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backing Said of the anti-clockwise change of direction of a wind, as opposed to veering.

- **backscattering cross-section** The ratio of the acoustic power scattered at an angle of 180° from the incident acoustic wave to the acoustic intensity incident on a unit volume or area. This measure, typically referenced to a unit distance, e.g. 1 m, is the ratio of the reflected acoustic power to incident acoustic power per unit area. The units of this ratio are area, e.g. m<sup>2</sup>.
- **backshore** That part or zone of a beach profile that extends landward from the sloping foreshore to a point of either vegetation development or a change of physiography, e.g. a sea cliff or a dune field. See Komar [1976].
- Baffin Bay A large sea located between the Canadian Archipelago and the Labrador Sea. It is about 1000 km and 400 km. Most of Baffin Bay is deeper than 1500 m, but deep water exchange with the Labrador Sea is restricted by a sill in Davis Strait with a depth of 670 m. A mobile ice cover forms during winter and moves southward under the prevailing winds. Icebergs calved from glaicers in southern and western Greenland drift across the bay and southward in the Baffin Current to southern latitudes. A significant oceanographic feature of Baffin Bay is the North Water, a partially open water area in the northern part where complete ice cover would be expected under prevailing climatological conditions.

The principal currents are a relatively warm northwards flowing current along the Greenland coast, and the cold southwards flowing Baffin Current. This cyclonic circulation is driven by surface inflows of low salinity Arctic water through the Canadian Archipelago in the north and by means of the West Greenland Current in the south. Current meter data from northern Baffin Bay show strong surface Arctic outflows to a depth of about 500 m, directed to the south and generally following the bathymetry. There is a strong annual cycle in the mean currents, with the currents stronger in summer and weaker in winter. This variability is probably driven by seasonal changes in buoyancy forcing, which enhances the coastal currents on the wide shelves. Tidal currents up to  $0.4 \text{ m s}^{-1}$  have been observed on the shelves and along the shelf slopes, and consist mainly of semidiurnal components, with a considerable diurnal component in some areas.

The surface layer, defined as the layer extending to the maximum depth influenced by wind stress, is a few tens of meters thick. The surface layer water has a density of 1026 kg/m<sup>3</sup> or less, with the deeper water weighing in at 1027 kg/m<sup>3</sup>. Their salinities are 32.5 and 34.0, respectively. In the eastern part of the bay there is a layer between about 200 and 800 m characterized by relatively warm and saline water. This is considered the result of inflow of Atlantic water through the Davis Strait. Substantial tidal currents have been measured in the eastern part of the bay, e.g. up to about 20 cm/s at locations where the water depth is 500 m. See Ingram and Prinsenberg [1998].

[http://www.bmp.gl/E/EB3\_petroleum/EB3\_50ba\_10na\_baffin.html]

- **baguio** The local name given to **tropical cyclones** in the Phillipines, especially those occurring from July to November.
- **balanced equations** Approximations to the primitive equations that filter out the inertia–gravity waves but retain the geostrophic motions. Examples include:
  - planetary geostrophic equations
  - quasi-geostrophic equations
  - semi-geostrophic equations

The primitive and planetary geostrophic equations can be seen as the limiting cases, with the former including all motions and the latter filtering a wide range of motions via its complete omission of inertia. The other equation sets are attempts to find a compromise between the former and latter. See McWilliams and Gent [1980], G. and Flierl [1981] (p. 508), Salmon [1985], Allen et al. [1990], Allen [1993], Allen and Newberger [1993], Muller [1995] and Mohebalhojeh and Dritschel [2001].

Balearic Channels The collective name give to the Ibiza Channel, the Mallorca Channel and the deep trough in the Gulf of Valencia, all features found within the Balearic Sea.

According to Pinot et al. [2002]:

The Balearic Channels are important passages for the meridional exchange between the cooler, more saline waters of the northern basin and the warmer, fresher waters of the southern (Algerian) basin of the western Mediterranean. The Northern Current carries northern waters from the Gulf of Lions southward along the continental slope in the Balearic Sea. This current bifurcates as it reaches the northern end of the Ibiza Channel. The main branch proceeds southward and crosses the sill carrying cool and salty water into the Algerian Basin, while the minor one is retroflected cyclonically and returns to the north-east forming the Balearic Current that crosses the continental slope of the islands. This latter current is also fed by warmer, fresher southern waters from the Algerian Basin, which flow northward through both channels. This smooth pattern obtained from a climatological analysis was later found to be the average picture of a highly fluctuating circulation.

. See Pinot et al. [2002].

Balearic Sea One of the seas that comprise the western basin of the Mediterranean Sea which is sometimes called the Catalan Sea. It lies between the Iberian coast and the Balearic Islands (Ibiza, Mallorca, Menorca) in the northwestern Mediterranean. It is separated from the Tyrrhenian Sea to the east by Sardinia and Corsica and abuts the Alboran Sea to the west. The bathymetry is dominated by the Balearic Abyssal Plain, which covers over 30,000 square miles, covering the majority of the basin floor at depths ranging from 2700-2800 m. This is bordered to the northwest by the Rhone Fan, a large sedimentary cone.

The circulation can be seen to first order to be a single oblong cyclonic cell with a divergence zone aligned with the shape of the basin. More detailed studies have shown the surface circulation to be strong year-round and characterized by two permanent density fronts. These are the Catalan Front on the continental shelf slope and the Balearic Front on the Balearic Islands shelf slope, with the former the more active. The northern area a plume of cold water frequently seen moving southward along the continental slope and shedding dipole eddies along its leading edge. Energetic filaments continuously spawned by the Catalan Front seem to be associated with this plume. See Fairbridge [1966], La Violette et al. [1990], Pinot and Ganachaud [1999] and Pinot et al. [2002].

Bali Sea A regional sea which is part of the Australasian Mediterranean Sea in the southwest Pacific Ocean. It is classified as a distinct sea for navigational purposes but is usually grouped with the Flores Sea for oceanographic purposes. It is centered at around 116° E and 8.5° S and is bordered by Bali and Sumbawa to the south and Madura to the west, and abuts the Java Sea to the north and the Flores Sea to the east. The Bali Sea covers an area of about 45,000 km<sup>2</sup> and has a greatest depth of 1590 m. It is mostly underlain by a small trough extending to the west of the Flores Trough and is bound by sills to the south (the 200 m Bali Strait and the 220 m Lombok Strait) and by a narrow, 600 m deep passage connecting it to the Makassar Stait to the north.

The circulation and water mass properties are continuous with the contiguous Flores and Java Seas to the east and north, repectively. Most of the oceanographic interest in the Bali Sea is concerned with its role in the Indonesian throughflow of Pacific Ocean waters into the Indian Ocean, with most if not all of this flow passing through the aforementioned Bali and Lombok Straits. See Fairbridge [1966].

- **BALTEX** Acronym for the Baltic Sea Experiment, a GEWEX project to study coupled hydrological processes between complicated terrain, sea and ice and the atmospheric circulation to determine the energy and water budgets of the Baltic Sea and related river basins. The scientific objectives are:
  - to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the BALTEX area and its interactions with surrounding regions;
  - to relate these mechanisms to the large–scale circulation systems in the atmosphere and oceans; and
  - to develop transportable methodologies to contribute to research in other regions.

[http://w3.gkss.de/baltex/baltex\_home.html]

### Baltic Current See Kattegat.

Baltic Operational Oceanographic System (BOOS) A cooperative endeavor among national government agencies in the countries surrounding the Baltic Sea responsible for the collection of observations, model operations and production of forecasts, services and information for the marine industry, and public and other end users. BOOS is a regional Task Team under EuroGOOS.

BOOS will be implemented from 1999–2003 by the accomplishment of nine projects:

- optimizing the existing operational observing network;
- use of remote sensted radar and satellite data;
- an operational mesoscale analysis system called PRODAS;
- optimization of existing models and coupled models;
- ecological modeling;
- study of harmful algae blooms via HABWARN;
- development of an anthropogenic load model;
- an assessment of the current state of the Baltic environment; and
- development of Info-BOOS.

[http://www.boos.org/]

Baltic Sea A dilution basin type of mediterranean sea that is connected to and experiences limited, intermittent water exchange with the North Sea. It comprises several parts separately known as the Gulf of Bothnia, the Aland Sea, the Gulf of Finland, the Gulf of Riga, Kattegat and Skagerrak. It has a mean depth is about 57 m, an area of about 370,000 km<sup>2</sup>, and a volume of about 20,000 km<sup>3</sup>, and is one of the largest brackish water bodies in the world. About 17% of its area is shallower than 10 m. The Baltic Sea depression is essentially a long fjord in the north-south direction (1500 km) with an average width of 230 km. The topography divides it into a series of relatively deep basins, with maximum depths ranging from 105-459 m.

The Baltic has a positive freshwater balance with an annual river runoff of  $440-480 \text{ km}^3$ , or about 2.2% of the volume. The runoff is usually maximum in May and minimum in January or February. A permanent salinity stratification results in a transition layer at 65–75 m. The residence time is on the order of several decades. The difference between precipitation (640 mm) and evaporation (500 mm) adds another 60 km<sup>3</sup> per year.

The circulation in the Baltic Sea is mainly driven by three forces:

- wind stress;
- horizontal density differences due to freshwater inflow from rivers and saline water inflow via the Danish Straits; and
- sea level inclination from the Danish Straits towards the interior.

On average, sea level rises about 25 cm from the Danish Straits towards the Gulf of Bothnia due to the river runoff.

If not interrupted by wind-driven currents, a continuous inflow of saline water from the Skagerrak forms the deep water of the Baltic. It is estimated that 740 km<sup>3</sup> of saline water enters the Baltic per year. The inflow enters through the Great Belt (65%), the Sound (25%) and the Little Belt (10%). After passing through these, the saline water passes over the shallow Darss Sill (18 m), crosses the Arkona basin, flows through Bornholm Strait into the Bornholm Basin, and finally flows through Stolpe Channel into the Gotland Basin. The value of  $\sigma_t$  increases from less than 5.0 in the Gulf of Finland to more than 25.0 in the Skagerrak. See Segerstrale [1957], Zenkevitch [1963], Rodhe [1998] and Stigebrandt [1999].

- Baltica A paleogeographic area during the late Precambrian and early Paleozoic that comprised northwestern Europe, including most of what are now the U.K., Scandinavia, European Russian and Central Europe. It formed the southeastern margin of the lapetus Ocean and was moved by the subduction of that ocean (during the Caledonian orogenic event) such that it made contact with North America and Greenland during the Silurian and Early Devonian.
- Banda Intermediate Water (BIW) See Rochford [1966].
- Banda Sea A regional sea in the Australasian Archipelago covering approximately 470,000 square kilometers and centered at about 126° E and 5° S. It consists of several basins and troughs interconnected by sills whose depths are mostly greater than 3000 m. See Gordon et al. [1994] and Arief [1998].
- **bank** The official IHO definition for this **undersea feature name** is "an elevation of the sea floor, over which the depth of water is relatively shallow, but sufficient for safe surface navigation."
- **bar** A unit of pressure equal to the pressure of 29.530 in. or 750.062 mm of mercury under the standard conditions of 0° C temperature and 9.80665 m/s<sup>2</sup> gravitational acceleration. Also, a popular locale during lengthty conferences.
- **barat** The local name given to strong, northwesterly squalls on the north coast of the island of Celebes that occur most frequently from December to February.
- Barents Sea One of the seas found on the Siberian shelf in the Arctic Mediterranean Sea. It is located between the White Sea to the west and the Kara Sea to the east and adjoins the Arctic Ocean proper to the north.

The Barents Sea is a key region for the modification of water masses in the Arctic, being one of several marginal seas in the Arctic wherein water flowing over shallow regions is transformed when heat loss and brine injection during the formation of sea ice increase density in the winter and sea ice meltwater and river runoff decrease surface water density in the summer. It differs from the other marginal seas in the region in that it has close connections with both the Norwegian Sea and the Arctic Ocean. See Zenkevitch [1963], Pfirman et al. [1994], Pfirman et al. [1995] and Harris et al. [1998].

**baroclinic** Descriptive of an an atmosphere or ocean in which surfaces of pressure and density intersect at some level or levels. The state of the real atmosphere and ocean, as opposed to **barotropic**. In a baroclinically stratified fluid total potential energy can be converted to kinetic energy. More later.

**baroclinic flow** In oceanography, the vertically varying circulation associated with horizontal imhomogeneities in the stratification of the oceans.

baroclinic instability To be completed.

baroclinicity vector A quantity that can be derived from the vorticity equation and expressed as:

$$\mathbf{B} = \frac{\nabla \rho \times \nabla p}{\rho^2} = -\nabla \left(\frac{1}{\rho}\right) \times \nabla p = -\nabla \times \left(\nabla \frac{p}{\rho}\right)$$

where  $\rho$  is the density and p the pressure. This indicates a tendency to generate vorticity whenever density surfaces are inclined to pressure surfaces. See Gill [1982].

- baroclinic radius of deformation See Rossby radius of deformation.
- **barotropic** Descriptive of a hypothetical atmosphere or ocean in which surfaces of pressure (isobaric surfaces) and density (isentropic surfaces) coincide at all levels, as compared to baroclinic. In a state of barotropic stratification, no potential energy is available for conversion to kinetic energy.
- barotropic flow In oceanography, depth-independent circulation due to changes in surface elevation. More later.
- barotropic instability To be completed.

barotropic radius of deformation See Rossby radius of deformation.

- barrier reef One of three geomorophologically distinct types of coral reefs, the other two being fringing reefs and atolls. Barrier reefs are separated from land by a lagoon usually formed by coastal subsidence. See Barnes and Hughes [1988].
- **barrier layer** In physical oceanography, the layer between the thermocline and the halocline. It is called this because of its effect on the mixed layer heat budget due to the temperature at the bottom of the barrier layer being zero, which excludes heat loss to the underlying water via mixing. It is defined as the difference between the thickness of the isothermal layer and the mixed layer (determined by a defined change in density), with the isothermal layer generally being greater than or equal to the mixed layer depth. In the Western Pacific, an area with a barrier layer, horizontal temperature gradients are also very small, leading to the conclusion that the net heat flux at the ocean surface must be close to zero. See Tomczak and Godfrey [1994].
- **BASFE** Abbreviation for Baltic Sea Fluorescence Experiment, conducted between March 1 and 10, 1994 aboard the RV A.V. Humboldt as a collaborative project between the IRSA in Italy and the Institute for Baltic Sea Research–IOW in Germany. Water was collected along several transects and at anchor stations over the diel cycle from four or five depths using a rosette. A pulse amplitude modulated (PAM) fluorometer was used on sample concentrated by gentle filtration to measure phytoplankton photosynthesis.

[http://me-www.jrc.it/other/data/balttext.html]

**basin** The official IHO definition for this undersea feature name is "a depression, in the sea floor, more or less equidimensional in plan and of variable extent."

**BASIS** Acronym for Barents Sea Impact Study, a research project developed under the auspices of IASC for studying the impacts of global change in the Barents region, which includes the Barents Sea and the northernmost parts of Sweden, Finland, Norway and European Russia. The main emphasis is on the Barents Sea and fisheries, and on terrestrial ecosystems, forestry and reindeer herding.

[http://www.urova.fi/home/arktinen/basis.htm]
[http://basis.uni-muenster.de/]

- **BASIS** Acronym for Baltic Air–Sea–Ice Study, a field experiment of BALTEX. The objective of BASIS is to create and analyze an experimental data set for optimization and verification of coupled atmosphere–ice–ocean models. The specific objectives are:
  - investigation of water budget, momentum and thermal interaction at air-ice, air-sea and sea-ice boundaries;
  - investigation of the atmospheric boundary layer (ABL);
  - investigation of the ocean boundary layer (OBL); and
  - validation of coupled atmosphere-ice-ocean models.

The intensive field phase of BASIS took place in the Gulf of Bothnia in the Baltic Sea in a boundary zone between the open sea and the ice–covered sea from February 16 to March 7, 1998. Ships used included the Swedish RV Argos and the Finnish RV Aranda.

[http://www2.fimr.fi/project/basis/index.htm]

- BASS Acronym for Basic Air Sea Studies, a series of experiments carried out in Bass Strait, Australia during the period 1975–1985. The data sets gathered results in a clearer understanding of the relationships between wave state, wind stress, and surface layer turbulence. See Chambers and Antonia [1981].
- **BASYS** Acronym for Baltic Sea System Studies, a project of the MAST and INCO program of the EU. The objectives of BASYS are to further the understanding of the susceptibility of the Baltic Sea to external forcing and to improve the quantification of past and present fluxes.

[http://www.io-warnemuende.de/Projects/Basys/]

Batchelor scale A length scale at which the steepening of scalar concentration gradients by the rateof-strain is balanced by diffusive smoothing. It is defined as:

$$L_B = \left(\nu \kappa^2 / \varepsilon\right)^{1/4}$$

where  $\nu$  is the kinematic viscosity of seawater,  $\kappa$  is the molecular diffusivity, and  $\varepsilon$  is the rate at which turbulent kinetic energy is lost, i.e.

$$\varepsilon = 2\nu e_{ij}^2$$

where

$$e_{ij} = \frac{1}{2} \left( u_{ij} + u_{ji} \right)$$

is the rate of strain tensor (with units of  $m^2 s^{-3}$  or  $Wkg^{-1}$ ). See McDougall et al. [1987].

**bathyal zone** The marine ecologic zone that lies deeper than the continental shelf but shallower than the deep ocean floor, i.e. those depths corresponding to the locations of the continental slope and rise. The depth range is from 100-300 m down to 1000-4000 m depending on such variables as the depth of the shelf break, the depth of light penetration, and local physical oceanographic conditions. See Fairbridge [1966].

- **bathymetry** The measurement and charting of the spatial variation of the ocean depths. See Fairbridge [1966].
- **bathypelagic zone** One of five vertical ecological zones into which the deep sea is sometimes divided. This is the zone starting from 100 to 700 m deep (coinciding with the upper limit of the psychrosphere) at the 10° C isotherm. The number of species and populations decreases greatly as one proceeds into the bathypelagic zone where there is no light source other than bioluminescence, temperature is uniformly low, and pressures are great. This overlies the abyssopelagic zone and is overlain by the mesopelagic zone. See Bruun [1957].

This is the lowest of the three vertical sections of the pelagic part of the ocean, the other two being the upper euphotic and the middle mesopelagic.

**bathythermograph** A device developed by Athelstan Spilhaus in 1938 to measure temperature/depth profiles in the ocean, the bathythermograph was basically a reworking of a mostly unworkable device called an oceanograph built in 1934 by Carl–Gustav Rossby for the same purpose. It consisted of an open, rectangular frame in which a compressible bellows with a pen arm and stylus was mounted at one end. The stylus rested on a smoked glass slide and moved across it to scratch a record of ocean temperatures. The stylus also moved vertically with changes in depth and thus created a temperature/depth profile.

The bathythermograph (or BT) was further improved by Maurice Ewing and Allyn Vine in 1940. Their version responded more quickly to temperature changes and was streamlined so it could be lowered and raised more quickly from a moving ship than could the previous more unwieldy version. In 1940 WHOI started doing military research for the government, a large part of which was concerned with sonar and the use of BTs with it. Knowledge of the vertical temperature structure of the ocean was extremely helpful to sonar operators since sound speed in sea water is a strong function of temperature, and various types of vertical temperature profiles would lead to sound traveling differently in the ocean. BT data was also useful for adjusting the buoyancy or trim of submarines since it could help provide an estimate of how much ballast would be needed to move a submarine from periscope depth to greater depths. A strong thermocline would require much more ballast for the submarine to descend.

The military research also led to further improvements in the BT including better aerodynamics for more stable operation at higher speeds as well as moving the glass slide and stylus from within the BT to inside the submarine. By early 1943 many submarines were outfitted with and used BTs. In an extremely helpful quid pro quo, the glass slides were given to WHOI and Scripps after missions in both oceans, allowing charts of the vertical temperature structure of the ocean to be constructed. Over 60,000 slides from the North Atlantic alone were thus made available to oceanographers. See Spilhaus [1938] and Schlee [1973].

**BATS** Acronym for Bermuda Atlantic Time-series Study, a JGOFS project to obtain and study long-term time-series of biogeochemical cycles in the Sargasso Sea near Bermuda. See Michaels and Knap [1996] and Steinberg et al. [2001].

More information can be found at the BATS Web site<sup>9</sup>.

**BAVAMEX** Acronym for the Baltic Sea Vertical Mixing and Advection Experiment, a BALTEX program to investigate vertical mixing and advection in the major basins of the Baltic Sea.

[http://w3.gkss.de/english/Baltex/campaign2.html]

 $<sup>^{9}</sup>$  http://www.bbsr.edu/bats/

Bay of Bengal The northeastern arm of the Indian Ocean, located between peninsular India and Burma. It covers about 2,200,000 sq. km and is bordered on the north by the Ganges and Brahmaputra River deltas, on the east by the Burmese peninsula and the Andaman and Nicobar Islands, on the west by India proper and Ceylon, and on the south by the Indian Ocean proper. The average depth is around 3000 m with maximum depths reaching over 400 m in the southern parts.

Major circulation features are the East Indian Current, a northward current flowing along the Indian shelf from January through October, and the East Indian Winter Jet, a southwestward flowing current that replaces during the remainder of the year. This current reversal is due to the seasonal change from the Northeast to the Southwest Monsoon and the concomitant wind forcing. General clockwise and conterclockwise circulation gyres are seen throughout the Bay accompanying, respectively, the Current and the Winter Jet, although the situation becomes a bit more complicated during the transition periods.

The monsoonal wind variations and the resulting circulations also serve to induce upwelling near the coasts during the spring (with the northward current) and the piling up of surface water along the coasts during the late fall and early winter (with the southward currents). Thus the isopycnals tilt upwards and downwards towards the shore during, respectively, the spring and late fall. The annual mean SST for the region is above 28.5° C., although upwelling can reduce this to 25-27° C during the spring. The salinities are kept lower than normal oceanic values (especially in the western parts) by extensive monsoonal river runoff. See Tomczak and Godfrey [1994], Fairbridge [1966] and Shetye et al. [1996].

- Bay of Bengal Water A water mass that originates in the northern Bay of Bengal via monsoonal input from the Ganges and Brahmaputra Rivers. It is a low salinity water mass that spreads across the Bay in an approximately 100 m thick layer that produces a strong halocline beneath (above the overlying Indian Central Water) and keeps the surface salinity in the eastern parts of the Bay below 33.0 throughout the year. Although there are no variations in temperature through the BBW layer, there are salinity variations below 50 m (and therefore above the main halocline) due to the fact that weak wind mixing erases variations over only about half the depth of the layer. This causes the permanent existence of a barrier layer. The low salinity surface water to the west of India, sometimes called East Arabian Sea Water (EAW), is usually subsumed under the BBW rubric due to its nearly identical properties. See Tomczak and Godfrey [1994].
- Bay of Biscay See Fairbridge [1966], pp. 637 and van Aken [2002].
- Bay of Bothnia See Gulf of Bothnia.
- Bay of Nice The Bay of Nice (5000 m long) is located in the north western Mediterranean basin, in the Côte d'Azur region, between 43°39' and 43°41'N and 7°12' and 7°18'E. The "Promenade des Anglais" hugs the coastline of the Bay. Its extension resulted in a general beach width reduction. Heavy swell arises mainly from east and south.

The Bay of Nice lacks a real continental shelf. There is a small shelf at the west side of the Bay in the Var prodelta area where the depth does not exceed 30 or 40 m. The Nice-Côte d'Azur airport, having undergone successive extensions from 1945 to 1985, covers 376 h of which two-thirds were obtained by filling the submerged Var prodelta area with Pliocene sediments. The extension obstructs the transport of sand and shingle from the Var embouchure to the East; it has also modified the previous near-shore current circulation. During the late 1960s and 1970s, the deficit of sand drifting to the east also resulted from the intensive extraction from the Var bed for the supply of building material. Today the Bay is fed almost entirely by the Paillon, a small river, 31 km long with a watershed of 236 km2. Its flow varies seasonally, usually between 1 and 40 m3/s, but it can exceptionally exceed 500 m3/s.

Since the Var sedimentary material no longer reaches the beaches of Nice, the Borough Council has adopted a coastal protection policy consisting of breakwaters in the western part of the Bay (in the late 1970s), and sediment replenishment on the beaches. The aim of these interventions is to broaden the beaches from 10 or 15 m to 20 or 25 m on average and stabilise them.' After Di Lauro et al. [2004].

- BBL In oceanography, abbreviation for benthic (or bottom) boundary layer.
- BBOP Abbreviation for Bermuda Bio-Optics Project.
- BBTRE The Brazil Basin Tracer Release Experiment was a WHOI program in 1996 and 1997 who goal was to use two independent methods to quantify turbulent mixing in the eastern Brazil Basin. The methods employed were:
  - injecting an SF6 tracer and tracking its dissipation over time; and
  - making discrete, instantaneous estimates of the turbulence using the HRP instrument.

The experiment involved released approximately 110 kg of sulfur hexafluoride on an isopycnal near 4000 m depth near 21deg 40' S, 18deg 25' W. The location is over a system of ridge spurs and canyons that run zonally towards the crest of the Mid Atlantic Ridge. The spurs attain depths of nearly 4400 m in the vicinity of the tracer release and the canyon valleys about 5000 m, with both shoaling to the east towards the Ridge crest where individual bathymetric peaks extend to about 2000 m depth.

The tracer was surveyed in 1996 within two weeks of its release, with HRP measurements indicating weak turbulent dissipation at all depths (with a diapycnal diffusivity of about  $0.1 \text{ cm}^2 \text{ s}^{-1}$ ) in the western half of the Brazil Basin where the bottom is smooth. Mixing rates were much greater over the rough topography, with measured diapycnal diffusivity values of about  $0.5 \text{ cm}^2 \text{ s}^{-1}$  for the depth and region of the tracer cloud (and values greater than twice this near the bottom). A survey cruise in 1997 sampled the distribution of sulfur hexafluoride about 14 months after its release. The average diffusivity over the 14 months on the injection isopycnal was estimated to be at least  $1.5 \text{ cm}^2 \text{ s}^{-1}$ , with values of  $10 \text{ cm}^2 \text{ s}^{-1}$  estimated near the bottom of the canyons. See Polzin et al. [1997] and Montgomery [1997].

[http://www.whoi.edu/science/AOPE/cofdl/tracerlab/bbtre.html]

- **beach berm** The nearly horizontal portion of a beach formed by the deposition of sediment by receding waves. A beach may have more than one berm. See Komar [1976].
- **beach face** The sloping section of a beach profile below the **beach berm** which is normally exposed to the action of the wave swash. See Komar [1976].
- Beaufort Sea The marginal sea consisting of the waters off the northern coast of Alaska and Canada. This is bounded to the east by Banks Island of the Canadian Arctic Archipelago and on the west by the Chukchi Sea. The bathymetric characteristics include the narrowest continental shelf found anywhere in the Arctic Ocean. This shelf is dissected by three submarine valleys, the largest of which is 45 km wide, and drops off rapidly to the Beaufort Deep, whose maximum depth is 3940 m. Although it is geographically identified as a separate entity, the Beaufort Sea is oceanographically an integral part of the Arctic Ocean and as such can't be described in isolation.

Substantially different circulation regimes are found on the inner and outer shelf regions, with the demarcation line corresponding approximately to the 50 m isobath. The inner shelf is strongly wind driven in summer, with a westward water motion driven by the prevailing easterly winds. This circulation varies seasonally, responding rapidly to large changes (including even an occasional reversal in prevailing wind direction), and is far less energetic in the winter (with wind effects persisting even

under the fast ice close to the shore). The outer shelf circulation is energetic at subtidal frequencies throughout the year, with the dominant feature being the Beaufort Undercurrent, a bathymetrically steered mean eastward flow extending from around the 50 m isobath to at least the base of the continental slope. This relatively strong current apparently increases with depth (to around 10 cm s<sup>-1</sup>) and is probably not locally driven but rather part of the large scale circulation in the Canadian Basin, although the portion of the Undercurrent overlying the shelf can be modified by local wind forcing. Frequent cross–shelf motions are found near the inshore edge of the Undercurrent, with daily means exceeding 5 cm s<sup>-1</sup> and durations typically 3 days or more. These serve to transport materials between the inner and outer shelf regions.

The most prominent hydrographic feature on the shelf is a subsurface summer temperature maximum generally found seaward of around 40–50 m depth which disappears during the winter. This is associated with an eastward flow of water originating in the Bering Sea. The warm water enters via the eastern Bering Strait and follows the Alaskan coast around Point Barrow. It is composed of two water masses called Alaskan Coastal Water (ACW) and Bering Sea Water (BSW). The ACW has summer temperatures of 5°–10° C west of Barrow with salinities less than 31.5. It mixes rapidly with local surface water as it moves eastward and is not clearly identifiable east of around 147°–148° W. The BSW is more saline and has a density range from 25.5–26.0  $\sigma_t$ , and can be traced as far east as Barter Island at 143° W. See Fairbridge [1966] and Aagaard [1984].

Beaufort Sea Mesoscale Project A NOAA ERL project undertaken to provide a quantitative understanding of the circulation over the Beaufort Sea Shelf and of its atmospheric and ocean forcing. Major emphasis was placed on providing extensive synoptic oceanographic and meteorological coverage of the Beaufort Sea during 1986–88. See Aagaard et al. [1989].

Beaufort Undercurrent See Beaufort Sea.

### Beaufort wind scale More later.

BEDMAP A project to develop a new ice thickness and subglacial topographic model of the Antarctic region, including bathymetry to 60°S.

[http://www.antarctica.ac.uk/aedc/bedmap/]

- **BEL** Abbreviation for Bottom Ekman Layer, the lowest of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BNL and the BML. The height of the turbulent BEL depends on the near-bottom current speed and varies in time. See Klein and Mittelstaedt [1992].
- Belgian Antarctic Expedition A research expedition carried out in the Antarctic regions from 1897 to 1899 aboard the ship "Belgica." This was the first vessel to winter in the Antarctic regions. See Murray and Hjort [1912], p. 16.
- Bellingshausen Abyssal Plain One of three plains that comprise the Pacific-Antarctic Basin (the others being the Amundsen and the Mornington Abyssal Plains. It is located at around 100-120° W.
- Bellingshausen Sea A marginal sea located off Antarctica from approximately 70 to 100° W northwards to the Antarctic Circle. It is located between Thurston Island to the west and the Antarctic Peninsula to the east and was named for the Russian admiral Baron Fabian Gottlieb von Bellingshausen who led an expedition to Antarctic waters at the behest of Alexander I in 1819. He is considered the first to have actually discovered the continent of Antarctic, those preceding him not having seen it because of ice and low visibility. The geographic features include Ronne and Marguerite Bay as well as

Peter I, Charcot and Alexander I Islands. See Fairbridge [1966], Turner and Owens [1995] and Grotov et al. [1998].

- Belt Sea More later.
- BEMEX Acronym for Bering Sea Experiment, a US/USSR study of the Arctic ice cap.
- BEMPEX Acronym for Barotropic Electromagnetic and Pressure Experiment, which took place in the North Pacific in 1986–87. See Luther et al. [1990].
- **BENGAL** Acronym for BENthic biology and Geochemistry of a north-eastern Atlantic abyssal Locality. This is a high resolution temporal and spatial study whose objective is to understand how the properties of the abyssal boundary layer respond to and modify the incoming chemical signal from the surface layers and therefore affect the paleoceanographic record in the underlying sediment. BENGAL aims to quantify and characterize the incoming flux (with time–lapse sediment traps and midwater particle cameras), its resuspension (with transmissometers and current meters), and its ultimate deposition (with chemical analysis of core samples and time–lapse sea–bed photography). See Billett and Rice [2001].

[http://www.marine.ie/datacentre/projects/bengal/]

Bengal, Bay of See Bay of Bengal.

- Benguela Current A current that flows northward along the west coast of southern Africa between about 15 and 35° S. This is the eastern limb of the subtropical gyre circulation system in the South Atlantic Ocean. See Fairbridge [1966], Peterson and Stramma [1991] and Garzoli and Gordon [1996].
- Benguela Current Experiment See Garzoli et al. [1999].

[http://www.aoml.noaa.gov/phod/benguela/]

- benthic Descriptive of organisms that are attached to or resting on bottom sediments, as opposed to pelagic.
- **benthos** One of three major ecological groups into which marine organisms are divided, the other two being the nekton and the plankton. The benthos are organisms and communities found on or near the seabed. This includes those animals (zoobenthos) and plants (phytobenthos) living on (epifauna) or in (endofauna) marine substrata as well as those that swim in close proximity to the bottom without ever really leaving it. In terms of size, this is generally divided into three categories: meiobenthos, the organisms that pass through a 0.5 mm sieve; macrobenthos, those that are caught by grabs or dredges but retained on the 0.5 m sieve; and epibenthos, those organisms than live on rather than in the seabed. Those in the latter category are usually larger.

Benchic life is subject to vertical zonation depending chiefly on light, moisture and pressure. This has led to the division of benchonic animals into two systems and seven zones. Proceeding from shallow to deep water, the first system is the phytal or littoral system, composed of the supralittoral, mediolittoral, infralittoral and circalittoral zones. The second system, the aphytal or deep system, is composed of the bathyal, abyssal and hadal zones. See Fairbridge [1966].

Berghaus, Heinrich (1797–1884) See Peterson et al. [1996], p. 65.

Bering Sea A marginal sea located on the northern rim of the Pacific Ocean centered at approximately 58° N and 160° W. It is surrounded by Alaska to the east, Siberia to the west and northwest, and

the Aleutian Island arc to the south. It has an area of about 2,300,000 km<sup>2</sup> and a volume of about 3,700,000 km<sup>3</sup>. The bathymetry is about equally divided between a vast shelf to the northeast that is at most 200 m deep and the Aleutian Basin where depths range from 3800-3900 m over most of the region. The Shirshov Ridge (along 171° E between 500-1000 m depth) and the shallower Bowers Ridge (along 180° E then turning west along 55° N) effectively divide the Basin into three parts. It is connected to the Arctic Mediterranean Sea via the Bering Strait and to the Pacific via several sills between the various Aleutian Islands, although the main connection is thought to be between 168° E and 172° W where the sill depth is about 1590 m.

The main circulation features include a large part of the westward flowing Alaskan Stream entering the Bering Sea through the passage centered at 170° W, turning east, and driving a cyclonic (counterclockwise) gyre in the Aleutian Basin. This largely barotropic current sees the two main ridges as obstacles which sets up a system of two eddies, one on each side of the Shirshov Ridge. Eddies have been observed separating from the eastern limb (often called the Bering Slope Current) of the Bering Sea gyre, the larger of the two systems. There is a countercurrent further up the Bering Slope whose dynamics are those of an eastern boundary current in a subpolar gyre. A series of currents and related fronts largely driven by Alaska Stream inflow through a shallower passage at 175° W flow north-northwestward on the broad shelf region.

The main circulation feature of the northern Bering Sea is the Anadyr Current, a largely seasonally invariant current flowing northeastward and supplying most of the Bering Strait throughflow. This throughflow, driven by sea level differences across the strait, varies from about 0.1 m/s in the summer to 0.5 m/s in the winter, with flow through the Shpanberg Strait seasonally shifting from northward to southward to compensate for the differences. The shelf flows also make some mostly unknown contribution to this throughflow. The western limb of the smaller gyre to the west of the Shirshov Ridge contributes to and becomes part of the southwestward flowing Kamchatka Current.

The local water masses are derived from Pacific Ocean water masses transported in to the area and modified by processes on the shelf. This results in a temperature minimum at or below 100 m, low surface salinities rapidly rising to about 300 m, and overall low oxygen concentrations. The water overlying the temperature minimum is surface water imported from the Alaska Stream, and the water below that is Pacific Deep Water. See Zenkevitch [1963], Tomczak and Godfrey [1994], Fairbridge [1966], Coachman [1986], Cokelet and Stabeno [1997] and Schumacher and Stabeno [1998].

Bering Slope Current A current that flows from southeast to northwest along the northeast continental slope of the Aleutian Basin of the Bering Sea, parallel to the continental slope of the eastern Bering Sea shelf. According to Johnson et al. [2004]:

Water property distributions, direct velocity measurements at the 1000-dbar float park pressure, and geostrophic transport estimates relative to near that park pressure all reveal robust signatures of the Bering Slope Current. The mean along-slope velocity estimates made at 1000 dbar from direct measurements within the current region yield an along-slope transport of 3.0 (+/-0.9) Sv when applied uniformly in the vertical to the upper 1900 dbar from the 1000-m isobath to 120 km offshore of that isobath. This value can be combined with the geostrophic transport estimates relative to 990 dbar, between the surface and 990 dbar and between 990 and 1900 dbar. The result is an absolute geostrophic estimate of the current transport, 5.8 (+/-1.7) Sv above 1900 dbar and offshore of the 1000-m isobath.

See Kinder et al. [1975] and Johnson et al. [2004].

Bering Strait A narrow ocean passage separating the North American and Asian continents. The transport of water through this passage, estimated at about 0.6 Sv of northward flowing low salinity water largely supplied by the Anadyr Current, contributes little to the global budgets of any ocean properties. Its principal role in large-scale circulation is apparently its contribution to the stratification of the Arctic Ocean. See Aagaard et al. [1985], Coachman and Aagaard [1988] and Cooper et al. [1997].

berm crest The seaward limit of a beach berm.

Bermuda Bio-Optics Project (BBOP) An ICESS project to explore the relationship between light and upper ocean geochemistry at the BATS site off the island of Bermuda. The goal is to evaluate the role that light plays in the cycling of carbon, nitrogen, silica, phosphorous and sulfur in the upper ocean and to assess the ability to study these processes using the SeaWiFS satellite sensors.

[http://www.crseo.ucsb.edu/bbop/bbop.html]

Bermuda High See Azores High.

Bermuda Testbed Mooring Program (BTM) A program run by the Ocean Physics Laboratory at ICESS. This mooring was deployed in June 1994 about 80 km southwest of Bermuda and has provided the oceanographic community with a deep-water platform for developing, testing, calibrating, and intercomparing instruments which can obtain long-term data sets.

[http://www.opl.ucsb.edu/btm.html]

Bernoulli function A function defined as:

$$B = gz + \alpha p + u^2$$

where g is gravitational acceleration, z is the vertical coordinate,  $\alpha$  is something, p is the pressure and u is the horizontal velocity. The first two terms of this are called the Montgomery potential, and sometimes the Bernoulli function in the geostrophic approximation. The gradient of this drives the flow in models with z, isopycnal or sigma coordinates in the vertical. See Saunders [1995].

**BERPAC** A joint US/USSR Bering and Chukchi Seas research program whose goal is to examine the status of marine ecosystems of the Pacific Ocean, Bering Sea and Chukchi Sea, and to assess their role in determining global climate. The objectives of BERPAC consist of the study of the biogeochemical cycles of contaminants, related oceanographical processes, and food–web interactions in the North Pacific waters that flow through the Bering and Chukchi Seas, including the study of the behavior of organic pollutants at the water/sediiment interface since sediments are source of the secondary pollution of ecosystems. See Nagel [1992].

[http://pices.ios.bc.ca/wg/wg5/wg5\_93.htm]

Beryllium-7 A radioactive nuclide with a half-life of 53.3 days produced by cosmic rays (i.e. electron capture decay to <sup>7</sup>Li) that can be used as a tracer of ventilation processes occurring on a seasonal timescale. It is deposited by rainfall on the ocean surface, and homogenized within the surface mixed layer, with a fraction found to penetrate into the upper thermocline. The extent of penetration before decay depends partly on the strength of vertical mixing and advective processes. The distribution below the mixed layer at any time depends largely on the depth history of the mixed layer, i.e. Beryllium-7 found in the thermocline can be remnant or previous mixed layers formed within several half-lives of the isotope (a seasonal timescale). Thus, if the depth history of the mixed layer is known, then the mixing and advection component affecting the Beryllium-7 distribution can be found. Conversely, given an understanding of these processes, it can be used to interpret mixed layer history on a seasonal timescale. See Kadko and Olson [1996].

BESIS Acronym for Bering Sea Impact Study.

- BEST Acronym for Benguela Sources and Transport program, a field program from June 1992 to November 1993 consisting of moored instruments and three hydrographic surveys, designed to address questions about the Benguela Current:
  - What is the transport, and what are the sources, of the Benguela Current and how do they vary with time?
  - What is the dominant means of transfer of Agulhas water into the Atlantic?
  - What is the interaction of the Agulhas eddy field with the large scale circulation?

The principal investigators were Arnold Gordon, Silvia Garzoli and Dale Pillsbury.

From WOCE Notes (Vol. 6, 1994, pp. 10–15):

The BEST (Benguela Source and Transport) project was designed to investigate the form of the Benguela Current and ratio of the Agulhas Current and South Atlantic Current source waters masses. The transport of the Benguela Current and its variability is measured by a moored array of instruments as well as analysis of the TOPEX/POSEIDON satellite altimeter and CTD density field observations. The source of the water is determined by analysis of the water mass properties measured from CTD observations.

To accomplish the BEST objectives, an extensive field program was carried out between June 1992 and November 1993. The field work consisted of three hydrographic surveys and a moored array of inverted echo sounders (IES), inverted echo sounders with pressure gauges (PIES) and current meter moorings (CMM). The BEST mooring array was deployed in June 1992 and, during October/November 1993, 4 PIES and 4 current meter moorings (CMM) along 30S, and 2 IES at the edges of the line Cape Town 37.5S, 12.3E were recovered.

The BEST objectives contribute to the WOCE international plan. The 30S array will provide the transport information of the WOCE ACM-4 mooring, as called for in the WOCE science plan, 1988. Paired with ACM-3 in the Brazil Current (part of the German WOCE program) the BEST 30S mooring array will aid in accomplishing the WOCE South Atlantic heat flux line objectives. The IES deployed off Cape Town will help to relate the Algulhas Retroflection characteristics to the transport across 30S. The main hydrographic work in the Agulhas Retroflection region and in the intervening region will define the water mass characteristics of the Benguela Current and assess the relative contributions of South Atlantic and Indian Ocean water to the Benguela Current.

[http://www.ldeo.columbia.edu/physocean/proj\_Best.html]

beta plane approximation In oceanography, a simplified coordinate system for the equations of motion where the variation of the Coriolis parameter f with latitude is approximated by

$$f = f_0 + \beta y$$

where  $f_0$  is the value of f at the mid-latitude of the region and  $\beta$  the latitudinal gradient of f at that same latitude. This is used to investigate both equatorial and mid-latitude phenomena (for which there are slightly different beta plane approximations) where f varies significantly over a few tens of degrees latitude. The beta plane approximation allows considerable simplification of the governing equations and therefore the use of analytical investigation methods. See Gill [1982].

The beta plane equations are obtained by introducing a background stratification into the shallow water equations, expanding them around a reference latitude  $\theta_0$  with respect to  $\varepsilon \sim \theta - \theta_0$ , and keeping

terms up to first order in  $\varepsilon$ . This approximation introduces the horizonal coordinates

$$x = r_0 \cos \theta_0 (\phi - \phi_0)$$
  

$$y = r_0 (\theta - \theta_0)$$

and expands the Coriolis parameter as

$$f = f_0 + \beta_0 y + \cdots$$

where  $\beta_0$  is the beta paramter at the reference latitude. The resulting equations (after Muller [1995]) are:

$$\frac{\partial u}{\partial t} + u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} 
- \frac{uv}{r_0}\tan\theta_0 - f_0v - \beta_0yv 
= -\frac{1}{\rho_*}\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial\delta p}{\partial x} 
\frac{\partial v}{\partial t} + u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} 
+ \frac{u^2}{r_0}\tan\theta_0 + f_0u + \beta_0yu = -\frac{1}{\rho_*}\frac{\partial\delta p}{\partial y} 
0 = g\delta\rho + \frac{\partial\delta p}{\partial z} 
\frac{\partial w}{\partial z} = -\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} + \frac{v}{\rho_0}\tan\theta_0 
\left[\frac{\partial}{\partial t} + u\left(1 + \frac{y}{r_0}\tan\theta_0\right)\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial t}\right]\delta\rho = wN^2\frac{g}{\rho_*}$$
(1)

where (u, v, w) are the velocity components in the (x, y, z) directions,  $r_0$  is the mean radius of the Earth,  $\theta_0$  is the reference latitude,  $f_0 = 2\Omega \sin \theta_0$  is the Coriolis parameter at the reference latitude,

$$\beta_0 = \frac{1}{r_0} \frac{\partial f}{\partial \theta} = \frac{2\Omega}{r_0} \cos \theta_0$$

is the beta parameter at the reference latitude,  $\rho_*$  is a constant reference density,  $\delta p$  and  $\delta \rho$  are motionally induced deviations from prescribed background fields, and N is the buoyancy frequency.

beta plane equations See beta plane approximation.

- **beta refraction** An effect that results from the latitudinal variation of Rossby wave phase speed which is, in turn, due to the **beta effect**. If a line of Rossby waves were started along a straight eastern ocean boundary, then those at low latitudes would arrive at the western boundary before those at high latitudes.
- beta spiral method An inverse method for determining the oceanic velocity field where the motion is geostrophic and the potential vorticity locally balanced. This method provides a mechanism for determining the absolute geostrophic circulation field rather than just the relative field. More later. See Schott and Stommel [1978].

- **bias** The amount by which the average of a set of values departs from a reference value. In statistics and signal processing, it is usually felicitous to remove this before proceeding to further and more complicated data manipulations.
- **bias correction** A method of flux correction that guarantees no long-term climate drift and reduces the other problems of flux correction. Fluxes are modified at the ocean-atmosphere interface but the correction is carried out on mean annual rather than monthly mean values, thus resulting in smaller and spatially smoother corrections. An interactive computation is also applied to reduce consistencies in the bias correction. This method was developed by J. Oberhuber at the DKRZ.
- **bibliography** The Scripps library contains a Cumulative Biography on the History of Oceanography, a Bibliography of Ocean Scientists, and a Handlist of Source Books on the History of Oceanography. All are available at the given URL.

[http://scilib.ucsd.edu/sio/archives/histoceanogr/]

Bigelow, Henry Bryant (1879-1967) A Harvard-trained zoologist who first went to see on an expedition to the Maldive Islands with Alexander Agassiz in 1901. He later participated in the Eastern Tropical Pacific Expedition also organized by Agassiz. He first led an expedition in 1908 when he took to Grampus to Gulf Stream waters to collect various faunal samples. After four years of writing and publishing the results from these expeditions, the desk-bound Bigelow embarked on a groundbreaking series of research cruises in the Gulf of Maine in 1912. He spent the next 15 years, interrupted briefly by service as a navigation officer on an army transport, doing repeated studies of the Gulf of Maine in the manner pioneered by the ICES in Europe twenty years before. He studied the fish, plankton and hydrography of the Gulf, repeatedly taking many measurements over the years including temperatures, water samples, water color and transparency, currents (using an Ekman current meter), salinity (using the ICES method of titration and their Standard Water), quantitative and regular plankton hauls, and dredging and trawling. In later years he would release drift bottles to deduce the overall Lagrangian circulation pattern in the Gulf.

Bigelow was an American pioneer in that he was the first to apply the ICES methods of repeated measurements over many years to American waters. The results of the Gulf of Maine studies were published in separate monographs for the fish (1915), plankton (1926), and physical oceanography (Bigelow [1927]). Bigelow also published an autobiography (Bigelow [1964]) and an economic overview of oceanography (Bigelow [1931]. See Graham [1968].

- bioacoustical oceanography The application of underwater acoustics to investigations of biological patterns and processes in the sea. This has been traditionally divided into two distinct groups of investigators, those who study the sounds produced by marine organisms, and those who produce sounds and listen to the returning echoes to study the distributions of marine organisms. See Greene et al. [1998].
- **BIODAFF** Acronym for Biodiversity and Fluxes in Glacial Arctic Fjords, a project to study the effects of seasonal fluctuations in salinity, turbidity and sedimentation rates in the glacial fjords on Svalvard on how the diversity of ice flora and fauna is structured by stress gradients and the physical ice habitat. Also studied will be the zonation of macrobenthic organisms on hard bottom substrates and how this zonation changes longitudinally in the fjord against the general stress gradients. The work will involve several diving transects from inner to outer fjord. This project is being performed by the Norwegian Polar Institute under the leadership of Haakon Hop during 1996.
- **biogenic** One of three major components of deep sea sediments, the other two being authigenic and detrital. Biogenic sediment consists mainly of calcite and opal produced as the hard parts of organisms and

eventually precipitated. Calcite is formed by coccoliths (plants) and foraminifera (animals) and opal by diatoms (plants) and radiolarians (animals). See Broecker and Peng [1982].

- biogeochemical province See also oceanic province. See Longhurst [1995], Longhurst et al. [1995] and Hooker et al. [2000].
- **BIOGEST** Acronym for Biogas Transfer in Estuaries, a research project funded by the European Union whose aim is to understand the distribution of biogases in the surface water of European estuaries and to quantify related atmospheric exchanges.

[http://www.ulg.ac.be/oceanbio/biogest/biogest.htm]

- biological oceanography The study of life in the oceans and how the physical and chemical properties of the ocean are influenced by marine life. The basic goal is to examine the distribution, abundance, and production of marine species and to obtain a basic understanding of the processes controlling them. Compare to chemical, geological and physical oceanography. See Mann and Lazier [1996], Parsons et al. [1984], Barnes and Mann [1980], Day et al. [1989], Falkowski [1980], Falkowski and Woodhead [1992], Mann [1982], Morris [1980], Valiella [1984] and Mills [1989].
- **biological pump** The transformation, via photosynthesis in the ocean surface layer by plant cells (primarily phytoplankton), of dissolved inorganic carbon (DIC) into biogenic carbon, including, for example, the CaCO<sub>3</sub> in shells of coccolithophorids. The photosynthetic organisms incorporating the inorganic carbon return much of it to  $CO_2$  in the surface layer via respiration, but a significant fraction settles below the main thermocline. This is an oceanic sink for atmospheric  $CO_2$  where a rain of small debris consisting of phytoplankton shells and zooplankton fecal pellets and molts sink out of the ocean surface waters. These sinking particles remove POC from surface mixed layers into stratified, relatively deep layers where, on a millenial time scale, it is no longer susceptible to exchange with the atmosphere. Particulate matter removed in this manner is called export flux.

It is estimated that 75% of the difference in DIC concentration between the surface and deep oceans is due to the biological pump. If this pump were eliminated, the carbon released from the deep ocean as it equilibrated with the atmosphere would more than double the CO2 concentration in the atmosphere. On a global scale, the downward transport of CO<sub>2</sub> by the physical (i.e. vertical transport of CO<sub>2</sub>–laden water) and biological pumps amounts to around 102 Gt C yr<sup>-1</sup>. The upward physical transport is about 100 Gt C yr<sup>-1</sup>, leaving a net uptake of about 2 Gt C yr<sup>-1</sup>. See Rowe and Baldauf [1995] and Chisolm [1995].

**BIOMASS** Acronym for Biological Investigations of Marine Antarctic Systems and Stocks, a program whose principle objective was to gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for the future management of potential living resources. BIOMASS has two major field campaigns, the First (FIBEX) and Second (SIBEX) International BIOMASS Experiments.

The goal of FIBEX was to determine how much krill is in the Antarctic. It was composed of 16 research cruises carried out between November 1980 and April 1981, and produced a synoptic picture of the distribution of krill over a large area of the southern ocean. The goal of SIBEX was to improve the understanding of the dynamics of the krill–dominated part of the Antarctic marine ecosystem. It involved two field seasons, SIBEX–1 (8 cruises, Oct. 1983 to Apr. 1984) and SIBEX–2 (10 cruises, Nov. 1984 to Apr. 1985), and produced a temporal sequence of observations focused mainly on the Bransfield Strait and Prydz Bay regions.

[http://ioc.unesco.org/iochtm/w107/w107www3.htm]

Biot number A dimensionless number or parameter expressing a ratio of thermal internal resistance to surface film resistance. It is generally used in heat transfer calculations such as unsteady state flow. It is defined as:

$$B_i = \frac{h_T \Delta x}{k}$$

where  $h_T$  is a heat transfer coefficient, k the thermal conductivity, and  $\Delta x$  a mid-plane distance.

- Biowatt A program to study bioluminescence and optical variability in the sea. See Marra and Hartwig [1984].
- bioturbation The stirring of sediment by animal life.
- **Bismarck Sea** A regional sea located in the northwest corner of the South Pacific Ocean. The Bismarck Sea is bounded to the southwest by New Guinea and to the north, east, and south by the Bismarck Archipelago. Its area and volume are about 40,000 km<sup>2</sup> and 60,000 km<sup>3</sup>, respectively.
- **BITS** Acronym for Biophysical Interdisciplinary Tropic Studies buoy, an instrumented and unmanned mooring designed to acoustically measure the size and abundance of marine life populations, collect the supporting data that characterizes the marine environment, and automatically transmit the data to shore stations for analysis. The BITS system was developed by Tracor and the University of Southern California. It employs a bi–frequency acoustic projector which operates at 165 kHz and 1.1 MHz, with backscattered acoustic signals received by the sensors transmitted via VHF packet telemetry to shore stations.

[http://www.aard.tracor.com/home/eco/MarEco.html]

- BIW Abbreviation for Banda Intermediate Water.
- Bjerknes, Jacob (1897-1975) One of the founders of modern meteorology, Bjerknes entered and revolutionized the field at the age of 20 with his discovery of the structure of extratropical cyclones. His father was the physicist and geophysicist Vilhelm Bjerknes.

[http://www.nap.edu/readingroom/books/biomems/jbjerknes.html]

- Bjerknes, Vilhelm More later.
- Bjerknes hypothesis The hypothesis that ENSO varies as a self-sustained cycle in which anomalies of SST in the Pacific cause the trade winds to strengthen or slacken, and that this in turn drives the changes in ocean circulation that produce anomalous SST. First advanced by Bjerknes [1969].
- Bjerknes' theorem A generalization of Stokes' theorem that enables the calculation of the circulation on a rotating Earth. See Turner [1973], Hide [1978], and Dutton [1986].
- Black Sea A mediterranean sea, centered at approximately 35° E and 44° N, that is the world's largest inland water basin. It has an area of about 461,000 km<sup>2</sup> and a volume of 537,000 km<sup>3</sup> with a mean depth of around 1200–1300 m, although depths greater than 2000 m are common in the central basin. The western part of the Black Sea is a wide shelf that gradually narrows to the south and breaks at around 100-150 m. In the rest of the basin the shelf doesn't exceed 10-15 km in width. It is connected to the Marmara Sea via the narrow (760 m wide) and shallow (27.5 m maximum depth) Bosporus Strait, and further connects to the Mediterranean Sea via the long and narrow Dardanelles. It is also connected to the Sea of Azov to the north.

The Black Sea is a dilution basin due to a large freshwater input from the Danube, Dniester, Dnieper, Severskiy Donets and Don rivers ( $350 \text{ km}^3/\text{yr}$ ). The flow through the Bosporus comprises a surface

flow of low salinity water towards the Mediterranean ( $260 \text{ km}^3/\text{yr}$ ) and an underlying return flow of salty Mediterranean water ( $120 \text{ km}^3/\text{yr}$ ). Precipitation ( $140 \text{ km}^3/\text{yr}$ ) and evaporation ( $350 \text{ km}^3/\text{yr}$ ) close the freshwater budget. The volume averaged salinity is 22, with surface salinities in the central part ranging from 16-18 and increasing to 21-22.5 at depths greater than 150-200 m. The surface temperatures range from  $25^{\circ}$  C in the summer to  $6-8^{\circ}$  C in the open sea, with the northwestern part and the Sea of Azov covered with ice during the winter. The deep water is 8-9° C year round. The upper 50 m are saturated with oxygen, the content of which diminishes until, at a depth of 150-200 m, hydrogen sulfide appears and renders the lower regions uninhabitable.

The most remarkable circulation feature is the cyclonicically meandering Rim Current, the interior of which is formed either by one elongated cell covering the entire basin or by two separate cyclonic cells occupying the western and eastern halves of the basin. The interior of the Western and Eastern Gyres contains a number of recurring cyclonic mesocale eddies. These are in contact with each other by a recurrent anticyclonic eddy called the Central Basin Eddy, a recurrent feature observed to form via the merging of two anticyclonic eddies pinched off from the baroclinically unstable Rim Current southeast of Crimea and off Cape Sinop.

The upper layer flow field also consists of several mesoscale eddies distributed along the periphery of the basin. The two most pronounced and persistent of such are the anticylonic Batumi Eddy in the southeastern corner of the basin and the anticyclonic Sevastapol Eddy in the continental shelf topography of the Danube Fan, west of the Crimean Peninsula. The latter has also been reported in the literature as the Trabzon Eddy. Two other quasi-permanent anticyclonic eddies are found along the Anatolian (Turkish) coastal belt. They are situated off the Sakarya and Kizilirmak Rivers and given their names. Another quasi-permanent anticyclonic feature is the Bosphorous Eddy located northwest of the Bosphorous-Black Sea junction. Two other recurrent coastal anticyclonic eddies have been identified between Sakarya Canyon and Cape Sinop. Along the northern coast, the anticyclonic Crimean and Causasian Eddies are the most pronounced mesoscale features, with the Kali-Akra Eddy a recurrent feature to the north of the Bosphorous Eddy.

The intermediate depth circulation is characterized by the disappearance of the Rim Current, the shifting of eddy centers, coalescence of eddies, persistence of some features for the whole water column but changes with depth in the structure of others, and more organized and large sub-basin features. See Caspers [1957], Zenkevitch [1963], Fairbridge [1966], Stanev [1990], Murray [1991a], Oguz et al. [1993], Özsöy and Ünlüata [1997] and Özsoy and Ünlüata [1998].

Black Sea Oceanography Expedition See Murray [1991b] and other papers therein.

Black Sea Water (BSW) A water mass formed in the Black Sea that flows into the Aegean Sea through the Strait of Bosporus, the Marmara Sea and the Strait of Dardanelles. The flux into the Aegean varies from  $180-200 \text{ km}^3 \text{ yr}^{-1}$  to a maximum of  $700 \text{ km}^3 \text{ yr}^{-1}$  between April and October. BSW is of primary importance to processes in the Aegean, but plays a secondary role in the overall water balance of the Mediterranean.

BSW is recognized by a surface salinity minimum, with the salinity off the mouth of the Strait of Dardanelles varying from 24 to 26 psu during the warm months and from 30–35 psu during the cold months. A pronounced halocline develops in the North Aegean, with the maximum depth ranging from 20–80 m. As it travels westward and southward, BSW is modified following the general cyclonic circulation of the Aegean. During the winter, it spreads westwards and then northwards, entering the Samothraki Plateau. It flows westwards over the plateau and then southwards along the eastern coast of the mainland to Evvia Island. If the thermohaline front in the Andros Strait is well developed, the BSW flows eastwards along the northern boundaries of the Kyklades Plateau, following the general cyclonic circulation. If the thermohaline front disappears, the BSW bifurcates, with one branch moving

eastwards along the northern boundary of the Kyklades Plateau and the other southwards into the Saronikos Gulf, causing the winter salinity minima seen there. During the summer, the general cyclonic circulation pattern still prevails, with the Etesian winds causing the BSW to flow southwestwards to Evvia Island and then southwards. The low salinity waters flow through Andros Strait and create the second salinity minimum observed in the South Evvoikos and Saronikos Gulfs. It has been detected (by the surface salinity minimum) as far south as the Kithira Straits. See Stergiou et al. [1997].

- Black Stream See Kuroshio Current.
- BLIPS Acronym for Benthic Layer Interactive Profiling System. See Adam Jr. et al. [1990].

# blocking

- BML Abbreviation for Bottom Mixed Layer, the middle of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BNL and the BEL. The thickness of the BML typically ranges from 20–80 m, although values between 10–150 m have been observed. The particle concentration within the BML is usually homogeneously mixed, although occasional episodes of local resuspension by strong bottom flows can change this. See Klein and Mittelstaedt [1992].
- BNL Abbreviation for Benthic Nepheloid Layer, the thickest and upper of three layers into which the bottom 1000 m of the ocean are sometimes divided, with the other two being the BML and BEL. The BNL is characterized by an increasing concentration of suspended material towards the bottom, and it extends from the clear water minimum (CWM) (at around 1000 meters above the bottom) down to the deep-sea bottom. See Klein and Mittelstaedt [1992].
- **BOFS** Abbreviation for Biogeochemical Ocean Flux Study, a U.K. contribution to JGOFS funded by the NERC. The goal of GOFS was to study differences in glacial-interglacial paleoenvironments of the eastern Atlantic Ocean, especially between the last glacial and the Holocene. The results are presented in a special issue of Paleoceanography (Vol. 10, No. 3, 1995). See especially the short review by Elderfield and Thomas [1995].

[http://www.bodc.ac.uk/projects/bofs.html]

Bohai Gulf See Bohai Sea

- Bohai Sea See Guan [1994] and Lin et al. [2001].
- Bohnecke mechanical recording current meter A mechanical current meter, first designed and used in the 1930s, in which the propellor and the compass both drive a set of horizontal dials with raised numbers on their vertical rims. A clockwork mechanism moves a strip of tin foil past the vertical rims of the dials and a hammer presses the the foil against the raised numbers on the rims every 5 or 10 minutes. The speed and direction can be obtained from the information on the foil. Wide use of this mechanism was forestalled by the difficulty in finding a material for the spring in the clockwork that could withstand the corrosive exposure to sea water. See Sverdrup et al. [1942].
- Bohol Sea A small sea centered in the Philippines at about 124° E and 9° S. It is surrounded by the islands of Mindanao to the southeast and Negros, Bohol and Leyte to the northwest. It is connected to the Sulu Sea to the west via a passage between Negros and Mindanao, the Visayan Sea to the north via the Tanon Strait, the Camotes Sea to the north via the Bohol Strait and a passage between Bohol and Leyte, and to the Leyte Gulf to the northeast via the Surigao Strait. Prominent geographic features include the islands of Siquijor and Camiguin and Sogod (in Leyte), Gingoog, Macajalar and Iligan (in Mindanao) Bays. This has also been called the Mindanao Sea.

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boiling water phenomena The name given to the intense surface signature of intense internal waves in the Strait of Gibraltar. According to Bruno et al. [2002]:

Those surface signatures in the Gibraltar Strait are known by the local Spanish fishermen and sailors as "hervideros" (boiling waters) and "hileros de corriente" (streamers), in reference to the visible behaviour of the surface waters. They were reported in the literature, for the first time, in the Spanish Navy Sailing Directions by Tofiño (1832), being mentioned and documented as well in the English Sailing Directory by Purdy (1840) and later editions of the Spanish Sailing Directions. A free translation of part of their description is as follows: "They appear instantaneously without previous signs. Suddenly a roughness in the sea surface appears as when the water is boiling, and a surfing chaotic sea is established. If wind and wind-induced forces are considered, the streamers are dangerous not only for smaller ships but for bigger ships also. Sometimes the vessel acquires a vortex motion without steerage".

See Bruno et al. [2002].

- Boltzman equation The Navier-Stokes equations can be derived from the Boltzmann equation by considering appropriate limits, i.e. Knudsen and Mach numbers tending to zero, and appropriate averaging procedures to define new coarse-grained variables (velocity and pressure) and associated transport coefficients (viscosity and density). See Farge et al. [1996].
- bolus velocity See eddy-induced transport velocity.
- BOMEX Acronym for Barbados Oceanography Meteorology EXperiment, a joint experiment between NOAA and the Government of Barbados conducted over the tropical Atlantic east of Barbados in the summer of 1969. See Holland [1970], Pond et al. [1971] and Geernaert [1990].

[http://rainbow.ldeo.columbia.edu/data/NASAentries/nasa611.html]

- BOOS Acronym for Baltic Operational Oceanographic System.
- BOP Abbreviation for Bayesian oscillation patterns, patterns found using BSA. See Ruiz de Elvira and Bevia [1994].
- BOPS Acronym for Bio-Optical Profiling System, an instrument for measuring optical and physical parameters in the water column.
- **borderland** The official IHO definition for this undersea feature name is "a region adjacent to a continent, normally occupied by or bordering a shelf and sometimes emerging as islands, that is irregular or blocky in plan or profile, with depths well in excess of those typical of a shelf."
- **Boreal period** A post-LGM European climate regime. This refers to the period from about 7000-6000 BC when temperatures continued to rise, e.g. the colder seasons of the year gradually became milder (although probably with some dry and frosty winters) and the summers became generally warmer than today. It was preceded by the Pre-Boreal period and followed by the Atlantic period. See Lamb [1985], p. 372.
- Bosphorus Straits The significance of these straits is summarized by Peneva et al. [2001]:

The transport through the Bosphorus Straits is one of the major factors controlling the stratification in the Black Sea, the latter impacting a number of important processes, such as the ventilation of deep layers, intermediate water formation, synoptic variability. Mass balance estimates yield an average upper layer outflow of 600 km3 year-1 and a lower layer

inflow of 300 km3 year-1, which gives 300 km3 year-1 for the vertically integrated transport through the strait. Long-term estimates of the components of fresh water balance (river runoff, precipitation and evaporation) in the 20th century show that the amplitude of extreme oscillations could exceed the long-term mean values. However, the temporal variability is largely unknown, particularly the low-frequency range.

The authors investigate the long-term variability using tide gauge and hydo-meteorological data over 1923-1997, and obtain the variability of basin volume and transport in the straits.

It is found that the main signal in the transport is the seasonal one, with maximum values in March-April and minimum in August. The amplitude of this signal is  $\sim 2/3$  of the amplitude of the net fresh water flux. In low frequency range, oscillations with periods 10 and 4 years have significant amplitudes. However, the ratio between the magnitude of oscillations in the forcing (fresh water flux) and the response (transport in the strait) tends to unity. This indicates that the resistance of strait to climatic variability with interannual and decadal time scales is negligible.

See Peneva et al. [2001].

# Bothnian Sea See Gulf of Bothnia.

bottom boundary layer models Killworth and Edwards [1999] review the use of these in numerical ocean models and present another model.

# Bottom Cold Water (BCW) See Isobe [1995].

Bourne, William (?1535–1582) A British innkeeper who wrote what some consider to be the first popularization of the extent ideas constituting that which we now consider to be the field of oceanography. In this book, entitled A booke called the Treasure for Traveilers, deuided into fiue Bookes and published in 1578, he invoked the primum mobilus concept as the driving force beyond the movement of the moon, but also ascribed to the moon itself some unknown power responsible for the observed tides and steady currents (whose complexity beyond the steady westward flow of the primum mobilus he also deemed partially due to the distrupting presence of land masses).

Bourne's picture of the flow in the Atlantic started with the general westward flow around the southern tip of Africa merging with that in the Atlantic, with the combined volume being too great to squeeze through the Straits of Magellan. Thus part of the flow was diverted northwards along the South American coast, into the Gulf of Mexico, and then out between Florida and Cuba and eastwards towards Europe. He also proposed a second type of steady, non-tidal current that flows against the wind during periods of strong winds, with the driving force being a hypothesized upward tilt of the sea surface downwind caused by waves piling up water there. See Peterson et al. [1996].

# Boussinesq approximation A set of filtering approximations originally developed by Boussinesq. According to Sander [1998]:

In his attempts to explain the motion of the light in the aether Boussinesq (in 1903) opened a wide perspective of mechanics and thermodynamics. With a theory of heat convection in fluids and of propagation of heat in deforming or vibrating solids he showed that density fluctuations are of minor importance in the conservation of mass. The motion of a fluid initiated by heat results mostly in an excess of buoyancy and is not due to internal waves excited by density variations. In other words, the continuity equation may be reduced to the vanishing of the divergence of the velocity field, and variations of the density can be

neglected in the inertial accelerations but not in the buoyancy term. Although used before him, Boussinesq's theoretical approach established a cardinal simplification for a special class of fluids which fundamentally differ from gases and may eliminate acoustic effects.

They result in an equation set applied to almost all oceanic motions except sound waves. The four approximation steps are:

- subtracting a motionless hydrostatically balanced reference state from the equations of motion;
- making the anelastic approximation;
- assuming that the vertical scale of motion is small compared to the scale depth (or height); and
- ignoring the inertial but not the buoyancy effects of variations in the mean density.

The term "Boussinesq approximation" is not always used identically with the above series of approximation steps, e.g. it may or may not include the assumption of incompressibility.

Mahrt [1986] addresses the issue of which assumptions properly constitute the Boussinesq approximations:

The derivation of conditions for the validity of the Boussinesq approximations is not as straightforward as many would assume. In the literature, a variety of sets of conditions have been assumed which, if satisfied, allow application of the Boussinesq approximations. The Boussinesq approximation can be divided into two parts. The first group of assumptions allows use of incompressible mass continuity and linearization of the ideal gas law, which are referred to as the shallow motion approximations. Additional restrictions allow neglect of the pressure influence on buoyancy. This more restrictive subclass of shallow motions is equivalent to the full Boussinesq approximations, also referred to as the shallow convection approximations.

The different derivations of the shallow motion approximations share the following conditions:

- the perturbations of variables of state must be small compared to basic state averaged values;
- the motion must be shallow compared to the scale depth of the basic flow; and
- restrictions on the time scale are required.

See Spiegel and Veronis [1960], Mihaljan [1962], Greenspan [1969], Phillips [1977] (pp. 15-20), Mahrt [1986], Zeytounian [1990] (pp. 142-176), Muller [1995], Thunis and Bornstein [1996] and Sander [1998].

### Boussole Strait See Okhotsk Sea.

- Bowen ratio The ratio of the amount of sensible to that of latent heat lost by a surface to the atmosphere by the processes of conduction and turbulence. See Hicks and Hess [1977] and Lewis [1995].
- BPR Abbreviation for bottom pressure recorder.
- Bransfield Strait A strait located between the northern tip of the Antarctica Peninsula and the South Shetland Islands. It is about 120 km wide and extends 460 km from Clarence Island in the northeast to Low Island in the southwest. It consists of three separate basins isolated from the surrounding ocean by relatively shallow sills, with local deep water formation processes resulting in different water characteristics in each of the basins. The basins deepen to the northeast, having a maximum axial depth in the west basin of 1100 m near Low Island and a maximum depth of 2700 m in the east basin south of Elephant Island. Sills shallower than 500 m almost entirely circle the strait, with the east

basin having the deepest access to outside water with sills deeper than 500 m. There are no passages deeper than 500 m into either the central or west basins, and the central basin is isolated from the adjacent basins by sills of 1000 and 1100 m at its western and eastern boundaries. See Clowes [1934], Wilson et al. [1999], López et al. [1999] and Gordon et al. [2000].

brash ice A type of sea ice defined by the WMO as:

Accumulations of floating ice made up of fragments not more than 2 meters across; the wreckage of other forms of ice.

See WMO [1970].

# brave west winds See roaring forties.

- Brazil Basin An ocean basin located off the eastern coast of Brazil in the west-central Atlantic Ocean. It is bounded to the north by the Belem (formerly Para) Rise, at which end there is also a broad depression called the Recife (formerly Pernambuco) Abyssal Plain. This has also been called the Tizard Deep. See Fairbridge [1966].
- Brazil Current A western boundary current that forms the western limb of the subtropical gyre in the South Atlantic Ocean. This current is conspicuously weak as compared with other western boundary currents since only about 4 Sv of the water from the northern limb of the gyre, i.e. the South Equatorial Current (SEC), turns south, with the rest turning north to feed the North Brazil Current (NBC). The BC is not only comparatively weak but also much weaker than might be expected from observed wind fields, more about which later.

The portion of the SEC that feeds the BC turns south at about  $10-15^{\circ}$  S. The incipient BC is shallow and flows closely confined to the continental shelf, with direct current measurements at 23° S showing that nearly half of its transport of 11 Sv was inshore of the the 200 m isobath. There also seems to be a semi-permanent offshore meander near 22–23° S that may be related to local upwelling. South of 24° S the BC flow intensifies at a rate of about 5% per 100 km, with the intensification apparently linked to a recirculation cell south of about 30° S (although there is some evidence for an more extensive recirculation cell extending from 20 to 40° S).

Geostrophic transport estimates for the southern BC based on shallow or intermediate zero flow levels (1300-1600 m) have ranged from 18–22 Sv at 33–38° S. Evidence for much deeper flow (from the examination of water mass characteristics) has led to estimates ranging from 70–76 Sv at 37–38° S with a zero flow level at 3000 m. The latter estimates are at latitudes very close to where the BC separates from the coast and thus may be considered as estimates of the maximum BC flow.

The BC separates from the continental shelf between 33 and  $38^{\circ}$  S with the average being near  $36^{\circ}$  S. There is some evidence for a seasonal variation in the latitude of this point, with it being generally farther north in the (local) winter than in summer. After it separates from the boundary, it continues to flow in a general southward direction together with the return flow from the Falkland Current, with the southern limit to the warm water it bounds fluctuating between  $38-46^{\circ}$  S on time scales of about two months. After the flow reaches it maximal southern extent it turns back towards the north (as what is sometimes called the Brazil Current Front) and appears to close back on its source flow near  $42^{\circ}$  S. The north–south excursions of its southern limit result in eddies averaging about 150 km in diameter being shed at a rate of about one per week.

It was first proposed by Stommel that the reason the BC is weaker than expected from observed wind fields is because of an opposing effect of the thermohaline circulation. The formation of North Atlantic Deep Water requires a net transfer of thermocline water from the South Atlantic to the North as well as

net northward fluxes of intermediate and bottom waters. This leads to the situation where the surface circulation of the South Atlantic subtropical gyre is not a closed system because the majority of the SEC flow turns north and crosses the equator due to the demands of the thermohaline circulation. See Peterson and Stramma [1991].

- Brazil Current Front See Peterson and Stramma [1991].
- Brazilian Coastal Current A relatively slow but highly energetic coastal current, flowing in the opposite direction to the Brazil Current. The BCC occurs over the Southern Brazilian Continental Shelf during from spring through winter, reaching its most northerly extreme at 25.2°S in August. After de Souza and Robinson [2004].
- Brazil-Malvinas Confluence A region where the Brazil Current meets the Malvinas Current at around 38°S. This collision of subtropical and subantarctic waters produces one of the most spectacular of the oceanic fronts and complex SST fields seen in the world ocean. At the BMC, subantarctic surface waters meet subtropical thermocline water in a front that can have a gradient as strong as 8°C per km. It is frequently marked by a ribbon of warm, low salinity water of Rio de la Plata origin that has folded over the northern tip of the cyclonic trough formed by the Malvinas Current and its return to the south. A warm, low salinity cap tens of meters thick often covers the western segments of the warm subtropical water. It is derived from the continental shelf north of the Rio de la Plata.

The specific configuration of the BMC at any given time is thought to depend on the relative strengths of the baroclinic and barotropic fields of the Malvinas and Brazil Currents. Its variability occurs over time scales ranging from the intra–annual to the inter–annual, with the spatial characteristics including changes in the latitudes of separation of the western boundary currents from the continental margin, and changes in the geometry of their extensions in the offshore region. On intra–annual time scales, the variability is dominated by the periodic production of transient, cold–core eddies from the Malvinas Current and warm–core eddies from the Brazil Current. These have associated SST anomalies that can be as large as 10°C on space and time scales of 1000 km and two months, respectively.

On annual time scales the variability of the western south Atlantic is dominated by the seasonal displacements of the BMC. It is found farther north during austral winter (July–September) than during the summer. Besides the annual cycle, thought to be driven by variations in the strengths of the Malvinas and Brazil Currents, there is a semi–annual component of variability with near zero amplitude at 30°S increasing to nearly half the magnitude of the annual signal at 50°S. This is probably a response to the semi–annual cycle in zonal winds over the Southern Ocean. See Garzoli and Garraffo [1989] and Goni et al. [1996].

- breaker zone The portion of the nearshore zone where waves arriving from offshore become unstable and break. See Komar [1976].
- Brewer-Dobson circulation The meridional atmospheric circulation that transports air poleward and downward from the tropical middle atmosphere. Air is transferred between the equator and poles by this circulation on a time scale of months, indicative of the strong control by the Coriolis force that deflects the air stream zonally and inhibits meridional motions. See Salby [1992].
- BROKE Acronym for Baseline Research on Oceanography, Krill and Environment, a study conducted off east Antarctica in the Austral summer of 1995–96. The primary focus was to describe the distribution and abundance of Antarctic krill and to determine possible sources of Antarctic bottom water in the region. See Nicol et al. [2000].

Brunt frequency See buoyancy frequency.

# Brunt-Vaisala frequency See buoyancy frequency.

- BSA Abbreviation for Bayesian signal analysis, a method designed to be optimal for analyzing short time series which can work with an SNR as low as 0.6. No hypotheses are made about the actual series belonging to any hypothetical ensemble or infinite series; only the given data are used to find the probability of some a priori signal being contained in the data. A measure of the accuracy of the estimate can also be obtained. See Ruiz de Elvira and Bevia [1994].
- **BSFOCI** Abbreviation for Bering Sea Fisheries Oceanography Coordinated Investigations, a NOAA COP program whose overall goal is to reduce uncertainty in resource management decisions through ecological research on recruitment and stock structure of walleye pollock, presently the largest single–species fishery in the world. A combination of basin circulation studies, analysis of recent and historical data, and development of genetic testing methods has advanced the definition of the stock structure of Bering Sea pollock in this program. See the BSFOCI Web site<sup>10</sup>.
- **BSPFTE** Abbreviation for Barents Sea Polar Front Experiment. See the BSPFTE Web site<sup>11</sup>.
- BTM Abbreviation for Bermuda Testbed Mooring Program.
- Buchanan Deep See Angola Basin.
- Buchanan, John Young More later.
- **bucket temperature** The surface temperature of the ocean as measured by a **bucket thermometer**. This can also be the temperature measured by immersing a surface thermometer into a freshly drawn bucket of water.
- **bucket thermometer** A thermometer with an insulated container around the bulb. It is used to measure ocean temperatures by lowering it on a line, allowing it to equilibrate with the temperature of the surface water, withdrawing it along with the water surrounding it, and reading the temperature. The water serves both as insulation for the thermometer (after withdrawal) and as a sample for a salinity determination.
- **buffer factor** Defined as the fractional change in atmospheric  $CO_2$  divided by the fractional change in oceanic DIC after equilibrium has been reached. This factor characterizes the fraction of the  $CO_2$  flux from the atmosphere to the mixed layer that will react to form carbonate and bicarbonate ions. This is also known as the Revelle factor. See Najjar [1991].
- **buffer sublayer** That part of a boundary layer where the viscous stress and the Reynolds stress have the same order of magnitude and the linear velocity profile turns smoothly into the logarithmic profile. See Kagan [1995].
- bulk parameterizations In studying air-sea interactions, it is difficult to obtain direct measurements of the surface fluxes, and those that are available are extremely limited in geographic scope. Therefore, extensive, global-scale estimates must be obtained via parameterizations of the surface fluxes that permit the use of more easily obtained quantities. The basic premise of the concept of bulk parameterizations is to relate the surface layer fluxes to logarithmic profiles of the mean quantities. The fluxes can then be determined from the mean wind, temperature and humidity at a single height by introducing bulk transfer coefficients of heat, moisture and momentum. This method is also used to quantify gas exchange processes. See Geernaert [1990] and Rogers [1995].

<sup>&</sup>lt;sup>10</sup>http://hpcc.noaa.gov/cop/96fact.html#FOCI

<sup>&</sup>lt;sup>11</sup>http://vaquero.who.edu/BSPFTE.html

#### buoyancy

**buoyancy frequency** The frequency with which a parcel or particle of fluid displaced a small vertical distance from its equilibrium position in a stable environment will oscillate. It will oscillate in simple harmonic motion with an angular frequency defined by:

$$N^2 = g\left(\alpha \frac{\partial \theta}{\partial z} - \beta \frac{\partial S}{\partial z}\right)$$

where g is the gravitational acceleration, theta is the potential temperature,  $\alpha$  is the thermal expansion coefficient, and  $\beta$  is the saline contraction coefficient. In practice, the equivalent formula:

$$N^2 = \left(-\frac{g}{\rho}\frac{\partial\rho}{\partial z}\right)^{\frac{1}{2}}$$

is often used, where c is the velocity of sound, although care must be taken to consistently evaluate  $\rho$  and c. See Turner [1973] and McDougall et al. [1987].

buoyancy scale An important length scale in stratified flow with internal waves. This is defined as:

$$L_B = \sqrt{\bar{w}^2}/N$$

where  $\bar{w}$  is the ratio of the vertical turbulent and internal wave fluctuations and N the buoyancy frequency. This is used instead of the Ozmidov scale if the vertical velocity fluctuations due to internal waves are small compared to those due to turbulence.

Burger number A dimensionless number indicative of the importance of baroclinicity in a flow field. It is the square of the ratio of the Rossby radius of deformation to the horizontal scale of the flow, and is given by:

$$B_u = \frac{NH}{fL}$$

where N is the buoyancy frequency, H the vertical scale of the flow (i.e. the depth), f is the inertial frequency, and L the horizontal scale of the flow. A Burger number of zero indicates a rotation dominated flow, while large values indicate stratification dominated flows. This was named for the mathematician/meteorologist Alewyn Burger.

### Burma Sea See Andaman Sea.

Buys Ballot's law A synoptic meteorology rule stating that if, in the northern hemisphere, an observer stands with his back to the wind, pressure is lower on his left hand than on his right, while in the southern hemisphere the converse is true. This was enunciated by Buys Ballot of Utrecht in 1857 and is basically a restatement of the fact that winds blow clockwise around a depression in the northern hemisphere and anticlockwise in the southern hemisphere.