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47

Ensuring the future of the oceans

Bernd J. Haupt and Maurie C. Kelly

Introduction

> The future depends on what we do in the present.
>
> Mahatma Gandhi

Our oceans, which cover more than two-thirds of the Earth's surface and sustain 80 per cent of all known living organisms, were once thought to be an inexhaustible resource that would forever provide sustenance, support economic development, and serve as the primary food source for our growing populations. These expansive and mysterious bodies of water were considered too vast and the biological resources too plentiful to be depleted or to be impacted by the behaviour and needs of the human race. However, over the past several decades an awareness of the precarious condition of our Earth's resources, particularly our oceans, has grown as we have learned more about this unique physical and biological environment which serves as a habitat for fish, birds and mammals, and has a direct impact on climate and thus human existence.

The driving force behind this increased understanding is the ability of scientists and researchers to understand and communicate the intricate and complex phenomena that encompass the geography of the areas known as our oceans. Additionally, media coverage of the development of greenhouse gases, temperature and climatic changes such as alterations in storm tracks and hurricanes, coral bleaching, the melting and formation of Artic and Antarctic sea ice, airborne pollution and contamination of the oceans though various incidents such as oil spills has led to greater public awareness of the importance and vulnerability of our oceans.

Since 1985, even greater attention has been focused on the health of our oceans as these factors began to affect economic development and the physical well-being of our population. During this time significant advances in understanding ocean circulation emerged – demonstrating, for the first time, that a global conveyor belt links the Atlantic, Indian, and Pacific Oceans together. Numerical ocean and climate simulations demonstrate that this system of ocean currents is in a delicate balance and, if disturbed, could cause dramatic global climate changes. The swiftness with which these changes could occur is revealed by studies of the geological past that have shown that dramatic changes in our oceans can cause major, rapid climatic changes, sometimes within decades.

This new knowledge and the recognition that the oceans will have to be managed to meet the needs of a population that has increased from less than 1 billion in 1790 to over 6 billion in 2000 (see Chapter 9) as a food resource, as a potential future energy supplier, and even more important as a climate stabilizer, has led to large-scale national and international scientific studies. The goals of these studies were to provide decision makers with more precise predictions and early detection and warning systems to be implemented to help ensure the future of our oceans, and thereby, our own future.

Historical view of detecting of environmental changes: air versus water

Undoubtedly, the process of detecting changes in the ocean started much later than the detection of changes in the quality of our air. There are many reasons for this disparate timeline – most notably that the pollution caused by fossil fuel emissions is frequently visible and thus much more obvious to the human eye, while changes in water quality are usually more difficult to trace.

Advances in technology over the past century have been both the cause of increased environmental changes and the basis for analysing those changes. With the onset of the Industrial Revolution, innovations in technology and industry occurred at a rapid pace, enabling immense economic growth, while simultaneously laying the seeds for environmental change (see Chapter 1). The Industrial Revolution changed the population from a largely rural population making a living almost entirely from agriculture to a town-centred society engaged increasingly in manufacturing and industry. These dramatic changes resulted at first in an increase in airborne pollution followed by pollution of streams and rivers, which then carried these toxins via river deltas into marginal or epicontinental seas, then eventually into our oceans.

Western European societies, most notably Great Britain, were particularly affected by the air and water pollution in the earliest years of the Industrial Revolution, since understanding of how industrial waste and pollutants impact humans or the environment was limited and the science of studying our environment was in its infancy. The study of how these massive changes in our societal structure might impact the deep oceans and thus our climate, as well as the technology to perform such studies, was still in the distant future. The earliest scientific tests involved simply taking samples of air and water and examining and weighing the remaining residue. This process was considered adequate for many years for air quality evaluation since most pollution originated primarily from fossil fuel emissions. On the contrary, this early method was less effective for water quality sampling since samples were taken from rivers and streams, or from tidal waters that carried sediment (suspended soil particles), making them appear muddy and turbid. Since the turbidity or clarity of water is not a criterion for water quality, other more complex methods like physical and biogeochemical analysis were required to measure factors such as salinity (historically the measurement of the chloride ion concentration in 1 kg of seawater, replaced by measurement of conductivity via the ion concentration), oxygen, pH, pathogens (bacteria and viruses), phosphorus (stimulates the growth of algae), and/or nitrogen (can affect drinking water). For many reasons, extending these types of analyses to the open ocean in the past had been a more difficult process. Pollutants in the open ocean usually originated from local discharge caused by agriculture, factories and towns and cities. The discharge drains from rivers and canals via river deltas into the open ocean, where it becomes diluted. Tides then rapidly disperse the contaminants, making monitoring and detecting changes through traditional water-quality testing an even greater challenge, with less reliable results.

Exploration of the ocean, atmosphere and climate

The human impact on the environment and the oceans

The regular recording of weather data began many years prior to the development of metrics for recording regular measurements in the open ocean. It was much easier to install and upgrade land-based weather stations for monitoring purposes. It was simpler to vertically profile the atmosphere than the ocean. A simple look into the sky gives us insight into some of the atmosphere's vertical dynamics, while the ocean allows us only to look only a few metres into its depths – in short, we can see only as far as the light penetrates (even in the twentieth century the deep ocean was seen as a dark and cold place). An example of the ease with which weather data, as opposed to ocean data, are gathered is exemplified by the release of a weather balloon carrying a weather data recording device which profiles the atmosphere. A gas-filled weather balloon rises through the atmosphere and expands with height due to decreasing atmospheric pressure. The recording device drops back to the ground after being either released by a timer or after the balloon explodes/bursts at a given height. Unlike the way an atmospheric data gathering device would drop down to Earth, gravity would not return a recording device dropped from a ship into the ocean; it requires more technical finesse to design a pressure withstanding device that rises back to the ocean surface.

Since very little was known about the deep ocean, very little attention was paid to any impacts or changes that might be occurring from pollution – industrial or otherwise. In fact, from earliest times, the ocean has been used for the disposal of civilization's wastes and untreated sewage. It provided a so-called economical NIMBY (Not in My Back Yard) outlet for waste disposal.

In Great Britain, the practice of ocean dumping of sewage sludge dates back to the end of the eighteenth century with the dumping of the city of London's wastes into the outer Thames estuary. In the United States, the first dumping of untreated municipal sewage sludge occurred in 1924 in the New York Bight. The expansion of towns and cities around the world, especially in low latitudes since 1950, continues to provoke the release of waste products to the environment, affecting both freshwater and marine environments, even though great progress has been made in waste management and water treatment.

Not surprisingly, the marine pollution severely affecting nearly enclosed seas and deltaic systems for long remained undetected. Large-scale oceanic changes in water quality were first detected in enclosed ocean basins that have a very limited water exchange with the global ocean: the Baltic Sea and Mediterranean Sea are two examples. They are linked to the global ocean via the Oresund (Denmark–Sweden) and Strait of Gibraltar (Morocco–Spain), respectively. Other partially enclosed seas, like the Caribbean Sea and Gulf of Mexico, differ from the Mediterranean and Baltic in two ways: population and ocean currents. Decades to centuries ago, the populations utilizing these seas were much smaller than those of the Baltic and Mediterranean Seas. More importantly, the Caribbean Sea and Gulf of Mexico have a system of ocean currents leaving and entering these two semi-enclosed ocean basins at two different localities ensuring a constant water exchange.

Even though British River Thames became a major transported of waste to the North Sea, that sea was less affected by waste than other coastal regions such as the New York Bight, the Houston Ship Channel, Japan's Bay of Minamata, the Baltic Sea and the Mediterranean

Sea. The Baltic Sea and Mediterranean Sea are in some ways unique because both have been heavily used for waste disposal by the bordering states, which were unable to agree on 'equal' standards for industrial, agricultural and waste discharges. Over centuries, these enclosed seas bore the burden of the dumping of unregulated discharges, as well as legal and illegal industrial dumping of toxic wastes (including ammunition and chemicals from World War I and World War II) emanating from vessels on the open water.

In the 1970s, the public awareness for environmental problems and coastal pollution began to emerge. Media coverage of organizations such as Greenpeace (since 1971), which campaigned against environmental degradation, showed algae blooms, disfigured and dead fish and seals with high levels of antibiotics and heavy metals, land-and sea-based illegal dumping of toxic waste in costal regions as well on the high seas, decreasing fish and shellfish populations, and other environmental impacts. This enhanced knowledge and access to information propelled the general public into action and helped increase public understanding. The awareness of the impact of the runoff from farms, animal feedlots and streets, and municipal waste water sewage plants which created huge 'dead zones' in many bays and estuaries was dawning on the public. Coastal marshes and wetlands, which trap floodwaters, filter out pollution and nurture fish, birds and other wildlife, were disappearing. The more the public learned about habitat deterioration as a result of coastal development and water quality degradation, the more the interest in protecting the oceans emerged. It was at this time, coincidentally, that the bordering states of the Baltic Sea and Mediterranean Sea established 'equal' standards in federal regulations (i.e. inland cities would be economically disadvantaged if coastal cities were allowed to discharge wastes into the ocean because regulations for water usage – and any kind of discharge – in streams and rivers existed much earlier than for the ocean). The ideas of environmental protection and the era of recycling were born. It was as a result of this new awareness and the growth of new technologies that humans intensified efforts in the twentieth century to systematically explore the oceans.

Exploring the ocean: past and present

While understanding of the integrated nature of our environment as a whole and the systematic analysis of our ocean environment may be a more modern phenomenon, it would be a mistake to ignore the early explorers and researchers of past centuries.

Some of the earliest known series of 'expeditions' are those of the Polynesian Seafarers, who sailed the Pacific Ocean about 30,000 years ago, and were known as the 'Masters of Ocean Currents'. These explorers made the earliest forms of navigational or oceanographic maps, called stick charts. Stick charts, which were made of pieces of bamboo or other wood tied together, were used to as navigational tools. Shells or knots marked the locations of islands while curved pieces of wood represented the pattern of ocean waves around the island or even the manner in which the waves rocked or shifted their canoes.

During a more active period of exploration covering the past several centuries, many more followed in the footsteps of the Polynesian Seafarers, piecing together the puzzle that is our ocean(s) and our globe. There are too many unique expeditions to mention in this brief text; however a few of the more interesting examples include: more than 1900 years ago sailors from Egypt, Phoenicia, and Crete mapped the regional coastlines to establish some of the earliest trading routes; approximately 650 years ago European explorers like Prince Henry, the Navigator of Portugal, recognized the oceans' importance to trade and commerce; Christopher Columbus sailed westward across the Atlantic Ocean to America and back; about 500 years ago Ferdinand Magellan, the Portuguese navigator, circumnavigated the globe.

Even the famous American statesman and diplomat Benjamin Franklin recognized in the second half of the eighteenth century the complexity and connectedness of our oceans by referring to the Gulf Stream as a 'river in the ocean' (see section 'The global ocean conveyor' for more information).

The beginning of the modern age of ocean exploration and scientific study dates back to the nineteenth century.

The HMS *Challenger* expedition can be considered the first major global oceanographic programme (Committee on Major U.S. Oceanographic Research Programs 1999; Pickard and Emery 1988). The expedition took place from 1872 to 1876 with the goal to investigate 'everything about the sea' – though driven primarily by biological and botanical interests. The expedition led a crew of 243 scientists to all major oceans except the Arctic. It was the first large-scale and interdisciplinary effort to make a systematic series of oceanographic measurements. The gathered data included a wide range of ocean features, including ocean temperatures' seawater chemistry, currents, marine life and the geology of the sea floor.

A half-century later, another major expedition took place in the North Atlantic, which is also frequently referred to as the first modern oceanographic research cruise: the German navy's *Meteor* expedition (1925–7). The scientific crew focused primarily on collecting physical oceanographic data: 67,400 soundings and detailed current, salinity, temperature and oxygen measurements were collected at 310 stations. The *Meteor* conducted plankton tows, collected a large number of bottom samples, and executed systematic atmospheric tests (using both instrument balloons and kites) while traversing the Atlantic Ocean 13 times.

These and many more oceanographic programmes that had already taken place or followed had an important impact on ocean and climate science.

Climate study and large-scale oceanographic programmes

The twentieth century introduced the era of modern large-scale oceanographic programmes (Table 47.1) which led to the modern understanding of ocean currents, the role of the ocean in the world's climate, the major chemical fluxes of the modern ocean and the history of both the ocean basins and the world climate through the analysis of sediments on the sea floor and cores from deep drilling into the rocks beneath the oceans.

Many of these projects focused on specific issues or time periods while others, like CLIMAP, GISP, GRIP and GRIP2, focused on the comparison of the past and present (see Alley 2000a, 2000b; and Schäfer *et al.* 2001 for an enhanced list of references).

The global ocean circulation scheme: an overview

The global ocean circulation system transports heat worldwide and affects climate in many areas. In a simple way, ocean currents contribute to the heat transport from the tropics to the poles, partially equalizing Earth surface temperatures. They also affect the routes taken by ships as they carry goods and people across the sea. Early Chinese, Arab and Portuguese navigators used this knowledge in their explorations and trading before Columbus discovered America. But in the twentieth century, ocean science advanced our view of the oceans, the currents and their impact on climate.

We learned that ocean currents flow in complex patterns not only affected by wind but also by the water's salinity and heat content, bottom topography and the Earth's rotation. Initially, most studies of the thermohaline circulation concentrated on individual basins.

Table 47.1. Large-scale oceanographic programmes

Programme name	*Acronym*	*Area or topic of concern*
1969 International Decade of Ocean Exploration	IDOE	Biogeochemical processes in the sea
Climate, Long-range Investigation, Mapping, and Prediction study	CLIMAP	Reconstruction of full glacial climates using fossil evidence from ocean and lake cores
Coastal Ocean Processes		Fluxes of matter in continental margin systems
Coastal Upwelling Ecosystems Analysis	CUEA	Atlantic and Pacific
Coupled Ocean Atmosphere Response Experiment	COARE (part of TOGA)	The region of the western Pacific known as the 'warm pool'
Danish-Swiss–US Greenland Ice Sheet Project	GISP	Greenland palaeoclimate record
Deep Sea Drilling Programme	DSDP	Progenitor of the ODP
French–American Undersea Study		The rift valley of the Mid-Atlantic Ridge
Geochemical Ocean Section Study	GEOSECS	Pacific, Indian and Atlantic
Global Atmospheric Research Programme	GARP	Detailed study of the entire global atmosphere in 1979
Global Ocean Data Assimilation Experiment	GODAE	Regular, complete descriptions of the temperature, salinity and velocity structures of the ocean
Greenland Ice Core Project	GRIP	Greenland palaeoclimate record
Greenland Ice Sheet Project Two	GISP2	Greenland palaeoclimate record
International Geophysical Year 1957–8	IGY	Global investigations: special attention to the Antarctic
International Indian Ocean Expedition 1962–5		Ocean floor and currents in the Indian Ocean
International Southern Ocean Study	ISOS	Antarctic circumpolar current
Joint Global Ocean Flux Study	JGOFS	Processes controlling, regional to global and seasonal to interannual fluxes of carbon between the atmosphere, surface ocean and ocean interior
Mid-Ocean Dynamics Experiment eddies division	POLYMODE	Atlantic current eddies
North Pacific Experiment	NORPAX	North Pacific
Ocean Drilling Programme	ODP	History of the ocean basins
Ridge-Interdisciplinary Global Experiment	RIDGE	Understanding the hydrothermal circulation
The 1974 GARP Atlantic Tropical Experiment	GATE	Role of tropical ocean in global atmospheric circulation
The Russian experiment Polygon70		Discovered synoptic eddies in the open ocean
Tropical Ocean Global Atmosphere	TOGA (related to WRCP)	The tropical oceans and their relationship to the global atmosphere
US Mid Ocean Dynamics Experiment	MODE	Atlantic
World Climate Research Programme	WCRP	Global programme developed from GARP
World Ocean Circulation Experiment	WOCE	Global observations (part of WRCP)

Source: See, for example: Committee on Major U.S. Oceanographic Research Programs 1999; Pickard and Emery 1988; Siedler *et al.* 2001; Wefer *et al.* 1996

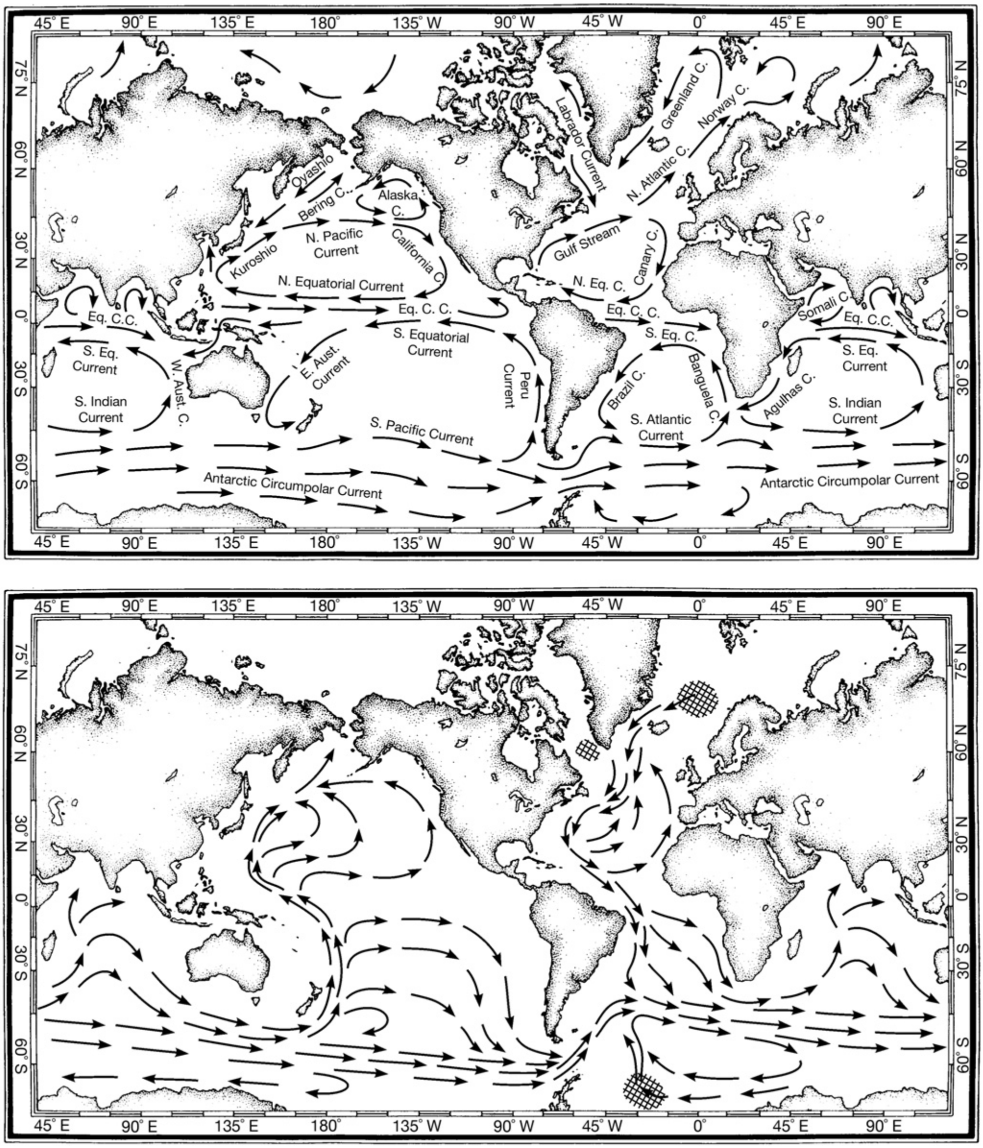

Figure 47.1. The (a) upper and (b) deep ocean circulation. Crosshatched areas indicate regions of production of bottom water

Source: Adapted from Stommel (1958)

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However, about half a century ago, Stommel (1958) published the first set of global maps showing schemes of surface and deep ocean currents (Figure 47.1). The dominant features are the large anticyclonic subtropical gyres in each ocean basin, the equatorial current systems and the Antarctic Circumpolar Current (ACC). Note that the large anticyclonic subtropical gyres have a common feature: the westward intensification, which means that the western boundary currents are faster and narrower than the eastern boundary currents. (Stommel and Arons 1960a, 1960b) have shown that the westward intensification of the

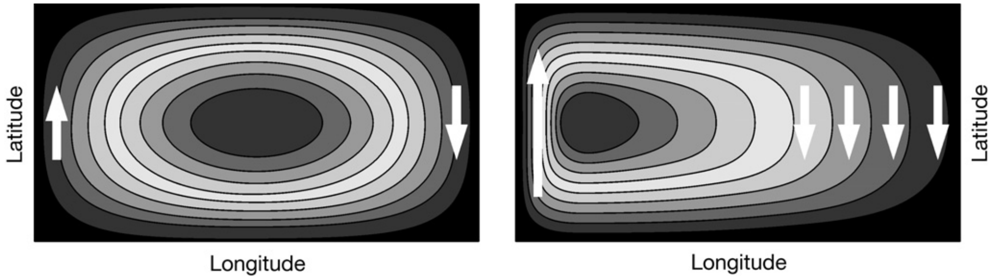

Figure 47.2. Streamlines for a non-rotating ocean (left panel) and a rotating ocean (right panel). The non-rotating ocean shows a symmetrical current system while the rotating ocean shows the westward intensification.

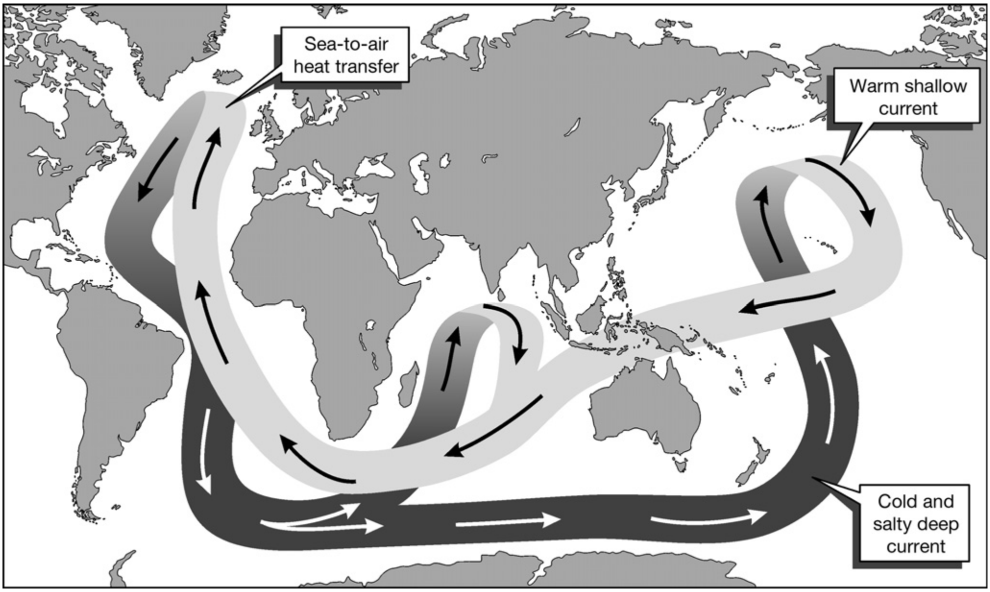

Figure 47.3. The loop of currents connecting the two most distant regions of the world ocean - the northern North Atlantic and northern North Pacific.

boundary current is due to the Earth's rotation and the fact that the Coriolis parameter is a function of latitude (Figure 47.2).

Furthermore, Stommel (1958) identified the high-latitudinal convection sites in the northern North Atlantic and near Antarctica, where bottom water is formed (Figure 47.1b). At those sites, cool and salty water sinks from the ocean surface water into the deep ocean. The exact nature of impacting this production is still under debate (e.g. Nilsson and Walin 2001). Stommel and Arons's (1960a, 1960b) and Stommel *et al.*'s (1958) ideas of dividing the ocean in a surface and deep ocean with different circulation schemes has been advanced by many scientists.

The global ocean conveyor belt

The present-day thermohaline circulation is seen as a global circulation scheme that is connected primarily through the Antarctic Circumpolar Current (ACC). Bottom water formed in the Weddell Sea and Ross Sea spreads to the bottom of the world oceans, while deepwater formed in the North Atlantic reaches the ACC, where it is partially mixed with the bottom water and spreads to the Pacific and Indian oceans, where it upwells. The deepwater formation in the North Atlantic is compensated by water flux from the Pacific and Indian oceans through certain paths (Figure 47.3). This knowledge has been around for several decades. This fact has been acknowledged and accepted for many years.

However, not until 1991 did Broecker publish his striking idea of describing the global ocean circulation as a 'global ocean conveyor belt' (Broecker 1991). This metaphor, which spread quickly throughout researchers in earth sciences, is also known as 'salinity conveyor belt'. Broecker introduced the concept of a loop of ocean currents connecting the two most distant regions in the world ocean – the northern North Atlantic and northern North Pacific (Figure 47.3; see also Brasseur *et al.* 1999). Broecker's idea was preceded by a number of studies of world ocean circulation as a global entity (e.g. Broecker and Denton 1989; Cox 1989; Gordon 1986; Stommel 1958; Stommel and Arons 1960a).

The sensitivity of the thermohaline circulation and climate shifts

As mentioned above, the majority of researchers in earth sciences see the three-dimensional ocean circulation as a continuous conveyor belt. Especially within the last two decades, many research efforts have focused on studying the deep thermohaline circulation (THC) of the world ocean. As computers became more powerful and accessible, numerical models for ocean and climate simulations became more easily available to a wider research community.

Studies using models throughout the hierarchy of complexity (e.g. Blackmon *et al.* 2001; Bryan 1969; Bryan and Cox 1972; Cox 1984; Hughes and Weaver 1994; Manabe and Stouffer 1988; Opsteegh *et al.* 1998; Pacanowski 1996; Petoukhov *et al.* 2000; Rahmstorf 1996; Stommel 1961; Wang and Mysak 2000; Weaver *et al.* 2001)) have been used to carry out either ocean-only or coupled ocean–atmosphere experiments. Some of them have indicated that the THC may display regime-like behaviour, and in particular may persist for geologically significant periods of time in circulation states quite different from that observed at the present. Such switches in the configuration of the THC have been implicated in abrupt climate shifts in the geological record and have been predicted to occur in response to increased anthropogenic greenhouse forcing (e.g. Schmittner and Stocker 1999). Scenarios were developed where the THC slowed or collapsed completely, which would have a disastrous effect on our climate and environment considering the ocean's role in transporting huge amounts of heat poleward.

While scientists currently agree that globally rising temperatures, sea level rise, melting icebergs and the retreat of glaciers are partially manmade, there are some climatic events still under debate that have influenced the THC and the climate in Europe.

Great salinity anomalies

Hydrographic time series from the Subarctic Gyre of the North Atlantic throughout the twentieth century show oscillations in temperature and salinity at more or less regular intervals. The Great Salinity Anomalies described during the 1970s (Dickson *et al.* 1988) and during the 1980s (Belkin 2004), however, had particularly large amplitudes and were climatically significant. Both of the Great Salinity Anomalies were described as low salinity anomalies with distinct features: They started out with a high propagation speed in the Greenland–Labrador region and slowed down considerably as they reached the Nordic Seas. There are still discussions about the cause for the low salinity anomalies and the persistence. The most plausible one seems that melting icebergs flowed further south into the Labrador Region than usual (Haekkinen 2002). The release of freshwater on their path/trajectories freshened and de-densified the surface waters, which slowed the production of bottom water, and thus the meridional overturning causing a slowdown of the THC. Seidov and Maslin (1999) showed that there are several sites in the northern North Atlantic that impact the formation of deepwater. The less saline water responsible for the slowed THC hit several of these key areas on its way from the Labrador Region towards the Nordic Seas.

Arctic and Antarctic ice as climate regulator

The THC, now identified as a major climate regulator, depends on a very delicate balance of deepwater formation in high-latitudinal key areas. Computer simulations show that an imbalance between the North Atlantic Deepwater (NADW, i.e. a Northern Hemisphere deepwater source) and the Antarctic Bottom Water (AABW, i.e. a Southern Hemisphere deepwater source) production can cause the global ocean conveyor to either speed up or slow down (e.g. Seidov, Barron and Haupt 2001; Seidov, Haupt, Barron and Maslin 2001; Seidov *et al.* 2005; Weaver *et al.* 2003). Proxy evidence also gives these indications of strengthening or weakening (Broecker 1991, 1997; Gordon 1986; Gordon *et al.* 1992; Stommel and Arons 1960a). The strengthening or weakening of the THC is accompanied by a heating or cooling of the surface climates in the Earth's two hemispheres (Figure 47.4). The Northern Hemisphere warms relatively while the Southern Hemisphere cools relatively when the North Atlantic THC strengthens and thus accounts for an increased northward cross-equatorial oceanic heat transport (Figure 47.4b) (Seidov and Maslin 2001). The opposite occurs when the North Atlantic THC is weak: the northward cross-equatorial oceanic heat transport is weak and keeps the Southern Hemisphere warmer relative to the Northern Hemisphere (Figure 47.4c).

The 'speed' of the global ocean conveyor depends on the rate of deepwater formation in both high-latitudinal hemispheres. This rate depends mainly on the density of the seawater and therefore on the water temperature and salinity, the amount of dissolved salt in water. Water becomes denser and heavier the colder and saltier it is, and lighter (less dense) the fresher and warmer it is. A useful rule of thumb is that the same density increase can be achieved by either increase of salinity by approximately 1 psu (practical salinity unit) or by decrease of temperature by about $-5°C$ (Pond and Pickard 1986). Why is this so important, especially in high latitudes in the Arctic Ocean and around Antarctica, where sea ice forms and melts?

As described above, the THC reorganizes itself when temperature and salt are redistributed in the ocean. The deep ocean can become warmer or colder, fresher or saltier. Once a hemisphere warms up due to a relative increase in cross-equatorial meridional heat transport into this hemisphere, the high latitudes become warmer, which can cause sea ice to melt and thus reduce the sea surface salinity. This de-densified (fresher and warmer) water is more buoyant and can reduce or even shut down the deepwater formation (e.g. Knutti *et al.* 2004). In contrast, the opposite hemisphere actually becomes colder due the equatorial heat piracy (Seidov and Maslin 2001). Sea ice formation might increase in this hemisphere, the

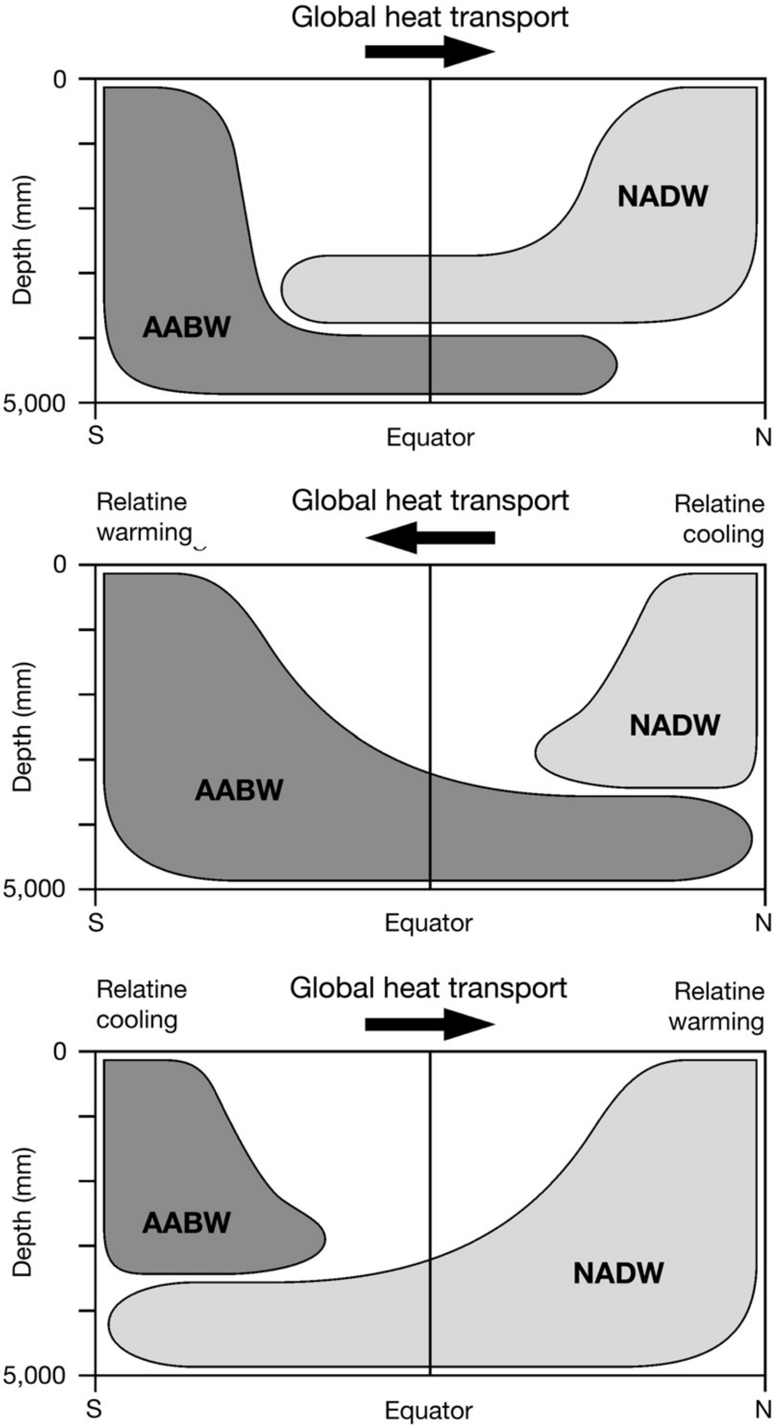

Figure 47_4. Schemes of water mass layering and overturning structure for the Atlantic Ocean: (a) present-day; (b) weakened North Atlantic THC (c) increased North Atlantic THC. Direction of cross-equatorial oceanic heat transport is shown by arrows above each scheme.

water becomes saltier due to brine rejection, the water becomes denser, and thus it increases the rate of bottom water formation (There are several studies that confirm the importance of brine rejection during formation of sea ice on salinity, e.g. England 1992; Stocker *et al.* 1992). This increase in turn reduces the previously observed heat piracy and therefore reverses the whole process. This process, which describes oceanic teleconnections between the hemispheres on millennial time scales and throwing our climate system abruptly from one state into a different one and back, is known as 'bipolar seesaw' (e.g. Blunier and Brook 2001; Broecker 1998, 2000; Dokken and Nisancioglu 2004; Knutti *et al.* 2004; Robinson *et al.* 2005; Seidov, Haupt, Barron and Maslin 2001; Seidov and Maslin 2001; Stocker 1998, 2002).

Exploitation and protection of the ocean

Earth's global commons are those areas that are not under the control of any single nation, the open ocean – essentially a still unexplored habitat – included. Thus, it seems to some as if these resources belong to no one and therefore are easily exploitable. To others, these areas are seen as a global resource, belonging to everyone, and therefore should be protected for the good of all – especially future generations. The ocean commons include only the high seas outside of national jurisdiction. Inside of national jurisdictions exist exclusive economic zones, within which certain economic development rights may be declared – differently handled by different nations, governments and authorities, which may extend 200 miles off a nation's shore. However, as marine wildlife, undersea habitats or pollution do not necessarily respect legal boundaries, protecting the open ocean from harm requires management of coastal and land-based activities on behalf of the global commons. More and more national governments officially cooperate with one another on environmental conservation through several institutions and instruments. This level of cooperation has not always been present and there continue to be many different opinions, regulations and policies about managing the oceans for fishing, mineral extraction and burial of waste, as well as about responsibilities and cleanup efforts after man-made disasters such as oil spills.

On 11 June 2003, the famous ocean explorer Jean-Michel Cousteau said, 'Ocean Exploration enters "Age of Management" to put preservation ahead of exploitation.' He insisted, 'The ocean is national security.'

> With more than half the world's population living in a coastal zone, with global warming delivering its force, and with 75 percent of all commercial fish populations fished to capacity or already collapsed, we cannot make exceptions to hard fought laws to protect the ocean environment.
>
> (Cousteau 2003)

Despite the development of new technologies and knowledge humankind has gained within the past 25 years about the ocean and what lies beneath its surface, more than throughout all of previous human history, still very little of the ocean's mysteries have been studied and deciphered. In order to protect and ensure the future of the ocean, Cousteau's mission of exploring our global ocean, inspiring and educating people throughout the world to act responsibly for its protection, documenting the critical connection between humanity and nature, and celebrating the ocean's vital importance to the survival of all life on our planet can be seen as a desirable goal.

We should remind ourselves that our oceans hold the key to our future. This is not only a reflection of the wealth of mineral, food and potential medicinal resources existing just under the surface. Just as significant is the magnetism of the oceans which encourages us to ponder, explore and simply enjoy their abundance. They provide us with life, recreational activities along waterfront communities such as clamming, crabbing, fishing, swimming and boating, and the basis for many cultural traditions handed down from generation to generation.

Advances in technology, medicine, ocean exploration and many more fields give humankind a sense of human progress and heritage. They provide the experience and knowledge necessary to undertake stewardship of the ocean and its resources, and thus set a course for future generations to navigate. What lies ahead is still unknown. Whatever it is, however, will be influenced by what is found through tomorrow's exploration and probably will differ from today's predictions! We should keep in mind that in just a few short decades, research and new technologies have opened doors to ocean exploration and exploitation as well. If humankind is able to avoid further damage of the oceans, this will require a better understanding of the oceans as ecosystems and part of the climate system. As more information is retrieved and analysed, we may be able to ensure the future of the oceans while extracting resources from them without causing significant damage.

Fisheries

There is no doubt that human impact has altered the biodiversity of the oceans. Pollution has had a significant impact on the health of species such as dolphins and whales. And in recent decades the impact of commercial fishing on ocean ecosystems has dramatically increased. In 2002, 72 per cent of the world's marine fish stocks were being harvested faster than they can produce (GEO Section 2004).

In addition, as transportation and storage mechanisms for food have improved over the past few decades, the demand for fish and seafood has increased, as these once rare food sources, whose availability was previously restricted to coastal areas, become more readily accessible. With increasing demand and over-exploitation of coastal fish stocks, commercial fishing industry has moved to the rich pickings that exist in deep waters. The industry has developed its boats and scaled up its trawl gear to enable it to extend its unsustainable fishing practices into previously unexploited deep waters using a technique called bottom trawling. Many of these deep sea fish stocks are vulnerable to over-fishing.

Many species, such as the orange roughy and Patagonian toothfish in the deeper waters, take a long time to reach sexual maturity, and so stocks can be quickly depleted once most of the older, actively reproducing fish have been harvested. Another aspect of the changing pattern of ocean fishing is that over-exploitation of the species at the top of the food chain means that a growing portion of the total fish catch come from species on which the traditional commercial fish, such as cod, used to feed. Managing ocean fisheries therefore requires attention to the whole marine ecosystem, not just the species in market demand (GEO Section 2004).

Other large-scale commercial fishing methods are longline and gillnet fishing, as well as whaling. (The motion to resume Japan's commercial whaling after a two-decade ban was defeated in 2005. In the same year, whale burger went on sale in Japan.) These fishing techniques are considered wasteful and are known to decimate populations of fish including tuna, swordfish and sharks, as well as sea birds, turtles and other marine mammals. Millions of these non-targeted species are destroyed every year and are simply considered expendable – as demonstrated by the terms applied to them by the fishing industry – by catch or discards.

In addition, these large commercial fishing operations have a direct economic impact on the small family fishing businesses which operate along the coastlines and help support the economic viability of many smaller communities.

There are some bright spots on the horizon. Frequent media reports of dolphin and whale beachings, mercury in swordfish, and the dire economic situations in some fishing areas, such as those faced by lobster fishing towns along the US coast, have helped to educate the public about the extent of human impacts on ocean ecosystems. In addition, scientists and researchers have mounted national and international efforts to collect information on disappearing habitats, as well as the effects of pollution, and have developed exhaustive databases of fish species information. In the United States, the US Geological Survey is working to create a National Biological Information Infrastructure (NBII) which is a series of interconnected thematic and regional Internet nodes focusing on biodiversity information. One component of this effort is specifically focused on Fisheries and Aquatic Resources (FAR). The FAR node works in cooperation with international efforts such as FishBase (http://www.fishbase.org), a global information system containing information on over 25,000 fish species.

As with many issues facing our globe, the health and sustainability of the oceans biodiversity and fisheries stock depends on cooperation, access to information and the continued heightening of awareness through media and scientific activities that help to educate the public and decision makers.

The importance of monitoring our oceans for future protection

Exploring and improving our understanding of the oceans and their influence on global events are among the most important challenges today. The Earth's oceans and the underlying seabed remain one of our planet's last frontiers. Recent trends give some clues as to what lies ahead.

The key element in earth science between the century of the *Challenger* and the last 50 years is adequate and organized sampling. For example, the climatically significant Great Salinity Anomaly (Dickson *et al.* 1988) was detected only by serendipity. Future operational observation systems have to provide spatial coverage that allows anomalies to be recognized, so eliminating any kind of speculation over trends and error bars. One of the most significant contributions to earth observations technology has been the orbital satellites that provide us with consistent time series for trend monitoring and change detection. A systematic monitoring programme is also necessary to ensure that restoration actions, if required or desirable, lead to success. In particular, long-term monitoring allows for the separation of environmental from anthropogenic impacts on changes in temperature, salinity, other chemical and biological parameters, biodiversity and movement of invasive species, ocean fertilization to increase the productivity of fisheries or for CO_2 mitigation, greenhouse gases, THC and sea level changes, and pollutants. Long-term monitoring also allows for early detection of changes.

Ocean observation systems initiatives usually face a common dilemma. High operational costs over an extended period of time require long-term funding commitment from public entities such as government agencies or other large funding mechanisms (e.g. Adams *et al.* 2000). In our more recent past, we have learned that the benefits of an observation/monitoring and forecast system might exceed its costs (e.g. Keller *et al.* 2000, 2004, 2005). For example, in agriculture, many decisions can be improved with a reliable seasonal weather forecast. High resolution satellite imagery can detect and monitor oil threats and sewer overflows that may damage beaches and impact both recreation areas and fishing grounds, affecting local and national economies. For example, in the case of oil spills – by accident or intentionally – detection is the best way of confining the damage and starting the deployment of clean-up equipment; strategies for clean-up depend heavily on oceanographic models that in turn rely on the kind of up-to-date high-resolution ocean circulation data – in time and space – that very often do not exist. Again, given the scale and range of the affected economic activities, an early investment in observational and forecast systems as well in strategic crisis management plans might be beneficial over the long term. Any data collected on major pollution events, if made available, will feed into basic research and into understanding of ecosystem responses, providing valuable indications of the risks that may have to be faced in any future spillage or similar accidents.

It is undeniable that climate change is taking place and will affect future generations. However, there are those who do not believe that global warming is taking place. They often find small faults over a wide array of research, and use these in an attempt to devalue all research that indicates the existence of global warming. Those who deny the existence of any changes are very often those who have an economic interest. Here the public as well as decision and policy makers are asked for help because scientists are not in the business of making policies. They analyse observations and make scientific predictions, assessing the possible outcomes of different strategies. Their role is to provide a sound basis for policies and to consult.

Conclusions

The past and present ocean is a biologically diverse habitat, a resource for life and recreation, and most importantly a stabilizer for our climate. Although this chapter does not provide direct answers to how we should protect the future of our oceans, it has outlined issues related to human impacts on the ocean. Through understanding the role of past and present usage, as well as the more momentous issue of exploitation of resources, we can understand how consumerism, industrial and commercial expansion, and inadequate knowledge have led to dramatic changes in our environment, particularly our oceans. More importantly, this chapter shows that cooperative research efforts designed to increase scientific knowledge have enhanced the world's ability to increase the effective and efficient use of marine resources. It is the job of all of us to change the ways in which our oceans are managed. This means that we must act to ensure that human activities are sustainable: in other words, that they meet human needs of current and future generations without causing harm to the environment.

This requires investing in sciences, global observation systems, the construction of early in-situ detection and numerical forecast systems for predicting changes in ocean dynamics, and in habitat diversity initiatives. Scientists and researchers need the ability to do independent research to understand and expand existing knowledge about the fragile ecosystem of our oceans – which encompasses Earth and atmosphere, ocean and climate. As scientists and researchers learn more, this information should be disseminated to be used by decision makers, teachers, students and the media as well as the general public. This knowledge can and should be the basis for policy making. It is important that science – including the financial support – and the process of policy and decision making are two separate and independent processes in order to guarantee unbiased observations, scientific predictions and guidance for future ocean management through regulations and education.

A quote found on one of Greenpeace's websites (Greenpeace 2005) should inspire the reader to build their own opinion about 'Ensuring the future of the oceans':

> Every second breath you take comes from the oceans. The oceans give life to our planet and us. In return we are suffocating them; dredging up too many fish, stealing food from needy mouths, carelessly killing countless creatures including whales, turtles, sea birds and thousand year old corals, we fill the oceans with pollution and warm them with climate change.

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