico)

- Habitat services (breeding and nursery habitats for marine species)

- Transportation / shipping (e.g., arctic ocean; reduction in travel time)

- Cultural services (scientific research; pharmaceuticals and health; cultural identity; religious significance; international squabbles over new territory)

- Carbon sequestration

Ocean - Impacts on People

- Reduced levels of sustainable catches
- Impacts on incomes, livelihoods, food security
- Extreme weather events inland
- Coastal impacts - storm protection, flood control, pollution protection, carbon sequestration;

Sea-Level Rise & Coastal Impacts on People

Risks expected to increase significantly in the absence of major additional adaptation efforts

- Erosion
- Flooding
- Salinization (e.g., the nile → impact on agriculture)

Sea-Level Rise & Coastal Impacts on People

Extreme sea level events that are historically rare (for example, today's hundred-year event) will become common by 2100 under all RCPs (scenarios) (high confidence). *Many low-lying cities and small islands at most latitudes will experience such events annually by 2050.*

Sea-Level Rise & Coastal Impacts on People

- Non-climatic drivers of risk such as demographic trends in coastal areas, and subsidence due to development have played an important role in increasing low-lying coastal community exposure and vulnerability to sea level rise and extreme sea level events.
- Diversity of responses to coastal risks and disasters around the world; Mitigation of coastal risks – through hard coastal protections, ecosystem based adaptation (EbA), and advance (creation of new land), early warning systems

Human Systems & Ecosystem Services – High Mountain and Polar Land

- Affect on polar marine ecosystems → risk for commercial and subsistence fisheries
- Food and water security - loss of fresh water, water quality (heavy metals contamination from melting glaciers)
- Risk of food and water-bourne diseases
- Infrastructure – (e.g., roads on permafrost)
- Natural hazards - floods
- Migration – decrease transit times across northern sea-routes, increased shipping activity during arctic summer
- Cultural services, tourism and recreation

Road collapse due to melting permafrost

Anchorage Daily News

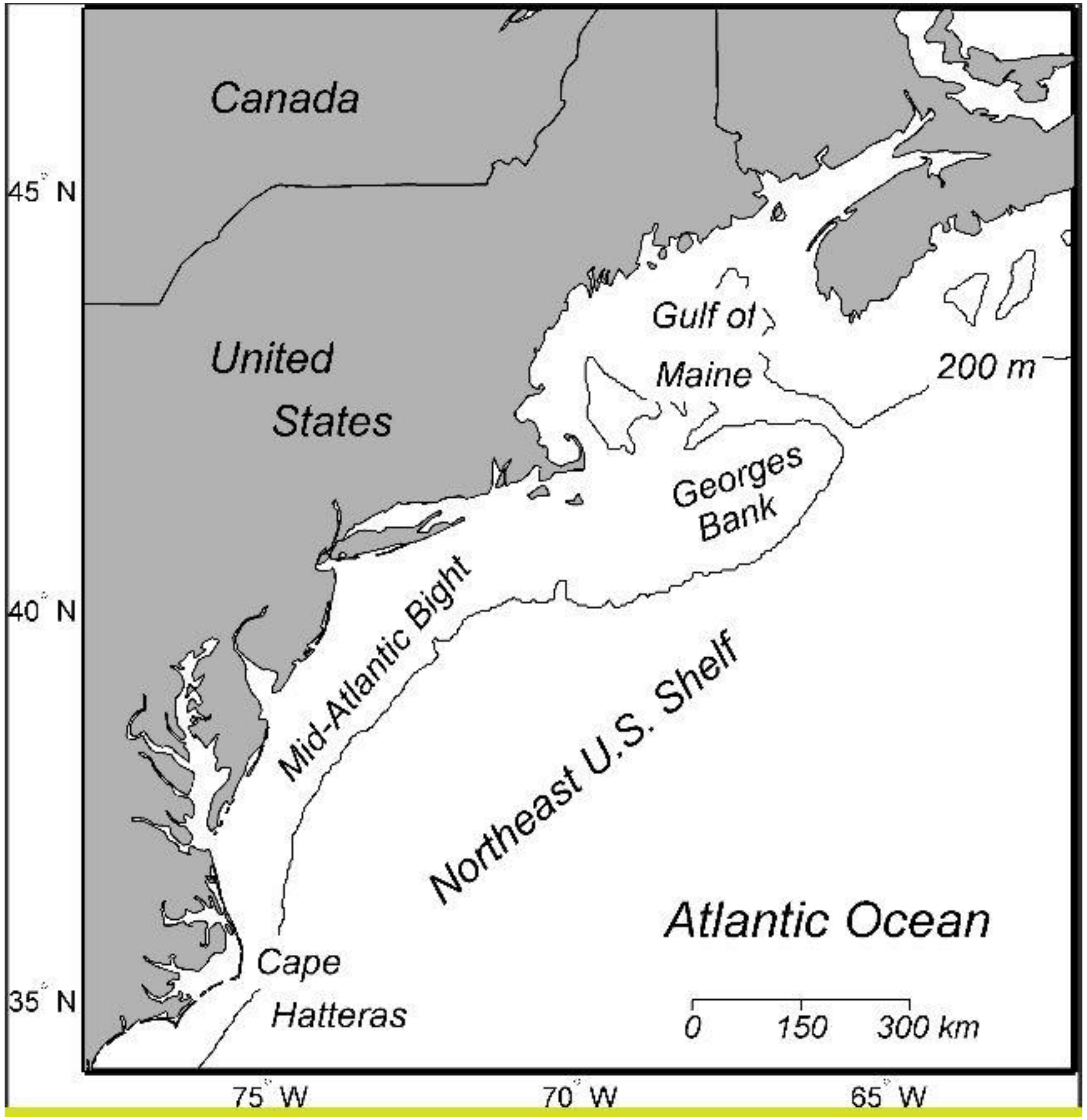
‘Local’ Impacts – Not in IPCC Report

- Published scientific literature

- NOAA’s Greater Atlantic Regional Office –(Gloucester) Presentations

- Press;

Northeast U.S. Continental Shelf Impacts



A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. Continental Shelf. Jonathan Hare, et.al. February 3, 2016. PLOS ONE

Northeast U.S. Continental Shelf - continued

- Overall climate vulnerability is high to very high for about ½ of species assessed (82 species assessed);
- Diadromous and benthic invertebrates exhibit the greatest vulnerability (e.g., eastern oyster, striped bass, Atlantic salmon);
- The majority of species have a high potential for changes in distribution;

Vulnerability to Climate Related Abundance Changes

Please note: These predictions have varying degrees of certainty

Biological Sensitivity

		Ocean & Northern Quahogs	Atlantic Salmon Bay Scallop
		14 Atlantic species including: Halibut Scallop Surfclam Tilefish Witch flounder Northern Shrimp	18 species including: Winter flounder Oysters River herring Shortnose & Atlantic sturgeons Shellfish (blue mussel, softshell crab, whelks, blue crab) Stripe bass Tautog
		12 Atlantic species including Cod Redfish Mackerel Sandlance Lobster Hagfish Pollock Skate species	Red drum American eel Conger eel Black sea bass Spotted sea trout
		21 species including Butterfish Squid species Bluefish Deep-sea red crab Hake species (silver, red, offshore) Skate species (winter, clearnose) Anchovies Flounders (yellowtail, windowpane) Haddock Atlantic Herring	Summer flounder Spanish mackerel Atlantic croaker Spot Northern kingfish Menhaden Weakfish Scup

Climate Exposure

Adapted from : Hare JA, Morrison WE, Nelson MW, Stachura MM, Teeters EJ, et al. (2016) A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf. PLoS ONE 11(2): e0146756. doi:10.1371/journal.pone.0146756 http://journals.plos.org/plosone/article?id=info:doi/10.1371/journal.pone.0146756

Rapid Climate-Driven Circulation Changes Threaten Conservation of Endangered North Atlantic Right Whales*

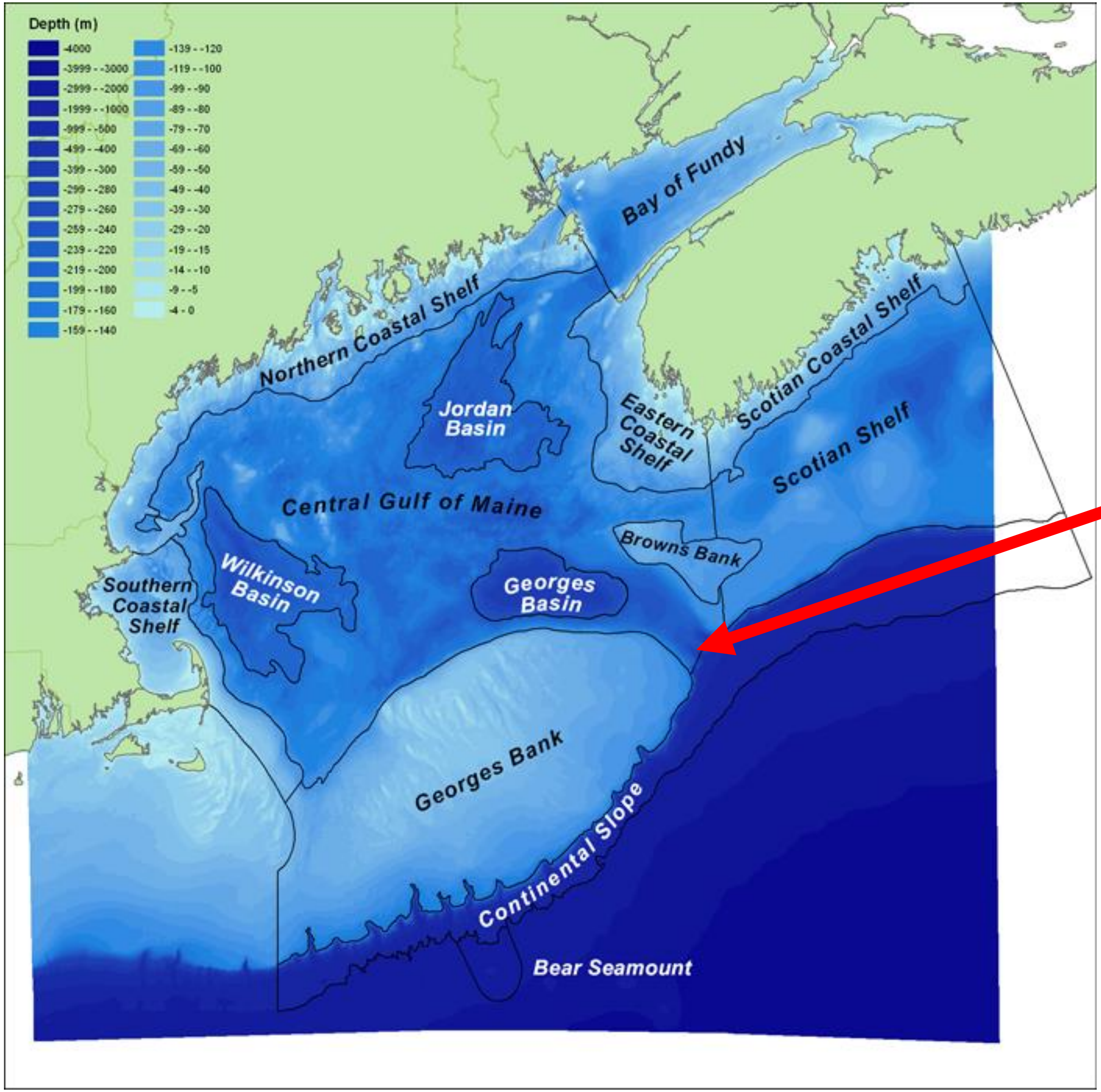
➢ Climate driven changes have restructured the Gulf of Maine ecosystem

- Gulf of Maine surface waters are warming faster than 99% of the global ocean
- Large amounts of warm slope water entering the Gulf of Maine
- Deep water warming
- Impacts late summer supply of copepods (*Calanus finmarchicus*)(70% fat content)
- Spring migration (from south) of whales (mothers and calves) to Gulf of Maine to feed.

- Deviation in seasonal feeding patterns in whales
- Increased vulnerability to ship strikes and gear entanglements

*Record, N.R, et. al. Oceanography. Volume 32, No. 2. Pages 162 -169

Gulf of Maine Bathymetry



Northeast Channel:

Deep water current entrance to Gulf of Maine

North pacific salmon vulnerability: Certain Chinook, coho, and sockeye salmon population groups are the most vulnerable to expected environmental shifts with climate change. These include more extreme high and low flows and hotter oceans and rivers.

Lisa G Crozier et. al. Climate Vulnerability Assessment for Pacific Salmon and Steelhead in the California Current Large Marine Ecosystem. July 24, 2019. PLOS ONE

Why is Global Warming/Climate Change Important?

- **Heat drives the climate**
- **The climate drives the ecological processes and ‘services’ that life depends upon**

IPCC Report: Responding to Changes

"The scale and cross-boundary dimensions of changes in the ocean and cryosphere challenge the ability of communities, cultures and nations to respond effectively within existing governance frameworks (high confidence).

Profound economic and institutional transformations are needed if climate-resilient development is to be achieved (high confidence)".

~ END ~

Additional Information

A3. Global mean sea level (GMSL) is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (*very high confidence*), as well as continued glacier mass loss and ocean thermal expansion. Increases in tropical cyclone winds and rainfall, and increases in extreme waves, combined with relative sea level rise, exacerbate extreme sea level events and coastal hazards (*high confidence*). {3.3; 4.2; 6.2; 6.3; 6.8; Figures SPM.1, SPM.2, SPM.4, SPM.5}

IPCC Report: Responding to Changes -coastal

“Pervasive human coastal disturbances will limit natural ecosystem adaptation to climate hazards (high confidence)”.

A5. Since about 1950 many marine species across various groups have undergone shifts in geographical range and seasonal activities in response to ocean warming, sea ice change and biogeochemical changes, such as oxygen loss, to their habitats (*high confidence*). This has resulted in shifts in species composition, abundance and biomass production of ecosystems, from the equator to the poles. Altered interactions between species have caused cascading impacts on ecosystem structure and functioning (*medium confidence*). In some marine ecosystems species are impacted by both the effects of fishing and climate changes (*medium confidence*). {3.2.3, 3.2.4, Box 3.4, 5.2.3, 5.3, 5.4.1, Figure SPM.2}

The Physics of Climate Change

- The relationships between the atmospheric concentration of greenhouse gases and their radiative effects are well quantified (i.e., they absorb heat and then radiate heat energy in all directions)

- Unlike other greenhouse gases, CO_2 is not destroyed in the atmosphere but instead cycles between the atmosphere, terrestrial biosphere, and oceans.

- Energy use is the primary source of greenhouse gases. The main factors that drive energy use are economic growth and population growth.

https://www.aps.org/policy/reports/popa-reports/energy/climate.cfm
American Physical Society

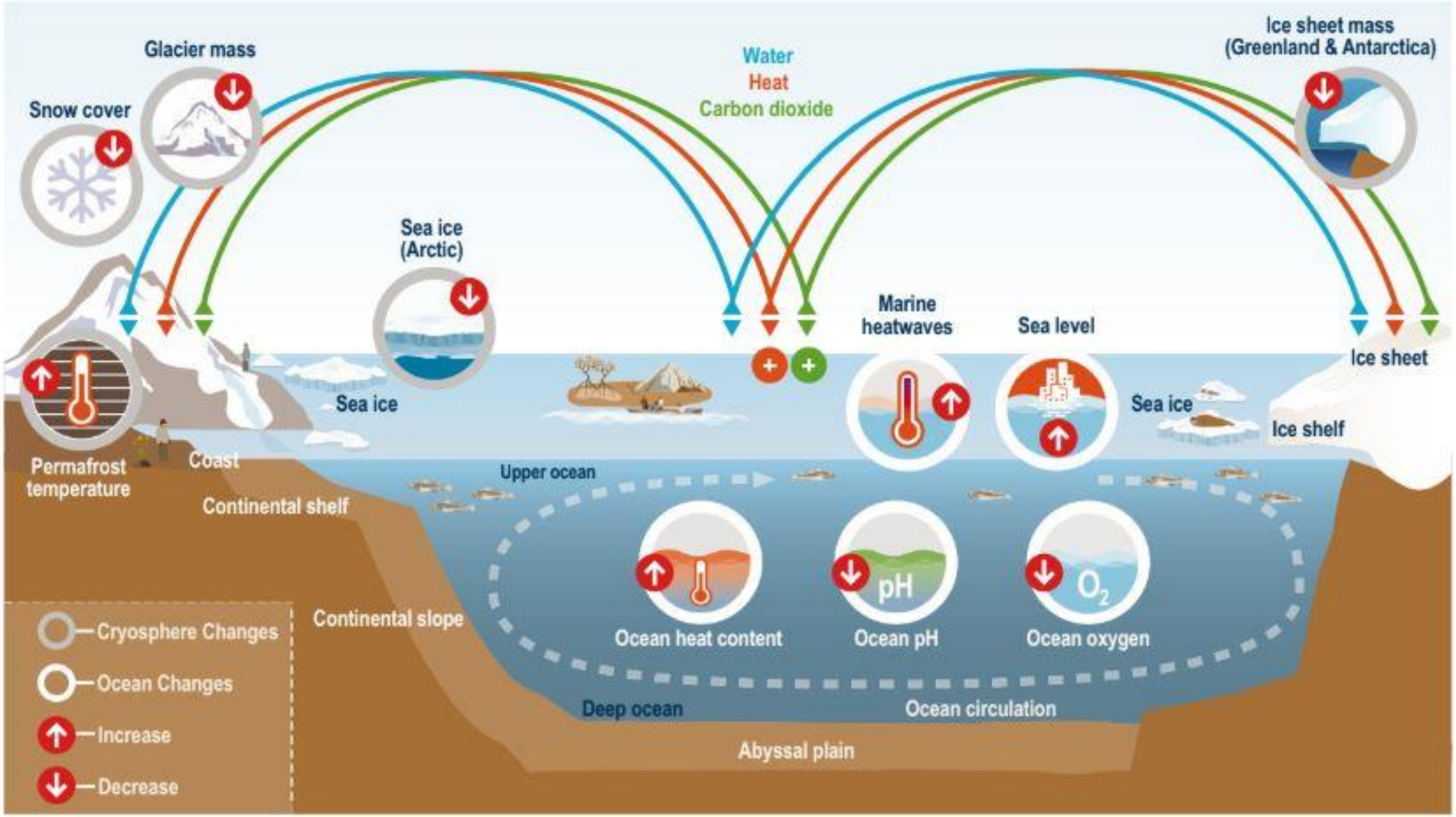


Figure TS.2 | Schematic illustration of key components and changes of the ocean and cryosphere, and their linkages in the Earth system through the global exchange of heat, water, and carbon (Section 1.2). Climate change-related effects (increase/decrease indicated by arrows in pictograms) in the ocean include sea level rise, increasing ocean heat content and marine heat waves, increasing ocean oxygen loss and ocean acidification (Section 1.4.1). Changes in the cryosphere include the decline of Arctic sea ice extent, Antarctic and Greenland ice sheet mass loss, glacier mass loss, permafrost thaw, and decreasing snow cover extent (Section 1.4.2). For illustration purposes, a few examples of where humans directly interact with ocean and cryosphere are shown (for more details see Box 1.1).

How do know that the increased $CO_2$is from fossil fuels?

- Carbon has three varieties (isotopes; C12, C13, C14): Same number of protons, three different numbers of neutrons;
- Plants: have both C12 and C13 but prefer C12 (lower C13/C12 ratio)
- As more CO2 from plants and fossil fuels are released into the atmosphere, the average C13/C12 ratio decreases.
- An decreased C13/C12 ratio is indicative of increased fossil fuel use.
- C13/C12 ratios are ‘recorded’ in tree rings, ice cores, and more recently in sea surface water samples. They provide a ‘snapshot’ of the atmospheric conditions at the time the ring was created.
- The C13/C12 ratios began to decline dramatically at the same time the amount of CO2 began to dramatically increase (about 1850)

Sources of Uncertainty

- Precise prediction of atmospheric concentrations of CO_2 based on emissions;
- Largest source of uncertainty: precise predictions in changes in climate based on greenhouse gases due to difficulty in determining the magnitude of climate feedbacks.
- For example, an increase in trapped radiation and the associated warming is expected to increase the level of water vapor in the atmosphere, which would tend to further enhance the greenhouse effect in a positive feedback. An example of a negative feedback would be an increase in clouds that reflected more sunlight back into space. The actual feedback from changes in clouds is uncertain since they also act to trap outgoing infrared radiation.
- It is the balance between positive and negative feedbacks which will determine the net effect of increased greenhouse gases. While climate models agree that the net effect will be warming, the amount of warming (and other changes) given by various models is different.

How CO_2 increases acidity and affects carbonate*

- When CO_2 mixes with seawater, results in reduced availability of carbonate ions, which marine organisms need to build shells;
- $CO_2 + H_2O \Rightarrow H_2CO_3$ (carbonic acid) $\Rightarrow H^+ + HCO_3^-$ (bicarbonate)
- carbonate (CO_3^{-2}) is simultaneously consumed by reaction of the excess of hydrogen ions produced from the reaction above:
- $H^+ + CO_3^- \Rightarrow HCO_3^-$
- Combining the two reactions, the net affect is approximately that *one unit of carbonate ion is consumed for each unit of carbon dioxide added to seawater.*
- $CO_2 + H_2O + CO_3^{-2} \leftrightarrow 2HCO_3^-$
- Because the reactions run simultaneously, both pH and the availability of carbonate are reduced as the atmospheric concentration of carbon dioxide rises.

*Woods Hole Oceanographic Institution

From 2/9/2020 NY Times

- Antarctica record temp set on 2/6/2020: northern tip of peninsula recorded temp of 64.9 degrees. (Argentina National Meteorological Service) – temps were also 64 in Huntsville, AL and Los Angeles on that day.
- The ice sheet contains 90% of the worlds fresh water.

Washington Post – 2/19/20 "Boston harbor rise brings ashore a new enemy: Rising seas"

- Boston ranked world's eighth most vulnerable to floods among 136 coastal cities (2013, Organization for Economic Cooperation and Development)
- ½ of the city is built on low-lying landfill (e.g., commercial piers, Logan Airport, south end, Seaport area)

Other New England ecological impacts

- Decline of kelp in southern Maine, increased bryozoans; ecological importance and CO_2 sink. Shortened growing season; Increase in invasive seaweed, “turf seaweed” (*Dasysiphonia jajonica*)

Ocean Heat Content Slide:

- The lines were independently calculated using different methods by government agencies in three countries: the National Oceanic and Atmospheric Administration (NOAA), Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), and Japan Meteorological Agency's Meteorological Research Institute (MRI/JMA). For reference, an increase of 1 unit on this graph (1×10^{22} joules) is equal to approximately 18 times the total amount of energy used by all the people on Earth in a year.[4]
- Data sources: CSIRO, 2016[5]; MRI/JMA, 2016[6]; NOAA, 2016[7]
  Web update: August 2016

- In three different data analyses, the long-term trend shows that the oceans have become warmer since 1955 (see Figure 1).
- Although concentrations of greenhouse gases have risen at a relatively steady rate over the past few decades (see the Atmospheric Concentrations of Greenhouse Gases indicator), the rate of change in ocean heat content can vary from year to year (see Figure 1). Year-to-year changes are influenced by events such as volcanic eruptions and recurring ocean-atmosphere patterns such as El Niño.

Localized predictions may have low confidence

Table 3.2: Model projections of trends due to climate-change driven alteration of phytoplankton properties under RCP8.5 from 2006–2100 across three zones of the Southern Ocean, from Leung et al. (2015). There is *low confidence* in predicted zonal changes in phytoplankton biomass due to *low confidence* regarding future changes in iron supply in the Southern Ocean (Hutchins and Boyd, 2016). Acidification was not reported as an important driver in this modelling experiment.

Zonal Band	Predicted change in phytoplankton biomass	Drivers	Mechanisms
40°S–50°S	↑	Higher mean underwater irradiance More iron supply	Shallowing of the summertime mixed layer depth Change in iron supply mechanism
50°S–65°S	↓	Lower mean underwater irradiance	Deeper summertime mixed layer depth Decreased summertime incident radiation (increased cloud fraction)
S of 65°S	↑	More iron supply Higher mean underwater irradiance Temperature	Melting of sea–ice Warming ocean