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Early Oceanography and the Development of Physical and Chemical Marine Sciences in Kiel after World War II

1. Introduction: Marine Research Institutions in Germany

The present marine research community in Germany is characterized by a great diversity in disciplines, research focal points, and locations. Germany's major marine science institutions are found near the coast in the northern part of the country, in Kiel, Hamburg/Geesthacht, Bremen/Bremerhaven/Oldenburg/Wilhelmshaven and in Rostock-Warnemünde. In addition, a considerable number of universities and federally funded institutions in the country contribute to marine science. The situation was quite different soon after the end of World War II, when ocean science had a modest reemergence in Germany.

The key marine sciences institute in the country before 1945, the Museum und Institut für Meereskunde of the Friedrich-Wilhelms-Universität[1] in Berlin (Engelmann, 1997; Röhr, 1981), was not continued after its building was destroyed by bombing during the war. The institute became part of the Soviet Zone in the east and was brought to an end in 1946. After some initial oceanographic developments in naval departments since 1948 and subgroups in Warnemünde from 1950 onward, the post-war Institut für Meereskunde was established in Warnemünde in 1958 as a naval institution of the German Democratic Republic. In 1960, it became part of the Academy of Sciences (Brosin, 1995, 1996). After the reunification of Germany, it was transferred to the Institute for Baltic Sea Research Warnemünde (IOW, Institut für Ostseeforschung) (Matthäus, 2015a), now part of the Leibniz Association.

In the west of the country, the Allied military governments combined the tasks of the former hydrographic services of the German Admiralty, the Marineobservatorium, and the Deutsche Seewarte into a German Maritime Institute. The institute was already established in 1945 as the German Hydrographic Institute (DHI, Deutsches Hydrographisches Institut[2]) to provide services to the Allied naval traffic in all German waters (DHI, 1947). The institution was controlled by the British military government. Once east-west conflicts began to increase starting in 1948 the service was restricted to the western coasts.

Sea fisheries sciences were renewed quickly in Hamburg in 1946 because of their relevance for food supply, and four Hamburg fisheries institutes were merged into a Central Institution of Fisheries (Zentralanstalt für Fischerei) in 1948 (Wegner, 2010). After the foundation of the Federal Republic of Germany in 1949, the central fisheries institution was renamed Federal Institution of Fisheries Research (Bundesanstalt für Fischerei[3]) in 1950. An Institut für Meereskunde was reestablished at Hamburg University in 1957 (Lenz, 2002).

Marine geology and geophysics research was largely conducted at the Federal Institute for Geosciences and Natural Resources (BGR, Bundesanstalt für Geowissenschaften und Rohstoffe) in Hanover in the early years (Dürbaum, Hinz 1997). The Max Planck Institute for Meteorology (MPI-M, Max-Planck-Institut für Meteorologie) in Hamburg followed in 1975 (von Storch, Olbers, 2007). Furthermore, the Alfred Wegener Institute for Polar and Marine Research (AWI, Alfred-Wegener-Institut für Polar- und Meeresforschung) in Bremerhaven with strong marine science components (not only in high latitudes) following in 1980 (Hempel, 1990). With the reorientation of marine research in Germany in the late 1970s, the Institute for Marine Research Bremerhaven (IfMB, Institut für Meeresforschung Bremerhaven), founded in 1919 (Krause, Schaumann, 1982) as Institute for Sea Fisheries, was merged with AWI under the joint directorship of Gotthilf Hempel. In 1998, the Biological Institute Helgoland (BAH, Biologische Anstalt Helgoland) with its long-standing maritime tradition since 1892 (Mielck, 1930; Werner, 1993) also became a division of the fast-growing AWI (Krause, Salewski, 2013/14).

An important group of marine research establishments developed in Bremen (Wefer, 2016): The Department of Geosciences (from 1986) and the Center for Marine Environmental Sciences MARUM at Bremen University (starting in 2001, as an associated institute of the Leibniz Association from 2013), the Leibniz Center for Tropical Marine Ecology (from 1991) (Ekau, Hempel, 2015), and the Max Planck Institute for Marine Microbiology (from 2002). The groups in Bremen have close connections to marine research groups at Senckenberg by the Sea (Senckenberg am Meer, from 1928, restart in 1947) in Wilhelmshaven and at the nearby Oldenburg University (Carl von Ossietzky Universität Oldenburg, founded in 1973). Among the smaller research units with marine interest at German universities, the tracer physics group at the University of Heidelberg (Ruprecht-Karls-Universität Heidelberg) played an important role in developing seaworthy methods for

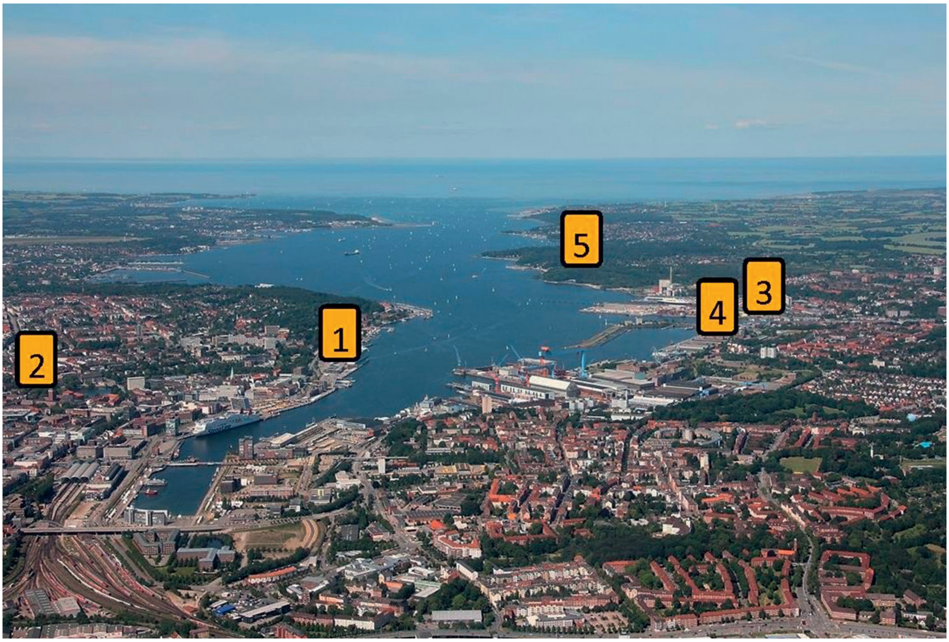


Fig. 1. City of Kiel, Harbor and Fjord seen from the south. Locations of the marine science institutions: (1) Formerly Institut für Meereskunde (IfM), now GEOMAR West Shore Buildings; (2) Christian-Albrechts-University (CAU) campus; (3) GEOMAR East Shore Buildings; (4) Federal Armed Forces Research Institute (FWG). The pre-war Institut für Meereskunde (5) was situated farther north on the east shore of the Kiel Fjord in Kitzeberg. (Photo: A. Villwock, GEOMAR)

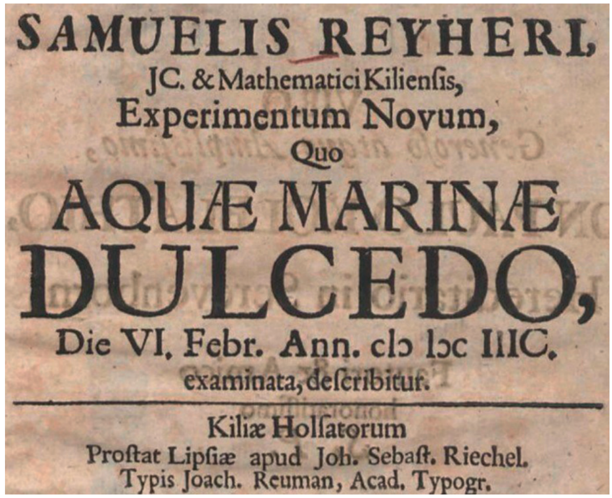
the determination of tritium, ^{3}He and chlorofluorocarbon (CFC) profiles from the deep ocean (Thiele et al., 1986).

Marine research has a long history in Kiel (Lohff et al., 1994; Hoffmann-Wieck, 2015) and succeeded in restarting quickly after World War II in the Institut für Meereskunde (IfM) of Kiel University (Christian-Albrechts-Universität zu Kiel, CAU) in 1946 (Wüst et al., 1956). Within a few years the IfM became the key institution for marine research and education in western Germany. Its research covered physical, chemical, and biological aspects of marine science. Its activities during the 1960s and 1970s ran parallel to developments in marine geology and geophysics at the CAU, and a GEOMAR Research Center for Marine Geosciences was established in 1987 (Thiede et al., 2018). All the marine science branches in Kiel joined in 2004 when the IfM and GEOMAR merged into IFM-GEOMAR as part of the Leibniz Association. In 2012, the joint institution became part of the Helmholtz Association of German Research Centres, adopting the name GEOMAR Helmholtz Centre of Ocean Research Kiel (Helmholtz-Zentrum für Ozeanforschung Kiel). Today one of the largest communities in basic marine science in Germany continues to be found in Kiel (Visbeck, Schneider, 2015). While some aspects of marine science in Kiel have been described in earlier publications (McElheny, 1964; Ulrich, 1983; Krauss, 1987; Lohff et al., 1994; Adelung, 1992), the detailed post-war history of the IfM between its new start in 1946 and the merge into IFM-GEOMAR in 2004 has never been described in context. This will be the aim of the following presentation with respect to physical and chemical marine sciences, and will also include a short review of the early history of marine sciences in Kiel which provided the foundation for a quick recovery.

2. The Roots: Early Marine Sciences in Kiel

Marine sciences and the Baltic Sea port of Kiel have a long common history (see fig. 1). Shortly after the foundation of Christian-Albrechts-University (CAU) in Kiel in 1665, the first paper in physical oceanography was published in Latin by Samuel Reyher (1635–1714), a professor of mathematics and law at CAU (Samuelis Reyheri, 1697). This milestone in marine science described observations of salinity differences in the frozen fjord of Kiel (figs. 2a–b). While compiling material for this manuscript, we learned from the CAU central library that the original publication is unfortunately missing in Kiel. However, we were able to track it down at the Saxon State Library in Dresden, where it is now available in digitized form. Although Reyher's experiment remained a singular event at that time (Kortum, 1994), this study in physical oceanography marked the beginning of marine science in Kiel (Hoffmann-Wieck, 2015).

Systematic marine science was initiated much later during the second half of the 19th century by biologists, in particular by zoologist Karl Möbius (1825–1908) and physiologist Victor Hensen (1835–1924), the respective inventors of the terms "biocenosis" and "plankton", and by Karl Brandt (1854–1931), who introduced the term "marine production biology" (Mills, 1990; Reise, 1990). Wilhelm Friedrich Georg Behn (1808–1885) from the Zoological Museum in Kiel participated in the around-the-world Danish expedition on Galathea from 1845–1848 (Fihl, 2011) and brought substantial marine zoological collections to Kiel. The German Plankton Expedition on the steamer National in the northern and tropical Atlantic in 1889 (Lohff, Kölmel, 1985) marked the beginning of blue-water oceanography in Kiel. Victor Hensen and his co-workers had established the early internationally recognized "Kiel School", which was in existence between 1870 and 1912 (Mills, 1989). Questions like the vertical circulation in relation to high production areas were taken up in the 1920s and 1930s by research groups outside Germany. Mills (1989) stated that the first Kiel School's short life was due to the lack of career opportunities in Kiel rather than the exhaustion of ideas or the effect of war and social upheaval.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JC. & Mathematici Kilienſis,
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Figs. 2a–b. Above: Title page of the “Experimentum novum, quo aquae marinae dulcado die VI, Februari anno 1697 examinata desceribetur” by Samuel Reyher (1635–1714). Below: Implementation of the experimentum on the frozen surface of the Kiel Fjord presumably in the presence of Samuelis Reyheri (the Latinized form of his Germanic name). (Reproduction from Reyher, 1697)

In 1870, the multi-disciplinary Prussian Commission for the Investigation of German Seas in Kiel (Kieler Kommission; Preussische Kommission zur wissenschaftlichen Untersuchung der deutschen Meere in Kiel) was established (Meyer et al. 1873; Matthäus, 2015b). The commission was the predecessor of the later Institut für Meereskunde and GEOMAR. The first German Antarctic Expedition in 1901–1903 (Drygalski, 1904; Lüdecke, 1992) started from Kiel. It used the dedicated polar research vessel Gauss, which was built from oak wood at a Kiel shipyard (Werft von Howaldt in Dietrichsdorf[4]). Since the German emperor Wilhelm II was disappointed with the scientific results of this expedition (Lüdecke, 1997), the vessel was soon after sold to Canada where it served as the Coast Guard vessel Arctic until 1926.

Had a different decision been made, German polar marine research might have developed differently.

Starting in 1900, the multi-disciplinary German Scientific Commission for International Marine Research (DWK, Deutsche Wissenschaftliche Kommission für die Internationale Meeresforschung) in Hanover and Berlin served as a partner of the International Council for the Exploration of the Sea (ICES) (Wegner, 1990). The commission established two Laboratories for International Marine Science (Laboratorien für die Internationale Meeresforschung) in Kiel. The Hydrographic Laboratory, the predecessor of later physical oceanography groups, was led by Otto Krümmel (1854–1912), the geographer and oceanographer who published two volumes of the first modern German physical marine science textbook, the "Handbuch der Ozeanographie" (Krümmel, 1907, 1911; Ulrich, Kortum, 1997; Matthäus, 2015b). In the Marine Biological Laboratory, plankton and sea floor fauna were investigated as well as marine chemistry. These DWK laboratories and the library of the Prussian Commission were transferred to the Institute of Marine Sciences of Kiel University when it was established in 1937 (Wüst et al., 1956).

At the university, the Institute and Museum of Zoology developed into the center of biological marine science. Between 1924 and 1934, Adolf Remane (1898–1976) became an internationally renowned marine zoologist (Storch, 2009). Robert P. Higgins and Hjalmar Thiel (1988) called him the father of meiofaunal research. Meiobenthology was established in Kiel in the 1920s, but the term only became recognized two decades later in the 1940s. Remane left Kiel in 1934 and served as the director of the Department of Zoology at the university in Halle/Saale.

Another field of ocean-related science and technology was also flourishing in Kiel: ocean acoustics. The cradle of the ocean acoustic echo-sounder is attributed to Alexander Behm (1880–1952), a citizen and manufacturer of Kiel. His invention was stimulated by the loss of the ocean liner Titanic on her maiden voyage in 1912. Behm wanted to provide a technical method for protecting ships against collisions with icebergs via an early warning system with horizontally oriented echo-sounders. Unfortunately, his test trials failed, probably due to severe downward refraction of which he could not have been aware (Wille, 1986; Ziehm, 1988). However, he also invented a vertical echo-sounder in 1916 (Behm, 1913). This system was used routinely during the famous German Atlantic Expedition (Deutsche Atlantische Expedition) from 1925–1927 (Maurer, Stocks, 1933; Stocks, Wüst, 1935). The expedition revealed a huge ocean ridge, now known as the Mid-Atlantic Ridge, following the contours of South America and Africa in the middle of the Atlantic. It supported the hypothesis of Alfred Wegener that later led to the concept of plate tectonics (Thiede et al., 2018). In 1928, Behm received an

Honorary Doctorate of the Medical Faculty of CAU to recognize his imaginative research and application of acoustic methods.

Another key person in the Kiel oceanographic sector was physicist Hugo Lichte (1891–1963), who worked for the Imperial Navy in Kiel from 1913–1916. Decades ahead of his contemporaries, he was the first to understand and quantify the refractive sound propagation resulting from the sound speed stratification of the ocean. These features form ocean-wide sound ducts with extremely low transmission loss (Lichte, 1919). It is not clear why Lichte's important work sank into oblivion. R.J. Urick (1979) commented that Lichte's paper *"was far ahead of his time, and is an indication of the highly advanced state of German physics in the early years of this century"*.

Finally, the work of Heinrich Hecht (1880–1961) marked the beginning of underwater communication with submarines, which was required by the Imperial Navy in 1906. He played a crucial role in pioneering the development of sound transmitters and receivers with directional characteristics (cf. textbook by Hecht, 1941, 1961). Much later, after World War II, the present Federal Armed Forces Research Institute (FWG, Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik) in Kiel and Eckernförde embraced and built on the heritage of the early decades of ocean acoustics in Kiel. The FWG was established in 1964 as an oceanographic research institute and belongs to the German Ministry of Defense. Today this institute provides scientific and technical advice on all issues of ocean acoustics to mariners (cf. Sellschopp, Alvarez, 2003; Sellschopp et al., 2006; Thiede et al., 2018).

Returning to the academic scene, in 1935 the Faculty of Philosophy at CAU called for a new institute for marine sciences to be established as the first institute with a multi-disciplinary approach to the marine ecosystems in the German Baltic Sea coastal region. Soon after his return to Kiel in 1936 and appointment as director of the Institute of Zoology and the Zoological Museum, Remane (figs. 3 & 4) also became the founding director of the new

Fig. 3. Commemorative plaque of the foundation of the Institut für Meereskunde of Kiel University in Kitzeberg in 1937. In 1937 the Institute for Marine Sciences of the Christian-Albrechts-University Kiel was founded here in the Niemeyer villa, the starting point of the present-day GEOMAR. (Photo: R. Schwarz, 2015)

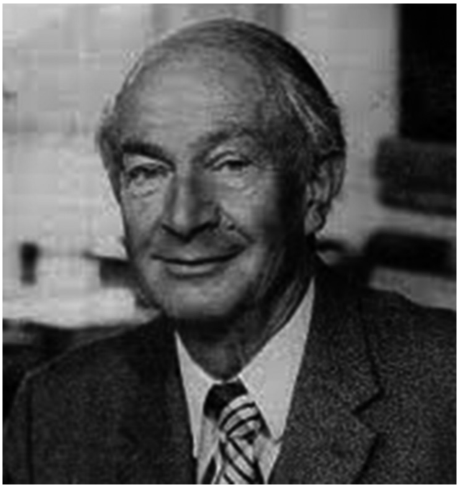

Fig. 4. Adolf Remane (1898–1976) (Photo: Müller-Karch)

IfM in 1937 (Gerlach, Kortum, 1998). The new institute was an official part of Kiel University (Gerlach, Kortum, 2000).

Remane pointed out at the inauguration (June 15, 1937) in Kitzeberg on the east shore of Kiel Fjord (Remane, 1937; Remane, Wattenberg, 1938) that the key research focus of the new institute would be the Kiel Fjord and the Baltic Sea, the world's largest body of brackish water. It should be noted here that oceanic research in deep waters was initially far beyond the scope and intentions of the founding fathers of the IfM in Kiel. Following Remane's suggestions, the new institute was organized into three departments: (1) Marine Biology with Zoology, Botany, Bacteriology and Fisheries Biology divisions, (2) Hydrography and Marine Chemistry, and (3) Marine Geology. The institute had its own library and published the scientific journal "Kieler Meeresforschungen" (KMF). A research vessel was urgently needed, but could not be obtained at this time.

Despite the successful hydrographic and chemical work in Kiel, the Institute and Museum of Marine Sciences (Institut und Museum für Meereskunde) of the imperial Friedrich-Wilhelms-Universität in Berlin (fig. 5/1) had developed into the leading German marine research institution, particularly in physical oceanography, during the 1920s.

It had been founded in 1900 (Penck, 1912) and inaugurated in 1906 by the German Emperor Wilhelm II in the presence of Prince Albert I of Monaco. The geographer Albrecht Penck (1858–1945) became director of the Berlin institute in 1906 and was succeeded by the Austrian-German oceanographer Alfred Merz (1880–1925) in 1921. Penck and Merz developed and promoted plans for the German Atlantic Expedition (DAE) together with Merz's student and assistant Georg Wüst (from 1919). This systematic hydrograph-

Fig. 5. A selection of plaques, badges and logos: (1) (Institut und) Museum für Meereskunde in Berlin (1900–1946) shown today at the entrance of the Deutsches Technikmuseum, Berlin; (2) Institut für Meereskunde (IfM) in Kiel (1937–2004), plaque at the entrance of the former "Parkhotel" in Kiel which had been transformed into an extension of the IfM (see fig. 13); (3) Modernized IfM sticker in the 1990s; (4) logo of the merged institutions IfM and GEOMAR; (5) initial logo of the GEOMAR Research Center for Marine Geosciences at the CAU (1987–2003); (6) GEOMAR logo after conversion into the Helmholtz-Zentrum für Ozeanforschung Kiel (since 2012).


MUSEUM FÜR MEERESKUNDE
BERLIN NW7 - GEORGENSTRASSE 34-36
1
INSTITUT FÜR MEERESKUNDE
DER
UNIVERSITÄT KIEL
Abt. für Meeresphysik
Planktologie
Fischereibiologie
u. Bibliothek
2
4
IFM-GEOMAR
Leibniz-Institut
für Meereswissenschaften
an der Universität Kiel
INSTITUT FÜR MEERESKUNDE
KIEL
3
GEOMAR
PAX OPTIMA RERUM
ACADEMIA HOLSATORUM CHILONIENSIS
5
6
GEOMAR
Helmholtz-Zentrum für Ozeanforschung Kiel

ic study of the Atlantic Ocean south of 30° N was carried out on METEOR from 1925 to 1927. It included physical and chemical measurements and was supplemented by meteorological observations, acoustical soundings of the sea bottom, and geological and zoological sampling (Spiess, 1928). Unfortunately, Merz died in Buenos Aires in 1925. The Captain of the METEOR, Fritz Spiess (1881–1959), became the leader of the expedition, and Wüst came to be the leader of the hydrographic work. The Austrian meteorologist and oceanographer Albert Defant (1884–1974), who became director of the Berlin institute in 1927, joined the expedition for the last three legs. Wüst and Defant then became the key scientists in the analysis and publication of the data, which is a fundamental data source to this day (Gould et al., 2013).

Wüst's and Defant's analysis provided a major breakthrough in the understanding of the generation and the movements of water masses in the Atlantic Ocean. Defant and Wüst also acted as academic teachers at the Friedrich-Wilhelms-Universität. During World War II the institute had to take on some naval tasks, in particular studies of internal waves in the Straits of Gibraltar and Messina and of tides and currents in the North Sea, the English Channel, and the Mediterranean Sea (Oberkofler, Goller, 1991).

The Berlin institute's building was destroyed in 1944/45 by bombing, and the institute was closed down in 1946. Defant returned to his former University of Innsbruck in Austria, and the other scientists moved to the western sections of the country. In Kiel, Remane had terminated his directorship of the IfM in 1944, and the chemist Hermann Wattenberg, then his deputy, had taken over. Kiel, being an important navy port, also experienced heavy bombing during the war. Unfortunately, on 23/24 July 1944 bombs destroyed the IfM building, and Wattenberg and 25 other staff and neighbors, who had been seeking shelter in the institute, lost their lives.

Although the IfM in Kiel thus lost its housing and many staff members, a quick new start after the end of the war with Wüst as director provided the opportunity for the Kiel institute to become the main scientific successor of the Berlin institute. It took over its orientation on the unity of multidisciplinary marine research and teaching the next generation. After the initial phase, an emphasis on blue-water oceanography evolved with intensification of physical and chemical oceanography. The work at IfM Kiel thus provided an essential basis for the further development of marine sciences in Germany after World War II (figs. 5 & 6). Today the Deutsches Technikmuseum in Berlin considers itself the formal successor of the Museum für Meereskunde Berlin.

3. Restart of the Institute of Marine Sciences (IfM) in Kiel

3.1 First Post-War Years

The activities at the IfM of the CAU in Kiel started soon after the war's end in 1946 when Wüst, until 1945 a member of the Berlin Institute, was appointed Professor of Oceanography and Maritime Meteorology at CAU and director of the IfM. Of great importance were his deep-sea research experience and his leading contributions to the deep circulation in the Atlantic Ocean, especially with respect to the kinematics of deep and bottom waters. He had also studied geostrophic currents in the Gulf Stream and Kuroshio and had provided a better understanding of the circulation in the Mediterranean Sea (Kortum, 2013).

As director in Kiel he was faced with finding solutions for four major problems: obtaining a building for the institute, recovering personnel, getting a ship, and determining the future direction of research. Wüst was lucky: he obtained help from James N. Carruthers, an oceanographer of the British Admiralty and member of the Allied Control Council Germany. Carruthers represented British interests and had been given the task of investigating German oceanography after the surrender, not least for safeguarding the navigation of Allied vessels in German waters. In February 1951 the University of the Free and Hanseatic City of Hamburg appointed Carruthers its highest respect, the Diploma and Gold Medal of its Citizenship of Honor (Deacon, 1973; Ramster, 1975; Lüdecke, 2001).

Provisional housing was first found in a former clog factory in Schleswig, a provincial town north of Kiel. In the same year, an old villa (fig. 6) was provided on the western shore of Kiel Fjord and was extended by an annex in 1952.

Fig. 6. Location of the Institut für Meereskunde (IfM) in Kiel, Hohenbergstrasse 2, after its restart in 1946. (Photo: W. Zenk, October 2013)

Fortunately, the library of the Berlin institute had been saved during the war by being hidden in a mine in Thuringia. This Berlin library arrived in Kiel in 1946 on U.S. Army trucks. Some former personnel could be reunited over the first years but amounted to only 15 people. Four disciplines were covered: physical

Figs. 7a–b. Two portraits of Georg Adolf Otto Wüst (1890–1977). (Photos: Left: www.gelehrtenverzeichnis.de; Right: with permission from Springer)

oceanography, fisheries biology, marine zoology, and marine botany. Unlike the pre-war institute, marine geology was not included.

Wüst was also successful in finding a ship. The former German naval survey vessel SÜDFALL, a 24-meter fishing cutter type, was provided to the institute. When her future captain, Hans Ohl (1911–1985), attempted to bring SÜDFALL from the port of Flensburg to Kiel in 1947, the ship had engine problems and had to be towed part of the way by the famous old METEOR, which was just being taken to the Soviet Union as part of war reparations (Ohl, 1976, personal communication). During the following years, SÜDFALL was employed as a research vessel in the Baltic Sea and the Skagerrak/Kattegat region.

Overall, there was a building including a complete oceanographic library, some personnel, and a small vessel. But there was also a change in the orientation of research which was related to the earlier Berlin institute. Nearly all its scientists had moved to Austria or western Germany, Wüst included (figs. 7a–b). The "Berlin School" had concentrated on blue water oceanography with a multi-disciplinary approach. They had emphasized physical oceanography, both from a descriptive standpoint (e.g. Wüst, 1935) and in physical process studies (Dietrich, 1935; Defant, 1961). Earlier work in Kiel had been mostly biological and largely concentrated on the regional seas of the Baltic and the North Sea. Wüst introduced the "Berlin School" approach to the Kiel institute, including the focus on physical oceanography (Wüst, 1953).

Upon retirement in 1959, Wüst received an honorable invitation to teach as a visiting professor at the Lamont Observatory of Columbia University in New York, USA (Stocks, 1960). His former collaborator Günter Dietrich (fig. 8) became his successor in Kiel. Dietrich also had a background from the "Berlin School" (Dietrich, 1935) and strengthened the orientation initiated by Wüst (Krauss, 1987).

3.2 Building up Marine Sciences at the IfM

Dietrich used the opportunities presented by the "Economic Miracle" of West Germany in the 1950s and 1960s to build up ocean sciences. Two fortunate circumstances paved the way:

In 1960 a recommendation for the development of marine science in Kiel and Hamburg from the German Council of Science and Humanities (Wissenschaftsrat), the key scientific advisory committee of federal and state governments;

The new establishment of the Senate Commission for Oceanography of the German Research Foundation (Senatskommission für Ozeanographie der Deutschen Forschungsgemeinschaft, DFG) (cf. below in chapter 5).

When he started in Kiel, Dietrich realized that up-to-date technology and new infrastructure was required. Hydrographic equipment was scarce and mostly limited to reversing water samplers and thermometers. Georg Wüst had already suggested to Werner Kroebel (1904–2001), the director of CAU's Institute for Applied Physics (IAP), that the IAP should develop a cable-lowered probe for measuring continuous temperature and salinity profiles. The cooperation between IfM and IAP resulted in the development of one of the world's first viable CTD (conductivity, temperature, depth) profilers (fig. 9), much later named Bathysonde, by one of Kroebel's first PhD students (Hinkelmann, 1956, 1957). The term Bathysonde had originally been suggested by Kroebel (1961) for a fast free-falling electronic CTD apparatus showing some conceptual similarity with today's cycling Argo floats (Roemmich et al., 2009).

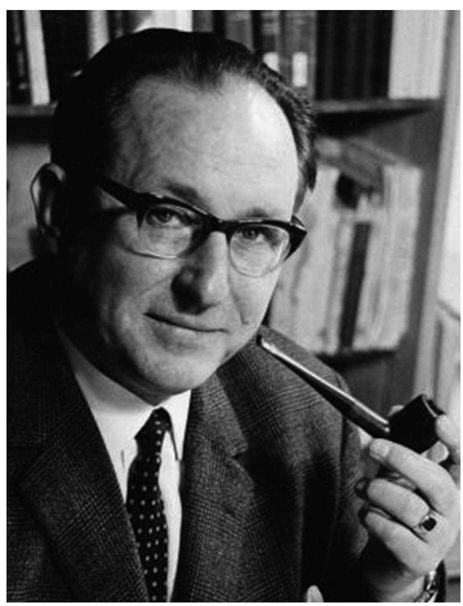

Fig. 8. Günter Dietrich (1911–1972). (Photo: E. Mempel)

Parallel to the Bathysonde development in Kiel, a similar device for replacing classical hydrographic series

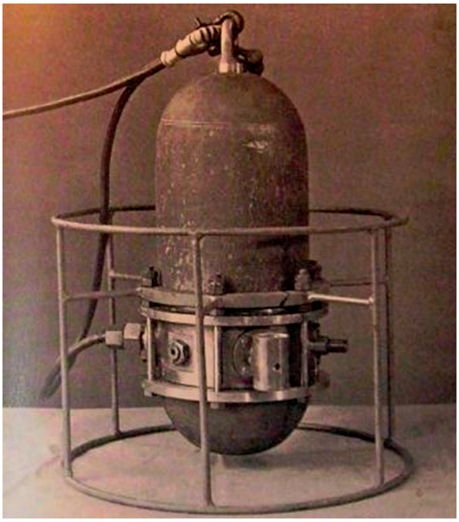

Fig. 9. The first electronic CTD probe for the *in-situ* observation of vertical temperature and salinity profiles in the upper ocean (Plate 24 in Hinkelmann, 1956). In the protective cage the one-conductor cable with oil filled connector, the pressure inlet, an electrode conductivity cell, and the platinum thermometer are shown from left to right. The upper housing was packed with dozens of thermionic valves.

was developed in Australia. A conceptual approach towards the Australian CTD profiler was published by Hamon as a letter on request of the Editor of the "Journal du Conseil International pour l'Exploration de la Mer" (1955). At the time of this *"brief preliminary description of the recorder"* the designer hoped *"that the equipment will be tested at sea within the next few months"*. More than a decade later out of this prototype accrued the American WHOI/Brown microprofiler. For a number of years this device became the world's leading and profitable CTD profiler (Fofonoff et al., 1974). The Kiel Bathysonde, however, never became a commercial success.

Dietrich also recognized the need to develop modern equipment within IfM. Gerold Siedler, another one of Kroebel's PhD students, joined the IfM in 1960 and was tasked with the establishment of instrument development facilities. Assisted by the able technician Uwe Huenninghaus, Siedler set up workshops for precision engineering and electronic laboratories, and engineering personnel was hired. During those first years new equipment for hydrographic profiling and for deep-sea current meter moorings was developed. Klaus Grasshoff joined in 1961 to establish the marine chemistry group, mostly adapting modern medical analysis equipment for precision chemical analyses in oceanography (see below in chapter 6.3).

Before arriving in Kiel, Dietrich worked at the German Hydrographic Institute (DHI) in Hamburg. During the 1950s he played a leading role in the first German post-war contributions to international marine science. His topic project was the Polar Front Survey, which was implemented by the International Council for the Exploration of the Sea during the International Geophysical Year (IGY) in 1957/58. The only vessels available in Germany suited to open-ocean work were the Gauss and the Anton Dohrn, but both were limited in operations by their size, type and governmental tasks. Based on the limitations on Gauss's operations posed by weather conditions during the Polar Front Survey, Dietrich was convinced that Germany needed a larger vessel for basic open-ocean research and became a key advocate for

Fig. 10. Research vessel METEOR during a stop in the Suez Canal on her onward IIOE cruise in 1964. (Photo: G. Siedler)

a new vessel, named METEOR (fig. 10). He found partners for promoting the construction of the new ship, in particular Günther Böhnecke (1896–1981), until 1960 president of DHI in Hamburg, and Eugen Seibold (1918–2013), professor of geology at CAU (Thiede et al., 2018). At the same time a strong effort was made to join the International Indian Ocean Expedition (IIOE) (McElheny, 1964).

In 1964 the new research vessel METEOR was put into operation (Weidemann, 1985) and, after a short test cruise, departed for her six-month maiden voyage to the Red Sea and Indian Ocean. Overall, 92 scientists and technicians participated, including groups from eleven disciplines (from meteorology and oceanography to biology, geology, and also shipbuilding) and 17 West German marine institutions. The new vessel, equipment, and joint work of numerous participating institutions represented landmarks in German marine research, not only but mainly initiated from Kiel. Most of the projects and 40 of the participants came from the IfM and several groups at CAU (figs. 11–12), guided by the chief scientists Dietrich and Seibold from Kiel University. With hindsight, the 1964/65 METEOR cruise marked the revival of blue-water oceanography in Germany (Zeitzschel, 2008).

During these post-war years, CAU became the leading educational

Fig. 11. Chief scientist's briefing in the library on the METEOR in 1964, G. Dietrich in the back on right side. (Photo: G. Siedler)

institution in Germany for most marine science disciplines. In 1965 Dietrich published the second edition of his textbook "Allgemeine Meereskunde" (General Oceanography) that was later translated into English and twice into Russian by different groups in Leningrad[5] and Moscow. The third edition (Dietrich et al., 1975) served generations of graduate students as a foundation for marine studies. The IfM grew rapidly, with many young scientists arriving from other fields like physics, engineering, chemistry, and biology and later graduates in marine sciences from Kiel University. Some of the first students after graduation from Kiel and several of the young scientists spent most of their later working life abroad or in international organizations: among them are/were Karl Banse (Seattle), Feodor Ostapoff, Walter Düing (both Miami), Klaus Wyrtki, Lorenz Magaard (both Honolulu), Taivo Lae-

Fig. 12. Mixed party of crew, scientists and students from different departments in the crew's mess room waiting for the start of the weekly cinema show on the METEOR in 1966. (Photo: W. Zenk)

vastu (Seattle and Stockholm), Selim Morcos (Alexandria and UNESCO, Paris), and Svend-Aage Malmberg (Reykjavik).

By 1968 personnel had reached 124 but was scattered over as many as ten buildings. The former Parkhotel belonged to a collection of properties that provided offices, an electronic laboratory, a mechanical workshop, and the library (fig. 13). The library contained the rescued stocks from the earlier Berlin Institute and Museum for Marine Sciences. Being the oldest IfM building, the colonial villa Parkhotel was originally erected as the official residence of the Commander of the Baltic Sea Division of the Imperial Navy (Kortum, 2004). The building and its later demolition in the immediate neighborhood of the new

Fig. 13. From 1967–1972 the former "Parkhotel" served as an extension of the IfM. The former ballroom on the ground floor to the left accommodated the library. (Photo: W. Zenk, ca. June 1967)

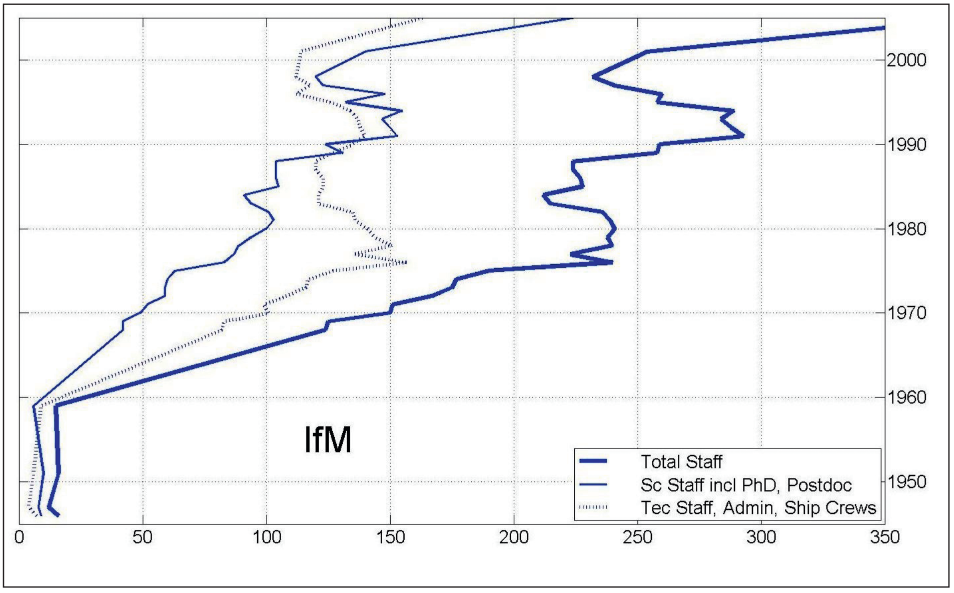

Fig. 14. Development of personnel numbers at IfM Kiel from its post-war restart. X-axis: number of employees, Y-axis: time beam. The numbers of total staff as well as the subsets of scientific personnel and non-scientific staff (technical and administrative employees, ships' crews) are specified. In 2004 (at the upper right end of the graph) IfM and GEOMAR merged into IFM-GEOMAR.

seven-story building (compare figs. 15 & 16) caused political strife that attracted nationwide attention in Germany (Anonymous, 1969).

Ten departments were formed at the IfM. They comprised Regional Oceanography, Theoretical Oceanography, Marine Physics, Maritime Meteorology, Marine Chemistry, Marine Botany, Marine Zoology, Fisheries Biology, Marine Planktology and Marine Microbiology (Ulrich, 1983). The work in the first five of these departments is the subject of this essay.

Operational costs at the IfM became too high for the university budget, and in 1968 a new funding base was established. Funding was provided by both the German federal state of Schleswig-Holstein and the federal government in Bonn, and the institute was able to have its own budget while preserving close links to CAU. The rapid development of the IfM after the bilateral funding agreement is evident in the extraordinary increase of human resources, documented in the institute's annual reports first published for the year 1968. The steady upward curves in figure 14 show modest fluctuations with two SFB (Sonderforschungsbereich) peaks. In 2004 (upper right end of graph in fig. 14) the IfM and GEOMAR merged into IFM-GEOMAR. Additional research grants supplemented the basic funding considerably over the years. The annual increase of 11.6 positions per year stands out in the decade from 1968–1978, the years of and immediately following Dietrich's directorship († 1972).

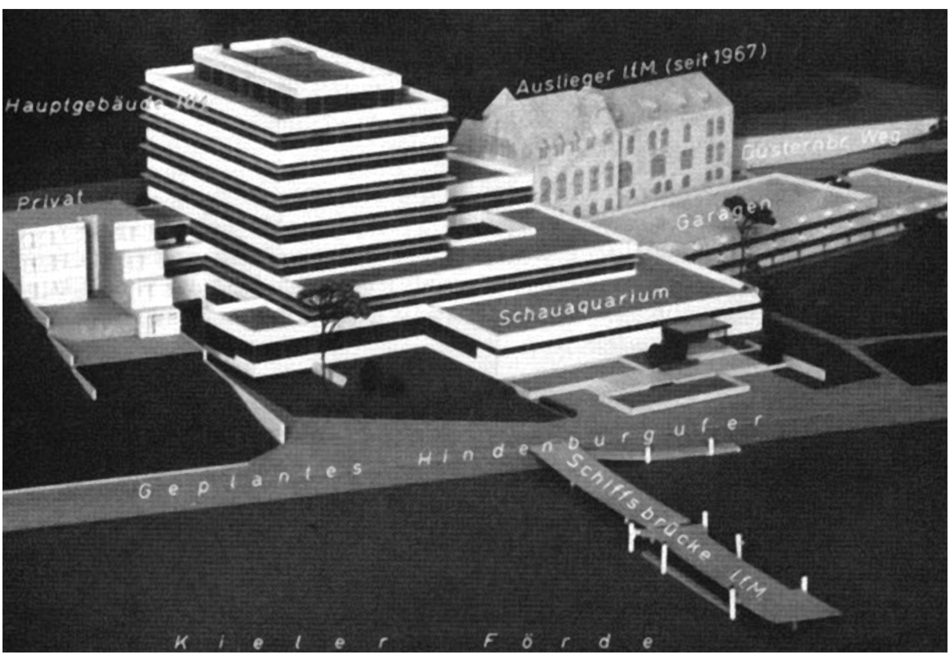

Fig. 15. Model of the main building of IfM situated immediately on the banks of the Baltic Sea at the inner part of Kiel harbour (cf. (2) in fig. 1). The staff moved into its newly constructed domicile in the fall of 1972. In the background the former IfM extension "Parkhotel" is shown (cf. fig. 13). (Reproduced from IfM Annual Report 1968)

Fig. 16. IfM Kiel with pier, aquarium and the Kiel research fleet. Shown are from left: Littorina, Poseidon (foreground), Polarfuchs (background), Alkor (middle), and Haithabu (visiting vessel). In 1987 the former extension "Parkhotel" was replaced by an annex hosting a conference room, numerous dry and wet laboratories, the computer center, and the comprehensive library. (Photo: © GEOMAR, ca. 1990)

The legacy of the IfM's rebirth as a small group was that everybody knew one another across disciplinary borderlines from the experience of joint work onboard research vessels (cf. fig. 12) and in international communities. This resulted in a long-lasting sense of new beginnings, a high motivation of the members of the staff and a sense of identification with the institute. There was similar motivation in the marine geology and geophysics groups outside the IfM at CAU, with increasingly closer cooperation with the IfM scientists (Thiede et al., 2018). Working and living together for weeks on research vessels like the Meteor played a major role in breaking barriers between groups from various institutions and with the ships' crews. Graduates took this research-based attitude to their later places of work, in particular to several governmental institutions in the country.

A milestone in the renewal process of the post-war years under Wüst and Dietrich concerned the paradigm shift from the original coastal, biology-oriented research institute to a deep water research laboratory, despite the institute's location being rather far from the open ocean. The causes of this shift were the prime research interests of the first two directors of IfM Kiel and their earlier professional careers. Furthermore, Dietrich emphasized the enormous importance of the flow along the Atlantic polar front as the crossroads between the subtropical and subpolar regimes. Water exchanges through the Denmark Strait and across the ridges between Iceland and Scotland were considered key regions for the three-dimensional Atlantic circulation with its impact on climate dynamics. Even today, these regions remain hotspots of oceanic research (cf. Lozier et al., 2016). In the early 1950s, fisheries issues and related geographic questions like the guidance of overflows by local topography and the continuity of the Reykjanes Ridge were considered important. With respect to their roles in the meridional overturning circulation, the Nordic Seas, the Irminger Sea, and the Labrador Sea remain in the focus of today's international research efforts.

A general comment on publication activities should be given. German was considered most appropriate language for IfM publications in the early years, and many physical results were published in the "Kieler Meeresforschungen", the "Deutsche Hydrographische Zeitschrift", the "'Meteor' Forschungsergebnisse" etc. By the 1960s, the shift of the main science language from German to English was almost complete (Lütjeharms, Kortum, 2005). Around the mid-1970s the German marine science community finally accepted the fact that English was the only language to use within the international community. Naturally, the early publications in German[6] did not have the large readership and corresponding citations found later in English-language publications. It is worth noting that other non-English writers, e.g. French, Russian and Japanese authors, faced the same difficulties during that time. Evaluating a publication's sustainable impact by its total citations in the literature therefore fails for that time period.

4. Research Fleet and SFBs

After the early and often multi-disciplinary work on the research cutter Südfall (from 1946, renamed Hermann Wattenberg in 1958) and the IfM's considerable participation in cruises of Gauss and Anton Dohrn, a number of research ships were added in Kiel (see fig. 16): research vessel Alkor (1966, replaced by the new Alkor in 1990), research cutter Sagitta (1966, replaced by Polarfuchs in 1997), research vessel Littorina (1975, originally operated by SFB 95 (see below) and later owned by CAU) and research vessel Poseidon (1976) (Ulrich, 1983). Kiel scientists also frequently used the larger German research vessels with different home ports and were often the chief scientists for cruises. These vessels included Meteor (1964) and its successor (since 1986), the old Planet of the 1970s, the old and the new (since 2014) Sonne, Polarstern (since 1982) and Maria S. Merian (since 2005). All these vessels except for the naval vessel Planet are now part of a German research vessel fleet for joint use. In the construction of many of these ships, Kiel scientists, in particular Klaus von Bröckel, provided an important link between the scientific community and marine engineers in both the planning and testing phases. Today there exists also a tri-partite barter arrangement with the United Kingdom and France for ship time exchange.

The DFG had become an important supporter of marine sciences and, through its demanding review system, ensured high quality standards. The DFG provided funding for individual projects and for major research programs. The Special Research Projects (SFB, Sonderforschungsbereich) played a particularly important role in bringing scientists together in major long-term, multi-disciplinary programs. DFG funds of a whole series of SFBs were acquired over the years. SFB 95 (1971–1985), an interdisciplinary study of sea/sea bottom interaction, was the first such program in Kiel (cf. Rumohr et al., 1987). The SFB was the perfect environment and breeding ground for interdisciplinary and team works. It generated a passion for science. *"The group – from new graduate students to post-docs to the researchers – was enthusiastic and fun and scientific discussion continuous"*[7]. By promoting young talents this elite research and training center had an enormous impact on the success of numerous scientific and administrative institutions outside of Kiel in the years to come (cf. Thiede et al., 2018).

SFB 95 was followed by SFB 133 (1980–1995) on the Warmwassersphäre (literally warm water sphere), which studied the North Atlantic Ocean from the Gulf Stream system to the North Atlantic subtropical gyre circulation (Krauss, 1994, 1996). The expansion of the warm water sphere of the North Atlantic is closely connected with the Gulf Stream and its extension. Without meridional drift the warm water sphere would end in the subtropics at about 25° N. Fluctuations of upper oceanic processes in the North Atlantic have a profound influence on climatic conditions in northern Europe.

SFB 460 (1996–2006) on the dynamics of thermohaline circulation variability focused on water mass formation in the Labrador Sea and deep circulation changes. SFB 313 (1985–1998) on environmental variations in the northern North Atlantic emphasized geoscience in this high-latitude region, and SFB 574 (1985–1998) was oriented to volatiles and fluids in subduction zones.

5. Strategies and the Evolution of Marine Sciences in Kiel

The evolution of marine sciences in Kiel after World War II is part of the common history of marine sciences in many countries during those decades. However, the field had its own specific routes related to the early history in Kiel and to the requirements and difficulties during the renewal process after the war.

Development of the common international marine science community during the second half of the 20th century was widely driven by modern technology, the development of new *in-situ* and remote observational methods and the arrival of computer power and advanced communication. However, there were differences in priorities and skills in the leading institutions. For example, operational work played an important role in the U.S., British, and French environments and was furthered by naval requirements in those countries (cf. Longuet-Higgins, 2010). Military applications were not permitted in the defeated Germany in the early years, and operational activities like tidal prediction were only continued in civilian applications. This restriction strengthened the focus on basic research in the Humboldt tradition and considerably influenced the priorities of marine research in Kiel.

The main foundations were similar to those in other countries: setting up groups of capable people, developing and/or adapting new technology, and obtaining funding for individual and joint projects. But of utmost significance was the rebuilding of strong connections to the international marine science community, preserving ties to CAU so as to teach new generations, and playing a role in the institutions that were set up for organizing research in Germany.

International relations of German scientists had been cut off during the war. Marine science needs international cooperation among regional and global communities in order to observe and understand processes in the world ocean. The re-establishment of direct collaboration between scientists and institutions and the coordination through intergovernmental and non-governmental organizations were most important. In restoring links to the international community, the intergovernmental International Council for the Exploration of the Sea (ICES) played an important role. The ICES had been established in 1902 in Copenhagen for regional investigations for sustainable fisheries in the Baltic and North Seas and the waters off Britain and Norway. Several scientists from Kiel were involved in its foundation, and the lawyer Walther Herwig from Hanover, president of the German Sea Fisheries Association, became the first ICES president (1902–1908). ICES had always provided an excellent multidisciplinary scientific forum for the exchange of information and ideas pertaining to the eastern half of the North Atlantic and the adjacent seas. The first post-war German participation in international programs (e.g. International Geophysical Year (IGY), Overflow) was made possible by the ICES framework. Later several scientists with roots in Kiel played leading roles in ICES, in particular Günter Dietrich as vice president (1967–1969), Gotthilf Hempel as president (1979–1982), Gerd Hubold as general secretary (2006–2012) and Johannes Krey as chairman of the Plankton Committee (1960–1965).

Another organization that became increasingly important for promoting basic marine science was the non-governmental Scientific Committee on

Oceanic Research (SCOR) of the International Council for Science (ICSU). SCOR was established in 1957 at the Woods Hole Oceanographic Institution (WHOI). Günther Boehnecke, the head of the German Hydrographic Institute in Hamburg, was the German representative during its foundation, and Gerold Siedler later became its president (1986–1989). SCOR initiated numerous important research programs, and Kiel scientists frequently had leading roles. Major programs with Kiel input included the International Indian Ocean Expedition, the Global Atmospheric Research Project (GARP) and the World Ocean Circulation Experiment (WOCE). Siedler chaired the responsible SCOR Working Group 43 for GATE (GARP Atlantic Tropical Experiment), John Woods served as a Steering Group member of WOCE. Siedler, another group member, chaired the International WOCE Scientific Conference at the UNESCO in Paris in 1988 and the WOCE Conference in Halifax in 1998. Bernt Zeitzschel chaired the Joint Global Ocean Flux Study (JGOFS) program for the first three years from 1988 to 1991.

While the work within the organizations was really important, building up personal relations between individual scientists within the international community was the prime confidence building measure. As described above, many of Kiel marine scientists went on to other leading ocean research institutions around the world on extended stays, and later a large number of foreign scientists came to Kiel or took part in collaborative cruises on German vessels. Student exchanges with institutions in established and emerging nations also became an essential component of international cooperation.

To ensure success locally, the IfM made an effort to rebuild close ties with CAU. IfM professors were selected for positions on joint committees, and undergraduate and graduate programs were established in physical oceanography and meteorology, fisheries biology, marine zoology, marine botany, marine microbiology, and biological oceanography. Germany's major doctoral program in marine sciences was established in Kiel. Evidence for the involvement of marine scientists in the university is also demonstrated by the fact that six marine scientists from the IfM served as dean of CAU's Faculty of Mathematics and Natural Sciences: Georg Wüst (1950–1952), Günter Dietrich (1965), Wolfgang Krauss (1970–1971), Dieter Adelung (1989–1991), Gerold Siedler (1991–1992), and Bernt Zeitzschel (1992–1994). Major research programs within the SFBs discussed earlier were joint IfM/CAU endeavors.

It was also necessary to integrate marine science into national science programs and funding systems. The DFG played a particularly important role in re-establishing marine science after World War II. Its senate formed a Commission for Oceanography, which took on the task of developing strategies for marine research in the country, planning the new research vessel Meteor, recommending funding schemes, and reviewing major programs and expeditions. Close collaboration was ensured with governmental bodies, in particular the federal ministries responsible for science and technology and hydrographic services. Many marine scientists from Kiel were active in related committees and a number of them chaired the DFG Senate Commission for Oceanography over many years: Günter Dietrich (1962–1969), Eugen Seibold (1969–1975), Gotthilf Hempel (1975–1986), Gerold Siedler (1986–1995), and later Karin Lochte (2004–2011). Fritz Schott served as a DFG senator from 1997–2003.

Ocean sciences in Kiel moved forward within these national and international frameworks during the second half of the 20th century but had certain characteristics and qualities that continue to this day. They include:

– Multi-disciplinary research leading to closer collaboration and interdisciplinary projects, with frequent collaboration with groups outside of Kiel;
– Increasing engagement in cross-disciplinary and interdisciplinary projects particularly within the DFG-funded SFBs;
– Increasing internationalization of the scientific staff of all institutions involved;
– A close link between ocean observations and modeling, including an early start of global modeling activities.

Due to the influences of Wüst and Dietrich, physical and chemical oceanography played particularly strong roles within marine sciences in Kiel. The developments in these fields will be discussed in more detail in the following chapters.

6. Developing Physical and Chemical Marine Sciences at the IfM

6.1 Physical Oceanography

Two approaches existed in physical oceanography during the early post-war years. The first approach, with a hydrographic/geographic emphasis, focused on the exploration and accurate description of bottom topography and water mass distributions preferably in the subpolar North Atlantic and the Indian Ocean. It was also always important for Dietrich and his collaborators to relate their physical results to biological and chemical properties and applications in fisheries. Through their work, the physical oceanographers in Kiel decisively contributed to the mapping of the Reykjanes Ridge as part of the global-scale Mid-Atlantic Ridge (Ulrich, 1960; Malmberg, 2004) and contoured the related overflows at the Greenland-Scotland Ridge (Dietrich, 1956; Meincke, 1967; Müller et al., 1974; Dooley, Meincke, 1981; Hansen, Meincke, 1979). The distribution of low salinity intermediate waters in the North Atlantic was identified as an important feature for understanding long-term changes (Meincke, 1978). This work was often closely connected to international ICES programs in the northern North Atlantic (Dietrich,

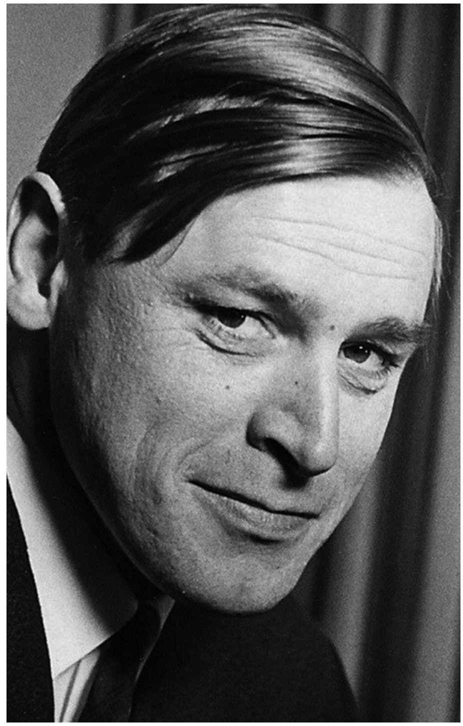

Fig. 17. Wolfgang Krauss (1931–2009). (Photo: E. Mempel)

1970). National programs included studies of seamounts in the eastern North Atlantic (Dietrich, Ulrich, 1961; Meincke, 1971) and the circulation in the Norwegian Sea and upwelling off Northwest Africa (Fahrbach, Meincke, 1978). Since its publication in 1968, the "Atlas zur Ozeanographie" by Dietrich and Ulrich (1968) serves as a reference for marine geographical names in the German-speaking area.

The gradual supersession of classical hydrographic series by electronic devices like the Bathysonde started in Kiel before the International Indian Ocean Expedition (IIOE) (Krause, Siedler, 1964). The work by Gunther Krause (1968) of the spreading of Red Sea Water between the continental rise and the abyssal off Somalia is an excellent example for the competing application of the classic and the modern observational methods. For better compatibility of bottle data with Bathysonde profiles, fine structures in the latter had to be eliminated by appropriate digital filtering. Conversely, highly resolved fine-structure temperature profiles were a prerequisite for the mapping of salt brine in the Discovery and Atlantis Deeps of the Red Sea (Krause, Ziegenbein, 1966).

The second approach aimed at a better understanding of ocean processes. Wolfgang Krauss (fig. 17) was the first one in Kiel to bring observations and models together. He observed internal waves in the Baltic Sea with especially designed moored observation masts (Krauss, 1960). Local time series measurements were arranged to assess the spatio-temporal characteristics of inertia-gravity waves and their generation by fluctuating atmospheric wind and pressure fields (Krauss, Magaard, 1961). The theory of internal waves (Magaard, 1965) remained a central theme until the early 1970s (Willebrand, 1975), later supported by the international internal wave experiment (IWEX) in the Sargasso Sea in 1973 (Müller et al., 1978). Process studies on waves (Düing et al., 1975; Käse, Siedler, 1980), exchanges in straits (Siedler, 1968; Zenk, 1975), fine structure (Siedler, Zenk, 1973), frontal zones (Willebrand, Meincke, 1980; Käse, Siedler, 1982; Kielmann, Käse, 1987; Zenk et al., 1991; Siedler et al., 2005), mixing (Fahrbach et al., 1986), and ventilation (Siedler et al., 1987) continued or were developed during the following years.

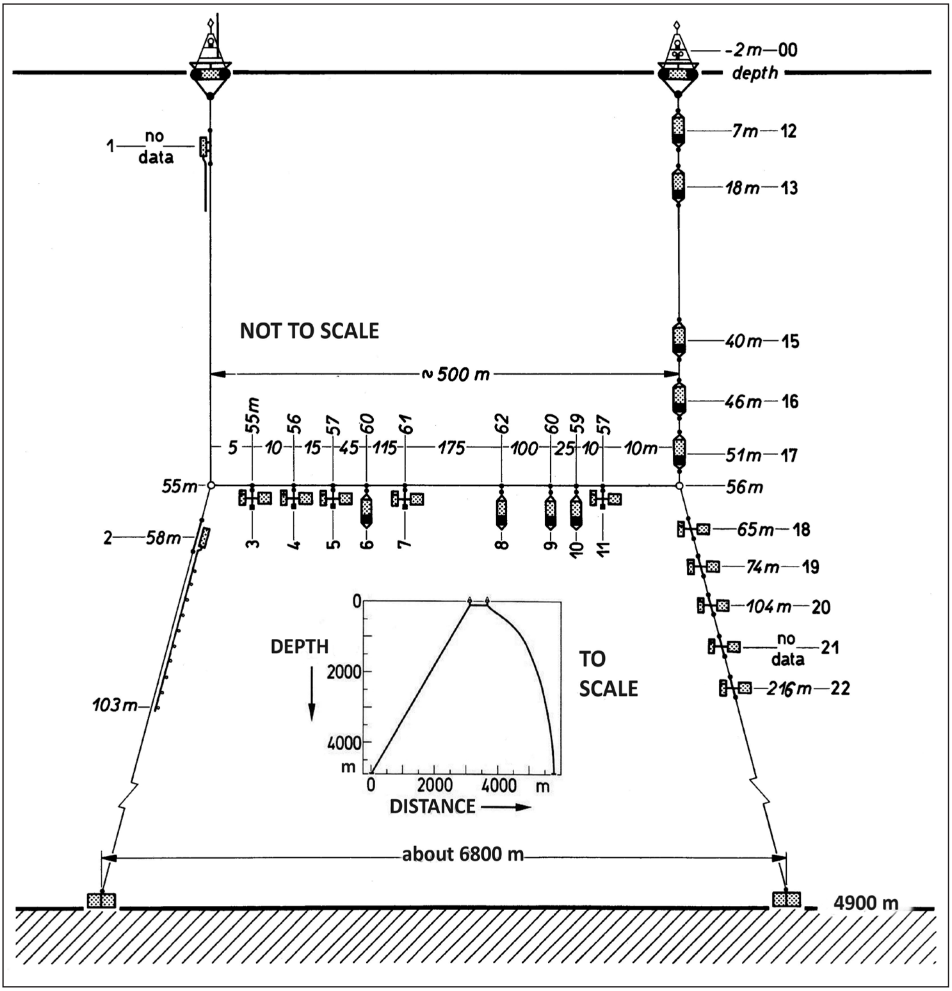

Fig. 18. Design of the GATE mooring F1 for studying internal wave kinematics with the cable configuration for a hypothetical current from left to right (not to scale). In the inner sub-frame the whole construction is shown to scale. (After Käse, Siedler, 1980)

New technology for physical oceanography was acquired by local development or by using and adapting equipment from commercial sources. The Kiel contribution to the "Technological Revolution in Physical Oceanography", as coined by Walter Munk (2002), started in the 1960s. Deep-sea mooring work was carried out first in 1964/65 during the IIOE (Siedler, 1968). Complex instrumented moorings were developed (Siedler, Grasshoff, 1970), but the new technology had its weak points, and recovery rates were below 50%. Step-by-step reliability increased due to improved techniques and the competent technical personnel, in particular by the thorough approach of Dieter Carlsen. A particularly ambitious mooring is shown in figure 18 (Käse, Siedler, 1980). Arrays were launched in the deep North Atlantic repeatedly for studies of subtropical gyre dynamics, mixing and tidal processes, and partially contributed to the international POLYMODE, NEADS, or JGOFS[8] arrays (Müller, Siedler, 1992). Kroebel and co-workers at CAU's Institute of Applied Physics and Siedler, Krause, Düing and the engineer Gebhard Grasshoff at the IfM were mostly responsible for the technical developments for physical oceanography at the IfM during this time.

The range of moored instruments, which included current meters and thermistor chains was gradually extended to sediment traps (Wefer et al., 1982) and a variety of sensors and records for chemical parameters (e.g. Körtzinger et al., 2005). The data provided new results on the vertical structure in fronts (Müller, Siedler, 1992), deep-sea tides (Siedler, Paul, 1991), variability of meridional flows in the western Atlantic (Schott et al., 1993b, Schott et al., 1998), bottom water flow between the Argentine to the Brazil Basin (Hogg et al., 1999), current structure in the Somali Current region in the western Indian Ocean (Visbeck, Schott, 1992; Schott, Fischer, 2000), and the abyssal water exchange between the Caroline Basins in the western Pacific Ocean (Siedler et al., 2004).

The rapid evolution of measurement technology in the late 1960s was complemented by a fundamental transition in data analysis methods due to the emergence of digital computers. This development is reflected in the gradual establishment of a central computing facility at the IfM under the supervision of Jürgen Kielmann during the 1970s (within annex in fig. 15). While first oriented primarily towards the support of digital data analysis, computing capacities eventually increased enough to foster the application of numerical methods to extend the theoretical models beyond analytical solutions.

Almost from its restart, the IfM was involved in time series observations using different technologies over periods from four days with observation masts to two years with moorings or RAFOS floats. An underwater winch system for shallow water with a cable connection to shore was developed for studying the seasonal cycle of mixed layer formation in the Baltic (Krause, Siedler, 1964; Münzer, 1970). A deep-water time series station (KIEL276) was set up for studies of eddies and fronts in the Azores Front region (Käse, Siedler, 1982; Käse et al., 1985). Deep-sea moorings with typically eight current/temperature meters were replaced once a year. An uninterrupted series on mooring KIEL276, nominally at 33° N, 22° W, began in 1980 (Siedler et al., 2005) and is still being continued. Since 2000 the mooring has been operated by the Leibniz Institute for Baltic Sea Research (IOW, Leibniz-Institut für Ostseeforschung Warnemünde). On station ESTOC north of the Canary Islands, joint operation with the Instituto Canario de Ciencias Marinas (ICCM) in Las Palmas, Gran Canaria/Spain and Bremen University started in 1991 and includes repeated ship observations. This station is still being operated in modified form by the Spanish partners (Neuer et al., 2002; Waniek et al., 2005; Neuer et al., 2007). Time series from repeated hydrographic measurements were used to document long-term changes such as the Antarctic Bottom Water flow into the Brazil Basin (Hogg et al., 1999; Zenk, Visbeck, 2013) and oxygen minimum zones (Stramma et al., 2008; Stramma et al., 2010).

The observation of oceanic properties by moored instruments, which employs the Eulerian method, was supplemented in Kiel by Lagrangian approaches from the early 1980s. John Woods was the prime advocate of this reborn technique that offered multiple opportunities for cooperation with planktologists (Woods, Barkmann, 1993; Barkmann, Woods, 1996). Later comprehensive applications of surface drifters (Krauss, Meincke, 1983) and mid-depth floats became standard methods favored by SFB programs (see below).

Other technical achievements concerned vertical profiling of horizontal currents. Already in 1976, four years before the foundation of AWI in Bremerhaven, a three-dimensional survey of the Antarctic Polar Front in Drake Passage was executed jointly by the Woods Hole Oceanographic Institution (WHOI) and the IfM (Joyce et al., 1978). Anisotropy of horizontal intrusions in the upper 800 m was documented by the high-resolution Profiling Current Meter (PCM) developed in Kiel (Müller et al., 1974) as a successor of the Miami model (Düing, Johnson, 1972). More than twenty years later, the method was replaced and significantly improved by Acoustic Doppler Current Profilers (ADCP). Jürgen Fischer and Martin Visbeck (1993) introduced a self-contained ADCP hardware and software package. This combination has been applied successfully with CTD rosette samplers by numerous external laboratories. Further developments included an undulating CTD (Sea Rover) for mixed layer and thermocline studies (Leach et al., 1985; Woods et al., 1986; Fischer et al., 1989). With the beginning of WOCE Thomas Müller took control over a central facility for the calibration of CTD sensors and maintenance of systems. He was assisted by Jürgen Langhof and later by Tiberiu Csernok.

Sea-going digitized technologies became increasingly available for research tasks. A multitude of research projects in physical oceanography developed in Kiel, largely within the SFB programs. International programs from the IIOE and ICES projects to GARP/GATE and WOCE were involved in these technological developments. During the IIOE, observations of water mass exchanges through Bab el Mandeb between the Red Sea and the Indian Ocean (Siedler, 1968) marked the beginning of a series of studies on straits and outflow regions, in particular the Strait of Gibraltar (Zenk, 1975) and the Shag Rocks Passage in the Scotia Ridge (Zenk, 1981). Studies on oceanic eddies began in international projects in the early 1970s (cf. Robinson, 1983). From the beginning of field observations of sub-mesoscale vortices, the IfM contributed to the study of salt lenses or Mediterranean eddies (Meddies) in the Northeast Atlantic in close cooperation with leading laboratories in the U.S.A., UK, Portugal, France, and Russia (Armi, Zenk, 1984; Bower et al., 2002; Siedler et al., 2005). Studies centered on the North Atlantic circulation, including the Gulf Stream, the North Atlantic Current, and the Azores Current (Kielmann, Käse, 1987; Sy, 1988; Klein, Siedler, 1989), and extended southward to the shadow zone in the Cape Verde region (Zenk et al., 1991; Krauss, 1996). During the first half of the WOCE period, eddy statistics of the intermediate and upper South Atlantic were the focus of the IfM's observations (Schmid et al., 1995; Schäfer, Krauss, 1995; Holfort, Siedler, 2001) and modeling efforts (Biastoch et al., 2008). Even with increasing interest in Atlantic sector, studies focused on the Indian Ocean also continued (Stramma, Lutjeharms, 1997; Schott, McCreary, 2001; Schott et al., 2002; Brandt et al., 2003; Lutjeharms, Kortum, 2005).

A major task of SFB 133 was the measurement of Lagrangian pathways by satellite-tracked surface drifters to determine mean surface flows and mesoscale eddy characteristics (Krauss, Käse, 1984; Krauss, Böning, 1987). RAFOS floats, adopted from the University of Rhode Island, followed (Rossby et al., 1986). About 200 eddy-resolving acoustically tracked RAFOS floats (figs. 19a–b) were built at the IfM (König, Zenk, 1992) under the technical management of Olaf Boebel in cooperation with Claudia Schmid. They were launched in the main thermocline of the North and South Atlantic

Figs. 19a–b. Preparations of RAFOS floats on deck of the Poseidon and the Sonne. The transparent housing of the instrument consists of hardened borosilicate glass (left). The launch procedure (right) is achieved by a cradle with unsymmetrical buoyancy on its long side. After a predetermined time RAFOS floats release a ballast weight, return to the surface and upload their recorded data via satellite link to a ground station. Typically, their *in-situ* mission lasts between one and two years. (Photos: W. Zenk)

(Richardson et al., 2000; Boebel et al., 2003; Lankhorst, Zenk, 2006) and the western tropical Pacific until 1996 (Zenk et al., 2005). From 2000 onwards RAFOS floats as roving current meters gradually were replaced by commercial Autonomous Lagrangian Circulation Explorer (ALACE) floats.

The later stages of the observational program of the SFB 133 were increasingly complemented by ocean modeling activities. A key event enabling an engagement in basin- or global-scale ocean modeling activities was the establishment of a high-performance computing facility with a CRAY X-MP system at CAU. To a large degree the CRAY was dedicated to the computing needs of the marine sciences. It was strongly promoted by Wolfgang Krauss and Jürgen Kielmann. Modeling programs initiated in the late 1980s included three main areas:

- Development of data assimilation for dynamically consistent interpretations of basin-scale hydrographic data, e.g. building on the beta-spiral ideas (Stommel, Schott, 1977; Schott, Zantopp, 1979; Olbers et al., 1985);
- Study of the fundamental dynamics and long-term behavior of the thermohaline circulation including instabilities and multiple equilibria (Marotzke, Willebrand, 1991; Rahmstorf, Willebrand, 1995);
- Simulation of the general ocean circulation at eddy-permitting resolution (Böning, Budich, 1992).

The experienced modeling group joined U.S. efforts in the framework of the WOCE's Community Modeling Effort (CME) (Böning et al., 1995). Subsequent developments in high-resolution ocean modeling contributed to an increasingly close linkage between observational and modeling studies, which became a main characteristic of physical oceanography in Kiel (e.g. Käse et al., 2003).

The main focus in physical oceanography in Kiel during the 1980s and 1990s was WOCE. In a way this ten-years lasting project reunited the two historic branches of research in Kiel again, the hydrographic/geographic and physical processes lines. In addition, traditional hydrographical and chemical parameters were extended by chlorofluorocarbons (CFCs) and other tracer parameters. A special laboratory for sea-going analyses of tracers had been set up prior to WOCE (Rhein, 1991; Hinrichsen et al., 1993).

Kiel scientists were deeply involved in the WOCE Steering Group by starting and maintaining this international program under the supervision of SCOR and IOC/UNESCO. The Halifax congress in 1998 substantially organized by IfM marked the end of WOCE observations. Results of the Halifax congress were summarized in book form (Siedler et al., 2001 and 2013). WOCE's legacy on the modeling of climate prediction and in providing the basis of a world-wide operational network remains to this day (Smith, 2001; Koltermann et al., 2011).

The follow-up SFB 460 "Dynamics of Thermohaline Circulation Variability" was dedicated to water mass formation and transport processes in the subpolar North Atlantic (Schott et al., 1993a; fig. 20). A combination of physical, chemical, and meteorological observations in close interaction with numerical circulation modeling and tracer box models were at the core of this long-term project. Studies on vertical convection intensified with SFB 460 and in projects concerning the Mediterranean Sea (Schott, Visbeck, Fischer, 1993; Schott et al., 1996; Visbeck et al., 1996; Marshall, Schott, 1999; Xie et al., 2002).

Fig. 20. Friedrich A. (Fritz) Schott (1939–2008) after the reception of his Prince Albert I Medal of the International Association for the Physical Sciences of the Oceans. (Photo: W. Zenk, 5th March 2005)

From the post-war restart of marine sciences in Kiel, physical oceanographers were eager to explore new ideas and technologies from other experienced groups elsewhere, in particular in the U.S.A. Several young scientists from Kiel became visiting or permanent investigators at American institutions, most of them at WHOI, the Scripps Institution of Oceanography, and the Rosenstiel School of Marine and Atmospheric Science at the University of Miami. After a few years, a flow of scientists started in the opposite direction, and numerous international scientists visited the IfM for extended periods. Some names are given as examples. From the U.S.A. came Amy Bower, William Emery, Terry Joyce, Worth Nowlin, Hank Perkins, Ray G. Peterson, Jim Price, Peter Rhines, Tom Rossby, Tom Sanford, Kevin Speer, Henry Stommel, John Toole, and Pierre Welander; from Portugal Daniel Rodrigues, from the UK Harry Dooley, from France Catherine Maillard, Michel Arhan, and Sophie Wacogne-Speer, from the Netherlands Peter Kruseman, from Brazil Joshimine Ikeda, from Russia Serge Gulev, Oleg A. Godin and Georgy Shapiro, from China Xu Jianping and Y. You, from Estonia Jury Elkin, and from South Africa Johann R. Lutjeharms.

Significant achievements arose from these visits. Among them are the papers on the beta spiral by Stommel and Schott (1977) and Schott and Stommel (1978), on the polar front analysis by Joyce et al. (1978), and on abyssal currents beneath the Antarctic Circumpolar Current in Drake Passage (Nowlin, Zenk, 1988). Further studies on the Namib Col Current by Speer et al. (1995), on the benefits of ships of opportunities (Rossby et al., 1995), on the North Atlantic subtropical gyre by Maillard and Käse (1989) deserve to be mentioned. The book on the Agulhas Current by Lutjeharms (2006) belongs to the row of achievements, as well. He worked in Kiel several months after having been awarded the Humboldt Prize, an award granted by the Alexander von Humboldt Foundation in recognition of a researcher's entire achievements.

In 2003 a generation change was initiated in the physical oceanography departments of IfM. Uwe Send, Siedler's successor as head of the marine physics department, continued and intensified multi-disciplinary time series observations. Among his research interests were integral and autonomous ocean observing techniques. Send developed and applied methods like acoustic tomography, glider technology, and zonally-integrating geostrophic transport arrays in the Mediterranean Sea and the North Atlantic Ocean (Send et al., 1999; Kindler et al., 2001; Kanzow et al., 2006). After Fritz Schott's retirement in 2004, Martin Visbeck became head of the physical oceanography research division at IFM-GEOMAR. Today the core of research activities in physical oceanography at GEOMAR consists of observational and modeling programs on the ocean's role in the climate system and interaction between physical, biological, and chemical processes (Visbeck, Schneider, 2015). In 1996 Wolfgang Krauss also became an emeritus professor. Jürgen Willebrand was appointed as Krauss' successor. Willebrand placed his main focus on the ocean circulation theory and numerical modeling and the role of the ocean for climate and climate fluctuations (Obers et al., 2012). From 2001 until the IfM's merge with GEOMAR in 2004, he also held the position of IfM director (see table 1 below).

6.2 Maritime Meteorology

In 1961 the Maritime Meteorology department was established at the IfM. The department was headed by Friedrich Defant (1914–1990) until his retirement in 1980 (fig. 21). Defant's special research interest was the General Circulation of the Atmosphere with an emphasis on the energetics of the atmosphere. Simultaneously to the department's establishment, a curriculum in "Meteorology" was introduced at CAU.

The new department's research concentrated on two areas: the interactions between the sea and the atmosphere, and the "General Circulation of the Atmosphere". In both domains basic research was performed with regard to atmospheric processes which influence the ocean and which are essential in coupled ocean-atmosphere models.

Interactions between the sea and the atmosphere are driven by the surface exchange of momentum and energy. For the elaboration of wind-driven ocean currents a knowledge is required of friction exerted by the wind on the sea surface. This wind stress can be determined directly by measuring small-scale turbulent vertical fluxes of momentum in the surface boundary layer. For the practical application, however, these fluxes must be parameterized. They must be expressed by larger scale oceanic and meteorological parameters which are measured routinely by the synoptic meteorological services. In addition, small-scale turbulent fluxes of sensible heat between the atmosphere and the ocean as well as short and long wave radiation fluxes are ingredients for the determination of the energy exchange between atmosphere and ocean.

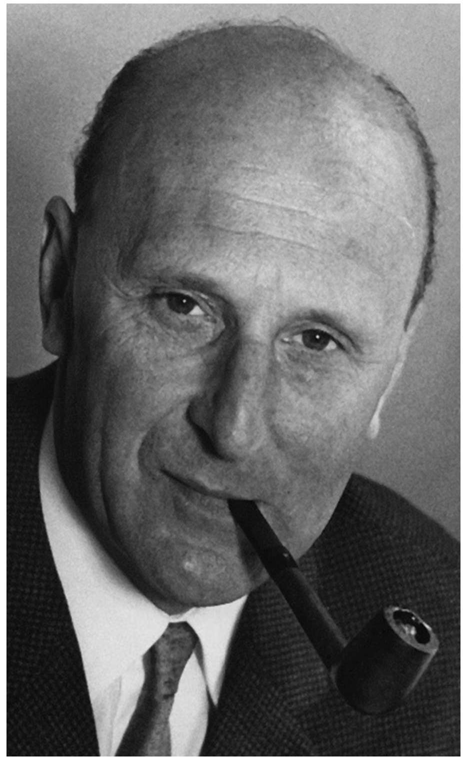

Fig. 21. Friedrich Defant (1914–1990). (Photo: E. Mempel)

In this context, direct measurements were performed of the turbulent fluxes of momentum (Clauss, v. Raden, 1973) and heat (Clauss et al., 1970a, 1970b; Müller-Glewe, Hinzpeter, 1974) and of the radiation balance within the atmospheric boundary layer (Hinzpeter, 1968; Heinrich, Hinzpeter, 1975). These measurements were used to verify existing theories and develop simple models for the parameterization of turbulent fluxes by large-scale atmospheric and oceanic parameters. Hitherto no generally accepted parameterization method had existed. This type of work was initiated and directed by Hans Hinzpeter (1921–1999) from 1961–1968. Details can be found in Hinzpeter and Lobemeyer (1969).

Instrumentation was developed for the measurement of turbulent fluctuations of horizontal and vertical wind components and temperature (up to a frequency of 20 Hz) and of radiation components. With the support of the IfM vessels Hermann Wattenberg, Alkor, Sagitta and other ships during international expeditions (see below), numerous measurements were carried out. Earlier suggestions for a parameterization were reviewed or new ones obtained. An iron tripod and a self-developed stabilized spar buoy were used for carrying the measuring instruments (fig. 22).

The research in this area was embedded in international projects and was carried out during the IIOE (with Meteor, 1964/1965), GATE (with Meteor and Anton Dohrn, 1974), "Atlantisches Passat Experiment" (with Meteor and Planet, 1969), "Atlantic Tropical Experiment ATEX 1969"

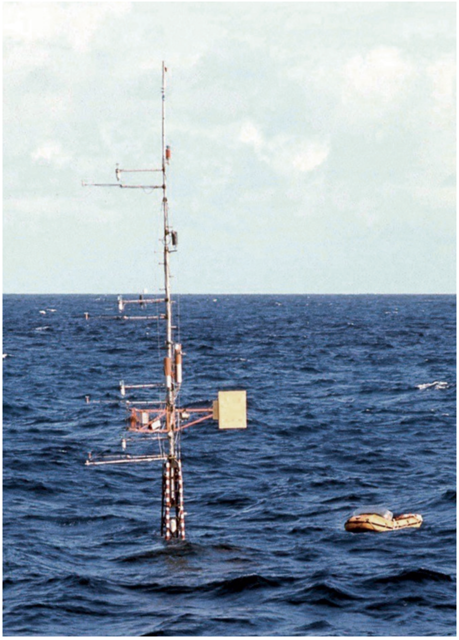

Fig. 22. Meteorological stabilized buoy with sensor packages in the tropical Atlantic Ocean during GATE, 1974. (Photo: H. Skade)

(with Meteor and Planet), "BALTIC 75 Experiment" (with Meteor, 1975), and "Joint Air-Sea Interaction Project: JASIN" (with Meteor, 1978).

The work in the area "General Circulation of the Atmosphere" focused on diagnostics from observational data and numerical analyses, with a special emphasis on atmospheric energetics. The research area's objective was twofold: to examine the large scale atmospheric driving forces and to improve general circulation models of the atmosphere. The research was mainly part of two DFG Priority Programs (Schwerpunktprogramm): "Energy budget and circulation of the atmosphere (Energiehaushalt und Zirkulation der Atmosphäre)" and "Physical basis of climate and climate models (Physikalische Grundlagen des Klimas und Klimamodelle)." The Priority Programs featured nationwide collaboration between participating researchers, in this case in the development of atmospheric forecast and climate models. Within the first mentioned Priority Program, Defant headed the working group "Diagnostics of empirical fields of the General Circulation of the Atmosphere" and stimulated atmospheric modeling effectively.

Core research areas of Defant's group were related to the aerology and heat budget above the atmosphere of the western Arabian Sea during the northeast monsoon (Behr, Defant, 1972), energetics of the devastating storm surge in Hamburg in February 1962 (Defant et al., 1972), the global energy budget (Defant, 1976a, 1976b, 1977; Defant, Moerth, 1978; Speth, 1974a, 1974b), the atmospheric heat and moisture balance in the Baltic Sea region (Behr, Speth, 1977), upwelling off northwest Africa (Speth et al., 1978; Speth, Detlefsen, 1979, 1980), and process studies of special meteorological phenomena (e.g. Defant, Arpe, 1974). In this context the IfM meteorologists participated in the IIOE (on Meteor, 1964/1965) and in GATE (on Meteor and Anton Dohrn, 1974).

Twenty years after its foundation, the Maritime Meteorology department required an expansion of research and teaching. A second professorship of meteorology was provided. When Lutz Hasse (1931–2016; fig. 23) succeeded

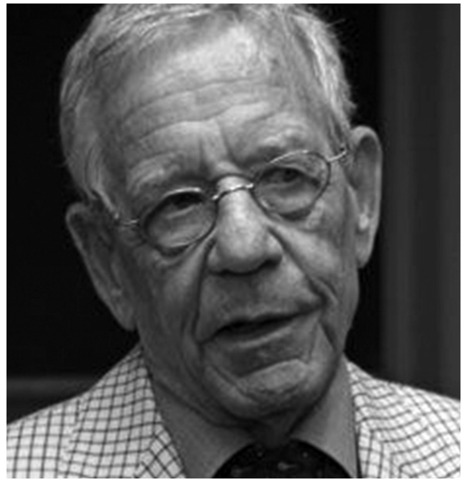

Fig. 23. Lutz Hasse (1931–2016). (Photo: A. Villwock, GEOMAR)

Friedrich Defant in 1980, Hartmut Grassl received the newly established professorship in 1981 and was later succeeded by Eberhard Ruprecht in 1985. Grassl and Ruprecht introduced the work with satellite data to the meteorology group. During the last two decades of the 20th century, meteorology research occurred in close cooperation with the physical oceanographers, in particular through the participation in SFB 133 and SFB 460 (see chapter 4). The interaction between atmosphere and ocean became the main focus of these research activities.

A climatology was derived of monthly energy and momentum fluxes at the sea surface over the North Atlantic. The basic data came from the so-called “Bunker Data Set” covering years the 1941–1972 (Isemer, Hasse, 1985, 1987). In order to construct the climatology, observational errors had to be eliminated and flux parameterizations had to be improved.

In historical data, wind speed was typically estimated by the state of the ocean surface using the Beaufort scale. A study with ship data over the North Atlantic showed a certain temporal change in the wind field. The meteorological team wanted to find out whether this trend was more than a spurious artifact from the Beaufort scale by considering changes in ship type and observation methods. In fact, the comparison between the wind speed estimates from the Beaufort scale and an objective analysis of the corresponding pressure gradients revealed a drift in the Beaufort scale. The surface winds of the “Bunker Data Set” were corrected correspondingly (Bunker, Hasse, 1989; Isemer, Hasse, 1991). The effect of the wind correction was tested by the calculation of Sverdrup transport in the North Atlantic with different parameterizations (Böning et al., 1991). Direct measurements over water during earlier years could be used to improve the parameterizations of energy and momentum fluxes. Finally, fine adjustments were carried out by directly estimating the ocean heat transport between 25°–65° N; the corrections of bulk coefficients, however, were small (Isemer et al., 1989).

New instruments were developed for better maritime meteorological observations, and direct measurements at the atmosphere-ocean interface were conducted. In particular, precipitation measurements over the ocean from ships are still difficult and have large inherent errors, especially at high wind speeds. Strong winds accompanied by large turbulence over the ship body have the effect that rain drops do not reach the horizontal surface of the rain gauge. Therefore a new instrument was designed with horizontal and vertical receiver surfaces (Hasse et al., 1992). The instrument was tested on a number of METEOR cruises in the Atlantic Ocean and compared to the results from an optical distrometer, which had also been developed at the IfM. The results were quite satisfactory, and a number of these instruments were used on voluntary ships crossing the Baltic Sea as part of the Baltic Sea Program "BALTEX". The results were then used to test satellite rainfall algorithms (Lindau et al., 1997).

Observations from ships cover only a small area of the vast ocean. Satellite observations have a much better spatial coverage. However, algorithms were needed to derive atmospheric and oceanic parameters from the radiation data measured by satellite radiometers at different frequencies. The groups of Grassl and Ruprecht developed such algorithms for sea surface temperature and the water cycle in atmospheric humidity profiles, in clouds and in precipitation.

Infrared measurements by NOAA satellites were used to derive sea surface temperature (SST) algorithms. The results were tested against direct SST measurements during the METEOR cruise M69. The results had errors of less than 0.5 Kelvin. Together with high-resolution measurements of upper ocean vertical temperature profiles, the cold bulk skin temperature could be resolved, and its effect on SST calculations was determined from satellite observations (Schlüssel et al., 1990). In 1978 a microwave radiometer (SS-MR/I) was launched at the NIMBUS 7 satellite. Its observations over seven radiation channels could be used to derive hydrological parameters like total water vapour, humidity profiles, and rainfall especially over the ocean.

A radiation transfer model was developed to calculate brightness temperatures for given humidity distributions. These profiles were used as the basic data set for algorithm development (Simmer, 1994). To reduce the high variability of the humidity profiles, typical structures were derived through EOF analyses. The results showed that the first two eigenvectors represented total water content and the cloud water. These results allowed the derivation of algorithms for these two parameters (Wagner et al., 1990). The algorithms were improved by applying neural networks in lieu of multiple regression analyses (Jung et al., 1998). The cooperation within SFB 460 and with paleo-oceanographers at GEOMAR led to research on ocean-atmosphere interaction by large-scale systems: the North Atlantic Oscillation and its variation in historical timescales derived from ice cores and tree rings (Jung et al., 2003; Timm, Ruprecht, 2004).

At the beginning of the winter semester 1995/96 Peter Lemke succeeded Hasse. Lemke brought a new research topic of global climate modeling to the meteorology department. This was achieved in cooperation with the oceanographic modeling group at the IfM. Lemke added his ice model to the ocean model in hopes of improving the representation of sea ice in global climate models. The use of more sophisticated dynamic-thermodynamic sea ice models was required because of their lower sensitivity to global warming. Lemke's ice model was based on the viscous-plastic model of Hibler (1979). Several model improvements pertaining to dynamics, ice thickness and roughness, and transports were made (Harder et al., 1998; Hilmer at al., 1998). Lemke organized the Sea Ice Model Intercomparison Project (SIMIP) initiated by the Sea Ice Ocean Modelling Panel of the Arctic Climate System Study (Lemke et al., 1997; Kreyscher et al., 2000), which showed that viscous-plastic models gave the best sea ice dynamic representations in global climate models. Due to his international recognition, Lemke was elected as a member of the Joint Scientific Committee for the World Climate Research Programme in 1995 and became its chairman in 2000. In 2001 Lemke left the IfM to return to AWI Bremerhaven. His position was filled by Mojib Latif in 2003. With the appointment of Latif, Global Climate Modelling was consolidated.

6.3 Marine Chemistry

The long history of chemical investigations of inorganic seawater constituents carried out at various institutions in Kiel was interrupted violently when Hermann Wattenberg, then director of the institute and an inorganic research chemist, died during an air raid in June 1944. Seventeen years later, in 1961, Klaus Grasshoff (fig. 24), also an inorganic chemist, was appointed research assistant at the re-established IfM. He set up a small working group within the oceanography department of Günter Dietrich, consisting of himself and two technicians, Alfred Wenck and Uwe Rabsch.

Participating in the first post-war International Indian Ocean Expedition (IIOE) on board the new research vessel Meteor, they assisted the physical oceanographers in their task of determining the density stratification of the water column by measuring temperature and salinity profiles. They also measured concentrations of dissolved inorganic nutrients for phytoplankton (ammonia, nitrite, nitrate, phosphate, silicate, and calcium) as well as dissolved oxygen in the inner Gulf of Aden, near the Somali coast, in the western Indian Ocean coastal region, the Arabian Gulf, and the Straits of Oman, assessing the capacity of these water bodies for phytoplankton primary production (Dietrich et al., 1966; Düing et al., 1967; Grasshoff, 1969). The enormous number of measurements carried out by such a small working group was possible only because Grasshoff had modified an AutoAnalyzer, an instrument originally developed for clinical analyses, for this work. It uses peristaltic pumps in a technique called continuous flow analysis to mix seawater with appropriate reagents to form dyed reaction products that are quantified colorimetrically.

Fig. 24. Klaus Grasshoff (1932–1981). (Photo: E. Mempel)

In 1966 the technician Hergen Johannsen joined the group. He and Alfred Wenck, also a technician, together with Hans Peter Hansen and Hannes Petersen eventually became the main guardians of the modified AutoAnalyzer, improving the instrument according to Grasshoff's ideas. Over the years the AutoAnalyzer was optimized for ever more complex observations at sea, culminating in the adoption of a towed intake system that permitted continuous dissolved nutrient measurements as well as salinity and pH determinations at pre-selected depths. Hansen and Petersen built and programmed, in machine language, the computer controlling the complex mechanism.

In 1968 the group became the Department of Marine Chemistry, with Grasshoff as its director. When the AutoAnalyzer system had reached a level of reliability and sophistication such that it no longer needed his immediate supervision, he began to develop a system, in 1972, which later was called the bell jar. It enclosed a volume of seawater in direct contact with the sea floor and was equipped with sensors for oxygen, pH, and salinity and with water samplers for determinations of inorganic nutrient concentrations. First operational test runs in 1974 revealed that with the enclosed water becoming anoxic, the phosphate, silicate, and ammonia concentrations started to rise while the pH dropped to 7.0. These findings remained unpublished.

One companion of the early formative years of the chemistry department, as distinguished a scientist as he was fun to have around, definitely needs mentioning: Joris Gieskes, of Dutch extraction. After graduation in Manitoba, Canada, he had spent a year at the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts, U.S.A., before he joined the group at Kiel in 1966. Initially he used a membrane salinometer with a temperature sensor to investigate horizontal and vertical density distributions at various locations in the Baltic Sea (Gieskes, 1967). With Grasshoff he published a paper on the lack of clear correlations between nutrient concentrations which phytoplankton remineralization processes would suggest (Gieskes, Grasshoff, 1969). They attributed this phenomenon to unequal liberation of nutrient ions from sediments. Late in 1968, Gieskes left Kiel again to accept a position at the Scripps Institution of Oceanography in La Jolla, California, U.S.A., where he stayed until his retirement with more than 100 publications to his credit.

In 1967 the organic chemist Manfred Ehrhardt, initially working within the planktology department under Johannes Krey, became loosely affiliated with the fledgling marine chemistry group, later to join its staff. He developed a method to measure concentrations of dissolved organically bound carbon in filtered seawater samples in order to expand the range of parameters necessary for characterizing a water body beyond inorganic constituents. In a flow-through system not unlike the AutoAnalyzer intense ultraviolet light oxidized organic carbon compounds to carbon dioxide that was then quantified in a simple conductometric flow-through cell, the analytical apparatus loosely based on Karl Heinz Szekieldas pioneering work (Ehrhardt, 1969a).

Adoption of an elemental analyzer for determining concentrations of particulate organic carbon and nitrogen completed the arsenal of instruments for measuring bulk concentrations of microscopic particulate and dissolved organic carbon in seawater. These were parameters mainly of interest to planktologists because concentrations of particulate and dissolved organic carbon are positively correlated with primary production by phytoplankton (Ehrhardt, 1969b).

The early 1970s saw many accidents involving tankers carrying crude oil or refined products. Sometimes large quantities of their spilled cargo ended up on beaches where samples could be collected to study the behavior of oil exposed to the environment. Because of this in early 1970 Ehrhardt was sent to WHOI to be trained in the necessary analytical techniques by the Swiss born organic chemist Max Blumer. The methods included gas chromatography for separating the vastly complex mixture of aliphatic, alicyclic, and aromatic hydrocarbon constituents of mineral oils into single compounds, and mass spectrometry to elucidate their chemical structure. The rather poor resolution of the packed gas chromatographic columns then available was no match for the complexity of crude oil and its refined products, but some compositional changes effected by weathering could be traced. Among them was the preferential decomposition of straight chain aliphatic hydrocarbons whose linear carbon skeleton micro-organisms apparently could metabolize more easily than their branched chain homologues. The analytical techniques studied at Woods Hole provided a solid foundation on which to expand in Kiel. Most of the methods eventually developed are described in the book "Methods of Seawater Analysis" by Grasshoff et al. (2007).

After his return in late 1971 Ehrhardt began to concentrate lipophilic dissolved seawater constituents by solid phase adsorption, expanding on an

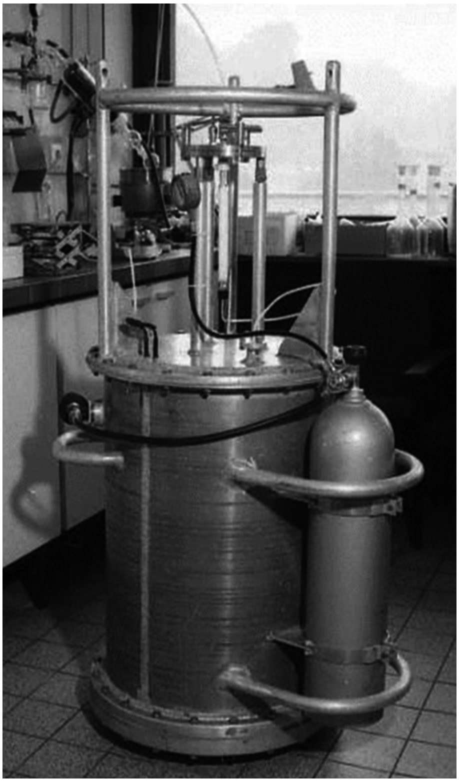

Fig. 25. Submersible version of the extraction buoy. Critical components of the machinery are pressurized with an aqualung. (Photo: M. Ehrhardt)

idea originally proposed by Karsten Palmork of the Institute of Marine Research in Bergen, Norway. This technique has the potential of collecting sufficient quantities for gas chromatographic separation and mass spectrometric structure elucidation. A peristaltic pump contained in a small buoy together with a battery to power it pressed seawater through glass fiber filters to retain particles and then through a glass adsorption column filled with the granulated adsorption resin Amberlite XAD-2. The rather primitive original surface buoy was later replaced by a more efficient unit and by a submersible version which, based on an idea of the affiliated planktologist Jens Derenbach, was pressurized with an aqualung (fig. 25). Both buoys were used mainly in the Gotland Basin of the Baltic Sea (Ehrhardt, 1976).

Gas chromatographic capillary columns with greatly improved separation efficiency had become available in the meantime. They revealed, in combination with mass spectrometric structure determinations and calibrated UV absorption measurements, that concentrations of dissolved mineral oil residues in the Baltic and the Mediterranean Sea were far smaller than anticipated. In addition to aliphatic and aromatic hydrocarbons many oxygenated derivatives of aromatic hydrocarbons were found whose mass spectra suggested formation by photo-oxidation with natural sunlight. In a controlled experiment, even the aliphatic hydrocarbon n-pentadecane (n-$C_{15}H_{32}$) which does not absorb solar UV radiation, revealed a fascinating complexity of photo-decomposition reactions (Ehrhardt, Petrick, 1985). In the presence of a sensitizer which was also found in seawater, irradiation with natural sunlight unexpectedly transformed this strait chain saturated hydrocarbon into a plethora of oxygenated products, with the original and with reduced numbers of carbon atoms. These substances probably are easy for microorganisms to metabolize, which may explain why they had not been detected in seawater in contrast with photo-oxidation products of aromatic hydrocarbons. Controlled photo-oxidation experiments mainly involving the bicyclic aromatic crude oil constituent 1-methylnaphthalene were later carried out in collaboration with Kathy Burns at the Bermuda Biological Station for Research and with Rolf Roland Weber at the Instituto Oceanográfico, Universidade de São Paulo, Brazil (Ehrhardt, Burns, 1990; Ehrhardt et al., 1997).

In 1968 Klaus Kremling, an inorganic chemist who had become familiar with fresh-water analysis at a laboratory supervising the quality of drinking-water, joined the staff. The focus of his work at the IfM was the development of methods, and their application, for measuring concentrations of trace metals dissolved in seawater or associated with particles. Polarography and voltammetry were the methods of choice for quantifying elements such as zinc, cadmium, copper, cobalt, nickel, lead, vanadium, titanium, manganese, iron, and platinum in the Baltic Sea, the Mediterranean (Kremling, 1973; Kremling, Petersen, 1981), and the Atlantic Ocean (Kremling, 1985; Kremling, Streu, 1993). Dramatic increases in concentrations of ≥100 were observed of zinc, cadmium, copper, nickel, cobalt, and iron across the interface between oxygenated and hydrogen sulphide containing water in the deep basin of the central Baltic Sea. Most likely they were due to the formation of relatively soluble metal derivatives with more than one sulfur atom per metal atom (Kremling, 1983). Measurements of trace elements were expanded eventually to include rare earth metals such as yttrium, lanthanum, cerium, praseodymium, ytterbium, gadolinium, terbium, dysprosium holmium, and lutetium (e.g. Kuss et al., 2001). He also investigated relations between chlorinity and conductometric salinity of Black Sea water (Kremling, 1974). Together with Frank Millero of the University of Miami, U.S.A., Kremling explored influences on the density of Baltic Sea water due to its elemental composition that deviates from oceanic values (Millero, Kremling, 1976).

Christoph Osterroht was the next chemist who became a member of the department's scientific staff in 1972. He combined expertise in mass spectrometry with knowledge on the use of solid adsorbents for concentrating lipophilic trace constituents of seawater (Osterroht, 1974). He initially joined forces with Ehrhardt (Derenbach et al., 1978), but later concentrated on the role of phytoplankton re-mineralization in the water column for the supply of seawater with nutrients. He found that nitrogen and phosphorous are liberated faster than carbon dioxide and thus enhanced primary production (Thomas et al., 1999; Osterroht, Thomas, 2000). He also studied phytoplankton primary production as a sink for atmospheric carbon dioxide, quantified biogenetic hydrocarbons such as n-pentadecane,(n-$C_{15}H_{32}$), n-hexadecane (n-$C_{16}H_{34}$), and all-cis-heneicosahexaene (n-$C_{21}H_{30}$) in seawater which showed strong seasonal variability, and used crown ether derivatives to quantify fatty acids. He also published papers on the distribution of dissolved organic copper compounds in the Baltic Sea (Osterroht et. al., 1985, 1988).

In 1981 the small community of marine research chemists suffered a severe loss when, after a short illness, Grasshoff passed away, not even 49 years old. For the next two years Ehrhardt was appointed acting chairman of the department until, in 1983, a worthy successor was found in the person of the Dutch ocean scientist Jan C. Duinker from the Netherlands Institute for Sea Research at Texel.

With the introduction of double hulled tankers equipped with slop tanks to collect tank washings, thus reducing the input of petroleum hydrocarbons into seawater, the focus of marine pollution research had in the meantime shifted from crude oil and oil products to polychlorinated biphenyls (PCBs). These substances are complex mixtures of up to 209 congeners with 1–10 chlorine atoms attached to biphenyl, itself composed of two benzene rings. The material found use as dielectric and coolant in electric transformers, cutting fluids in machining operations, and the production of carbon paper. Some of the congeners are acutely toxic, even carcinogenic, and because of the lipophilicity they share with all of them, they accumulate in the fatty tissue of fish and marine mammals. Thus, Duinker set his sight on this malicious trace contaminant of seawater and developed, together with Gert Petrick, sophisticated analytical procedures to concentrate PCBs from seawater, separate the complex mixture of congeners into single compounds by two-dimensional capillary gas chromatography that also enabled their quantification. Their chemical structures were elucidated by mass spectrometry. Soon, these techniques were also applied to measure the distribution of other anthropogenic chlorinated hydrocarbons between seawater and the atmosphere. More highly chlorinated PCB congeners were found enriched in rainwater which was collected over the Kiel Bight (Duinker et al., 1988).

Because of their toxicity, PCB production was banned in the United States in 1979 and by the Stockholm Convention on Persistent Organic Pollutants in 2001, but because of their stability in the environment, they continued to be a matter of concern. To study the association of PCBs, trace metals, and amino acids with sinking particles and their sedimentation rates, Duinker and Kremling deployed stainless steel water samplers of 400 liters capacity equipped with particle traps between 1,000 to 4,000 m below the surface at several locations in the North Atlantic Ocean (Kremling et al., 1996). In cooperation with the zoology department, PCBs were also analyzed and quantified in auks, penguins, and seals.

Under Duinker's spirited leadership the scientific staff of the marine chemistry department continued to grow as did the scope of its research efforts. To win his diploma, Arne Körtzinger from the Institute of Organic Chemistry at the CAU was assigned the task of developing a technique based on gas chromatography in combination with mass spectrometry, to separate, quantify, and chemically characterize fatty acids in organic particles. Samples were collected in moored traps for sinking particles. After his graduation he became a staff member of the Marine Chemistry Department. Since then he has authored a number of publications on a variety of subjects centered on the distribution of carbon dioxide and oxygen dissolved in seawater (e.g. Körtzinger et al., 1996, 2004, 2005).

Before this came to pass, however, Duinker, in 1996, decided to follow his physician's advice and terminated his assignment for health reasons. He ceded his leadership of the department to Kremling as acting chairman until, in 1998, Douglas W.R. "Doug" Wallace of Dalhousie University in Halifax, Nova Scotia, Canada, was introduced as its new director. He had been an earlier collaborator on the Meteor in the South Atlantic during the International World Ocean Circulation Experiment (WOCE). In the meantime, gauging the capacity of the oceans to absorb anthropogenic carbon dioxide in conjunction with WOCE had become fresh challenges for the department. Further topics were the exchange of volatile biogenic sulfur and iodine compounds between the oceanic surface and the atmosphere (Quack, Wallace, 2003). Birgit Quack, trained as a foodstuff chemist, developed the necessary methodology for the latter (Shi et al., 2014; Lennarts et al., 2015), while Duinker, Kremling, Osterroht, Schneider, and Wallace, together with various co-workers, were busy to find answers for the first question (Schneider et al., 1992).

This condensed history of the Department of Marine Chemistry may illustrate, inter alia, its response to changing research priorities which have their roots not only in the desire to better understand the intricate interactions within a vastly complex system, but also in the wish to comprehend its response to external forcing such as pollution and rising concentrations of atmospheric carbon dioxide. As the Romans were fond of saying: *tempora mutantur et nos mutamur in illis*. Most of the work described here would have been impossible to accomplish without the dedicated efforts of additional scientific and technical staff not mentioned here by name. They were given due credit for their work as authors and co-authors of peer-reviewed publications.

7. The Route from IfM to GEOMAR

The fusion of the IfM and GEOMAR (for logos, see fig. 5/3 and 5/5) into the Leibniz Institute IFM-GEOMAR in 2004 generated a single organizational structure that included all disciplines of marine sciences in Kiel (cf. fig. 5/4). The merger terminated the existence of the IfM with its rotating directorship that was introduced in 1968. Table 1 contains the names of all post-war executive IfM directors and their fields of expertise in chronological order.

Years	Name	Discipline
1946–1959	Georg Wüst	Physical Oceanography
1959–1968	Günter Dietrich	Physical Oceanography
1969–1971	Friedrich Defant	Maritime Meteorology
1972–1975	Gotthilf Hempel	Fishery Biology
1976–1978	Gerold Siedler	Physical Oceanography
1979–1982	Bernt Zeitzschel	Planktology
1983–1987	Wolfgang Krauß	Physical Oceanography
1988–1989	Jan Duinker	Marine Chemistry
1990–1994	Dieter Adelung	Marine Zoology
1994–1995	Friedrich A. Schott	Physical Oceanography
1996–1997	Bernt Zeitzschel	Planktology
1998–2000	Peter Lemke	Maritime Meteorology
2001–2003	Jürgen Willebrand	Physical Oceanography

Table 1. IfM Executive Directors, 1946–2003, after 1968 elected for two-year periods from the group of department directors.

The Leibniz Association is named after the philosopher, mathematician, historian, and diplomat Gottfried Wilhelm Leibniz (1646–1716), a prominent Age of Enlightenment figure in European history. The Association includes about 90 research institutions and museums in Germany and is funded jointly by the federal government and the individual German states.

The institute was transferred to the Helmholtz Association and renamed the GEOMAR Helmholtz Centre for Ocean Research Kiel in 2012 for political and financial reasons (fig. 5/6). The Helmholtz Association of Ger-

Institute	Location in fig. 1	Coordinates
GEOMAR (ex-IfM) West Shore Buildings	1	54° 19.8′ N 010° 08.9′ E
CAU	2	54° 20.3′ N 010° 07.4′ E
GEOMAR East Shore Buildings	3	54° 19.65′ N 010° 10.9′ E
FWG	4	54° 19.85′ N 010° 10.0′ E
Pre-war IfM in Kitzeberg	5	(54° 21.3′ N) (010° 10.8 E)

Table 2. Location of marine scientific institutions in Kiel (status: 2016).

man Research Centres is a union of 18 major scientific-technical and biological-medical research centers in Germany. It is named after physiologist and physicist Hermann von Helmholtz (1821–1894) and is funded almost completely by the federal government in Berlin. This transition marked the end of the Institut für Meereskunde at Christian-Albrechts-Universität but certainly did not end the much longer era of marine research in Kiel. GEOMAR has continued to grow and widen its scientific scope, and the institute includes more than 1,000 staff members (thereof 563 scientists including 110 guest investigators in June 2017). For completeness, we have included the geographical coordinates of the various marine scientific centers in Kiel in table 2.

It could be said that the vision of the founding director of IfM Kiel, Adolf Remane (1937) has come true. In his inauguration speech on June 15, 1937 he wished for the new institute to host numerous generations of scientists. *"This will only happen when we gain achievements and develop problems that will stimulate and inspire coming generations of researchers."*[9] In fact, the above characteristics embedded in the build-up period after World War II can still be found in present day's activities of GEOMAR.

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Notes:

1 Since 1949 Humboldt-Universität.
2 Today: Federal Maritime and Hydrographic Agency of Germany (BSH, Bundesamt für Seeschifffahrt und Hydrographie).
3 Today: Institute for Sea Fisheries (Institut für Seefischerei) of the Thünen-Institute.
4 Later Howaldtswerke-Deutsche Werft (HDW), today ThyssenKrupp Marine Systems Kiel.
5 Today St Petersburg.
6 In order to assist English-speaking readers in this presentation, all the titles of German papers in the reference list are given with English translations in square brackets.
7 U. Passow, University of California, Santa Barbara (UCSB), private communication.
8 POLYMODE is a combination of the Russian word полигон (Polygon) and the American abbreviation of Mid Ocean Dynamic Experiment, NEADS stands for North East Atlantic Dynamic Studies, JGOFS for Joint Global Ocean Flux Studies.
9 Original German text: *"Dies wird nur dann geschehen, wenn wir Erkenntnisse erzielen und Probleme aufstellen, die kommende Generationen zum Weiterforschen anregen und begeistern."*
10 See note 6: In order to assist English-speaking readers, all the titles of German papers in this collection are given with English translations in squared brackets.

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Frühe Ozeanographie und die Entwicklung der marinen physikalischen und chemischen Wissenschaften in Kiel nach dem Zweiten Weltkrieg

Zusammenfassung

Unter den großen Meeresforschungsstandorten in Deutschland hat Kiel die längste Geschichte und hatte eine bemerkenswert schnelle Entwicklung nach dem Ende des Zweiten Weltkriegs. Der Erneuerungsprozess der physikalischen und chemischen Meeresforschung in der Nachkriegszeit steht im Mittelpunkt unseres Übersichtsartikels. Gleichwohl begann bereits am Ende des 17. Jahrhunderts erste Meeresforschung in Kiel: Samuel Reyher, Professor an der Kieler Christian-Albrechts-Universität, veröffentlichte Untersuchungen zur Salzgehaltsschichtung unter dem Eis der zugefrorenen Kieler Förde.

Zur Einordnung der späteren Entfaltung skizzieren wir eingangs die allgemeine Entwicklung in Deutschland. Im Anschluss an den frühen Start der physikalischen Ozeanographie entwickelten sich ab dem 19. Jahrhundert vorrangig die biologischen Disziplinen. Vom Ende des 19. Jahrhunderts an folgten maßgebliche hydrographische Arbeiten und im frühen 20. Jahrhundert Pionierarbeiten zur Meeresakustik. Allerdings spielte das in Berlin im Jahre 1900 gegründete Institut und Museum für Meeresforschung bei der Entwicklung der marinen physikalischen und chemischen Wissenschaften in Deutschland die führende Rolle. Das Kieler Institut für Meereskunde wurde 1937 als Teil der Universität gegründet. Der regionale Schwerpunkt der Arbeiten lag in Ost- und Nordsee, mit dem Hauptgewicht bei der Biologie, wobei aber auch Hydrographie und Meereschemie Gegenstand der Untersuchungen waren.

Nach der totalen Zerstörung beider Institute in Kiel und Berlin, bei der es auch zu erheblichem Verlust an Personal durch Bombenangriffe kam, ist das Berliner Institut nicht neu errichtet worden. Hingegen übernahm Georg Wüst, einer der führenden Wissenschaftler des Berliner Instituts, bereits 1946 die Aufgabe, das Kieler Institut wieder aufzubauen. Zu seinen ersten Herausforderungen gehörte es, ein Gebäude, wissenschaftliche Mitarbeiter und ein kleines Forschungsschiff zu finden. Mit dem Neubeginn erfolgte eine lang anhaltende Ausrichtung der Forschungsarbeiten hin zum tiefen Ozean. Ab 1959 setzte sein Nachfolger Günter Dietrich, ein früherer Student und später ebenfalls Wissenschaftler am Berliner Institut, den Wiederaufbau kontinuierlich fort. Dabei spielte auch die Ausbildung von Studenten eine wesentliche Rolle. Auf diese Art und Weise wurde das Kieler Institut in Forschung und Lehre zum Nachfolger der Berliner Schule.

Der Startschuss zur Forschung im tiefen Ozean erfolgte mit der Inbetriebnahme des neuen Forschungsschiffs Meteor anlässlich der Internationalen

Indischen Ozean-Expedition 1964/65. In den folgenden Jahren entwickelten sich multidisziplinäre Forschungsschwerpunkte. Sie führten zu einer stetigen Zunahme des Personalbestands. Infolge der Pionierarbeiten von Wüst und Dietrich kam es zu einem nachhaltigen Aufschwung insbesondere der physikalischen und chemischen Ozeanographie in Kiel. Dabei spielten neue technische Entwicklungen eine wichtige Rolle. Bereits vor 1956 wurde in Zusammenarbeit mit dem Institut für Angewandte Physik eine der ersten Sonden zur elektronischen Messung von elektrischer Leitfähigkeit und Temperatur in Vertikalprofilen entwickelt. Schon ab 1964 wurden Verankerungssysteme zur Langzeitbeobachtung entworfen und ausgebracht. In Zusammenarbeit mit den Universitäten in Miami und Rhode Island kamen in den 1970er Jahren hochauflösende Profilstrommesser zum Einsatz. In den 1980er und 1990er Jahren folgten mit Satelliten geortete Oberflächendrifter und RAFOS-Floats. Ab den 1980er Jahren wurden Rechnerkapazitäten zur Datenanalyse und numerischen Modellierung geschaffen.

Nationale Forschungsprogramme, einschließlich der Gewinnung von Zeitserien, und die Teilnahme an internationalen Forschungsprogrammen wie dem Weltozean-Zirkulationsexperiment WOCE standen im Fokus der Kieler Wissenschaftler, vorrangig aus der physikalischen und chemischen Meeresforschung. Erstklassige Ergebnisse zur großskaligen Vertikalzirkulation im Nordatlantik wurden durch Studien zur Zwischenwasser- und Tiefenwasserbildung, zu Overflow und Rezirkulation erzielt. Ferner wurden die Zirkulation in tropischen und subtropischen Ozeanen und der Wasser- und Wärmeaustausch im Südatlantik und in der Agulhas-Region untersucht. Ebenso sind die Studien zu turbulenten Flüssen an der Ozeanoberfläche sowie Arbeiten zu Konvektionsprozessen mit ihren tief reichenden Auswirkungen auf die globale Zirkulation von maßgeblicher Bedeutung. Die Ergebnisse bilden eine wichtige Grundlage der heutigen Forschung zu Klimaänderungen. Zusammenfassend kann man sagen, dass durch die Entwicklungen im Institut für Meereskunde und später in den Geowissenschaften an der Kieler Universität die Grundlagen für den bis heute andauernden Aufschwung der Meeresforschung in Kiel geschaffen wurden.

Des débuts de l'océanographie et du développement des recherches en physique et en chimie à Kiel après la Seconde Guerre mondiale

Résumé

Parmi les principaux centres de recherche océanographique, Kiel a connu en plus de sa longue histoire, un développement spectaculaire depuis la fin de la Seconde Guerre mondiale. Ce développement est au centre de notre synthèse. C'est à la fin du XVII° siècle à Kiel que débuta l'étude des milieux marins : Samuel Reyher, Professeur à l'université Christian-Albrecht y publia ses recherches sur le degré de salinité sous la glace du fjord de Kiel.

Nous allons tout d'abord préciser le contexte du futur développement de la recherche sur le milieu marin à Kiel. A la suite du développement des études en biologie, débuta la recherche océanographique liée à la physique. A la fin du XIX° siècle suivirent des travaux décisifs en hydrographie. Mentionnons aussi, les travaux pionniers sur l'acoustique marine dans le premier XX° siècle. Ainsi, la fondation en 1900 à Berlin de l'Institut-musée sur la recherche maritime, joua un rôle majeur dans le développement de l'océanographie physique et chimique. L'Institut océanographique de Kiel fut rattaché à l'université en 1937. Le point nodal de la recherche régionale en mer du Nord et Baltique se concentrait sur l'océanographie biologique mais aussi l'hydrographie.

Après la destruction totale des deux Instituts de Kiel et Berlin, dans des bombardements où des personnels trouvèrent la mort, il fut décidé de ne pas reconstruire l'Institut de Berlin. Georg Wüst, un des anciens chercheurs de Berlin, fut chargé de fonder un nouvel Institut à Kiel. Une de ses premières tâches fut de trouver un local, des collègues scientifiques et un petit navire de recherche. Avec ce nouveau départ, le travail s'orienta vers des activités de recherche sur les profondeurs océaniques. A partir de 1959, son successeur Günter Dietrich, ancien étudiant puis chercheur de l'Institut de Berlin, poursuivit la reconstruction de l'Institut de Kiel. C'est alors que la formation universitaire devint décisive. C'est par ces actions que l'Institut de Kiel, maintient l'héritage de l'école de Berlin dans le domaine de l'enseignement de l'océanographie des profondeurs. Les missions de recherche dans les profondeurs océaniques débutèrent avec la mise à l'eau du navire scientifique Meteor et son expédition de 1964/65 dans l'océan indien. Dans les années qui suivirent, l'accent fut mis sur la pluridisciplinarité, ce qui engendra une augmentation croissante du nombre de collaborateurs. A la suite des travaux pionniers de Wüst et Dietrich, l'océanographie physique et chimique trouva à Kiel sa continuité. C'est alors que des progrès technologiques jouèrent un rôle décisif. A partir de 1956 et en collaboration avec l'Institut de Physique appliquée, une des premières sonde électronique de mesure de température

en profils verticaux fut mise au point. Déjà en 1964, un système d'ancrage permettant des observations sur le long terme fut conçu et utilisé. En partenariat avec les Universités de Miami et Rhodes Island furent utilisés les premiers systèmes profilés à haute résolution de mesure des courants. Dans les années 1980/90 suivirent les dériveurs de surface et RAFOS-Floats. A partir des années 80, le calcul et l'analyse des données furent modélisés de façon numérique.

Des programmes nationaux incluant le gain des séries chronologiques et la participation à des programmes internationaux comme le WOCE (World Ocean Circulation Experiment) sur la circulation transocéanique, portèrent les chercheurs de Kiel à se concentrer sur les domaines de l'océanographie physique et chimique. Une des grandes premières fut la démonstration à grande échelle de la circulation verticale en Atlantique-nord par l'étude de la recirculation des eaux de moyenne et grande profondeur. Plus tard l'étude se porta sur la circulation des océans tropicaux et subtropicaux et sur les échanges d'eau et de chaleur dans l'Atlantique sud et la région du Cap Agulhas. Les études des courants de turbulence de la surface océanique, tout comme les travaux sur les processus de convection, eurent d'importantes répercussions du fait de la portée de leurs résultats. Toutes ces découvertes sont aujourd'hui à la base des progrès sur l'étude du changement climatique. Pour conclure, on peut dire que l'Institut d'océanographie fut après la Seconde Guerre mondiale à l'origine d'un épanouissement de la recherche océanographique à Kiel, épanouissement qui se poursuit aujourd'hui.