0.15 Q

QBO Acronym for Quasi-Biennial Oscillation.

Quasi-Biennial Oscillation The alternation of easterly and westerly winds in the equatorial stratosphere with an interval between successive corresponding maxima of 20 to 36 months. The regimes start at about 30 km and propagate downwards at about one kilometer per month.

quasi-geostrophic approximation A set of filtered equations to the equations of motion governing atmospheric or oceanic flow, the chief of which is the vorticity equation. In this, the horizontal wind is replaced by the geostrophic wind in the term representing the vorticity but not in the term representing the divergence.

quasi-geostrophic equations A set of equations developed using the quasi-geostrophic approximation. These are formally valid only when the planetary vorticity is large compared to the relative vorticity of the fluid, when the variation in the Coriolis parameter over the domain is small compared to its mean value, and when free surface and topographic fluctuations are both much smaller than the average fluid depth. See Pedlosky [1987].

quantum meter An instrument used to measure PAR.

QuikSCAT Acronym for the NASA Quick Scatterometer Mission, a satellite launched from Vandenberg Air Force base aboard a Titan II vehicle on June 19, 1999. QuikSCAT was a quick recovery mission to fill the gap created by the loss of data from the ADEOS–1 satellite, which lost power in June 1997. It was launched into a sun–synchronous, 803 km, circular orbit with a local equator crossing time at the ascending node of 6:00 AM ± 30 minutes. The recurrent period is 4 days (57 obits), the orbit period 101 minutes (14.25 orbits per day) and the inclination 98.616°. QuikSCAT consists of two major systems, the spaceborne observatory and the ground data processing system.

The main sensor on QuikSCAT is the SeaWinds scatterometer, an active microwave radar designed to measure winds over the oceans. It is a conically scanning pencil–beam scatterometer, which provides a higher SNR, is smaller, and provides better coverage than a fan–beam scatterometer. It measures near–surface wind speed and direction under all weather and cloud conditions over the oceans.

`[http://podaac.jpl.nasa.gov/quikscat/]`

Q–vector method A method for diagnosing vertical motion from measured data in the atmosphere or ocean. The Q–vector method is similar to the quasigeostrophic equations, except it introduces an ageostrophic component neglected by the latter. In the ocean, the vertical velocity is estimated from the following Q–vector equation:

$$\left(\nabla^2 + \frac{f_0^2}{N^2}\frac{\partial^2}{\partial z^2}\right) w = \frac{2}{N^2}\nabla\cdot\mathbf{Q}$$

$$\mathbf{Q} = \frac{g}{\rho_0}\left(\frac{\partial u_g}{\partial x}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial x}\frac{\partial \rho}{\partial y}, \frac{\partial u_g}{\partial y}\frac{\partial \rho}{\partial x} + \frac{\partial v_g}{\partial y}\frac{\partial \rho}{\partial y}\right)$$

where f is the Coriolis force, N is the buoyancy frequency, g is gravitational acceleration, ρ_0 is a reference density, ρ is the density, and $(u,v)_g$ are the horizontal geostrophic velocities. A detailed derivation and discussion can be found in Pollard and Regier [1992]. See also Wang and Ikeda [1997].

0.16 R

RACER Acronym for Research on Antarctic Coastal Ecosystem Rates, a JGOFS program designed to test several hypotheses regarding the interaction of biological and physical processes in antarctic coastal regions in general, and the importance of the study area as nursery ground for antarctic krill in particular. The principal objective of this 1986–1987 program was the study of the physical and biological processes causing the high productivity in the coastal waters of the Antarctic Peninsula. RACER was a comprehensive, 4–month field study conducted in a 25,000 km^2 region of the western Bransfield Strait during the 1986–1987 austral summer.

Some of the significant results of the RACER program were:

- the documentation of an extensive phytoplankton bloom in the northern Gerlache Strait with biomass estimates >750 mg Chl *a* m^{-2} and primary production rates in excess of 4 g C m^{-2} day^{-1}, the initiation, continuation, and demise of which was controlled largely by the physical conditions of the water column and, specifically, by the depth of the surface mixed layer;
- the partial pressure of CO_2 was reduced to $\leq$100 μatm in the regions of extensive bloom formation, thereby creating a potentially large sink for atmospheric CO_2;
- investigations of the population dynamics, distribution, abundance and growth of the krill species *Euphausia superba* identified at least two year classes of immature and adult populations in the study area, with three biogeographic zones identified;
- comprehensive hydrographic surveys confirmed the presence of several different water masses, two major frontal structures, and a flow from the southwest to the northeast across the study area called the Bransfield Current; and
- a second RACER field experiment was designed for November–December 1989, which would focus more closely on the initial stages of the spring bloom phenomenon in a smaller geographic area.

See Huntley et al. [1991].

[http://hahana.soest.hawaii.edu/racer/racer.html]

radar An acronym for radio detection and ranging, the use of reflected electromagnetic radiation to obtain information about distance objects. The wavelength used in normally in the radio frequency spectrum between 30 m and 3 mm.

RADARSAT An earth observation satellite developed by Canada to provide information for researchers in such fields as agriculture, cartography, hydrology, forestry, oceanography, ice studies, and coastal monitoring. The satellite, launched on Nov. 4, 1995 by the Canadian Space Agency (CSA), carries a C-band SAR capable of imaging a ground swath 500 km wide at 100 meter resolution. The expected lifetime of RADARSAT is five years.

RADARSAT–1 circles the Earth at an altitude of 798 km and an inclination of 98.6 deg. to the equatorial plane. It has a sun–synchronous orbit, making its overpasses always at the same local mean time. The satellite's SAR can shape and steer its beam from an incidence angle of 10 to 60 degrees, in swaths from 45 to 500 km in width, with resolutions ranging from 8 to 100 m. It covers the Arctic daily and most of Canada every three days, with data downlinked in real time or stored onboard until the satellite is within range of a receiving station. A RADARSAT–2 is in the planning stages.

[http://www.space.gc.ca/csa_sectors/earth_environment/radarsat/]

radar altimeter An instrument that uses radar to determine a vehicle's (e.g. a satellite) height above the surface and for measuring the height of small objects (e.g. waves, hills) on a planetary surface. In oceanography, the former capability is used to obtain the absolute sea surface height in relation to the geoid, and the latter to gather information about oceanic wave fields.

An altimeter works by transmitting an electronic pulse in the microwave frequency to the Earth's surface. The pulse reflects off the surface and returns to the sensor, with altitude determined from the pulse travel time and from the waveform of the returned pulse.

radiance The radiation energy per unit time coming from a specific direction and passing through a unit area perpendicular to the direction.

radiant flux density See irradiance.

radiation stress A mechanism whereby waves can exert a stress on the fluid in which they propagate. This stress tensor was discovered and named by Longuet-Higgins and Stewart [1964] and defined as the excess flux of momentum due to the presence of waves. Gradients in this quantity therefore correspond to a net addition of loss of momentum to a water column, i.e. a net force, arising from the processes of wave shoaling and breaking. The theoretical work was prompted by laboratory experiments with breaking waves that showed a mild depression or set-down in sea level in the vicinity of the wave breaking point and a larger elevation or set-up throughout the rest of the surf zone.

If longshore uniformity is assumed, then the The x-directed flux of x-directed momentum is given (correct to second order) by

$$S_{xx} = E\left(\frac{2kh}{\sinh 2kh} + \frac{1}{2}\right)$$

where k is the wavenumber, L the wavelength, h the depth below still water, and E the wave energy density given by

$$E = \frac{1}{8}\rho g H^2$$

where ρ is the fluid density, g the acceleration due to gravity, and H the wave height. This will given, for equilibrium conditions, a momentum balance of the form

$$\frac{dS_{xx}}{dx} + \rho g(\bar{\eta} + h)\frac{d\bar{\eta}}{dx} = 0$$

where $\bar{\eta}(x)$ is the adjustment of the sea level away from still water level, i.e. the sea level will adjust until the radiation stress gradients are everywhere balanced by the sloping sea level. See Holman [1990],

radio altimeter See radar altimeter.

radiocarbon See carbon-14.

radiocarbon dating See carbon dating.

radioisotopic dating methods Dating methods that take advantage of the fact that unstable atoms called radioactive isotopes undergo spontaneous radioactive decay by the loss of nuclear particles and may transmute into a new element. If the decay rate is invariable a given amount of a radioactive isotope will decay to its daughter product in a known interval of time, creating a geological clock by which large time intervals can be measured. Measuring the present isotope concentration indicates the amount of time that has passed since the sample was emplaced and the clock, i.e. the decay process, started. An important factor is the time it takes for the material to decay to half its original amount, i.e. its half-life, an indicator of the length of the time interval over which it can be used.

A radioisotope's usefulness for dating is dependent on whether it or its daughter products occur in measurable quantities and can be distinguished from other isotopes or have a measureable decay rate.

It must also have a half-life appropriate to the period being dated, a known initial concentration, and some connection between the event being dated and the start of the radioactive decay process.

Radioisotopic dating methods can be divided into three major groups:

- those that entail the direct measurement of radioisotopes or decay products, e.g. carbon-14 dating and potassium-argon dating;
- those that measure the degree to which members of a chain of radioactive decay are restored to equilibrium following some initial external perturbation, e.g. uranium-series dating; and
- those that measure the effect of some local radioactive process on the sample materials compared to the environmental flux, e.g. fission-track dating and thermoluminescence dating.

See Bradley [1985].

radiolaria See Racki and Cordey [2000].

radiolarian ooze A deep-sea sediment composed of at least 30% of the remains of siliceous radiolarians. These sediments occur in the equatorial Pacific and Indian ocean regions where the depth exceeds the carbon compensation depth and therefore aren't overwhelmed by calcareous ooze. These form deep deposits covering 1-2% of the ocean floor, and are a type of siliceous ooze along with diatom ooze. See Tchernia [1980].

radiometer A device that uses a photocell to measure the power of a specific light field.

radiometry The use of a radiometer to quantitatively describe the power from a specific light field. The description can be made in terms of several properties including magnitude, geometrical distribution (or direction), spectral distribution, state of polarization, and time variability. Before the advent of satellite oceanography, the primary use of radiometry was to sample the radiant power in the vicinity of an organism to obtain quantitative information about how it reacts to light. Now the use of radiometers in instruments aboard satellites to measure various properties of incident, reflected and emitted radiation is nearly ubiquitous, with new types of radiometers seemingly developed for each new mission. See Tyler [1973] for a discussion of the physics of radiometry and its appliation to studying the responses of organisms to light.

radium-228 An isotope of radium that is useful as a tracer in ocean studies. It is the 5.75 year half-life daughter of thorium-232. Thorium, a highly insoluble substance, is delivered to shelf and deep ocean sediments chiefly in detritus of continental origin. This decays into radium which dissolves off the particles and diffuses into the water column where it is mixed by diffusion and advection. This leads to a generic profile with a relative maxima at the surface and near bottom with the surface concentration decreasing with increasing distance from the shore (and the near-surface shelf sediment sources). See Sarmiento [1988] and Broecker and Peng [1982].

radius of deformation See Rossby radius of deformation.

RAFOS A subsurface float introduced by Thomas Rossby in 1985 that listens to acoustic signals instead of transmitting (like the earlier SOFAR float). At the end of its mission it surfaces by dropping a weight and uploads to the Argos satellite all the information it collected at depth, including the Times of Arrovals (TOAs) of pulses sent by sources at known geographical positions. See Rossby et al. [1986].

rafting A sea ice process defined by the WMO as:

> Pressure process whereby one piece of ice overrides another. Most common in new ice and young ice.

A type called “finger rafting” involves the formation of interlocking thrusts, with each floe thrusting “fingers” alternately over and under each other. This is commonly found in nilas and grey ice. See WMO [1970].

random variable A function (or mapping) from the sample space of possible outcomes of a random experiment to the real line, the complex plane, or some other such mappable entity. Basically, it’s a variable denoting and containing the outcome of a random experiment, families of which comprise a stochastic process.

RAR Abbreviation for Real Aperture Radar.

RARGOM Acronnym for Regional Association for Research on the Gulf of Maine, an association of institutions which have active research interests in the Gulf of Maine and its watershed. It was founded in 1991 and is housed at Dartmouth College. The missions of the association are to advocate and facilitate a coherent program of regional research, to promote scientific quality, and to provide a communication vehicle among scientists and the public. See the RARGOM Web site[136].

Ras al Hadd Jet An intense offshore jet that forms at the easternmost tip of Oman as the East Arabian Current (EAC) separates from the coast at the eastern tip of the Arabian Peninsula. The RAH Jet is found at the northern edge of EAC during the southwest monsoon, and may be considered as its offshore extension. As the wind regime reverses and the EAC weakens, the RAH Jet becomes the southern edge of the warm circulation in the Gulf of Oman. See Böhm et al. [1999].

RASCALS Acronym for Research on Antarctic Shallow and Littoral Systems.

Rayleigh–Bénard convection See Bodenschatz et al. [2000].

Rayleigh number A dimensionless number used for describing unstable stratified flows. It expresses a balance between thermal expansion, temperature, thermal diffusivity, viscosity, and the thickness of a convecting layer, with the most significant parameters being the depth and viscosity of the layer. The Rayleigh number can be defined as:

$$R_a = \frac{g\alpha\Delta T d^3}{\nu\kappa}$$

where g is gravitational acceleration, α the thermal expansion coefficient, ν the kinematic viscosity, κ the thermal diffusivity, and d a width scale. This is equivalent to:

$$R_a = G_r P_r$$

where G_r is the Grashof number and P_r is the Prandtl number. It expresses the competition between overturning due to top–heavy density due to temperature expansion and viscous and diffusive smearing of the buoyancy.

Convection begins at a Rayleigh number of around 2000, with irregular chaotic convection being near 10^6. The higher the number, the more mixing occurs in the substance being convected. It is around 10^{16} in the ocean thermocline and 10^{17} in the atmosphere boundary layer. This is the natural convection equivalent of the Peclet number used in forced convection.

recirculating current See recirculating gyre.

[136] http://fundy.dartmouth.edu/rargom/

recirculating gyre Strong opposing flow elements adjacent to western boundary currents, e.g. the Gulf Stream in the upper ocean and the deep western boundary current in the deep water of the North Atlantic. These are a subbasin-scale component to the large-scale gyre flow, and can dominate the distribution of transport in the basin interior. See Schmitz and McCartney [1993], Hogg and Johns [1995] and McCartney [1992].

Alfred Redfield (1890–1983) Discover of the Redfield ratios.

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

Redfield ratios These represent the relatively constant proportions maintained between the elements C, N, P and O taken up during the synthesis and released by subsequent remineralization of organic matter by marine organisms. It was originally suggested that during organic matter cycling, carbon, nitrogen, phosphorous and oxygen are cycled in the ratio C:N:P:O2 = 106:16:1:138, i.e. for every phosphate ion taken up during photosynthesis, 16 nitrate ions and 106 molecules are taken up and 138 molecules of oxygen are produced. More recent studies have modified the ratios to 140:16:1:172. See Redfield et al. [1963] and Takahashi et al. [1985].

red noise Noise with relatively enhanced low frequency power that results simply from serial correlation. The resulting power spectrum will have a negative slope. This is usually a good model for the noise component in a variety of climatic time series including proxy records, historical sea and air surface temperatures, and precipitation records. This type of noise can be explained in terms of the slow-response components of the climate system, such as the thermal inertia of the oceans, providing a memory that effectively integrates the forcing of such fast-reponse and more white noise-like components such as the weather. The produces a temporal persistence that leads to great noise energy at lower frequencies. Contrast with white noise.

Red Sea A long, narrow marginal sea centered at about 38° E and 22° N which separates the African and Asian continents. Its total length is 1932 km and the average width 280 km, with a maximum width of 306 km and a minimum width of 26 km. The area is about 450,000 km^2 and the volume around 50,000 km^3. The average depth is about 491 m with the greatest depths over 2500 m in the trough between 19 and 22° N. The Sinai peninsula divides the northern part into the shallow Gulf of Suez to the west and the deep Gulf of Aquaba to the east. The southern limit, which separates it from the Gulf of Aden, is a line joining Husn Murad and Ras Siyan.

The circulation in the Red Sea is summarized in RSMAS [2000] as:

> The Red Sea is similar to the Arabian Gulf in that it acts as an inverted estuary, with dense, salty water formed by evaporation and deep convection in the northern Red Sea flowing out into the Gulf of Aden underneath a fresher inflowing layer from the Gulf of Aden (Fig. 3b). Unlike the Arabian Gulf, however, the exchange is known to be highly seasonal, with maximum exchange occurring in winter. Indirect estimates of the transport of Red Sea water through the Bab el Mandeb Strait suggest an annual mean transport of 0.33 Sv (Siedler, 1968), varying from approximately 0.6 Sv in winter to nearly zero in late summer (Patzert [1974]). The winter period (November-May) is characterized by a classical two-layer exchange flow (Siedler, 1968). However, in summer the northwesterly winds apparently drive a three-layer exchange, consisting of a thin surface outflow from the Red Sea, an inflowing layer of Gulf of Aden thermocline water, and a weak outflowing deep layer (Maillard and Soliman [1986]).
>
> Estimates of the annually averaged rate of Red Sea deep water formation range from 0.06 Sv to 0.16 Sv (Cember [1988]). This water forms in the northern Red Sea predominantly during winter, and fills the deep basin below the Bab el Mandeb Strait sill depth

(approximately 160 m) with a nearly homogeneous water mass of temperature 21.7 C and salinity 40.6 psu (Neumann and McGill [1962]). A second source of somewhat less dense Red Sea water, or Red Sea "intermediate" water, is believed to be formed also predominantly in winter by an open sea convection process in the northern Red Sea that remains poorly understood (Morcos [1970]). This process appears to be distinct from the Red Sea deep water formation process that occurs in the northern gulfs of the Red Sea (Gulf of Suez and Gulf of Aqaba) and that fills most of the deep volume of the Red Sea. Another class of intermediate waters may be formed on shallow shelves in the southern Red Sea. Volumetrically, the rate of intermediate water formation appears to be greater than the rate of deep water formation, and is thought to supply the main contribution to the lower layer outflow from the Red Sea through Bab el Mandeb.

The seasonal cycle of the Red Sea exchange through the Bab el Mandeb is driven primarily by the seasonal change in winds over the southern Red Sea and Gulf of Aden (Fig. 1). In winter the southeasterly winds act to reinforce the thermohaline circulation of upper layer inflow and deep outflow. Conversely, in summer the northwesterly winds act in opposition to the thermohaline forcing and this may partly explain the reversal to outflow in the surface layer of the strait in summer. Upwelling in the western Gulf of Aden during summer is also believed to play a role in forcing the surface current reversal in the Strait and thermocline layer intrusion into the Red Sea, by changing the stratification and sea level in the western gulf and hence affecting the alongstrait pressure gradient (Patzert [1974]). The relative importance of these two wind-forced effects, one direct and one indirect, is not yet clear. Seasonal changes in surface buoyancy forcing may also affect the seasonality of the exchange, but this possibility has yet to be investigated.

The Red Sea water exits the Bab el Mandeb strait with a sill depth of ∼160 m and spills down the topography of the western Gulf of Aden where it entrains resident Gulf waters and sinks to an average depth of about 600 m. Hydraulic control of the outflow is much debated and there is as yet no consensus on the exact nature of hydraulic controls that may govern the exchange. The overflow character of the outflowing Red Sea water is suggestive of hydraulic control. However, there is no evidence of a Gibraltar-like internal bore, a feature that would serve as indirect evidence for hydraulic control. Recently, a three-layer hydraulic model that reproduces the gross characteristics of the stratification and exchange in both summer and winter has been constructed. However the critical conditions required in the summer and winter solutions differ considerably from direct wave speed calculations based on data collected by at the sill and narrows.

The horizontal circulation of the Red Sea appears to consist of a number of gyres or eddies distributed along the length of the Sea (Fig. 3b), of which some may be semi-permanent (Quadfasel and Baudner [1993]). There is little detailed information on this circulation as most studies have tended to treat the Red Sea as a two-dimensional basin. Most oceanographic measurements are therefore confined to its central axis. In the northern Red Sea, drifter trajectories point to a cyclonic gyre at least in winter (Clifford et al. [1997]). This gyre may be linked to the aforementioned intermediate water formation process in the northern Red Sea, and could possibly serve in a preconditioning role for the intermediate water formation. In the central Red Sea the circulation appears to be dominated by anticyclones that occur most regularly near 23-24 N and 18-19 N. These locations may be tied to coastline and topography variations (Quadfasel and Baudner [1993]). Both cyclonic and anticyclonic features are found in the southern Red Sea but no persistent gyre pattern seems to exist there. When present, these gyres usually span most of the width of the Red Sea and can have horizontal velocities of 0.5 m/s or more. Thus they are energetic compared to the 0.1 m/s mean flows in the surface layer associated with the large scale thermohaline circulation of the Red Sea.

Coastal boundary currents may exist both in the southern Red Sea off Yemen and in on both sides of the northern Red Sea (Eshel and Haik [1997]) Little direct evidence is available for these currents, however. Particularly in the northern Red Sea, the opposing influences of the wind and thermohaline forcing throughout the year make it unclear what sense should be expected for these boundary currents.

The central axial zone of the Red Sea contains a series of 0.02–60 km^2 basins between 1500 and 2800 m deep. These are filled with anoxic, dense and hot brines whose temperatures range from 23.25–44.60°C and salinities from 144 to 270 ppt. The transition zone between brines and overlying seawater is marked by strong gradients, and therefore extremely stable, i.e. the transfer of properties across it is controlled mostly by molecular diffusion. See Neumann and McGill [1962], Siedler [1969], Morcos [1970], Patzert [1974], Maillard and Soliman [1986], Cember [1988], Quadfasel and Baudner [1993], Tomczak and Godfrey [1994], Clifford et al. [1997] Eshel and Haik [1997] and Bower et al. [2000].

`[http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html]`

red tide More later.

redox discontinuity layer A zone of rapid transition between areas of aerobic and anaerobic decomposition in oceanic sediments. Its depth within the sediment depends on the quantity of organic matter available for decomposition and the rate at which oxygen can diffuse down from the overlying water. For example, in organic muds, relatively impermeable to oxygen-carrying water, the upper aerobic layer may only be a couple of millimeters deep, while in permeable sands with a low rate of organic input aerobic conditions can extend for tens of centimeters. See Barnes and Hughes [1988].

reduced gravity In oceanography, a term that arises when the Boussinesq approximation is made where variations in density are neglected when they affect inertia but retained when they affect buoyancy, i.e. when they occur in the combination

$$g' = \frac{g\rho'}{\rho_0}$$

where g' is the reduced gravity, g the normal gravitational acceleration, ρ' a density perturbation, and ρ_0 a standard reference density. See Turner [1973].

reef The official IHO definition for this undersea feature name is "a mass of rock or other indurated material lying at or near the sea surface that may constitute a hazard to surface navigation." See coral reef.

ReefBase A global database on coral reefs and their resources. This is available on CD-ROM from ICLARM. See the ReefBase Web site[137].

reference level A depth, pressure or density level at which the horizontal current field is either known from direct measurements or indirectly estimated. This may be zero velocity surface or one with non-zero horizontal velocities. This reference level is combined with the relative velocity fields obtained via the geostrophic method to obtain fields of absolute geostrophic velocitiesa The techniques of satellite altimetry have provided another possibility for a reference level, i.e. the ocean surface. If the vertical departure of the ocean surface from the local geoid can be measured with sufficiently accuracy then it can be used as a reference level. This is also known variously as the level of no motion, the level of known motion, the zero velocity surface, etc.

reflectance In radiation transfer, the fraction of incoming radiation that is reflected from a medium. The sum of this, the transmittance, and the absorptance must equal unity.

[137] http://www.cgiar.org/iclarm/resprg/reefbase/

regenerated production The uptake of ammonium by phytoplankton in the euphotic zone. It is so-called because ammonium is a product of internal processes within the euphotic zone and it is therefore recycled or regenerated nitrogen. See Najjar [1991].

regional modeling In climate modeling this is defined as simulating the climate over a limited area or region rather than over the entire globe using Regional Circulation Models (RegCM). The boundary conditions needed to drive these models are supplied either from GCM output via a procedure called nested modeling or from analyses of observations. The RegCMs perform consistently better when driven by observations than by GCM output. This is largely due to the lack of regional scale geographical features (e.g. coastlines, lakes, etc.) and their concomitant climate effects in the output of GCMs, effects which are implicitly included in observations. Increased GCM resolution is found to improve RegCM simulations. This is a felicitous result since a lack of adequately dense observational data is the major limitation of using observations to drive RegCM simulations. See Houghton and Filho [1995].

regional sea A body of water smaller than the main sections of the world ocean that is bound by geographic and/or hydrographic regions. Regional seas whose names can be encountered in the literature include the Adriatic Sea, Aegean Sea, Aland Sea, Alboran Sea, Amundsen Sea, Andaman Sea, Arabian Sea, Arafura Sea, Aral Sea, Australasian Mediterranean Sea, Sea of Azov, Balearic Sea, Bali Sea, Baltic Sea, Banda Sea, Barents Sea, Beaufort Sea, Bellingshausen Sea, Belt Sea, Bering Sea, Bismarck Sea, Black Sea, Bohol Sea, Bothnian Sea, Burma Sea, Camotes Sea, Caribbean Sea, Caspian Sea, Catalan Sea, Celebes Sea, Celtic Sea, Ceram Sea, Chukchi Sea, Chukotsk Sea, Coral Sea, Cretan Sea, East China Sea, East Siberian Sea, Flores Sea, GIN Sea, Greenland Sea, Halmahera Sea, Iceland Sea, Ionian Sea, Irish Sea, Irminger Sea, Japan Sea, Java Sea, Jawa Sea, Kara Sea, Labrador Sea, Laptev Sea, Levantine Sea, Ligurian Sea, Lincoln Sea, Maluku Sea, Marmara Sea, Mediterranean Sea, Mindanao Sea, Molucca Sea, Nordenskjold Sea, Nordic Seas, North Sea, Norwegian Sea, Okhotsk Sea, Red Sea, Ross Sea, Samar Sea, Sargasso Sea, Savu Sea, Sawu Sea, Scotia Sea, Seram Sea, Sibuyan Sea, Solomon Sea, South China Sea, Sulawesi Sea, Sulu Sea, Sunda Sea, Tasman Sea, Tethys Sea, Timor Sea, Tyrrhenian Sea, Visayan Sea, Weddell Sea, White Sea, and the Yellow Sea.

relative humidity The ratio of the observed mixing ratio in a sample of moist air to the saturation mixing ratio with respect to water at the same temperature. It is given by

$$U = \frac{q(1 - q_w)}{q_w(1 - q)}$$

where q is the specific humidity and q_w the saturation specific humidity.

relative vorticity The vorticity imparted to a parcel or column of fluid by fluid motion. It is a characteristic of the kinematics of the fluid flow which expresses the tendency for portions of the fluid to rotate. Technically speaking, this is the curl of the fluid velocity vector, although in oceanography and meteorology it is usually only the vertical component of the curl of the horizontal velocity vector since all other components are usually negligible.

Rennell, James (1742–1830) See Peterson et al. [1996], p. 47.

Rennell's Current "A relatively strong (1.0 to 1.5 knots) nonpermanent current that sets northward across the western approaches to the English Channel. The current appears to be independent of the North Atlantic Drift or local winds and occurs most frequently during winter." From Baker, Jr. et al. [1966].

research submersibles More later.

[http://itri.loyola.edu/subsea/toc.htm]

research vessels See Estok and Boykin [1976], Guberlet [1964], Nelson [1971], Rice [1986a], Treadwell et al. [1988], Wust [1964] and the oceanography history section for further details.

[http://scilib.ucsd.edu/sio/archives/histoceanogr/mills-handlist.html]

Research Vessel Technical Enhancement Committee (RVTEC) An organization of technical support personnel associated with the university oceanographic Research Vessel fleet of the U.S. RVTEC is charted by UNOLS and publishes a newsletter called "INTERFACE." See the RVTEC Web site[138].

resolution In numerical modeling, the distance between contiguous points in the computational grid. This can refer to either temporal or spatial resolution, with the two being dependent in procedures using both.

resonance angle The angle at which the component of the wind speed acting in the direction of a wave field is equal to the wave speed. From Baker, Jr. et al. [1966].

resurgence A general class of phenomena where, after a storm surge, the water level falls, rises, falls again, rises again, and so on for many hours after the passage of a hurricane. This has been variously explained as being due to oscillating long waves, edge waves, Kelvin waves or some combination thereof. See Wiegel [1964].

retardation See daily retardation.

retroflection In oceanography, this refers to a geographical looping of a current away from its original direction to a substantially different direction. See Schmitz and McCartney [1993].

Revelle, Roger (1909-1991) More later.

[http://scilib.ucsd.edu/sio/archives/siohstry/revelle-biog.html]
[http://www.nap.edu/readingroom/books/biomems/rrevelle.html]

Revelle factor See buffer factor.

reversed tide A tide completely out of phase with the apparent motions of the principal attracting body, i.e. the lowest heights are directly under the body on opposite sides of the earth. See also direct tide. From Baker, Jr. et al. [1966].

reversing current See Baker, Jr. et al. [1966].

reversing thermometer

Reynolds equations An equation set for turbulent flow wherein the instantaneous values of the dependent variables in the equations of motion are split into mean and fluctuating parts, e.g. $\tilde{u} = U + u$ where U is the mean and u the turbulent or fluctuating part. These are substituted into the equations of motion and an average is taken over a suitable period of time (where "suitable" means an averaging interval large compared to the timescale of the turbulent fluctuations yet small compared to the timscale of the change of the mean flow) to obtain the Reynolds equations. These have the same form as the original motion equations – with mean quantities replacing total quantities – except for new terms involving velocity fluctuations that arise from the nonlinear terms in the original equations. These terms represent the effect of velocity fluctuations or turbulence on the mean flow, and are called Reynolds stresses since

[138]http://www.gso.uri.edu/unols/rvtec/rvtec.html

the turbulence has an effect equivalent to stress on the mean flow. The Reynolds equations can be expressed as:

$$
\begin{aligned}
\frac{\partial U_i}{\partial x_i} &= 0 \\
\frac{\partial U_j}{\partial t} + \frac{\partial}{\partial x_k}(U_k U_j) + \varepsilon_{jkl} f_k U_l &= -\frac{1}{\rho_0}\frac{\partial P}{\partial x_j} + \frac{\partial}{\partial x_k}\Sigma_{kj} - g_j \rho - \frac{\partial}{\partial x_k}\left(\overline{u_k u_j}\right) \\
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k}(U_k \rho) &= \frac{\partial}{\partial x_k}\left(k_T \frac{\partial \rho}{\partial x_k}\right) - \frac{\partial}{\partial x_k}\left(\overline{u_k \rho}\right)
\end{aligned}
$$

where U_i and u_i are the mean and fluctuating velocity components, respectively, x_i are the spatial components, ε_{ijk} is the alternating, third–order tensor, $f_k = \delta_{k3} 2\Omega \sin\theta$ is the vertical component of the rotation vector (i.e. the Coriolis force), ρ_0 is a constant reference density, P is the pressure, Σ_{ij} is the mean part of the second–order, symmetric viscous stress tensor defined as:

$$\Sigma_{ij} = 2\nu \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)$$

where ν is the kinematic viscosity, g_j is gravity, ρ is the density,

The Reynolds equations give rise to what is known as the closure problem, where the averaging procedure results in new unknowns in the form of the fluctuating quantities obtained from the nonlinear terms. Specific expressions for these fluctuating quantities can be obtained but at the price of generating yet more unknowns, ad infinitum. At some point a closure assumption must be made and the fluctuating quantities parameterized in terms of known quantities like the mean flow. The use of the eddy viscosity concept is the simplest way of obtaining closure.

This is ultimately a problem of flow resolution. If we could explicitly model the flow at a sufficiently high resolution (i.e. on a sufficiently small grid) then we wouldn't need to use an eddy viscosity since the molecular viscosity would suffice. Unfortunately, the length scale required for this is on the order of a millimeter or less, rendering it infeasible to explicitly model flow in a pipe (much less atmospheric or oceanic flow) without parameterizing the turbulent, i.e. unresolved, portion of the flow in terms of the mean, i.e. resolved, portion of the flow.

Reynolds stresses Stress terms obtained by transforming the equations of motion into the Reynolds equations. They are so–called in analogy to the terms in the original motion equations involving the molecular viscosity, and to further the analogy the concept of an eddy viscosity is used to perform closure on the Reynolds equations and render them soluble.

The forces that give rise to the stresses are due to the fact that in a turbulent flow there are rapidly fluctuating as well as mean components. The fluctuating components oppose the mean motion and redistribute energy and other properties via a physical effect analogous to molecular friction, i.e. turbulent friction. This causes a more rapid distribution of momentum, heat and salt than would occur solely via molecular processes, and the analogous stresses are called Reynolds stresses.

Reynolds stress tensor A quantity arising in the development of the Reynolds equations defined as

$$\tau_{ij} = -\rho_0\, \overline{u_i u_j}$$

where ρ_0 is a constant reference density and $\overline{u_i u_j}$ is a matrix of the time average of the products of the turbulent velocity components. The instantaneous velocity $\tilde{u}_i$ has been decomposed into average and fluctuating quantities, i.e. $\tilde{u}_i = U_i + u_i$ and the overbar indicates a time average.

Reynolds number A dimensionless number expressing the ratio of viscous to inertial forces. It is expressed by

$$Re = \frac{UL}{\nu}$$

where ν is the kinematic viscosity, U an appropriate velocity scale, and L a horizontal length scale. If this is at least one order larger than unity then viscosity cannot significantly affect the motion; if it is much less than unity then molecular viscosity plays a significant role. See Kraus and Businger [1994], p. 29.

RGPS Acronym for RADARSAT Geophysical Processor System, a computer system that takes RADARSAT SAR images of Arctic sea ice for input and creates geophysical data products for output. These include sea ice motion, the thickness distribution of new ice, and the backscatter history of the ice. See the RGPS Web site[139].

RH Abbreviation for relative humidity.

Rhodes Gyre See Milliff and Robinson [1992].

Richardson, Lewis Fry More later.

Richardson number A ratio of buoyancy to inertial forces which measures the stability of a fluid layer. There are several different definitions of this for various situations,including the overall, gradient, and flux Richardson numbers. See Turner [1973].

ridging A sea ice process defined by the WMO as:

> The pressure process by which sea ice is forced in ridges. A ridge is a line or wall of broken ice forced up by pressure. It may be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed in ice keel.

Antarctic ridges a commonly point features, whereas they are more often long and linear in the Arctic. See WMO [1970].

The official IHO definition for this in the context of undersea feature names has three meanings:

- an elongated narrow elevation of varying complexity having steep sides;
- an elongated narrow elevation, often separating ocean basins; and
- the linked major mid–oceanic mountain systems of global extent; also called mid–oceanic ridge.

RIDGE Acronym for Ridge Inter–Disciplinary Global Environments Initiative, a coordinated program aimed at understanding the geology, physics, chemistry and biology of processes occurring along the global mid–ocean ridge system. See the RIDGE Web site[140].

rigid lid approximation A filtering approximation incorporated into oceanographic models to increase their computational efficiency. This approximation filters out the fast barotropic gravity waves by setting the time variation of the surface elevation in the equations of motion equal to zero. A computational price is paid for this approximation since it requires that a prognostic Poissonlike elliptical equation be solved for the barotropic stream function (or surface pressure) at each model time step. This can be a problem as the condition number increases faster than linearly with the resolution of the computational grid, causing the equations to become increasingly difficult to solve.

[139] http://psc.apl.washington.edu:80/RGPS/
[140] http://ridge.unh.edu/

This approximation also has dynamical effects that can be non-negligible. For example, although a surface elevation can be calculated from the prognostic surface pressure solution, it is strictly applicable only in the limit of a steady-state and as such the surface height cannot be accurately computed for transient and nonequilibrated flow. Additionally, this approximation effectively makes the phase speed of all barotropic Poincare waves infinite and equilibrates them at all scales. This is a reasonable approximation at mid- and high-latitudes where Poincare waves exist at high frequencies, but not so good near the equator where they evolve on a time scale equivalent to the Rossby waves. Finally, this approximation affects the phase speed of Rossby waves with wavelengths greater than the Rossby radius of deformation. See Dukowicz and Smith [1994] and Thacker and Raghunath [1994].

Rim Current A permanent, strong current system encircling the Black Sea basin cyclonically over the continental slope zone. It is accompanied by a series of anticyclonic mesoscale eddies as well as transient waves with an embedded train of mesoscale eddies propagating cyclonically around the basin. According to Oguz and Besiktepe [1999]:

> The Rim Current is identified as a well-defined meandering jet stream confined over the steepest topographic slope and associated cyclonic–anticyclonic eddy pairs located on both its sides. It has a form of highly energetic and unstable flow system, which, as it propagates cyclonically along the periphery of the basin, is modified in character. It possesses a two-layer vertical structure with uniform upper layer speed in excess of 50 cm/s (maximum value ≈100 cm/s), followed by a relatively sharp change across the pycnocline (between 100 and 200 m) and the uniform sub-pycnocline currents of 20 cm/s (maximum value ≈40 cm/s) observed up to the depth of ≈350 dbar, being the approximate limit of ADCP measurements. The cross-stream velocity structure exhibits a narrow core region (≈30 km), flanked by a narrow zone of anticyclonic shear on its coastal side and a broader region of cyclonic shear on its offshore side.

See Oguz and Besiktepe [1999].

Río de la Plata Estuary After Sepúlveda et al. [2004], the Río de la Plata Estuary is located in South America on the Atlantic coast, at 35°S, 57°W, between Argentina and Uruguay. It has an approximate length of 320 km and a width of 230 km at the mouth. The average depth is 10 m. It drains the second largest basin of South America, receiving the combined discharge of the Paraná and Uruguay rivers, the two major tributaries, with a total yearly average discharge of 22,000 m3/s, comparable to the discharge of the Mississippi river. Freshwater discharge to the Río de la Plata exhibits monthly variations with the combined peak discharge appearing in the austral fall and the lowest discharge occurring in the austral summer. The Paraná River has an average discharge 3 to 4 times greater than the Uruguay River but its volume shows low seasonal variability. Episodic events in the Uruguay River exhibit high discharge rates, comparable to those of the Paraná River that can modulate the runoff into the Ro de la Plata.

The estuary can be divided, on the basis of hydrodynamical considerations, in two regions separated by the turbidity maximum zone. In the inner or upstream portion, between the turbidity maximum and the head of the estuary, the regime is predominantly fluvial, i.e. the inner part is dominated by river flow interacting with tidal currents and affected by winds. In the outer or downstream portion the estuary width increases rapidly. It is mostly in this area where riverine discharge interacts with saline shelf waters. Shallow areas (4–10 m) and channels dominate the bottom topography, with the deepest channels (20-25 m) located along the Uruguayan coast.

The tides in the estuary are mixed with semidiurnal dominance. The main tidal constituents are M2, S2, N2, K1, and O1. The M2 constituent is the most energetic explaining 80% of the total variance; the O1 is the main diurnal component and produces a difference in the amplitude of the two maxima during one day, the diurnal inequality, which is characteristic in the area. Tidal amplitude varies across the estuary with greater values along the Argentinean coast (amplitude 1 m) than along the Uruguayan coast (amplitude 0.3 m). Due to the considerable length of the Río de la Plata, semidiurnal constituents have the very unusual feature of a nearly complete wavelength within the estuary at all times. The distribution of the phase and amplitude for these tidal constituents has been described as the result of a Kelvin wave that propagates northward around the continental shelf and enter the estuary, in general, from the southeast. Tides in the estuary can be strongly modified by meteorological events; storm surges of over 4 m have been recorded during strong southeasterlies.

The orientation of the buoyant plume presents a bimodal pattern: In the spring and summer, when freshwater discharge is lowest and northeast winds are predominant, a buoyant strip of water extends along the Argentinean coast. During the fall and winter, freshwater discharge peaks and downwelling favorable winds combine with Coriolis acceleration to move the buoyant waters along the northern coast. Bottom salinity is controlled by bathymetry and exhibits weak seasonality. Temperature patterns follow atmospheric variability (air–sea heat flux) with a seasonal range of about 10°C. The warm period spans from December to March while the cold period is from June to September. During the summer, coastal upwelling is observed at the mouth of the estuary along both coasts. Coastal upwelling modifies the estuarine outflow, favoring a buoyancy outflow off the coast of Argentina, and also reinforces a southward ambient current.

A characteristic feature in the estuary is the turbidity front, located approximately in the vicinity of the Barra del Indio. The front is the surface signature of the transition between fresh and more saline shelf waters. The position of the turbidity front exhibits strong seasonality. During the summer months (low freshwater discharge and northeasterly winds) the turbidity front is at its northwesternmost position. During winter and fall, the turbidity front extends seaward. After Guerrero et al. [1997] and Sepúlveda et al. [2004].

rip current A narrow seaward return flow caused by waves breaking in the surf zone and piling up water against the coast. This establishes a hydraulic head which, combined with bathymetric irregularities along the coast, causes the narrow seaward flow. See Komar [1976].

rip feeder current A current that flows parallel to the shore before converging and forming the neck of a rip current.

rise The official IHO definition for this undersea feature name has two meanings:

- a broad elevation that rises gently and generally smoothly from the sea floor; and
- the linked major mid–oceanic mountain systems of global extent; also called mid–oceanic ridge.

RISP Abbreviation for Ross Ice Shelf Program or Project, a New Zealand project.

Rissaga An instance of the meteorological tsunami phenomenon in the harbor of Ciutadella on the Island of Menorca in the Balearic Islands. See Monserrat et al. [1991].

RNODC Abbreviation for Responsible National Oceanographic Data Center, a facility established within the framework of the IOC IODE structure to take on the responsibility of assisting the WDCs. This scheme was developed to enable to international exchange system to cope with an increasing variety and volume of oceanographic data being collected by providing special data processing and compilation support for specific programs and certain areas.

The RNODCs as of mid-2001 are:

- RNODC–SOC, operated by the NODC of Argentina for data from the Southern Oceans;

- RNODC for Drifting Buoys Data, operated by MEDS, Canada for data from drifting buoys;
- RNODCs for IGOSS, operated by the NODCs of Japan, the USA and the Russian Federation for BATHY and TESAC datasets;
- RNODCs for MARPOLMON, operated by the NODCs of Japan, the USA and the Russian Federation for holding worldwide marine pollution data;
- RNODC-WESTPAC, operated by the NODC of Japan for data from cruises in the WESTPAC region;
- RNODC-Waves, operated by the BODC for archiving instrumented wave data;
- RNODC-JASIN, operated by the BODC for archiving data from the JASIN project;
- RNODC-Formats, operated by the Service Hydrographique of ICES for international or project oriented oceanographic data formats;
- RNODC-ADCP, operated by the NODC of Japan for archiving and processing ADCP data; and
- RNODC-INDO, operated by the NODC of India for storing data from research activities in the Indian Ocean.

[http://ioc.unesco.org/iode/structure/rnodc/rnodc.htm]

RNODC-SOC Abbreviation for RNODC from the Southern Oceans, a data center commissioned in 1988 within IODE to acquire the physical and chemical data obtained by the international scientific community in cruises and research programs carried out in the Southern Oceans, control their quality, store them in standard format, and distribute them upon request. This center is a part of CEADO. See the RNODC-SOC Web site[141].

roaring forties The region between 40 and 50° S latitude where the prevailing westerly winds blow largely unobstructed by land over the open oceans, and also the winds themselves. They are constant and of great velocity, whence comes the term "roaring". The weather is stormy, rainy, and comparatively mild in the wake of constantly appearing depressions. The land areas that do obstruct them, the western mountainous coasts of southern Chile, Tasmania and New Zealand, experience tremendous rainfall through the year on the western sides (up to 100 in.) and much less on the eastern sides (around 20 in.). These are also known as brave west winds.

ROLAI^{2}D A free vehicle benthic lander designed to characterize reaction at and transport across the sediment–water interface. ROLAI^2 was designed for long duration deployments (i.e. greater than 30 days) to measure the small fluxes and low reaction rates typical of most of the deep ocean. The lander does this my autonomously collecting sediment and pore water samples as well as samples from benthic chambers. Tracers can be released into the chambers to define such processes as non–diffusive exchange across the interface. See Sayles and Dickinson [1991].

Romanche Fracture Zone See Mercier and Morin [1997] and Messias et al. [1999].

RONMAC Acronym for Red de Observacion del Nivel del Mar para America Central, or Water Level Observation Network for Latin America. RONMAC was initiated as a response to the 1998 impact of Hurricane Mitch on El Salvador, Guatemala, Honduras and Nicaragua, with the objective being to provide support for the development and improvement of the geodetic framework of Central America. The development phase will be executed from June 2000 to Dec. 31, 2001, with the project continuing on an operational basis thereafter. The activities include:

[141] http://www.conae.gov.ar/~ceado/rnodcsoc.html

- installing six sea–level and meteorological monitoring stations;
- installing a ground station and facilitating real–time access to and distribution of information;
- development of a national and regional capacity to install and maintain the stations and to conduct data acquisition, analysis, archiving and dissemination using automated database management technology; and
- strengthening the skills of host–country agencies via technology transfer and capacity building.

[http://www.oas.org/ronmac/]

ROPEX Acronym for the Ronne Polynya Experiment, carried out in the southern Weddell Sea in January and February 1998 using the HMS *Endurance*. The primary goal of the program was to obtain oceanographic, sea–ice and atmospheric measurements to improve the understanding of the physical processes coupling the southern Weddell Sea to the circulation and properties of the global ocean and atmosphere.

[http://www.esr.org/ropex/ronice.html]

ROSCOP Acronym for Reports of Oceanographic Cruises and Oceanographic Programs, a program conceived by the IOC in the late 1960s to provide a low level inventory for tracking oceanographic data collected on research vessels. It is a form to be completed by a scientist on each cruise that provides various metadata about what kinds of data were taken on the cruise. It was renamed the Cruise Summary Report (CSR) in 1990 but the acronym ROSCOP persists. See the ROSCOP Web site[142] where digitized forms of collected ROSCOP info from the 1960s through the present can be obtained.

ROSIS Acronym for Reflective Optics System Imaging Spectrometer, a compact airborne imaging spectrometer. This device was designed for the detection of spectral fine structure in coastal waters. See the ROSIS Web site[143].

Ross, James Clark More later.

Ross Sea See Jacobs et al. [1970], Arrigo et al. [1998] and Jacobs and Giulivi [1999].

Rossby, Carl-Gustav Arvid (1898-1957) Rossby was born in Sweden and joined a group studying under V. Bjerknes in 1918 after receiving his "Kandidat" in theoretical mechanics. There he started his career in meteorology as well as his interest in oceanography. In 1921 he followed Bjerknes to the University of Leipzig for a year and then returned to Stockholm in 1922 to a position with the Swedish Meteorological Hydrologic Service. Over the next three years he accompanied, as a meteorologist, oceanographic expeditions to Jan Mayen in the Nordic Seas, around the British Isles, and to Portugal and Madeira. He also studied mathematical physics at the University of Stockholm during this time and received his "Licentiat" in 1925.

In 1926 Rossby moved to the United States and continued his research at the only extent meteorological center, the Government Weather Bureau in Washington, D.C. He wrote several significant papers on atmospheric turbulence and stratospheric dynamics during this period and also organized the first airway meterological service on an experimental basis in California which provided the pattern for future systems. In 1928 he organized the first university level meteorological program in the United States at the Massachusetts Institute of Technology 9MIT), in which he soon became a full professor.

He spent eleven years at MIT and contributed to such areas as the thermodynamics of air masses, turbulence in the atmosphere and in the oceans, lateral mixing, and the interaction of the ocean–atmosphere boundary layers. He gradually turned his attentions to large–scale motions and the general

[142] http://ices.dk/ocean/roscop.htm
[143] http://www.man.ac.uk/Arts/geography/rs/emac.html

circulation of the atmosphere, to which he began to apply the concepts of vorticity and momentum that permeate the field today. In 1939 he became the assistant chief of research at the U.S. Weather Bureau and in 1940 the chairman of the Department of Meteorology at the University of Chicago, during which time he developed his theory for the long waves in the atmosphere that later came to be called Rossby waves.

During World War II he organized the training of military meteorologists and continued his research on long waves in the atmosphere. After the war he recruited many outstanding future researchers for the University of Chicago and played a significant role in the development of equations for the prediction of weather using electronic computers. In 1947 he became the director of the newly formed Institute of Meteorology in Stockholm and divided his time between there and Chicago (although, for convenience, his American affiliation was transferred to Woods Hole in the early 1950s.

At Stockholm Rossby's principal activities were concerned with developing numerical prediction systems for European weather. He also founded the geophysical journal Tellus. In 1954 he turned his attention to the field of geochemistry and also became interested in deep circulation processes in the ocean. He worked in these areas until his death in 1958. See Lewis [1996] and Phillips [1998].

Rossby-gravity wave See Yanai wave.

Rossby number A non-dimensional number expressing the ratio of inertial to Coriolis forces in the atmosphere or oceans. The Rossby number R_0 is defined by

$$R_0 = U/fL$$

where U is a characteristic velocity scale, f the Coriolis parameter, and L a characteristic length scale. If the Rossby number is large, then the effect of the Earth's rotation on the phenomenon in question can be neglected. This is also called the Kibel number.

Rossby radius of deformation The fundamental horizontal length scale in fluids that are affected by both gravity and rotation. It is the length scale at which rotation effects become as important as buoyancy effects. In transient problems an initial disturbance at a scale small compared to the Rossby radius will result in an adjustment process about the same as would occur in a nonrotating system. If the disturbance is on a scale comparable to the Rossby radius, the Coriolis acceleration becomes as important as the pressure gradient term and the response is markedly different than would be seen in the nonrotating system.

In a homogeneous layer of fluid the barotropic Rossby radius λ is given by

$$\lambda = c/f$$

where c is the gravity wave propagation velocity $\sqrt{gH}$, g the gravitational acceleration, H the water depth, and f the Coriolis parameter. In the deep ocean where H is 4 or 5 km, the baroclinic radius is around 2000 km, but on the continental shelves with depths closer to 50 to 100 m it is around 200 km.

In a stratified fluid the baroclinic Rossby radius is similarly computed, except that c is now the wave speed of the nth baroclinic mode as would be found in a normal mode decomposition of the system. The baroclinic radius is a natural scale in the ocean associated with boundary phenomena such as boundary currents, fronts, and eddies. The first mode baroclinic radius is typically around 10-30 km in the ocean. See Gill [1982].

Rossby wave Large scale waves in the ocean or atmosphere whose restoring force is the β-effect of latitudinal variation of the local vertical component of the earth's angular rotation vector, i.e. the Coriolis force. In the atmosphere they are easily observed as the large-scale meanders of the mid-latitude jet stream that are responsible for prevailing seasonal (via blocking) and day-to-day weather patterns. They are more difficult to detect in the ocean as their sea surface height signature is on the order of 10 cm, their propagation speeds of order 10 cm/s, and their wavelengths hundreds to thousands of kilometers.

Rossby waves in the ocean are responsible for establishing the westward intensification of circulation gyres, the Gulf Stream being one example of this. They are also the dynamic mechanism for the transient adjustment of the ocean to changes in large-scale atmospheric forcing, e.g. information is transmitted from the tropical oceans to mid- and high-latitudes via Rossby waves acting in concert with coastal trapped waves. They are generated by wind and buoyancy forcing at the eastern boundaries and over the ocean interior. They are also known to be generated by perturbations along the eastern boundaries caused by coastal trapped waves originating at low latitudes. They subsequently freely propagate away from their source regions.

Standard theory derives the properties of freely propagating Rossby waves from the linearized equations of motion for large-scale, low-frequency motion about a state of rest, which yields an equation for normal modes. These normal modes can be found by specifying surface and bottom boundary conditions and solving an eigenvalue problem that depends only on the local stratification. There are an infinite number of wave modes ordered by decreasing phase speed, which are westward for all modes. Solutions for low frequencies and long wavelengths are zonally nondispersive, i.e. the phase speed is independent of the wavelength.

The lowest mode is the barotropic mode. It is uniform vertically and propagates across an ocean basin in about a week. The next gravest, or first baroclinic, mode is surface intensified, depends strongly on the stratification profile, has a velocity profile that changes sign at the depth of the thermocline, and takes months to cross the same basin as the first mode does in a week. The surface height variations of this mode are mirrored as thermocline depth variations of the opposite sign, which are also about three orders of magnitude larger, i.e. a 5 cm surface elevation variation would correspond to a 50 m depression in the thermocline.

History. Platzman [1968] thoroughly reviewed the historical development of the Rossby wave concept:

> Rossby was himself explicit about the antecedents of his trough formula. In his paper of 1939 he said: "In the attempt to understand the dynamics of the upper level trough over the United States, the author found great help in a remarkable paper by J. Bjerknes (1937) which offers a simple explanation for the displacement of perturbations imposed upon the zonal pressure distribution which normally prevails in the upper parat of the troposphere." He then reproduced the 'isobaric-channel' diagram from Bjerknes's paper, and referred to this paper again the the second part of his work, published in 1940.
>
> An earlier source of inspiration which Rossby cited in both of his planetary-wave papers, and to which he often alluded in conversation, was Ekman's classic papers of 1923 and 1932. Here Ekman formulated in detail the central role played by vorticity in the quasi-geostrophic control of ocean circulations, and distinguished clearly between the various types of induction of relative vorticity. In particular, he referred to the effect of variation of Coriolis parameter with latitude as the "planetarische Wirbelwirkung," and the effect of change of depth as the "topographische Wirbelwirkung." Ekman's work certainly must have had a strong influence on Rossby's formulation of the potential-vorticity theorem. Of course, any correct historical perspective on this subject must include the great circulation theorem of V. Bjerknes (1898).
>
> I believe Rossby was at first not aware of the fact that the global counterpart of the regional planetary wave is a limiting case of a class of solutions of the equations for free oscillations of an ocean on a rotating sphere - Laplace's 'tidal' equations as they are called.

Margules in 1893 had shown that these equations admit two quite different classes of solutions: first, oscillations of predominantly gravitational type, mainly of importance for the analysis of the semidiurnal and diurnal tides; and second, oscillations of predominantly inertial type, which owe their existence entirely to the rotation of the Earth, and may be important for the long-period tides. Margules called the gravitational modes "Wellen erster Art" and the rotational modes "Well zweiter Art." Hough, about five years later, without knowledge of Margules' work, made the same discovery and used virtually the same terms, namely "oscillations of the first class" and "oscillations of the second class." It is sometimes said that these categories were noticed by Laplace but that is not true – and I daresay his reputation can not be much affected by this oversight! However, there seems to be little awareness of the fact that in the second edition of `Hydrodynamics` (the first with that title), published in 1895, Lamb worked out some details of the oscillations in a rotating cylindrical basin with parabolic law of depth, and discussed explicitly the rotational as well as the gravitational modes. Like Hough, he was at that time not aware of Margules' work.

Margules' investigation of the tidal equations was the first in which the global planetary wave was explicitly studied from the standpoint of applications to meteorology. It was not taken up again from this point of view until the late 1920s and early 1930s when the Leipzig school enlisted it in an attempt to find a theoretical basis for numerous 'empirical' periodicities then believed to exist in meteorological data, ranging from a few days to 37 or more days. The principal theoretical outcome of these efforts was a paper by Haurwitz in 1937, in which Margules' calculations were extended and improved, using the more powerful methods developed by Hough. When in 1939 the trough formula was announced, Haurwitz saw its connection with the theory of oscillations of the second class that had come down from Margules and Hough, and through his own hands. He showed how the formula could be extended to allow for finite width, first on the 'beta plane' (Haurwitz 1940a) and then on the sphere (Haurwitz 1940b). In the latter paper the westward-drift formula $2\Omega/n(n+1)$ – first stated by Hough – was deduced directly for Rossby's prototype 'barotropic nondivergent' atmosphere, rather than indirectly from the intricate context of Laplace's 'tidal' equations.

See Platzman [1968], Dickinson [1978] and Kuo [1973].

roughness height In atmospheric boundary layer dynamics, the height above a surface where the wind speed reaches zero. This is used when surface irregularities are larger than the 1 mm depth of the layer where molecular diffusion dominates and an analogous "turbulent" diffusion depth is needed. It is a constant in expressions used to find the logarithmic velocity profiles in boundary layers, and ranges from about a millimeter for average seas to more than a meter for cities with tall buildings. See Hartmann [1994].

ROWS Acronym for Remote Ocean Wave Spectrometer, an airborne remote sensor used to support the development and refinement of satellite radars that measure the ocean surface. It is an instrument which uses the specular backscatter from a rotating near–nadir radar to estimate the two-dimensional ocean surface wave spectrum. ROWS is implemented from aircraft flying 5–10 km above the ocean. See Jackson [1987].

`[http://rows.wff.nasa.gov/]`

RSMAS Abbreviation for Rosensteil School and Marine and Atmospheric Sciences. See the RSMAS Web site[144].

[144] http://www.rsmas.miami.edu/

RSVP Abbreviation for Rapid–Sampling Vertical Profiler, a free–fall instrument tethered on a thin fiber optic cable designed for making repeated vertical profiles rapidly and continuously. See Caldwell et al. [1985].

Rumford, Count See Benjamin Thompson.

RV Abbreviation for research vessel.

RVTEC Abbreviation for Research Vessel Technical Enhancement Committee.

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SAA Abbrevation for Satellite Active Archive, a digital library of real-time and historical satellite data from NOAA's POES. SAA allows users to search inventories of satellite data, preview representative Earth images of that data, and to download the data for further processing and analysis.

[http://www.saa.noaa.gov/]

SAARI Acronym for the South Atlantic Accelerated Research Initiative, an ONR research program primarily directed toward improvement of the description of the subtropical South Atlantic. It focused on the poleward corners of the subtropical gyre, i.e. the separation of the Brazil Current and its confluence with the Malvinas or Falkland Current in the southwest, and the Agulhas Retroflection and Benguela Current in the southeast. See Gordon [1988].

SABRE Acronym for South Atlantic Bight Recruitment Experiment, a NOAA program to stud the birthdate history of survivors (larvae, late larvae, and juveniles) to determine which life history phase or passage (spawning, transport across the shelf, inlet ingress, estuarine development, inlet egress) regulates recruitment variability in annual cohorts of transgressive species like Atlantic menhaden.

[http://www.ccpo.odu.edu/~wheless/sabre.html]

SABSOON Acronym for South Atlantic Bight Synoptic Offshore Observational Network, a NOPP funded program to develop a real–time observational network on the continental shelf offshore of South Carolina and Georgia. The network consists of eight large offshore platforms – currently operated by the U.S. Navy for flight training – being instrumented to provide a range of oceanographic and meteorological observations on a continuous, real–time basis. The grid covers an area of 155 km by 50 km and a depth range from 25 to 45 m, with an existing communcations system allowing high bandwidth, real–time data transmission to shore.

[http://www.skio.peachnet.edu/projects/sabsoon.html/]

SAC Acronym for Shipboard ADCP Center, now renamed to JASADCP.

SACCF Abbreviation for the Southern ACC Front.

SADCO Acronym for the South African Data Centre for Oceanography, a center that stores, retrieves and manipulates multi-disciplinary marine information from the areas around Southern Africa.

[http://fred.csir.co.za/ematek/sadco/sadco.html]

S-ADCP Abbreviation for Salinity–ADCP.

saddle The official IHO definition for this undersea feature name is "a broad pass or col, resembling in shape a riding saddle, in a ridge or between contiguous elevations."

SAF Abbreviation for Subantarctic Front.

SAFDE Acronym for the Sub–Antarctic Flux and Dynamics Experiment, a program designed to collect observations of the ACC south of Tasmania that would permit direct evaluation of the momentum, energy and vorticity budgets. The experiment lasted two years - from April 1995 to March 1997 - and collected multi–year observations of currents and temperatures in both a small current meter mooring array with a diameter of about 70 km, and along a SSW–NNE section perpendicular to the expected mean axis of the ACC at the Subantarctic Front. The measured variables were found to be coherent horizontally and vertically in broad, sub–inertial frequency bands, a rarity with such oceanic measurements.

The center of the SAFDE array consisted of nine subsurface, nearly full depth moorings deployed as a local dynamics array (LDA), of which four were fully and three partially recovered. The array also included a suite of 17 (15 recovered) horizontal electrometers (HEM) and 18 (all recovered) inverted echo sounders (IES) to obtain time series of the vertically averaged horizontal water velocity, the temperature structure, and the dynamic height structure. The HEMs measure the horizontal electic fields which are theoretically related to the conductivity–weighted, vertically–averaged horizontal water velocity Chave and Luther [1990].

[http://www.soest.hawaii.edu/~dluther/SAFDE/]

SAHFOS Abbreviation for Sir Alister Hardy Foundation for Ocean Science, whose mission is to further the understanding of marine pelagic ecosystem processes through:

- the maintenance and expansion of the Continuous Plankton Recorder (CPR) survey;
- cooperation in the establishment of global long–term oceanic plankton monitoring programs;
- the development of new sampling and sensor systems; and
- the dissemination of the results of original research.

It was originally established in 1990 to operate the CPR survey, a program started in 1931 by Alister Hardy.

[http://www.npm.ac.uk/sahfos/sahfos.html]

saline contraction coefficient A quantity arising from taking derivatives of the density in the (p, θ, S) representation of the equation of state. This is defined in seawater as:

$$\beta = \frac{1}{\rho}\left.\frac{\partial \rho}{\partial S}\right|_{\theta,\rho} = \frac{1}{\rho}\left.\frac{\partial \rho}{\partial S}\right|_{T,\rho} + \alpha\left.\frac{\partial \theta}{\partial S}\right|_{T,\rho}$$

where ρ is the *in situ* density, θ is the potential temperature, S is the salinity, and T is the temperature. In practice, $\frac{\partial \rho}{\partial S}$ can be obtained from the International Equation of State of seawater, and $\frac{\partial \theta}{\partial S}$ from Bryden [1973].

McDougall [1987b] gives a polynomial expression for β:

$$\begin{aligned}\beta &= 0.785567\times10^{-3} - 0.301985\times10^{-5}\theta + 0.555579\times10^{-7}\theta^2\\ &- 0.415613\times10^{-9}\theta^3 + (S-35.0)[-0.356603\times10^{-6} + 0.788212\times10^{-8}\theta\\ &+ 0.408195\times10^{-10}p - 0.602281\times10^{-15}p^2] + (S-35.0)^2[+0.515032\times10^{-8}]\\ &+ p[-0.121555\times10^{-7} + 0.192867\times10^{-9}\theta - 0.213127\times10^{-11}\theta^2]\\ &+ p^2[+0.176621\times10^{-12} - 0.175379\times10^{-14}\theta] + p^3[+0.121551\times10^{-17}]\end{aligned}$$

The units of β are psu^{-1} and the rms error of this fit is 0.163×10^{-6} psu^{-1}. A test value is 0.72088×10^{-3} psu^{-1} at $S = 40$ psu, $\theta = 10.0$°C and $p = 4000.0$ db. See McDougall et al. [1987] and the related thermal expansion coefficient and adiabatic compressibility.

salinity An oceanographic concept conceived to provide a measure of the mass of salt per unit mass of seawater. The first systematic attempt to define this was made by a commission appointed by the International Council for the Exploration of the Sea in 1899 and chaired by Knudsen. Attempts to measure salt content by drying samples were accompanied by losses of volatile compounds along with the water, and the hygroscopic nature of the residue also served to complicate matters. A dry residue method where the sample was evaporated and dried to a stable weight at 480° C after processing with hydrochloric acid was offered as an alternative method. This led to the definition of the salinity as "the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, all the bromine and iodine replaced by chlorine, and all the organic material oxidized."

When this dry residue method also provided practical difficulties aboard ship the commission defined a chlorinity that could be determined via a volumetric titration using silver nitrate. This measurement could be combined with the assumption of constant ionic ratios in seawater to obtain a measure of the salinity, with the relationship between the two quantities being defined as

$$\mathrm{S}(^\circ/_{\circ\circ}) = 0.03 + 1.805\,\mathrm{Cl}(\,\circ/_{\circ\circ}).$$

A small adjustment was made in the definition of chlorinity in the late 1920s, but it remained basically the same until the development of reliable and precise electronic instrumentation in the 1950s led to a qualitative redefinition of the chlorinity, and therefore the salinity, in terms of measurements of the electrical conductivity of a water sample. This led to the creation and publication of the the International Oceanographic Tables giving salinity as a function of conductivity ratio above 10°. These tables were adequate for the laboratory determination of salinity, but could not be used with in-situ salinometers since most such measurements were made at temperatures below 10° C. A separate set of tables were developed in the mid-1960s that covered the range 0-30° C, although this led to discrepancies between in-situ and bench measurements of salinities and many separate attempts to patch together the two data sets. This in turn led to confusion in the comparison of salinity data amongst the major oceanographic institutes.

A solution was found in 1978 in the form of a new definition called the Practical Salinity Scale (PSS–78) where the practical salinity is defined in terms of the ratio of the electrical conductivity of a seawater sample at atmospheric pressure at 15°C to that of KCl solution containing 32.4356 g of KCl in a mass of 1 kg of solution at the same pressure and temperature. See Lewis [1980] and Lewis and Perkin [1978].

SALR Abbreviation for saturated adiabatic lapse rate.

salt fingering See double diffusive instability.

salt fountain A hypothesized perpetual fountain where a long, narrow heat-conducting pipe inserted vertically through a region of ocean where warm, salty water overlies colder, fresher (and therefore denser) water. Water pumped upwards through the pipe would reach the same temperature as the surroundings at the same level (by conduction of heat through the wall of the pipe), while it remained fresher and therefore lighter. A fountain started thusly (in either direction) will continue to flow so long as there is a vertical gradient of salinity to supply potential energy. The idea was first advanced by Stommel et al. [1956] and is discussed in Turner [1973].

Samar Sea A small sea contained within the Visayan Islands that comprise the central portion of the Philippines. It is centered at approximately 124° E and 12° N and connected to the Visayan Sea to the southwest, the Philippine Sea to the northeast via the San Bernardino Strait, and the Sibuyan Sea to the northwest.

SAMBA Acronym for Sub–Antarctic Motions in the Brazil Basin, a component of the WOCE float program aimed at describing the absolute general circulation of the Antarctic Intermediate Water (AAIW) as it spreads northward at about 800 m depth in the Brazil Basin. During the SAMBA experiment a total of 100 MARVOR floats were launched between February 1994 and December 1998 at 800 ± 30 dbar in the Brazil Basin.

[http://www.ifremer.fr/lpo/samba/]

sample In signal processing, to pick out values from an analog signal, usually at regular intervals, to create a corresponding digital signal.

SAMW Abbreviation for Subantarctic Mode Water.

sand More later.

Sandstrom's Theorem An ocean circulation theorem that states that a closed steady circulation can only be maintained in the ocean if the heat source is situated at a lower level than the cold source. Sandstrom considered to momentum balance of the steady circulation of the oceans, and concluded that, to overcome friction, there should be a net input of mechanical energy over each closed streamline, i.e.

$$w = -\int_s \nu \, dp > 0 \tag{17}$$

where ν and p are the specific volume and pressure, and the integration is taken along closed streamlines s. He modeled the oceanic circulation in terms of a heat engine by assuming four idealized stages within each cycle of the oceanic heat engine:

- heating–induced expansion under a constant pressure;
- adiabatic transition from the heating source to the cooling source;
- cooling–induced contraction under a constant pressure; and
- adiabatic transition from the cooling source to the heating source.

Within this cycle, the net amount of work would be negative if the system is heated under low pressure, and cooled under high pressure. Positive work is only possible when heating takes place at a higher pressure and cooling at a lower pressure.

The application of this theorem to the ocean was a vexing issue for years, as is summarized by Huang [1999]:

> However, the application of Sandstrom's theorem to the oceanic circulation does pose a serious puzzle. The ocean is mostly heated and cooled from the upper surface. Due to thermal expansion, the sea surface level at low latitudes where heating takes place is about one meter higher than the sea level at high latitudes where cooling takes place. Therefore, according the Sandstrom's theorem, there should be no convectively driven circulation.'

According to Huang [1999], the resolution lies in Sandstrom's original model excluding diffusion and friction. He used an idealized loop model of the oceanic thermohaline circulation that included mixing to discover that the circulation can be classified into two types, depending on the vertical locations of the heating and cooling sources.

- When the cooling source is at a level lower than the heating source, the circulation is mixing controlled and the rate of thermal circulation is primarily controlled by the amount of external energy available for mixing. Without the external energy the support mixing, the mixing rate would be at a very low level determined by molecular diffusion, and there would be no detectable thermal circulation as per Sandstrom's theorem. With an external energy source, e.g. wind stress, tidal dissipation, etc., there can be a strong thermal circulation even if the cooling source is below the heating source.
- If the cooling source is at a level higher than the heating source, the circulation is friction controlled, and the amount of external energy available for mixing is unimportant.

An unexpected result from the same study was that geothermal heating can contribute a substantial portion of the energy for the mixing of deep water. Another interesting result was finding the diapycnal mixing rate due to tidal energy and geothermal heat flux to be about 0.22–0.28 $\times 10^{-4} m^2 s^{-1}$. See Defant [1961] and Huang [1999].

San Matías Gulf A gulf located at around 42°S along the Argentine coast of eastern South America. According to Piccolo [1998]:

> It has a significant interaction with the adjacent shelf. A sill at a depth of 74 m is found at the entrance of the gulf. It is a basin with 200-m depths at its center. Unfortunately, very few studies were performed to learn its circulation and dynamics, and therefore only a brief review is presented here. The temperature structure of the gulf in winter reveals a well–mixed water column indicative of deep–reaching and bottom water ventilation. Near 41°50'S a relatively intense thermohaline front is found. Relatively cold fresh waters similar to the open shelf waters are found south of the front, while warm salty waters typical of the gulf are found north of the front. This front is produced by tidal mixing. The gulf circulation is dominated by a cyclonic gyre about 70 km in diameter located north of the front. South of the front the thermocline structure is complex and not well resolved by the observations. The San José Gulf communicates with the San Matías Gulf, and there is a strong water interaction between both coastal bodies.

See Piccolo [1998].

Santa Barbara Channel A 100 km long (east-west) and 50 km wide (north-south) channel bounded by the U.S. mainland to the north and island to the south. The Santa Barbara Channel (SBC) has relatively deep topography (100-500 m) except for narrow shelves (about 5 km wide) to the north and south. The SBC is a mixing zone between the warm water of the Southern California Bight and the cooler upwelled water of the central California shelf/slope. The strongest east-west thermal contrast - about 5-6°C near the surface - occurs during the summer at the time of peak upwelling off CCSS and the warmest sea surface temperature in the SCB.

The SBC is partially sheltered from intense north and northwesterly wind by a mountain range along the channel's northern coast, allowing for large differences in wind strength from west (stronger) to east along the channel. The resulting wind stress curl can be an order of magnitude greater than the values found farther offshore over the California Current. The winds also tend to be strongest in midchannel, tapering off north and south near the coasts. The combination of strong therrmal contrast and large changes in wind stress curl over relatively small distances leads to an especially complex circulation. See Harms and Winant [1998] and Oey et al. [2004].

SAR Abbreviation for Synthetic Aperture Radar, a side-looking imaging radar system that uses the Doppler effect to sharpen the effective resolution in the cross-track direction. Basically, high resolution is achieved by measuring the travel time of short emitted pulses, while comparable resolution is achieved in the azimuthal (flight) direction by collecting the amplitude and phase histories of the returned signals from a large number of individual pulses to reconstruct the signal of a large virtual antenna. An SAR on a polar orbiting satellite at 800 km can typically scan a swath about 100 km wide with a resolution of 20 m by 20 m at incidence angles of 20 to 25°.

Incident electromagnetic microwaves resonantly interact with short ocean ripple waves and backscatter via the mechanism of Bragg scattering. An SAR system is capable of detecting a variety of large scale oceanic phenomena which modulate the short (Bragg) ocean ripple spectrum, e.g. fronts, internal waves, natural surface films or man-made slicks, bottom topography, and ocean gravity waves. These modulations may be of either the tilt moduluation or hydrodynamic modulation varieties. See Komen et al. [1996].

Sargasso Sea A clockwise-circulating region in the North Atlantic Ocean bound by the Gulf Stream on the west and north and less definitely to the east at 40° W near the Canary Current and to the south at 20° N near the North Equatorial Drift Current. It is so named because of the indigenous, yellow-brown seaweed called Sargassum that is found there in great abundance. The Sargasso is part of the subtropical gyre circulation system in the North Atlantic and comprises a large part of its interior circulation, covering an area of around 5.2 million square kilometers.

A large volume of a type of mode water known as 18° water forms in the Sargasso in the winter and is seen as a thick layer of water at that temperature between 250 and 400 m depth. In the summer an excess of evaporation over precipitation results in a thick (nearly 900 m deep near the center) lens of water warmer and more saline than surrounding waters. The anticyclonic sense of the circulation causes this water to pile up such that it is almost a meter higher than the sea level along the eastern U.S. coast. This water lens also serves to inhibit the upwelling of nutrient-rich, colder water which results in a sparsity of marine life in the region. It is has been called the clearest, purest and biologically poorest ocean water ever studied.

The northwestern part of the Sargasso is a region of recirculation for the Gulf Stream. This recirculation region is dominated by cold core eddies pinched off from the Gulf Stream, with as many as 10 clearly identifiable rings found there at any one time. This makes this northwestern region one of the most energetic in the world ocean.

Sargasso Sea Water (SSW) See 18° Water.

Sargassum The name given to about eight species of seaweed that float in clumps and long windrows in the Sargasso Sea. It was so named by Portuguese sailors who followed the voyages of Columbus through the region and noticed the resemblance of the small air bladders that allow Sargassum to float to a type of grape called Salgazo.

SASS Acronym for the SEASAT-A Scatterometer System, an active backscatter scatterometer operating at a frequency of 13.0 GHz which produced earth locatino and time tagged backscatter coefficients, surface wind stress, and surface wind vectors (with a 180 degree directional ambiguity).

satellite altimetry See Fu. and Cazanave [2001].

satellite oceanography More later.

saturated adiabatic lapse rate The temperature lapse rate of air which is undergoing a reversible natural adiabatic process. Abbreviated SALR.

saturated humidity mixing ratio The humidity mixing ratio of air which is saturated at a specified temperature and pressure, with saturation defined with reference to either liquid water or ice.

saturation mixing ratio An atmospheric quantity given by

$$m_s = \frac{0.622 e_s}{p - e_s}$$

where m_s is the ratio, e_s the saturation vapor pressure and p the atmosphere pressure.

saturation vapor pressure Usually measured with respect to water, this is the maximum water vapor pressure that can occur when the water vapor is in contact with a free water surface at a particular temperature. It is the water vapor pressure that exists when effective evaporation ceases.

SAUW Abbreviation for Subantarctic Upper Water.

SAVE Acronym for South Atlantic Ventilation Experiment, an experiment taking place from 1987-1989.

Savonius rotor A rotor originally developed for power generation (i.e. it's a propellor in reverse that spins when placed in moving water) that has been extensively used as a sensor on various ocean current meters. Its advantages are that it is rugged, omni-directional and linear in steady flow, but its response to time-varying flow and susceptibility to contamination by vertical flows make it unsuitable for measurements near the surface where wave action creates both time-varying and vertical flow fields. See Heinmuller [1983].

Savu Sea See Sawu Sea.

Sawu Sea One of the several connected seas that comprise the Australasian Mediterranean Sea. This is centered at approximately 123° E and 9° S and is situated between Timor to the south and east, Sumba to the south and west, and Flores to the north. The basin is mostly greater than 1500 m deep and reaches depths greater than 3000 m over most of its northern and eastern parts.

SAXON-FPN Abbreviation for Synthetic Aperture Radar and X Band Ocean Nonlinearities-Forschungsplatform Nordsee program, a 3-year effort to investigate radar backscatter from the ocean and synthetic aperture radar (SAR) imagery of the ocean. A secondary objective was to explore the relationship between acoustic and microwave scattering from the ocean surface. This joint U.S./Federal Republic of Germany program consisted of Phase I, a major field experiment in the North Sea on and around the German Forschungsplatform Nordsee during November 1990, Phase II, a second and smaller field experiment on the same platform in November 1991, and a series of four data analysis workshops. See Plant and Alpers [1994].

SAZ Abbreviation for Subantarctic Zone.

scale depth A means of characterizing a (oceanic or atmospheric) density field. It is defined by $H = c^2/g$ where c is the speed of sound and g gravitational acceleration. In the ocean this is on the order of 200 km. The largeness of this in comparison to the water depth (5 km) is one of the key assumptions in the Boussinesq approximation.

scale height In the atmosphere, the height at which the pressure has fallen to e^{-1} (i.e. the e-folding scale) of its value at the surface. This occurs at about 370 mb which, for a temperature of 250 K, is about 7.4 km.

scarp See escarpment.

scattering The process by which some of a stream of radiation is dispersed to travel in directions other than that which from it was incident by particles suspended in the medium through which it is travelling.

scatterometer A high-frequency radar instrument that transmits pulses of energy towards the ocean and measures the backscatter from the ocean surface. It detects wind speed and direction over the oceans by analyzing the backscatter from the small wind-induced ripples on the surface of the water. See the NASA JPL scatterometer site[145].

[145] http://www.jpl.nasa.gov/winds/scatterometry/#what_is

SCAVE Acronym for the Sound Channel Axis Velocity Experiment, where SOFAR explosive charges were fired at the depth of the sound axis off Antigua and the resulting signals received and processed at Eleuthera and Bermuda. In this experiment, taking place in 1961, travel times were ascertained to within 30 ms with rms variations estimated at at 200 ms over a period of 27 months with time scales of a few months. The variations were most likely caused by the mesoscale variability that characterizes this region. See Munk et al. [1995].

SCAWVEX Acronym for Surface Current and Wave Variability Experiment, an EC MAST project whose primary objective is to measure the spatial and temporal variability of waves and currents in coastal regions using the full range of state of the art measurement techniques and models. The measurement systems used in this experiment include HF radar, synthetic aperture radar (SAR), satellite altimetry, accelerometers, ADCP, current meters, pressure cells, and X-band ground-based radar since one of the primary goals is the intercomparison of these techniques.

[http://www.shef.ac.uk/~sceos/environmental/scawvex/home.html]

Schlutsky-Yule effect A consequence of smoothing a time series with a low-pass filter. In a relatively short time series, even purely random fluctuations can give the impression of there being significant quasi-cyclic fluctuations present if they are smoothed by some sort of running mean. This is name for two statisticians who demonstrated in 1927 that some trade cycles that had been apparently discovered in some 19th century data could be reproduced from a series of random numbers. See Burroughs [1992], p. 20.

Schmidt number A nondimensional number that relates the competing effects of gas diffusion and fluid viscosity on the piston velocity, a key variable in measuring gas transfer across the air-sea interface. The Schmidt number is given by

$$Sc = \frac{\nu}{D}$$

where ν is the kinematic viscosity and D the molecular diffusivity of gas in sea water. See Najjar [1991].

SCICEX A 5–year program (1995–1999) in which the U.S. Navy made available a Sturgeon–class, nuclear powered attack submarine for unclassified science cruises in the Arctic Ocean. A test cruise in 1993 started a collaboration between civilian scientists and Navy personnel wherein a variety of information on the geology, physics, chemistry and biology of the Arctic was gathered. The 100,000 miles of shiptrack traveled during the program allowed data to be gathered from regions that have never before (at least officially) been visited.

[http://www.ldeo.columbia.edu/SCICEX/]
[http://psc.apl.washington.edu/scicex/scicex2000.html]

scirocco A warm, southerly wind in the Mediterranean region. Near the north coast of Africa the wind is hot and dry and often carries much dust. After crossing the Mediterranean, the scirocco reaches the European coast as a moist wind and is often associated with low stratus.

SCOPE Acronym for San Clemente Ocean Probing Experiment, a NOAA ETL program conducted in September 1993. It was an experiment to study the effects of the atmosphere on active and passive microwave remote sensing measurements of the ocean surface.

[http://www6.etl.noaa.gov/projects/scope.html]

SCOPEX The South Channel Ocean Productivity Experiment was a multidisciplinary study of a whale–zooplankton predator–prey system in the southwestern Gulf of Maine that focused on the oceanographic factors responsible for the development of dense patches of the copepod *Calanus finmarchicus*, the major prey resource for right whales. See Kenney and Wishner [1995].

SCOR Acronym for Scientific Committee on Oceanic Research, the oldest interdisciplinary committee of the ICSU, established in 1957 for the promotion and coordination of international oceanographic activities. SCOR doesn't directly fund research although its scientific groups organize international meetings, publich scientific literature, and propose and plan large international collaborative efforts such as JGOFS and GLOBEC. SCOR consists of its members – the national committees for oceanic research of its 39 member countries, each represented by three individual oceanographers. An Executive Committee, elected at biennial General Meetings, also includes ex officio members from allied disciplinary organizations including IAPSO, IABO, CMG, and IAMAS. A SCOR Secretariat located at Johns Hopkins University in Baltimore, Maryland provides routine administrative support for SCOR activities as well as publications such as the JGOFS and GLOBEC Report Series, the annual SCOR Procedings, and the directory or SCOR Handbook.

There are two major categories under which SCOR work can be subsumed. The first is the traditional mechanism of the SCOR working group wherein small international groups address narrowly focused scientific problems that will benefit from such a cooperative effort. These groups generally have about ten members, meet two or three times, and produce either a book or special journal volume or organize an international conference or workshop to complete their efforts. They are estblished on the basis of proposals received from national committees, other organizations, or even individual scientists. While the working group exists for short term (four years or less) projects, longer term and more complex activities are the province of the second mechanism, i.e. scientific committees.

The names of the currently (1998) constituted SCOR working groups (along with their respective numbers) are:

- Ecology of Sea Ice (86),
- Sea Level Rise and Erosion of the World's Coastlines (89),
- Pelagic Biogeography (93),
- Sediment Suspension and Sea Bed Properties (95),
- Acoustic Monitoring of the World Ocean (96),
- Physiological Ecology of Harmful Algal Blooms (97),
- Worldwide Large–scale Fluctuations of Sardine and Anchovy Populations (98),
- Linked Mass and Energy Fluxes at Ridge Crests (99),
- Sediment Coring for International Global Change Research (100),
- Influence of Sea State on the Atmospheric Drag Coefficient (101),
- Comparative Salinity and Density of the Atlantic and Pacific Ocean Basins (102),
- The Role of Wave Breaking on Upper Ocean Dynamics (103),
- Coral Reefs Responses to Global Change (104),
- The Impact of World Fisheries Harvests on the Stability and Diversity of Marine Ecosystems (105),
- Relative Sea Level and Muddy Coasts of the World (106),
- Improved Global Bathymetry (107), and
- Double Diffusion (108).

[http://www.jhu.edu/~scor/]

Scorpio Expedition A name of a 1973 expedition, led by Henry Stommel, to perform trans-Pacific hydrographic sections at 28 and 43° S. See Stommel et al. [1973].

Scotia Front (SF) A front located north of the Weddell–Scotia Confluence which marks the boundary between the Weddell and Scotia Seas in the Southern Ocean. The SF is a distinct subsurface front marked by a maximum thermal gradient in the maximum temperature core layer (200–700 m) of the Circumpolar Deep Water (CDW). Crossing the SF from north to south, the temperature maximum decreases from 1.5°–2.0° C to below 0.5°, with the CDW salinity maximum in the 800–1200 m layer similarly decreasing southward across the SF from 34.70–34.72 to 34.67–34.68. In the minimum temperature layer, the SF appears as a thermal front across which the minimum temperature decreases southward from 0°–0.5° C to below -1.0° C. There is usually no distinct sign of the SF in the surface layer. The 1° isotherm in the 300–500 m layer is considered a good single indicator of the SF axis. See Belkin and Gordon [1996].

Scotia Ridge A ridge connecting South American and Antarctica located at about 70° W in the Southern Ocean that, along with the narrowing of the Drake Passage 2000 km to the west, impedes the flow of the Antarctic Circumpolar Current (ACC). It is generally less than 2000 m deep with some openings at the 3000 m level. After the ACC accelerates to squeeze through the Drake Passage it hits to Ridge and an increased speed and shifts northward.

Scotia Sea See Garabato et al. [2002].

SCSMEX Abbreviation for South China Sea Monsoon Experiment, a large–scale experiment to study the water and energy cycles of the Asian monsoon regions. The goal is to provide a better understanding of the key physical processes for the onset, maintenance and variability of the Southeast Asian monsoon. See Lau et al. [2000].

[http://ncc.cma.gov.cn/scsmex/html/scsmex_e.htm]
[http://www.bom.gov.au/bmrc/wefor/research/scsmex.htm]
[http://www.siesip.gmu.edu/Science/sci_scs.html]

sea breeze A wind blowing from the ocean towards land caused by the effects of differential heating. In the summer when the land surface is warmer than the ocean, the air over the land heats up more than over the ocean, expands and becomes less dense, and rises. This rising air is replaced, due to the constraints of continuity, with moisture–rich air from over the oceans.

seachannel The official IHO definition for this undersea feature name is "a continuously sloping elongated discrete depression found in fans or abyssal plains and customarily bordered by levees on one or both sides."

Sea Grant The idea of a Sea Grant College Program was first suggested by Athelstan Spilhaus at a meeting of the American Fisheries Society in 1963. He predicted the proposed sea–grant colleges would spur advancements in the ocean sciences that would be "modernized parallels of the great developments in agriculture and the mechanical arts which were occasioned by the Land–Grant Act of about a hundred years ago." In 1965, Senator Claiborne Pell of Rhode Island introduced legislation establishing Sea Grant colleges on campuses nationwide, leading to the adoption of the National Sea Grant College Act in 1966.

The first four universities to achieve Sea Grant College status were Oregon State, Texas A&M, the University of Rhode Island and the University of Washington in 1971. As of 2001, there are 30 Sea

Grant Colleges divided into Great Lakes, Northeast, Mid–Atlantic, Southeastern Atlantic and Gulf of Mexico, and Pacific Regions.

[http://www.nsgo.seagrant.org/]

sea ice Sea ice is defined by the WMO as:

> Any form of ice found at sea which has originated from the freezing of sea water.

See WMO [1970] and Weeks and Ackley [1986].

sea ice formation The various processes comprising sea ice formation are described by ASPeCt:

> The first stage in sea ice development is the formation of individual ice crystals in the surface layer of the ocean. These crystals, known as frazil, form in open water areas when the temperature of the water is below -1.8 deg. C. Frazil ice gives the water an oily appearance and with further freezing the crystals coagulate together to form a soupy layer at the surface known as grease ice.
>
> How the sea ice proceeds to develop depends on whether the surface is calm or disturbed. With calm conditions the frazil and grease ice may consolidate into continuous flexible sheets called nilas. Nilas may be up to 10 cm thick, but is easily rafted under pressure, which can rapidly increase its thickness. Ice 10-30 cm thick is termed young ice, and with further rafting and ridging it develops into first–year ice (>30 cm). Finger rafting is a common process observed with nilas, where interlocking fingers of ice are thrust alternately over and under each other where two nilas sheets converge.
>
> A common process of sea ice development in the Antarctic, which occurs under rougher conditions, is the "pancake cycle". With the influence of wind and wave action the frazil crystals coagulate, eventually consolidating into small circular discs of ice called pancakes. The pancakes have raised rims due to collisions with other pancakes, and grow by accumulating ice crystals from the surrounding water. By rafting and bonding together the pancakes may rapidly increase to a few metres in diameter and up to 40 cm thick, and eventually freeze together to form larger floes or a consolidated ice cover.
>
> Although new ice forms most rapidly in open water areas with the development of frazil crystals, ice also grows on the underside of existing floes as heat is conducted from the ice-water interface through the floe. This ice is called congelation ice and consists of characteristic long columnar crystals, distinct from the small randomly oriented crystals of frazil ice.
>
> New ice may also be formed from the freezing of flooded snow overlaying the sea ice. When the weight of the snow is sufficient, the ice surface may be depressed below sea level. The influx of sea water through the permeable snow saturates the lower layers of snow which may subsequently refreeze to form "snow-ice". Snow ice has a similar texture to ice formed from coarse grained frazil but may be discriminated from frazil by stable isotope analysis. Compared with sea water, Antarctic snow is relatively depleted in the heavy stable isotope, 18O, and therefore has a highly negative del18O value.

sea level Much more later.

sea level change Recent analyses indicate that the global or eustatic sea level has risen about 2 mm per year over the last century, with the rate probably being much smaller for the previous several millennia. The rate is predicted to be larger over the next century – although how much larger is still uncertain. Quantifying sea level change is a difficult task given the complexity of the contributing processes including:

- the regional submergence or emergence of tide gauges due to Post Glacial Rebound (PGR) that continues from the last deglaciation, as well as to other tectonically–induced vertical crustal movements;
- the thermal expansion and contraction of the ocean due to climate change, along with possible accompanying changes in circulation and necessarily water levels;
- the contribution of the Greenland and Antarctic ice sheets as they shrink or expand;
- the shrinking or expanding of smaller glaciers; and
- water storage in artificial reservoirs that would otherwise have flowed into the oceans, e.g. one estimate that storage in above–ground reservoirs over the last 40 years was equal to a fall of global sea level of 0.7 mm per year.

See Douglas [1995].

Sea of Azov See Azov, Sea of.

Sea of Candia See Cretan Sea.

Sea of Crete See Cretan Sea.

Sea of Japan See Japan Sea.

Sea of Okhotsk See Okhotsk Sea.

sea state More later.

SeaBASS Acronym for SeaWiFS Bio–Optical Archive and Storage System, a product of the calibration/validation element of the SeaWiFS project which provides an interface to the project holdings of bio–optical and laboratory instrument calibration data.

[http://seabass.gsfc.nasa.gov/]

SEA LION Acronym for SEa ice in the Antarctic LInked with OceaN–atmosphere forcing, a project whose aim is to assess and improve the performance of coupled global atmosphere–sea ice–ocean models in reproducing sea ice in the high southern latitudes.

[http://www.iup.physik.uni-bremen.de/iuppage/sealion_ed1.html]

seamount The official IHO definition for this undersea feature name is "a discrete (or group of) large isolated elevation(s), greater than 1000m in relief above the sea floor, characteristically of conical form; see also guyot."

seamount chain The official IHO definition for this undersea feature name is "a linear or arcuate alignment of discrete seamounts, with their bases clearly separated."

SEAREX Acronym for Study on Sea–Air Exchanges program. See Riley and Chester [1989].

SEAS Acronym for Study of the European Arctic Shelf, an LESC program.

SEAS Acronym for Shipboard Environmental (Data) Acquisition System, a program developed by NOAA to provide accurate meteorological and oceanographic data in real time from ships at sea through the use of satellite data transmission techniques. The shipboard data is transmitted to NOAA via either the GOES or INMARSAT C satellites.

[http://www.dbcp.nos.noaa.gov/seas/seas.html]

SEASAR Acronym for Synthetic Aperture Radar for Sea Studies.

SEASAT A NASA satellite that operated from June 1978 to October 1978. Instruments on board included SASS, an altimeter, SMMR, a microwave SAR, and VIRR. The altimeter was an active radar altimeter which produced earth location and time-tagged satellite heights, significant wave heights, and geoid information. The SAR produced 25 meter resolution surface roughness imagery on a 100 km wide ground swath. See Stewart [1988].

SeaSoar An open ocean undulating data acquisition vehicle originally designed and built by the Institute of Oceanographic Sciences (now the Southampton Oceanography Center, UK). SeaSoar is capable of undulating from the surface to 500 m at tow speeds of up to 12 knots (with a faired cable) following a controlled and adjustable undulating path through the ocean. Data obtained from sensors mounted in SeaSoar are transmitted to the towing vessel via a multi–core tow cable.

[http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm]

seasonal thermocline In oceanography, a weakly stratified layer of water that appears when the mixed layer makes a rapid transition between its winter maximum and its summer mimimum. It is created by deep convection during the winter, and several processes are responsible for its restratification during the rest of the year. These processes, in chronological order starting in early spring, are the creation of a fossil thermocline during the ascent of the mixed layer, solar heating below the mixed layer, geostrophic advection, and thermohaline intrusion.

seasonal thermostad See seasonal thermocline.

sea spray See Andreas et al. [1995].

sea surface film A microlayer hundreds of microns thick located at the sea–air interface. These are the site of intense accumulation of organic matter from underlying waters or atmospheric deposition. See Romano [1996].

sea surface slick A sea surface film in which organic accumulation exceeds a threshold such that it becomes visible as a slick, i.e. a sea surface feature that appears as smooth grey spots or stripes in contrast to the surrounding deep blue waters. The smoothing effect is due to the accumulation at the sea–air interface of organic compounds, many of them surface–active, which enhance solar reflection at the surface by damping the capillary waves. Slicks are thought to play a significant role in heat flux and gas exchange, biogeochemical cycles, and pollutant dispersion dynamics as a consequence of the organic enrichment and their location at the boundary between atmosphere and ocean. See Romano [1996].

sea valley See valley.

seawater See Fofonoff [1962] and Fofonoff [1985].

SeaWiFS Acronym for Sea-viewing Wide-Field of view Sensor, an ocean color sensor to study ocean productivity and interactions between the ocean ecosystems and the atmosphere. For more information see the SeaWiFs Web site[146].

SeaWinds A scatterometer flown aboard the QuikSCAT mission.

[146]http://seawifs.gsfc.nasa.gov/SEAWIFS.html

SEBSCC Abbreviation for Southeast Bering Sea Carrying Capacity, a NOAA PMEL investigation whose goal is to document the role of juvenile pollock in the eastern Bering Sea ecosystem, to examine the factors which affect their survival, and to develop and test annual indices of pre–recruit abundance.

According to Macklin et al. [2002]:

> The goal of SEBSCC was to increase understanding of the southeastern Bering Sea ecosystem, to document the role of juvenile walleye pollock (Theragra chalcogramma) and factors that affect their survival, and to develop and test annual indices of pre-recruit (age-1) pollock abundance. SEBSCC was divided into monitoring, process, modeling, and retrospective and synthesis components. They focused on four central scientific issues: (1) How does climate variability influence the Bering Sea ecosystem? (2) What limits population growth on the Bering Sea shelf? (3) How do oceanographic conditions on the shelf influence biological distributions? (4) What influences primary and secondary production regimes? These broad issues supported SEBSCC's narrower goal of understanding the ecosystem in terms of pollock and provided a basis for selection of research components. SEBSCC also was envisioned as a source of information to support the regional fishing industry and its management. For example, results from SEBSCC research related to short-term forecast of pollock recruitment may improve stock assessments used to recommend "allowable biological catch" estimates to the North Pacific Fishery Management Council. Similarly, research results pertaining to the availability of juvenile pollock to apex predators could assist Council decisions regarding restriction of fishing around marine mammal rookery areas. SEBSCC's focus on ecosystem response to changes in environmental conditions provides a context for resource management in a changing environment.
>
> SEBSCC research spanned disciplines from atmospheric physics to marine ornithology and addressed questions on processes ranging from atmospheric teleconnections to intimate associations between juvenile pollock and tentacles of jellyfish. The centerpiece of SEBSCC research was a time series of physical and biological data from an oceanographic mooring located in 70 m water at site M2. First deployed in 1995, the site M2 mooring measured vertical profiles of temperature and salinity and time series of currents and fluorescence year around. SEBSCC shipboard studies were repeated several times annually along transects from the Bering Sea basin to the 70 m isobath, then northwestward along this isobath. One summer cruise and five fall cruises investigated the region around the Pribilof Islands that is believed to be an important nursery for young pollock. Annual, collaborative, summer cruises aboard the Japanese fishery training vessel Oshoro Maru enabled sampling and abundance estimates of juvenile pollock.

`[http://www.pmel.noaa.gov/sebscc/]`

Secchi disk A white target lowered from a vessel and viewed from above the surface in full solar illumination to estimate the attenuation in the water column. This is done by empirically relating the depth at which the disk disappears to the attenuation. This method was devised in the 1860s by an Italian astronomer named Angelo Secchi who used it while he worked in the Mediterranean aboard the papal vessel Immacolata.

The Secchi disc is usually 20–30 cm in diameter, and is either all white or has four quadrants, two painted white and two black. The empirical relation used is:

$$Z_S = \frac{F}{C + +K \sin\theta}$$

where Z_S is the Secchi depth, C is the attenuation coefficient for directional light, K is the diffuse attenuation coefficient for non–directional light (sometimes known as the extinction coefficient), F is a background factor depending on the reflectivity of both the disc and the background and the observer's threshold perception of contrast, and θ is the sighting angle from the horizontal. Typically, F ranges from about 8.7 in clear oceanic water to 6 in turbid estuarine water.

The disc is typically used to estimate the diffuse attenuation coefficent K or the attenuation coefficent C. For the former, it has been found that the product of K and Z_S is relatively constant, with measurements in many types of water indicating that $1.4 < K \times Z + S < 1.7$. An empirical relationship has also been derived for the latter, i.e. $V = 0.7Z_S$.

SEC Abbreviation for South Equatorial Current.

SECC Abbreviation for South Equatorial Countercurrent.

SECHIBA Acronym for Schematisation des Echanges Hydriques a l'Interface entre la Biosphere et l'Atmosphere, an LSP. See Ducoudre et al. [1993].

SECTIONS Acronym for a research program which translates to Energetically Active Zones of the Ocean and Climate Variability. This was a joint program among Poland/USSR/Bulgaria/Germany/Cuba that gathered the largest data set ever collected in the tropical Atlantic. The six ships used in the program were the **Academic Vernadsky** and the **Mikhael Lomonosov** from the Marine Hydrophysical Institute (MHI) of the Ukrainian Academy of Science in Sevastopol and the **Volna**, **Jakov Gakkel**, **Dmitry Ushakov**, and **Parshin** of the State Oceanographic Institute (SOI) of the USSR. The MHI vessels collected hydrographic data at 5 m vertical intervals with 65% of the stations extending to 1200 m, while the SOI vessels collected data at 10 m intervals (although it was archived only at 16 standard levels). The combined data set archived at MHI consists of 4931 temperature and salinity profiles collected during 26 surveys carried out from 1984 to 1990.

The surveys were divided into three stages. The first stage (1984–1985) comprised eight surveys conducted near the South American coast between 2° S and 20° N, with each survey consisting of 8 to 10 hydrographic sections perpendicular to the coast. The sections were 100 km and the stations 50 km apart in a survey designed to define the seasonal cycle in the northwest. The second stage (1986–1988) comprised twelve surveys conducted between 2° S and 12° N latitude and 58° and 5° W longitude. During the first two years of this stage the sections were 166 km and the stations 55 km apart, with the between-section spacing increased to 333 km durin the final year. Two or three vessels were usually simultaneously collecting data in a survey designed to investigate the seasonal variability of the North Equatorial Countercurrent (NECC). The third stage (1989–1990) saw seven surveys organized into three experiments designed to observe synoptic variability, with one experiment in the west and one in the central basin. The first experiment took place in the spring of 1989 with two vessels in the western region; the second was in the fall of 1989 in the east with two vessels; and the third took place in the winter of 1990 using two vessels in the west. See Chepurin and Carton [1997].

SEEP-I A program to examine shelf edge exchange processes on the outer margin of the U.S. Mid Atlantic Bight. The SEEP program began in 1980 when a group of investigators met to propose an interdisciplinary, inter–institutional program called SEEP (Shelf Edge Exchange Processes) to test what was known as the "shelf–export hypothesis." This was a conjecture that the large fraction of the spring phytoplankton bloom that was observed to not be consumed by the local pelagic food web was exported from the continental shelves to the central ocean basins or to the sediments of the upper continental slope. It was predicted that the net export of particles across the shelf–slope break would increase with successive, more southerly experiments because of an expected southerly increase in primary productivity, and also because of a southerly decrease in the width of the shelf. A primary problem with the hypothesis was the existence of a strong temperature–salinity front separating the continental shelf and slope, the sort of barrier particles would find difficult to cross. However, iseveral other mechanisms for exporting particles from the shelf – e.g. entrainment of shelf water by passing warm core eddies, sinking across the front, advection by the benthic boundary layer – were identified and thought to be collectively sufficient for the task. They were also collectively referred to as “diffusive” processes.

SEEP–I took place from July 1983 to October 1984 in the waters of the Mid–Atlantic Bight (MAB) shelf and slope south of Cape Cod and Long Island. The field program consisted of two experiments run by two different groups, with little overlap between them. This fragmentation of effort led to estimates of particle export ranging from <10% diffusive exchange across the shelf edge (with some indication of an increase towards the southwest), to 10–20% with most oxidized on the shelf, to from <10% to nearly 40% in model results. This led to the design and implementation of SEEP–II. See Walsh et al. [1988].

SEEP-II A program to examine shelf edge exchange processes on the outer margin of the U.S. Mid Atlantic Bight. This follow–up to SEEP–I took place from February 1988 to June 1989, during which 10 cruises took place and 10 moorings were placed at 12 locations on the shelf and upper slope south of the Delmarva Peninsula. The vanishing likelihood of a SEEP–III led to the moorings being deployed in two transects parallel to the mean isobaths and 90 km apart, the latter to attempt to identify the hypothesized increase in across–shelf particle flux to the south. SEEP–I was more integrated than SEEP-I, with the instrumentation from different institutions intercalated throughout the experiment. The result was perhaps the most extensive set of moored, synoptic measurements of temperature, salinity, phytoplankton chlorophyll fluorescence, macrozooplankton, oxygen, current conditions and verticle particle flux yet acquired in an oceanographic program.

According to Biscaye et al. [1994]:

> The results of the SEEP–II study overwhelmingly show that the hypothesis of export of a large proportion of the MAB [Mid–Atlantic Bight] shelf primary productivity is untenable. All the observational data suggest that although a small fraction of carbon is exported across the shelf–slope break and through the front to the slope decpocenter, the principal fate of shelf carbon is, in fact, oxidation on the shelf. That small portion that does escape the shelf to the shelf water and depocenter appears to increase from the northern to the southern MAB.

Several key questions remained unresolved, though, including:

- the sources of nitrogen for the shelf to support the measured production are unclear, i.e. it is difficult to reconcile the flux of nitrate onto the shelf without imposing an export flux of water (or particles);
- the rate of the oxidation of phytoplankton carbon and its fate do not appear to be that previously proposed for the metazoic metabolism, i.e. there was not a monotonic increase in phytoplankton phase–lagged by a monotonic increase of zooplankton;
- food web dynamics in the shelf ecosystem are still not well understood, e.g. the microbial oxidation of carbon is much more significant than previously acknowledged; and
- most of the shelf water leaves the shelf before it reaches the southern terminus of the MAB (i.e. Cape Hatteras), and the amount of slope water incorporated into the shelf water along the way leads to an estimate of water discharged into the slope of 125–150% of the initial alongshelf transport, i.e. it has yet to be quantified exactly where, how much, and by what mechanisms water leaves or comes onto the shelf; and
- horizontal as well as vertical gradients of physical and biological quantities will have to be measured to fully understand their interactions, and probably on a nested grid due to the range of time and space scales involved.

See Biscaye et al. [1994].

seiche More later.

seismic sea wave Much more later.

Seismic Sea-Wave Warning System A network of seismographs across the Pacific Ocean to serve as an early warning system against the arrival of seismic sea waves (SSW) (also called tsunamis or, in an egregious misnomer, tidal waves). The SSWWS was established in 1946 after a particularly destructive SSW originating at Unimak, Alaska struck Hawaii and killed 159 people. Its headquarters are in Honolulu, Hawaii and it is operated by the Coast and Geodetic Survey of the U.S. Dept. of Commerce.

SEMAPHORE An experiment that took place in the northern Canary Basin from July to November 1993. A large data set was obtained from three hydrographic arrays, current meter moorings, surface drifters drogued at 150 m, and 2000 m deep RAFOS floats. See Eymard [1998].

semidiurnal Descriptive of a tide that has a cycle of approximately one-half a tidal day, as opposed to diurnal.

semi-geostrophic equations According to Roulstone and Sewell [1997]:

> The semigeostrophic equations are an approximation to Newton's second law for a rotating fluid, in which the acceleration is replaced by the time derivative (following the particle) of the so–called geostrophic velocity. The hydrostatic approximation is used in the vertical direction. These equations are regarded as a good approximation for certain two– and three–dimensional atmospheric motions on a synoptic scale, such as warm and cold fronts, and solutions can be continued in time beyond the point of the formation of a discontinuity modelling a front.

Delving a bit deeper, they are a set of balanced equations that filter out the high frequency inertia–gravity waves while exactly conserving low Rossby number approximations to the energy and the potential vorticity on particles. Unlike the quasi–geostrophicequations (QGE), they do not demand that the fluid depth and vertical separation between isothermal surfaces be nearly uniform. The main problem with the semi–geostrophic equations (SGE) is that they are significantly harder to solve numerically than the QGE.

In the case of a constant Coriolis parameter, the semi–geostrophic equations are equivalent to the primitive equations wherein the velocities in the total derivative, i.e. $D/Dt(u, v)$ are replaced with the geostrophic velocities, i.e. $D/Dt(u_G, v_G)$. In the case of a non–constant Coriolis parameter, the complexities found using ordinary physical coordinates led Salmon [1985] to propose a generalization involving a transformation to geostrophic coordinates, defined implicitly by:

$$\begin{aligned} x_s &\equiv x + \epsilon \frac{v_G}{f(x_s, y_s)} \\ y_s &\equiv y + \epsilon \frac{u_G}{f(x_s, y_s)} \\ z_s &\equiv z \end{aligned}$$

where:

$$\begin{aligned} u_G &\equiv -\frac{1}{f(x_s, y_s)} \frac{\partial \pi}{\partial y} \\ u_G &\equiv \frac{1}{f(x_s, y_s)} \frac{\partial \pi}{\partial x} \end{aligned}$$

and

$$\pi \equiv g(\eta - z) - \int_z^\eta \theta dz' \tag{18}$$

is the hydrostatic pressure.

Roulstone and Sewell [1997] write that Hoskins [1975] contained the first use of the adjective "semi-geostrophic" to describe the equations, although the latter remarked that they had also been introduced by Eliassen [1948] and Fjortoft [1962].

Salmon [1985] further developed a version of the equations with an additional assumption that the flow has horizontal length scales larger than the internal deformation radius. These are called the large–scale semi–geostrophic equations (LSGE) and, unlike the regular semi–geostrophic equations, are much easier to solve. See G. and Flierl [1981], Salmon [1985] and Roulstone and Sewell [1997].

semi-implicit method A numerical approximation algorithm that allows longer time steps than an explicit method and is less computationally onerous than a fully implicit method. Algorithms can usually be designed using this compromise method that both allow the longer time step and don't sacrifice numerical accuracy.

sensible heat The portion of total heat associated with a temperature change, as opposed to latent heat. This is so-called because it can be sensed by humans. The sensible heat is calculated by

$$\Delta Q = m\, C_p\, \Delta T$$

where C_p values are

$$C_{pd} = 1004.67\,\mathrm{J\ kg^{-1}K^{-1}}$$

for dry air,

$$C_p = C_{pd}\,(1 + 0.84\,r)$$

for moist air (where r is the mixing ratio of water vapor), and

$$C_{\mathrm{liq}} = 4200\,\mathrm{J\ kg^{-1}K^{-1}}$$

for liquid water.

sensible heat flux The flux of heat between the ocean surface and atmosphere that results mainly from their difference in temperature. The heat exchange is accompished via molecular conduction in the first few millimeters above the surface and via turbulent mixing and convection above that. The flux is usually from the ocean to the atmosphere during the day and opposite during the evening and night. See Peixoto and Oort [1992].

separation formula A method for computing the adiabatic inter–hemispheric meridional transport. See Nof [1998].

SEQUAL Acronym for the Seasonal Response to the Equatorial Atlantic research program. See Katz [1987] and Richardson and Reverdin [1987].

Seram Sea One of the seas that comprise the Australasian Mediterranean Sea. This is centered at about 130° E and 2–3° S and surrounded by Buru and Seram to the south and by Halmahera and the wester part of Irian Jaya to the north. It connects with the Arafura Sea to the southeast, the Banda Sea to the southwest, and the Halmahera Sea to the north. It is variously spelled Ceram Sea.

Seven Seas A term used long ago to collectively refer to the Indian Ocean, the Red Sea, the Persian Gulf, the Black Sea, the Sea of Azov, the Adriatic Sea and the Caspian Sea. The term is no longer much used although it is generally conceded that a modern and more geographically generous grouping would be the Arctic Ocean, the Southern Ocean, the Indian Ocean, the North and South Atlantic Ocean and the North and South Pacific Ocean.

shallow atmosphere approximation In meteorology, an approximation made to simplify the equations of motion in spherical coordinates where the radial distance r is replaced by a+z, where the altitude z is much smaller than the radius of the Earth r. See Salby [1992].

shallow scattering layer A layer of marine organisms found over a continental shelf which scatter sound. These layers are usually composed of patchy and horizontally discontinuous groups whose horizontal dimensions are usually less than their vertical dimensions. There are also surface and deep scattering layers.

shallow water approximation In oceanography, an approximation made for motions where the aspect ratio $\delta = H/L$ (where H is the vertical length scale and L he horizontal scale) is small. An example arises in the study of the tides, where the horizontal scale of the wave motion is thousands of kilometers and the vertical scale in constrained by the maximum depth of the oceans, and as such the applicable dynamics are those of shallow water gravity waves, i.e. gravity waves that "feel" and are influenced by the bottom.

The shallow water equations are obtained (after Muller [1995]) by applying the spherical approximation to the Boussinesq equations, expanding them with respect to δ, and keeping only zeroth order terms. One obtains:

$$
\begin{aligned}
\frac{\partial u}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial u}{\partial\phi} + \frac{v}{r_0}\frac{\partial v}{\partial\theta} + w\frac{\partial u}{\partial z} - \frac{uv}{r_0}\tan\theta - fv \\
&= -\frac{1}{\rho_* r_0\cos\theta}\frac{\partial p}{\partial\phi} \\
\frac{\partial v}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial v}{\partial\phi} + \frac{v}{r_0}\frac{\partial v}{\partial\theta} + w\frac{\partial v}{\partial z} + \frac{u^2}{r_0}\tan\theta - fu \\
&= -\frac{1}{rho_*}\frac{\partial p}{\partial\theta} \\
0 &= \frac{\partial\rho'}{\partial z} + \rho' g \\
\frac{\partial w}{\partial z} &= -\frac{1}{r_0\cos\theta}\frac{\partial u}{\partial\phi} - \frac{1}{r_0\cos\theta}\frac{\partial(v\cos\theta)}{\partial\theta} \\
\frac{\partial\rho'}{\partial t} &+ \frac{u}{r_0\cos\theta}\frac{\partial\rho'}{\partial\phi} + \frac{v}{r_0}\frac{\partial\rho'}{\partial\theta} + w\frac{\partial\rho'}{\partial z} = 0
\end{aligned}
$$

where (u, v, w) are the velocity components, r_0 is the mean radius of the Earth, (ϕ, θ, r) are spherical polar coordinates where ϕ is longitude, θ latitude, and r radial distance, f is the Coriolis parameter, ρ_* is a constant reference density, p is the pressure, ρ' is the deviation from the reference density and g is gravitational acceleration. See Muller [1995].

shallow water equations See shallow water approximation.

SHEBA Acronym for the Surface Heat Budget of the Arctic project, a WCRP program to address the interaction of the surface energy balance, atmospheric radiation, and clouds over the Arctic Ocean.

`[http://sheba.apl.washington.edu/]`

shelf The official IHO definition for this undersea feature name is "a zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths."

shelf break See shelf edge.

shelf edge The official IHO definition for this undersea feature name is "the line along which there is marked increase of slope at the seaward margin of a continental (or island) shelf; also called a shelf break."

shelf sea A shallow sea that occupies a portion of a wide continental shelf. This is one type of epicontinental sea. Compare to epeiric sea and inland sea.

Shelikof Strait A strait located between the Alaska Peninsula and Kodiak Island at around 58°N, 154°W. See Reed and Bograd [1995].

SHIVA Acronym for Studies of the Hydrology, Influence and Variability of the Asian summer monsoon, a project sponsored by the European Commission. The project goals are:

- to improve the simulation of the mean evolution of the monsoon, including its intraseasonal characteristics;
- to assess the ability of models to simulate the intraseasonal characteristics, particularly active/break phases, monsoon depressions, and sensitiivty of the simulations to horizontal resolution;
- to investigate the mechanisms involved in the intraseasonal variability through coordinated sensitivity experiments, i.e. to study the roles of land surface processes, atmosphere–ocean interactions over the Indian Ocean and Arabian Sea, and internal dynamics; and
- to investigate the relationship between intraseasonal and interannual variability.

[http://www.enm.meteo.fr/ufr/umt/shiva/main.html]

shoal The official IHO definition for this undersea feature name is "an offshore hazard to surface navigation with substantially less clearance than the surrounding area and composed of unconsolidated material."

short-crested waves A propagating surface gravity wave with a free surface elecation which is doubly periodic in two perpendicular directions, along and normal to the direction of propagation. These can be produced either by the interaction of two progressive waves angles to each other or by oblique reflection from a maritime structure. The doubly periodic nature is characterized by the pattern of island crests that are formed at intersections of the component waves, rendering the surface shape of such a wave system much more complex than its wave components. The isolated crests thus produced propagate in a combined direction with a wavelength and a definite crest length equal to the distance between successive crests normal to the former at the same time. The transverse distance between adjacent crests is finite as opposed to the original two-dimensional wave motions that combine to form short-crested waves, thus giving them their name. See Hsu [1990].

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

> An accumulation of spongy white lumps, a few centimeters across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

See WMO [1970].

Siberian Coastal Current See Weingartner et al. [1999].

Siberian High One of the centers of action that tend to control large scale weather patterns around the globe. This center forms over Siberia during the winter and is centered around Lake Baikal. The sea level pressure exceeds 1030 millibars from late November to early March. The resulting anticyclonic circulation pattern is enhanced by the tendency of the surrounding mountains to prevent the cold air from easily flowing away. This pattern is replaced by a low pressure pattern in the summer related to the monsoon circulation.

SIBEX Acronym for Second International BIOMASS Experiment.

Sibuyan Sea A regional sea contained within the Philippines between the northern island of Luzon and the central island group the Visayan Islands. It is centered at about 122.5° E and 12.3° N and connected to the Visayan Sea to the southeast, the Samar Sea to the east, the Sulu Sea to the southwest via the Tablas Strait, and the South China Sea to the northwest via the Verde Island Passage. Geographical features of note include Sibuyan Island and Marinduque Island as well as the Ragay Gulf in the southeast arm of Luzon.

Sierra Leone Basin An ocean basin located to the west of Africa at about 3° N in the east-central Atlantic Ocean. See Fairbridge [1966].

SIGMA Acronym for Significant Interactions Governing Marine Aggregation, a group that conducted an investigation of the aggregation of a diatom bloom in a laboratory mesocosm to test the ability of coagulation theory to predict aggregation in complex marine systems. See Alldredge and Jackson [1995].

sigma-t (σ_t) A conventional definition introduced into physical oceanography for purposes of brevity. It is the remainder of subtracting 1000 kg m^{-3} from the density of a sea water sample at atmospheric pressure, i.e.

$$\sigma_t = (\rho_{S,T,0} - 1000)$$

where S and T are the in situ salinity and temperature. The density of water ranges from 1000 kg/m3 to about 1028 kg m^{-3} for the densest ocean surface water, so sigma-t ranges from about 0.00 to 28.00, with the units usually omitted.

sigma-theta (σ_θ) A measure of the density of ocean water where the quantity sigma-t is calculated using the potential temperature θ rather than the in situ temperature, i.e.

$$\sigma_\theta = (\rho_{S,\theta,0} - 1000)$$

where S is the in situ temperature.

significant wave height A quantity defined by Walter Munk in 1944 (in an SIO technical report) as the average height of the one–third highest waves. He stated that this was about equal to the average height of the waves as estimated by an experienced observer. The quantity is usually written as $H_{1/3}$ or H_S and estimated using the calculated root–mean–square height of the observed waves. The latter is calculated as

$$H_{rms} = \sqrt{\frac{1}{N}\sum_{j=1}^{N} H_j^2}$$

where N is the total number of observed waves and H their heights. The significant wave height is estimated via:

$$H_S \approx \sqrt{2}H_{rms}.$$

See Bauer and Staabs [1998].

significant wave method See S-M-B method.

silica One of the major nutrients in marine ecosystems, which is also used as a tracer in physical oceanography. According to Greenwood et al. [2001]:

> Silicon, as ortho-silicic acid, is a major nutrient in marine ecosystems. The uptake of silicic acid from surface waters by siliceous organisms (mainly diatoms) to form amorphous silica skeletons, and their post mortem dissolution are important biogeochemical processes. Dissolution begins in the water column when the silica skeleton is exposed to the undersaturated seawater, and can continue after deposition at the seafloor. Rapid sedimentation of skeletal material incorporated in faecal pellets may partly avoid dissolution resulting in the burial of biogenic siliceous sediments. Equally though, grazing may enhance dissolution as a result of physical or chemical changes to the frustule silica. Further interest in the dissolution of biogenic silica arises not only from the speculation that silicon may limit new production at times in ocean waters, coastal waters and estuaries, but also from concerns about the integrity of the sedimentary record of biosiliceous remains.

See Broecker and Peng [1982], Dugdale et al. [1995] and Greenwood et al. [2001].

silicate pump A mechanism that acts in diatom–dominated communities to enhance the loss of silicate from the euphotic zone to deep water compared to nitrogen, which is more readily recycled in the grazing loop, thus leading the system to silicate limitation. The silicate pumping to deep water results in low silicate, high nitrate conditions in the mixed layer. In such situations silicate dynamics may control and dominate new production processes and consequently control the rate at which newly upwelled CO_2 in the surface regions is reduced by the phytoplankton. See Dugdale et al. [1995].

siliceous ooze A fine-grained sediment of pelagic origin found on the deep-ocean floor. It contains more than 30% siliceous material of organic origin and is usually found below the carbon compensation depth at depths greater than 4500 m. Two types of this are radiolarian oozes and diatom oozes.

sill The official IHO definition for this undersea feature name is "a sea floor barrier of relatively shallow depth restricting water movement between basins."

SIMIP Acronym for Sea Ice Model Intercomparison Project, an international effort to develop an improved representation of sea ice in climate models. SIMIP is carried out in the framework of ACSYS within the WCRP. A hierarchy of sea ice rheologies is evaluated on the basis of a comprehensive set of observational data. Four different sea ice rheology schemes are compared:

- a viscous–plastic rheology;
- a cavitating–fluid model;
- a compressible Newtonian fluid model; and
- a simple free drift approach with velocity correction.

The same grid, land boundaries, and forcing fields are applied to all models, with the prognostic equations solved on a spherical grid for the whole Arctic with a resolution of 110 km and a daily time step. The results as summarized at the project web site are:

> Overall, the viscous-plastic rheology yields the most realistic simulation. In contrast, the results of the very simple free drift model with velocity correction clearly show large errors in simulated ice drift as well as in ice thicknesses and ice export through Fram Strait compared to observation. The compressible Newtonian fluid cannot prevent excessive ice thickness

buildup in the central Arctic and overestimates the internal forces in Fram Strait. Because of the lack of shear strength, the cavitating-fluid model shows marked differences to the statistics of observed ice drift and the observed spatial pattern of ice thickness. Comparison of required computer resources demonstrates that the additional cost for the viscous-plastic sea ice rheology is minor compared with the atmospheric and oceanic model components in global climate simulations.

See Kreyscher et al. [2000].

[http://www.ifm.uni-kiel.de/me/research/Projekte/SIMIP/simip.html]

Singular Spectrum Analysis A method of time series analysis, sometimes abbreviated as SSA, designed to extract as much information as possible from short, noisy time series without prior knowledge of the dynamics underlying the series. It is a form of Principal Component Analysis applied to lag-correlation structures of time series. It was developed by Broomhead and King [1986] and applied to the analysis of paleoclimate time series by Vautard and Ghil [1989] and Vautard et al. [1992]. The SSA Toolkit[147] includes SSA amongst several time series analysis tools.

SSA performs better than traditional Fourier analysis at separating closely spaced relevant spectral peaks, but retains problems such as the requirement of stationarity and the limitation to situations of high SNRs. See Ruiz de Elvira and Bevia [1994].

singular vector Singular vectors are the perturbations that, under dynamics linearized about a basic flow state, grow most rapidly over a given time interval and in a given measure of amplitude, or norm. These optimal perturbations have been advanced as explanations for midlatitude cyclogenesis, and have been applied to forecast error growth and ensemble forecasting. See Buizza and Palmer [1995].

SIO Abbreviation for Scripps Institution of Oceanography.

SIR-C Acronym for the Shuttle Imaging Radar-C used for geologic, hydrologic, and oceanographic studies. It can image the Earth through cloud cover and its sensitivity to surface roughness, soil moisture, and sea-ice-water contrast makes it useful in studies of geological features, canopy morphology, sea-ice dynamics, and ocean surface temperature. See the SIR-C Web site[148].

SISMER Acronym for Systemes d'Informations Scientifiques pour la Mer or, in translation, the French National Oceanographic Data Center. See the SISMER Web site[149].

SIW In physical oceanography, a water mass. See Tomczak and Godfrey [1994], p. 161.

Six thermometer A self-registering maximum and minimum thermometer invented by James Six (1731?-1793) of England in 1782. It consisted of a U-shaped tube with mercury in the bend, one side filled with alcohol, and the other partially filled. Indices marked the highest and lowest temperatures. This was the most widely used thermometer for taking deep sea temperatures up until the 1870s. See Deacon [1971].

SIZEX Acronym for Seasonal Ice–Zone Experiment.

Skagerrak A circulation controlled sedimentary basin that provides part of the connection (along with Kattegat) between the North Sea and the Baltic. It is surrounded by Norway to the northwest, Sweden to the northeast, Denmark and Kattegat to the southeast, and the North Sea to the southwest. It is

[147] http://www.atmos.ucla.edu/~weibel/ssa/ssa_kit.html
[148] http://www.jpl.nasa.gov/mip/sirc.html
[149] http://www.ifremer.fr/sismer/

centered at approximately 9° E and 58° N and is the deepest part (> 700 m) of the the Norwegian Trench.

The circulation in Skagerrak is counterclockwise with North Sea water masses entering via the Jutland Current in the southwest, proceeding northeastward along the Denmark coast, combining with some of the brackish Baltic Current, turning and flowing northwestward along Sweden, turning again and becoming the Norwegian Coast Current (NCC) as it flows southwestward along Norway, and finally leaving Skaggerak and turning northwards as the NCC. There is also a deep countercurrent beneath the NCC that injects high salinity Atlantic water into the Skagerrak deep. See Svansson [1975], Rodhe [1996] and Danielssen et al. [1997].

SKAGEX Acronym for Skagerrak Experiment, an ICES experiment carried out from spring 1990 to spring 1991 in the Skagerrak. The main stage lasted four weeks with shorter and less intensive stages occurring at other times. The objectives of the experiment were to identify and quantify the various water masses entering and leaving the Skaggerak area and their variation over time, to investigate the mechanisms that drive the circulation in the area and its link with biological processes, and to investigate the pathways of contaminants through the Skagerrak. The project leader was B. Dybern.

`[http://www.ices.dk/ocean/project/data/jskag66.htm]`
`[http://www.ices.dk/ocean/project/data/skagex.htm]`

skin effect A temperature inversion in a thin near-surface ocean layer with a thickness of several millimeters. This is a source of uncertainty in radiometric measurements. The inversion layer, created mainly by evaporation, results in an underestimation of the SST compared with what it would be as determined by conventional methods in a layer with a thickness ranging from several tens of centimeters to several meters. See Kagan [1995].

skin temperature The temperature of the millimeter thick skin layer at the surface of the ocean. The skin temperature is 0.1–0.5°C cooler than the water a few millimeters below the surface. The skin is cooler than the layer just beneath because the net heat balance at the surface is from the ocean to the atmosphere, even during strong solar insolation and weak winds. This is because the sensible and latent heat fluxes at the air–sea interface are usually net losses from the ocean. The net longwave emission at the surface is also usually a heat loss. The incoming shortwave solar radiation is absorbed by the upper layers, with the infrared absorbed in the upper meter, the ultraviolet in the upper 3–5 m, and the visible in the upper 100 m. The shortwave absorption at the surface is therefore small, and the ocean surface loses heat. The heat lost is obtained from a flux from the interior via molecular conduction since turbulence is damped close to the surface. A large temperature gradient is required to accomodate the surface heat losses, which causes the skin temperature to drop sufficiently such that the resulting gradient can handle the flux from the interior. See Kantha and Clayson [2000].

slab ocean A simple, non-dynamic ocean model used in coupled model simulations. SSTs are calculated from surface energy balance and heat storage in a fixed-depth mixed layer but there are no ocean currents, i.e. we account for the effects of local and temporal but not non-local processes. The salient equilibration time of this type of model is that of the slab ocean, usually on the order of about 20 years for a 50 m thick slab.

SLEUTH Acronym for System for Locating Eruptive Underwater Turbidity and Hydrography.

slippery sea A phenomenon occurring in the wind-driven layer at the surface of the sea. In conditions of strong surface heating, a well-mixed warmer (and lighter) layer if formed, which is of limited depth because the stabilizing density distribution inhibits vertical mixing with the deeper, colder water. At the bottom of this surface layer is a strong density gradient where the turbulence is suppressed and the Reynolds stresses are small. A given wind stress at the surface can thus accelerate the water to produce stronger surface currents in this case compared to an unstratified ocean. This is true because both the depth of the layer involved is smaller and the retarding stress below it is reduced. This creates the slippery sea phenomenon. See Turner [1973].

slope The official IHO definition for this undersea feature name is "the deepening sea floor out from the shelf edge to the upper limit of the continental rise, or the point where there is a general decrease in steepness."

Slope Water (SW) A water mass that forms between the Gulf Stream and the continental shelf in the northwestern Atlantic Ocean. It is isolated by the Stream from contact with oceanic water masses in its depth range and therefore forms via interactions among shelf water, water from the Labrador Current, and water from the Gulf Stream. The Slope Water thus formed extends over the upper 1000 m of the water column north of Cape Hatteras along the continental rise and has a nearly linear T-S curve similar to that evinced by North Atlantic Central Water (NACW). The T-S curve typically extends from 21° C-36.0 to 15° C-35.1. Slope Water is intermittently transported by cyclonic rings across the Gulf Stream and into the Sargasso Sea. See Tomczak and Godfrey [1994].

slow manifold A hypothetical N-dimensional manifold (i.e. surface) embedded in the 3N-dimensional phase space of a primitive equation model that is devoid of gravity waves. This has been called the Holy Grail of initialization schemes for weather forecasting since if a numerical weather prediction model could be initialized with observations filtered to retain just their components on the slow manifold, then the large-amplitude gravity waves that have wrecked numerical forecasts since Richardson would no longer be a problem. The concept was introduced by Leith [1980] and is reviewed by Boyd [1995].

SLP Abbreviation for sea level pressure.

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

> Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after heavy snowfall.

See WMO [1970].

S-M-B method A method of wave forecasting developed by Sverdrup, Munk and Bretschneider, whence comes the name. This approach yields predictions of significant wave height $H_{1/3}$ and significant wave period $T_{1/3}$ from known storm conditions, i.e. wind velocity U, fetch distance F and storm duration t. This method can be used for a partially arisen sea. Predictions are made empirically using graphs of all the available data in terms of the dimensionless ratios gF/U^2, gt/U, gH/U^2 and gT/U. The empirical equations used to develop the graphs are:

$$\begin{aligned}
\frac{gH}{U^2} &= 0.283 \tanh\left[0.0125\left(\frac{gF}{U^2}\right)^{0.42}\right] \\
\frac{gT}{2\pi U} &= 1.20 \tanh\left[0.077\left(\frac{gF}{U^2}\right)^{0.25}\right] \\
\frac{gt}{U} &= K\, e^{\left(\left\{A\left[\ln\left(\frac{gF}{U^2}\right)\right]^2 - B\,\ln\left(\frac{gF}{U^2}\right) + C\right\}^{1/2} + D\,\ln\left(\frac{gF}{U^2}\right)\right)}
\end{aligned} \tag{19}$$

where g is the gravitational acceleration, U is the estimated wind velocity, F is the fetch length, t is the wind duration, T is the significant wave period and H is the significant wave height. The constant values are $K = 6.5882$, $A = 0.0161$, $B = 0.3692$, $C = 2.2024$ and $D = 0.8798$. See Komar [1976].

smeddie See Pingree and LeCann [1993].

SMHI Abbreviation for Sveriges Meteorologiska och Hydrologiska Institut or Swedish Meterological and Hydrological Institute. See the SMHI Web site[150].

SMILE Acronym for Shelf Mixed Layer Experiment, a WHOI research program designed to study the response of the oceanic surface boundary layer over the continental shelf to atmospheric forcing. SMILE took place over the northern California shelf between Pt. Arena and Pt. Reyes from mid–November to mid–May 1989. See Alessi et al. [1991].

[http://uop.whoi.edu/data/smile/smile.html]

SMMR Abbreviation for Scanning Multichannel Microwave Radiometer, an instrument that has been on board both SEASAT and NIMBUS-7. It produced earth location and time-tagged SSTs, surface wind stress, atmospheric water vapor, liquid water content, and precipitation rate information. See Liu [1984].

SMONEX Acronym for Summer Monsoon Experiment, a program taking place from May 1 to August 31, 1979 in eastern African, the northern part of the Indian Ocean, the Arabian Sea, the Bay of Bengal, and in adjacent continental areas.

[http://www.meteo.ru/fund/inter.html]

SMWG Abbreviation for Synthesis and Modeling Working Group, a WOCE committee.

Snellius Expedition An oceanographic expedition taking place in 1929–1930 in the southwest Pacific Ocean.

Snellius II Expedition See van Aken et al. [1988].

SO See Southern Oscillation.

SOAR Acronym for Satellite Ocean Analysis for Recruitment, a OSLR project.

SOEST Acronym for the School of Ocean and Earth Science and Technology at the University of Hawaii at Manoa. It was established in 1988 and currently has approximately 700 faculty and staff. It consists of departments in Geology and Geophysics, Meteorology, Oceanography, and Ocean Engineering, as well as three institutes:

- Hawaii Institute of Geophysics and Planetology (HIGP)
- Hawaii Institute of Marine Biology (HIMB)
- Hawaii Natural Energy Institute (HNEI)

[http://www.soest.hawaii.edu/]

SOFAR 1. Acronym for Sound Fixing and Ranging channel, another name for the sound channel. 2. Acronym for SOund Fixing And Ranging floats, subsurface floats used since the mid 1970s that freely drift at prescribed pressures. These provide direct measurements of the ocean circulation by sending acoustic pulses, typically at 300 MHz, once a day which can be used to calculate their positions from their Times of Arrivals (TOAs) at listening stations moored near the SOFAR channel depth at known geographical positions. See Rossby and Webb [1970].

[150]http://www.smhi.se/

SOFeX Acronym for Southern Ocean Iron (Fe) Experiment. The original name for this was IronEx III.

SOFIA Acronym for Surface of the Ocean, Fluxes and Interactions experiment. See Dupuis et al. [1993].

soft tissue pump See organic matter pump.

SOI See Southern Oscillation Index.

SOIREE Acronym for Southern Ocean Iron RElease Experiment, an experiment taking place from January 31 to March 1 1999 on the R.V. Tangaroa in the Southern Ocean. A patch of seawater was enriched with iron to test the hypothesis that iron limits the primary production of phytoplankton.

The iron and sulphur hexafluoride (as a tracer) were initially released on Feb. 10 at a site with a mixed layer depth of about 65 m and with low chlorophyll α levels. The dissolved iron concentration was considerably elevated over the 50 square kilometer area, although the levels quickly decreased leading to three more iron infusions during the 13–day experiment. The patch moved about 40 nautical miles eastward and expanded to about 150 square kilometers during the experiment.

Five days after the initial release significant increases in algal photosynthetic competence were observed, followed by elevated algal biomass. Chlorophyll α and upper ocean dimethylsulfide levels increased significantly by the end of the experiment, while macronutrient levels, the partial pressure of carbon dioxide, and the contnet of total dissolved inorganic carbon decreased. See Boyd et al. [2000] and Boyd and Law [2001].

`[http://tracer.env.uea.ac.uk/soiree/index.html]`

solitary wave See soliton.

soliton A fundamentally nonlinear wave that propagates undistorted over great distances. The soliton or solitary wave was discovered by Scottish engineer John Scott Russell (1808–1882) in 1834 while conducting experiments to determine the most efficient design for canal boats. He describes his first observations of what he called a "Wave of Translation" Russell [1845]:

> I was observing the motion of a boat which was rapidly drawn along a narrow channel by a pair of horses, when the boat suddenly stopped - not so the mass of water in the channel which it had put in motion; it accumulated round the prow of the vessel in a state of violent agitation, then suddenly leaving it behind, rolled forward with great velocity, assuming the form of a large solitary elevation, a rounded, smooth and well-defined heap of water, which continued its course along the channel apparently without change of form or diminution of speed. I followed it on horseback, and overtook it still rolling on at a rate of some eight or nine miles an hour, preserving its original figure some thirty feet long and a foot to a foot and a half in height. Its height gradually diminished, and after a chase of one or two miles I lost it in the windings of the channel. Such, in the month of August 1834, was my first chance interview with that singular and beautiful phenomenon which I have called the Wave of Translation.

See Bullough [1988] and Sander and Hutter [1991] for the historical development of the concept of solitary waves, which weren't wholly appreciated until the advent of digital computers made it possible to much more thoroughly investigate their characteristics and use them to model physical situations. Today solitons or solitary waves are used as a constructive element to formulate the complex dynamical behavior of wave systems in almost all facets of science, e.g. hydrodynamics, nonlinear optics, plasmas, shock waves, tornados, the Great Red Spot of Jupiter, etc.

`[http://www.ma.hw.ac.uk/~chris/scott_russell.html]`

SOLO Acronym for Sounding Oceanographic Langrangian Observer, a second–generation ALACE float designed to correct the design flaws of the latter. The SOLO uses a single–stroke hydraulic pump allowing full up–down control, and eliminates the internal oil bladder. See Davis et al. [2001].

Solomon Sea More later.

solubility pump The process by which the ocean maintains a vertical gradient in DIC (CO2 plus bicarbonate and carbonate ions) – such that DIC is concentrated in the deep ocean – as a result of gas exchange. Surface water at equilibrium with a given CO2 concentration will increase its DIC concentration (uptake CO2) when the water temperature decreases since the solubility and dissociation of CO2 increase in cold water. The regions of deep water formation are located in high latitudes so the deep ocean is filled with cold water with relatively high DIC concentration. It is estimate that about 50% of the vertical DIC gradient can be accounted for by this process. See Najjar [1991] and Chisolm [1995].

solution drift See climate drift.

Somali Current A current near the western boundary of the Indian Ocean that flows southward during the boreal winter and northward during the summer. The southward flow during the northeast monsoon is limited to south of 10°N. It occurs first in early December near the equator and expands rapidly north in January with velocities from 0.7–1.0 m/s. The surface flow reverses in April during the inter–monsoon period, and develops into an intense jet during the southwest monsoon with velocities reaching 3.5 m/s in June. During the southwest monsoon a two gyre system develops in the region – the Great Whirl between 5–10°N with clockwise rotation and a secondary eddy towards its south. This two gyre system is stable until August or September, when the southern gyre propagates northward and merges with the Great Whirl. This has also been called the East Africa Coast Current.

After Schott and McCreary Jr. [2001], the details of the annual cycle of the Somali Current system are:

- *March-May*: Before the onset of the monsoon the southern Somali Current is an extension of the East African Coast Current (EACC) that flows northward across the equator to about 3-4N. There, it turns offshore, and a cold wedge develops along its shoreward shoulder. Farther north, alongshore winds cause an upwelling regime to develop with a shallow northward coastal flow overlying a southward undercurrent (see Section 4.3). Its width scale is of the order of 50-100 km.
- *June-July*: With the monsoon onset in June, the Great Whirl develops from 4-10N, and a second cold wedge appears at the latitude where it turns offshore (10-12N). The onset of the Great Whirl is thought to be a response to the very strong anticyclonic wind-stress curl offshore from the Somali coast by long Rossby waves reflecting into short Rossy waves at the boundary and accumulating energy there.

  The cross-equatorial flow continues during this time, now transporting about 20 Sv in the upper 500 m. It leaves the coast south of 4N, where part turns eastward and part flows back across the equator in a circulation pattern referred to as the 'Southern Gyre'.
- *August-September*: In the late phase of the summer monsoon the Great Whirl has become an almost-closed circulation cell with very little exchange between its offshore recirculation branch and the interior Arabian Sea.
- *October-November*: When the Southwest Monsoon dies down, the cross-equatorial Somali Current turns offshore again at 3N, while the Great Whirl continues to spin in its original position.
- *December-February*: During the Northeast Monsoon, the winds blow away from the Indian subcontinent and the surface Somali Current reverses to flow southward. After crossing the equator,

it encounters the northward-flowing EACC, resulting in a confluence and eastward turnoff at 2-4S that supplies the South Equatorial Countercurrent. At the equator, the southward Somali Current is quite shallow, carrying 5 Sv in the upper 150 m, because there is a northward undercurrent at this time.

The northern Somali Current during this time is characterized by an inflow from the east that causes a divergence to develop at the coast somewhere near 6-8 deg. N, with northward surface flow north of these latitudes and equatorward flow south of them. The northward surface flow passes through the Socotra Passage, but also veers eastward along the southern banks of Socotra. It then flows northward through the region occupied by the Socotra Eddy during the summer.

See Schott [1983] and Schott and Fischer [2000].

Somali Jet See Halpern and Woiceshyn [1999].

SOMARE Acronym for Sampling, Observations and Modeling of Atlantic Regional Ecosystems, a program whose overall goal is to unify the diverse European research groups investigating the functioning, effects and responses of the regional ecosystems of the Atlantic Ocean and shelf seas to anthropogenically forced and climate related changes. The scientific goals of SOMARE include improving knowledge of:

- biogeochemical and bio–optical provinces of the ocean basins and marginal seas of the Atlantic Ocean in terms of bio–optical, physical and biogeochemical properties;
- bio–optical properties and biological processes including primary and secondary production, plankton community structure and nutrient cycling using on–line, autonomous and towed sensor methods;
- spatially extensive calibration, validation and quality assurance of remotely sensed observations of oceanic biology;
- novel climatologies of key biological state variables and process rates; and
- development of sub–models of key biological processes for incorporation in basin–scale productivity models.

[http://www.pml.ac.uk/amt/somare/]

SOOP Abbreviation for Ship of Opportunity Program, an IOC project that uses merchant and other volunteer ships that transit a series of tracklines over existing trade routes. These ships deploy XBTs and other sampling instrumentation to obtain upper ocean thermal and salinity data. The primary goal of SOOP is the fulfill upper ocean data requirements established by GOOS and GCOS, which can be met at present by measurements from ships of opportunity.

[http://www.ifremer.fr/ird/soopip/]

SOPRANE Acronym for Systéme Océanique de Prévision en Atlantique Nord–Est, an ocean mesoscale forecasting system aimed at routinely providing real–time nowcast and forecast bulletins of the mesoscale ocean circulation in the Eastern North–Atlantic basin to support sea activities such as naval operations and oceanographic research cruises. According to the web site:

> The system is based on routine assimilation of TOPEX/POSEIDON and ERS-2 real time altimeter data into a quasi-geostrophic ocean model of the Eastern North Atlantic basin. The system modules include:
>
> - operational external data acquisition and processing (altimetry, meteorology, hydrology),

- quasi-geostrophic modelling (SIMANE),
- the computation of derived oceanographic variables (temperature, salinity, sound velocity).

SIMANE is a high-resolution 10-level 1/10 deg. quasi-geostrophic model extending from 24N to 54N and from 35W to the eastern coastal 200 m isobath. It is derived from the Blayo et al. [Blayo, 1994] North-Atlantic QG model. The model is designed to perform sequential assimilation (P. De Mey's optimal interpolation assimilation scheme SOFA) of ERS-2 and TOPEX/POSEIDON altimeter data in real time conditions, and real-time daily wind-stress forcing from the Mitio-France meteorological model ARPEGE forecasts.

The system retrieves and processes Topex (JPL and NAVOCEANO) and POSEIDON (CNES) IGDRs in real time, both with a 48-hour Doris orbit provided by CNES, and ERS-2 (ESA) FDPs with a 3-day orbit provided by DEOSDelft Institute of Earth-Oriented Space Research (Delft).

SOPRANE provides a complete depiction of the mesoscale ocean circulation from October 1992 to the present day (”hindcast” mode). Every week, a new assimilation cycle is processed with the latest altimeter tracks available in near real time (3-day latency max. for TOPEX/POSEIDON and ERS-2 data), to provide a ”nowcast” bulletin. The model run provides reliable ”forecasts” of ocean changes for up to two weeks.

`[http://sirius-ci.cst.cnes.fr:8090/HTML/information/publication/news/news6/bahurel_uk.html]`

Soret effect In fluid mechanics, mass diffusion caused by a temperature gradient. See Hurle and Jakeman [1971].

SOSUS Acronym for Sound Surveillance System, a component of the U.S. Navy's Integrated Undersea Surveillance Systems (IUSS) network used for deep ocean surveillance during the cold war. SOSUS consists of bottom–mounted hydrophone arrays connected by undersea communication cables to on-shore facilities. The arrays are primarily installed on continental slopes and seamounts at locations optimized for undistorted long range acoustic propagation. Beginning around 1990, the Navy allowed SOSUS to be used for various research activities. See Nishimura and Conlon [1994].

`[http://www.pmel.noaa.gov/vents/acoustics/sosus.html]`

sound channel A narrow channel in which sound waves can be effectively trapped. A region of minimum sound speed is created where the bottom of the thermocline meets the top of the deep isothermic layer. The velocity of sound slows as water temperatures decrease approaching the thermocline from above. The temperature is relatively constant below the thermocline, but increasing pressure causes the speed of sound to increase downwards. This causes obliquely traveling horizontal sound waves to vertically bend back and forth within the sound channel and travel great distances with relatively minor energy loss. This is also known as the SOFAR channel.

sound speed See Del Grosso [1974] and Yaremchuk and Krot [2002].

source water type In physical oceanography, a point on a T-S diagram indicative of a water mass. In practice, few if any water masses have T-S values identical to that of their source water types due to transformation by atmosphere-ocean interface processes and/ mixing, but they are almost inevitably within the theoretical standard deviation and as such readily identifiable as to their origin. See Tomczak and Godfrey [1994].

South Atlantic Bight See Boicourt et al. [1998].

South Atlantic Central Water (SACW) A variety of Central Water found in the Atlantic Ocean south of about 15°N. It shows uniform properties throughout its range, with the T–S curve well described by a straight line between the points 5°C, 34.3 and 20°C, 36.0. Part of the SACW is thought to be Indian Central Water (ICW) brought into the Atlantic by Agulhas Current intrusions. See Stramma and England [1999].

South Atlantic Current The current band of increased zonal speeds associated with the Subtropical Front (STF) in the South Atlantic Ocean. It originates in the western Atlantic as the STF becomes clearly distinguished from the Brazil Current front somewhere between 40 and 45° W. It then flows eastward typically to the north of the STF and closes the circulation in the South Atlantic subtropical gyre by becoming its southern limb. The SAC is clearly separated from the ACC by a region of weak flow just to the south of the STF, and is seen to not follow the STF exactly in some observations. It is recognizable as an enhanced current core at depths of 800–1000 m and has an average volume transport of about 30 Sv in the upper 1000 m in the western Atlantic (reaching as high as 37 Sv). The transport diminishes to less than 15 Sv in the vicinity of southern Africa where it turns northward to feed the Benguela Current. See Stramma and Peterson [1990] and Peterson and Stramma [1991].

South China Sea A regional sea in the western Pacific Ocean centered at about 115° E and 12° N that includes the Gulf of Thailand and the Gulf of Tonkin. It is bordered to the west by Vietnam, Thailand and the Malay Peninsula, to the south by a line joining the southern tip of the Malay Peninsula to Borneo, to the east by Borneo, the Phillipines and Taiwan, and to the north by the Taiwan Strait and China. It covers an area of 3,685,000 km^2, has a volume of 3,907,000 km^3, a mean depth of 1060 m, and a maximum depth of 5016 m.

It is connected to the East China Sea via the Taiwan Strait, the Andaman Sea via the Strait of Malacca, the Java Sea via the Karimata Strait, and to the Philippine Sea via Luzon Strait, and the Sulu Sea via the Balabar Strait and the Mindoro Channel. The main freshwater input from rivers is from the Red and Mekong Rivers of Vietnam and the Si Kiang River of southern China. See Qu et al. [2000].

Southeast Indian Subantarctic Mode Water (SEISAMW) A type of Subantarctic Mode Water formed in the southeastern Indian Ocean south of Australia. It is the dominant mode of ventilation for the Indian Ocean, leading to a subsurface oxygen maximum layer extending northward into the tropical and northern Indian Ocean.

Southeast Pacific Deep Water (SPDW) The SPDW flows through the Drake Passage with the ACC south of the Polar Front, at which point it is identifiable by its potential temperature ($0.2°C < \theta < 0.6°C$), salinity (34.703 < S < 34.710), and its silicate maximum (reaching 140 μmol kg^{-1}). It is the densest water mass of the ACC system in the Drake Passage.

When crossing the Scotia Sea, it is drastically cooled (by 0.14°C) and freshened (by 0.018) along isopycnals via mixing with WSDW and WDW in the Weddell–Scotia Confluence. This results in the SPDW south of the Southern ACC Front being transformed into WDW and becoming incorporated into the ACC, while north of the front two cores carrying modified SPDW exit the Sea. One of these is on the northern flank of the Southern ACC Front south of South Georgia, having followed the front from Drake Passage. The other overflows the North Scotia Ridge through Shag Rocks Passage and can be found just south of the Polar Front skirting the Falkland Plateau. See Siecers and Nowlin Jr. [1984].

South Equatorial Countercurrent An eastward current in the Atlantic and Pacific that flows between 5 and 10° S., the limited evidence for which shows it to be much less well developed than the North Equatorial Countercurrent (NECC). In the Indian Ocean the SECC is almost totally confined between the equator and the northern boundary of the South Equatorial Current (SEC) at 4° S. This was first described by Reid [1959] and the evidence is later reviewed by Leetmaa et al. [1981].

South Equatorial Current A westward flow in the Atlantic and Pacific located south of the North Equatorial Countercurrent (NECC) generally below 5° N. It flows between about 3° N and 10° in the Pacific with speeds estimated at around 50 to 65 cm s^{-1} and an average mean transport of 17 SV, although this latter quantity annually varies by about 10 Sv about the mean. The SEC is strongest during July and August and usually vanishes during the northern winter and spring. This is also seen in the Indian Ocean south of 4° S. See Leetmaa et al. [1981] and Stramma [1991].

South Equatorial Current Bifurcation The phenomenon wherein the Atlantic South Equatorial Current (SEC) – upon approaching the easternmost tip of South America – splits into the Brazil Current flowing to the south and the North Brazil Current flowing northwestward along the northern coastline of Brazil.

South Equatorial Undercurrent An eastward flow in the Atlantic Ocean whose core is located near 200 m depth a few degrees south of the Equator. A satisfactory dynamical explanation for this is as yet nonexistent. See Tomczak and Godfrey [1994], p. 260.

South Java Current See Tomczak and Godfrey [1994].

South Subtropical Front (SSTF) The southern boundary of the Subtropical Frontal Zone (STFZ).

South Tropical Countercurrent See Donguy and Henin [1975].

Southern ACC Front A front in the Southern Ocean that separates the Antarctic Zone (AZ) to the north from the Continental Zone (CZ) to the south. The position of the SACCF is usually indicated by a distinct temperature gradient along the σ-maximum of the Upper Circumpolar Deep Water (UCDW) as it shoals southward to near 500 m. The property indicators of the SACCF are $\theta > 1.8°$ along θ-maximum at $Z > 500$ m, $\theta < 0°$ along θ-minimum at $Z < 150$ m, $S > 34.73$ along S-maximum at $Z > 800$ m, and $O_2 < 4.2$ ml/l along O_2 minimum at $Z > 500$ m. The SACCF is one of three fronts found in the Antarctic Circumpolar Current (ACC), the others being (to the north) the Polar Front (PF) and the Subantarctic Front (SAF). See Orsi et al. [1995].

Southern Ocean In oceanography, an unofficial term used to describe the oceans surrounding the continent of Antarctica, which cover approximately 30,000,000 km2, or about 20% of the total world ocean area. While Southern Ocean is not considered an official term by the International Hydrographic Bureau (IHB), it is considered sufficiently distinct by oceanographers to merit a separate designation. The northern limit is generally considered to be the broad zone of transition where the permanent thermocline reaches the surface at the Subtropical Convergence/Front (STC/STF), and the southern limit the continent of Antarctica. It is distinguished from the other oceans by the relative uniformity of its characteristics of hydrography and circulation and that it influences more than it is influenced by the others.

The Southern Ocean bathymetry consists of three major basins where the depth exceeds 4000 m separated by three major ridges that reach at least to the 3000 m level. The major basins are:

- the Atlantic-Indian-Antarctic Basin (or African-Antarctic Basin or Valdivia Basin), bounded to the north by the South Orkney-Sandwich Ridge, the Atlantic-Antarctic Ridge, and the Prince Edward-Crozet Ridge, and to the east by the Kerguelan-Gaussberg Ridge;
- the Eastern Indian-Antarctic basin (or Australian-Antarctic Basin or Knox Basin), bounded to the west by the Kerguelan-Gaussberg Ridge, the north by the Amsterdam-St. Paul Plateau, and to the south by the Indian Antarctic Ridge; and

- the Pacific-Antarctic Basin (or Bellingshausen Basin), bounded to the west and north by Pacific-Antarctic Ridge and the South-Eastern Pacific Plateau.

See Belkin and Gordon [1996].

Southern Oscillation The name given to the atmospheric component of the El Nino/Southern Oscillation (or ENSO) phenomenon. The SO is a large-scale shift in atmospheric mass between the western and eastern Pacific, monitored by computing the SOI. An SOI indicating El Nino conditions means that there is reduced rainfall over the Indonesian region and that the west Pacific convective center is displaced eastward along the equator.

Southern Oscillation Index An index that is calculated to monitor the ENSO phenomenon. It is defined as the pressure anomaly at Tahiti minus the pressure anomaly at Darwin, Australia. Anomalously high pressure at Darwin and low pressure at Tahiti are indicative of El Nino conditions.

Southern South Equatorial Current (SSEC) One of three distinct branches into which the South Equatorial Current splits in the western South Atlantic. See Stramma [1991].

Southern Subsurface Countercurrent (SSCC) An eastward flowing countercurrent that flows beneath the surface east of 155° in the South Pacific Ocean. It flows between the eastward flowing South Equatorial Countercurrent (SECC) to the north and the westward flowing South Equatorial Current to the south. See Gouriou and Toole [1993].

South Pacific Equatorial Water (SPEW) In physical oceanography, a water mass partly formed by convective sinking of surface water at SSTs of 26° C and above in the tropics in the area of Polynesia. It is identified at temperatures greater than 20° C by a higher salinity than WSPCW, although below 20° C it seems to be a mixture of WSPCW and ESPCW. See Tomczak and Godfrey [1994], p. 166.

South Pacific Tropic Water (SPTW) A water mass identified as a salinity (>35.25 psu) maximum with homogeneous oxygen concentration (about 3.3 ml l^{-1}) around $25\sigma_\theta$. it is found in the equatorial region south of 5°N. See Qu et al. [1999].

South Trench Current See North Sea.

Southwest Area Monsoon Project (SWAMP) A NSSL project begun in 1990 to measure the central Arizona thunderstorm environments, examine the local monsoon structures and moisture fluxes, and study Mexican convective systems. The field operations for SWAMP began in 1990 and included scientists and technicians from several institutes and laboratories. See the SWAMP Web site[151].

Southwest Monsoon Current See Vinayachandran et al. [1999].

SOWEX Acronym for Southern Ocean Waves Experiment, an international collaborative air-sea interaction experiment in which a specially instrumented meteorological research aircraft simultaneously gathered atmospheric turbulence data in the marine boundary layer and sea surface topography data over the Southern Ocean for a wide range of wind speeds. The aim was to increase present knowledge of severe sea state air-sea interaction. SOWEX was carried out from June 10–16, 1992 over the Southern Ocean off the southwest coast of Tasmania, Australia at 42–45°S, 143–147°E. See Banner et al. [1999] and Chen et al. [2001].

[151] http://doplight.nssl.uoknor.edu/projects/swamp/

Soya Current An extension of the Tsushima Current that flows northward from the Japan Sea into the Okhotsk Sea via the Soya Strait. It is a fairly rapid curent with velocities reaching 1 m/s and traveles close to the coast with the character of a boundary current.

Soya Strait See Okhotsk Sea.

S-PALACE Abbreviation for Salinity–Profiling ALACE float.

Spanish Basin See Iberia Basin.

SPCZ Abbreviation for South Pacific Convergence Zone, an atmospheric convergence zone in the southwestern Pacific Ocean that is characterized more by a convergence in wind direction than as a wind speed minimum. It extends from east of Papua New Guinea in a southeastward direction towards 120° E and 30° S. See Philander and Rasmusson [1985].

specific heat A thermodynamic quantity indicating the rate of change of heat content with temperature. More specifically, this is the heat required to raise the temperature of a unit mass of a given substance by one degree. It is normally expressed in units of calories/gm °K. The specific heat of water is 1.00 cal/gm °K (although this varies about 1% with temperature), and the specific heat of dry air at constant pressure (C_p) is 0.240 cal/gm °K and at constant volume (C_v) 0.171 cal/gm °K. For water vapor the constant pressure (C_{pv}) value is 0.441 and the constant volume (C_{vv}) value 0.331 cal/gm °K.

For seawater, the specific heat at surface pressure is calculated in two stages. First, the value in joules per kilogram per degree Kelvin for fresh water is calculated as:

$$c_p(0,t,0) = 4217.4 - 3.720283t + 0.1412855t^2 - 2.654387 \times 10^{-3}t^3 + 2.093236 \times 10^{-5}t^4$$

. Then, the value at a given salinity is calculated with:

$$c_p(S,t,0) = c_p(0,t,0)+S(-7.64444+0.107276t-1.3839\times10^{-3}t^2)+S^{3/2}(0.17709-4.0772\times10^{-3}t+5.3539\times10^{-5}t^2)$$

. The standard deviation of the algorithm fit is 0.074, and a check on the formula is given by $c_p(40,40,0) = 3981.050$. See Millero et al. [1973] for the derivation and details. Values at nonzero pressures are found using the following relation:

$$\left(\frac{\partial c_p}{\partial p}\right)_T = -T\left(\frac{\partial^2 v_s}{\partial T^2}\right)_p$$

where v_s is the specific volume. See also Cox and Smith [1959].

specific humidity The ratio of the mass (m_v) of water vapor to the mass ($m_v + m_a$) of moist air in which m_v is contained, where m_a is the mass of dry air, or

$$q = \frac{m_v}{m_v + m_a}$$

.

specific volume The reciprocal of density. In the determination of the specific volume of sea water, the specific volume $\alpha_{S,T,p}$ is decomposed as

$$\alpha_{S,T,p} = \alpha_{35,0,p} + \delta_S + \delta_T + \delta_{S,T} + +\delta_{S,p} + \delta_{T,p} + \delta_{S,T,p}$$

where the second through seventh terms on the right-hand-side are called the specific volume anomaly and the second through fourth terms the thermosteric anomaly.

specific volume anomaly The portion of the specific volume differing from a standard specific volume determined at a salinity of 35 ppt, a temperature of 0° C, and the pressure at the depth at which the sample was taken. This has also been known as the steric anomaly and the anomaly of specific volume.

spectral element method A method for approximating solutions to the governing equations of fluid motion in the ocean. It was developed to combine the geometrical flexibility of the traditional low-order finite element methods with the accuracy and high convergence rates of spectral methods. See Iskandarani et al. [1995].

spectral nesting See nested modeling.

spectral signature This refers to the particular form or shape evinced by the power spectrum calculated from the data comprising the time series of a process. For example, if the spectrum shows peaks at around 20, 40 and 100 thousand years it might be said to have the spectral signature of Milankovitch orbital variations.

SPEW See South Pacific Equatorial Water.

spherical approximation The fundamental geometric approximation in oceanography. It maps the approximate oblate spheroidal shape of the geoid on a sphere and introduces spherical polar coordinates (ϕ, θ, r) where ϕ is longitude, θ is latitude, and r radial distance. This approximation also assumes that the metric coefficients do not vary with radial distance, and that gravitational acceleration is constant.

This approximation represents the lowest order in an expansion of the metric with respect to two small parameters $d^2/4r_0^2$ and H_0/r_0 where d is the half distance between the foci of the geoid, r_0 the mean radius of the Earth, and H_0 the ocean depth. A vertical coordinate $z = r - r_0$ is also introduced. See Stommel and Moore [1989] and Muller [1995].

Spice Experiment An exploratory experiment to observe spiciness in the upper ocean, including the mixed layer, at horizontal scales of 10 m to 1000 km. The objectives of the Spice Experiment are:

- to quantify the density ratio in the mixed layer and seasonal thermocline;
- to find if salinity varies on shorter horizontal scales than temperature;
- to confirm that there is more spiciness in the mixed layer than in the seasonal thermocline; and
- to find where and over what length scales the reduction in spiciness occurs.

The data for the experiment were taken from a cruise in the eastern North Pacific between 25 and 35deg N from Jan. 24 to Feb. 20, 1997. Measurements were made using a SeaSoar equipped with a CTD and a fluorometer.

[http://chowder.ucsd.edu/~rudnick/spice/spice.html]

spiciness The variability of temperature and salinity along a surface of constant density due to air–sea fluxes, turbulent mixing and advection.

Spilhaus, Athelstan (1912-1998) Inventor of the bathythermograph and possibly the only oceanographer to have ever authored a regular comic strip.

According to his obituary in The Economist, Spilhaus can also apparently be blamed for the Roswell Incident that's spawned an entertainment industry:

In 1947 the Americans were working on ways to monitor nuclear tests in the Soviet Union. One plan was to put aloft balloons equipped with the necessary detection equipment. The first experiments were failures. The balloons all blew away. Mr Spilhaus, then a professor of meteorology at New York University, was brought in. As a weather man, so the reasoning went, surely he would know how to ensure that the balloons stayed quite steady in the stratosphere.

On June 4th 1947 the Spilhaus prototype was launched. On July 7th it came down with a bump, disintegrating on a ranch near Roswell in New Mexico. The rancher phoned the local sheriff. He thought the debris might have come from "a flying disc". By the time the story got into the newspapers the "disc" had become a flying saucer. A neighbour of the rancher later said that in the debris there was "something like aluminium, something like satin, something like well-tanned leather in its toughness, yet was not precisely like any one of those materials". Could this have been a dead alien, or possibly several? Many people came to think so.

An air force team removed every scrap of debris, assuring reporters that it was just an ordinary balloon, nothing to be bothered about; and compounding suspicions that the federal government was trying to cover up the fact that aliens had landed, fearing panic by the public. It was not until 1994 that it disclosed the background to the incident. Even now, the government version is widely disbelieved. The myth was much more interesting. Mr Spilhaus could say little: this was a secret of the cold war. But the fact that he was known to be associated with the incident only added to public speculation about it. Mr Spilhaus enjoyed playing the role of a slightly dotty scientist, a bit of a dreamer, or, as he called himself in later life, a "retired genius".

[http://www.whoi.edu/media/news_spilhaus.a.obit.html]
[http://vh1.economist.com/editorial/justforyou/11-4-98/sf1047.html]

spin up In numerical modeling, this refers to the transient initial stages of a numerical ocean simulation when the various fields are not yet in equilibrium with the boundary and forcing functions. Three techniques are generally used to initialize and spin up the ocean components of coupled models: (1) initializing with climatological values of temperature and salinity (typically using the Levitus climatology) throughout the volume of the ocean; (2) start with the aforementioned Levitus ocean and then spin it up for about 100 years using surface climatological forcing; (3) run the ocean to equilibrium by either combining surface forcing terms with atmospheric model fluxes or just using the surface forcing (and perhaps using an acceleration method with either option). The entire ocean is not in equilibrium using the first two methods, although the second method does allow the thermocline to adjust to equilibrium. This is due to both systematic errors and other shortcomings in the Levitus data. The third method may produce and ocean in equilibrium, but it may differ considerably from the observed ocean and the circulation may be distorted. For example, the deep ocean is often too warm using this method.

spiral eddy Frequently observed, distinct sea surface patterns with a horizontal scale of around 10 km. The eddies are large–scale arrangements of sea slicks or streaks with a spacing on the order of 1 km and width 100 m. The streaks are domains of reduced surface roughness that make them visible to remote instruments such as SAR and space shuttle cameras, and are caused by surface convergence.

The eddies have been observed in both hemispheres in both coastal areas and the open ocean. They generally appear in an interconnected pattern. They range from 100-25 km in size and are overwhelmingly cyclonic. See Munk et al. [2000] and Eldevik and Dysthe [2002].

SPMW Abbreviation for subpolar mode water.

spring retardation See age of tide.

spring tide The high tides of greatest amplitude caused by the Earth, Sun and Moon being almost colinear. This causes the gravitational pulls of both the Sun and Moon to reinforce each other. The high tide is higher and low tide is lower than the average, and spring tides occur twice a month at the times of both new moon and full moon. See also neap tide.

SPTW Abbreviation for South Pacific Tropical Water.

spur The official IHO definition for this undersea feature name is "a subordinate elevation or ridge protruding from a larger feature, such as a plateau or island foundation."

SPURV Acronym for Self-Propelled Underwater Research Vehicle. See Widditsch [1973].

SQM Acronym for SeaWiFS Quality Monitor. See Hooker and Aiken [1998].

squall A violent wind that begins suddenly, lasts for a short time, and dies suddenly. It is sometimes associated with a temporary change of direction.

squall line One of the most severe kinds of storms in the tropics. The system is typically hundreds of miles long and consists of a line of active thunderstorms. The cumulonimbus clouds representing individual storms have lifetimes on the order of an hour or less, but new ones replace dying cells allowing the system as a whole to last from hours to days. They form preferably over land and move with speeds from 10-20 m/s.

In a squall line warm moist air enters the base of the cloud at its leading edge and rises in a convective updraft with accompanying condensation. An extensive cloud anvil forms to the rear of the convective tower with precipitation falling from both the main cloud column and the anvil. The evaporation of this precipitation into dry mid-tropospheric air leads to cooling and downdrafts concentrated in the region of intensive convection although extending to the rear of the squall line. This downward rushing cold air causes a pseudo cold front or gust front at the leading edge. This front undercuts the warm moist air ahead, causing more convection and new cumuliform clouds ahead of the line and fostering the propagation of the convective region. See Hastenrath [1985].

SSA See Singular Spectrum Analysis.

SSALT Acronym for the single–frequency solid–state radar altimeter flow flown as an experimental instrument on the TOPEX/POSEIDON mission (with this being known as the POSEIDON instrument). The SSALT, a solid–state Ku–band (13.65 GHz) altimeter, was developed by the French (CNES) as a demonstration project for a low–power, low–weight altimeter for future Earth–observing missions. It shares the same antenna with ALT, the operational altimeter, and thus cannot be operated at the same time. The SSALT was operated 12.5% of the time during the 6 month verification phase of the mission, and thereafter for one (10 day) cycle approximately every 10 cycles.

SSCC 1. Abbreviation for Southern Subsurface Countercurrent. 2. Abbreviation for subsurface countercurrent.

SSEC Abbreviation for SouthernSouthEquatorialCurrent.

SST Abbreviation for sea surface temperature.

SSTF Abbreviation for South Subtropical Front Zone.

SSW Abbreviation for Sargasso Sea Water.

SSWWS Abbreviation for Seismic Sea-Wave Warning System.

stability 1. See numerical stability. 2. In physical oceanography, a measure of the tendency of a water parcel or particle to move vertically in comparison with its surroundings. Neglecting adiabatic effects, the stability is defined (over short vertical distances) by

$$E = \frac{1}{\rho}\frac{d\rho}{dz}$$

where ρ is the density and z the vertical coordinate. There is a correspondingly more complicated expression for the stability when adiabatic effects are taken into account as is usually necessary at great depths. Typical values of E in the upper 1000 m range from 100 to 1000 x 10^{-8}/m, with the largest values generally occurring in the upper few hundred meters. Below 1000 m values decrease to less than 100 x 10^{-8}/m and can get as small as a hundredth of that in deep trenches.

stability frequency See buoyancy frequency.

STABLE Acronym for Stable Antarctic Boundary Layer Experiment.

STACS Acronym for Subtropical Atlantic Climate Study, a NOAA project directed at increased understanding of the role of western boundary currents of the Atlantic ocean in meridional heat flux and development of strategies to monitor important western boundary features. See Molinari [1989].

staggered grid In numerical analysis this refers to a computational grid in or on which separate dependent variables are represented on alternate or staggered grid points. For example, a 1-D equation set for pressure and velocity would be solved on a grid where the pressure is represented at points n, n+2, n+4, etc. while the velocity is represented at n+1, n+3, n+5, etc. This procedure can confer numerical advantages and is also used for problems with more than one spatial dimension. See Kowalik and Murty [1993].

stagnant film model The simplest of several models developed to understand the processes that determine the gas flux in and near the liquid boundary layer that is the air-sea interface. It assumes that the boundary layer is a discrete, stagnant layer in which only molecular diffusion takes place. This stagnant layer sits on top of a well-mixed, purely turbulent layer. The flux across the interface is assumed to be equal to the flux in the stagnant film which, using Fick's law, gives a linear concentration profile within the film. This leads, with the additional use of Henry's law, to an expression for the flux involving the gas concentration at the base of the film (C_w), the partial pressure of the gas in the atmosphere (p_a), the solubility of the gas in seawater (α), and the piston velocity (K_w), i.e. $F = K_w(C_w - \alpha p_a)$. See Najjar [1991].

Standard Atmosphere An idealized, dry, steady-state approximation of the atmospheric state as a function of height that has been adopted as an engineering reference. It was not computed as a true average but rather approximates average atmospheric conditions at mid-latitudes. It is a piecewise continuous curve consisting of straight-line segments with breaks at 11, 20, 32, 47, 51 and 71 km. The surface temperature is 15° C and the gradients, starting from the surface, are -6.5, 0.0, 1.0, 2.8, 0.0,-2.8, and -2.0 K/km. Pressure variations can be found from this by combining the hydrostatic equation with the equation of state for dry air and integrating the result, i.e.

$$\frac{1}{p}\frac{dp}{dz} = \frac{-g}{RT}$$

with respect to height. See Minzner [1977].

standard density A conventional value for the density of mercury, adopted for the sake of uniformity in the conversion of pressure readings from units of pressure to units of height (or the converse). The value adopted by the WMO is the density at 0° C, i.e. 13.5951 gm/cm^3.

standard gravity A conventional value for the acceleration due to gravity, adopted for the sake of uniformity. The value adopted by the WMO is 980.665 cm/sec^2.

standard seawater See Culkin and Smed [1979], Culkin and Ridout [1998] and Bacon et al. [2000].

STARE Acronym for Southern Tropical Atlantic Regional Experiment, a project within BIBEX. STARE is an aircraft– and ground–based measurement program initiated in May 1990 by a committee of scientists from Europe, Brazil and the U.S. to investigate the sources of trace gases, their atmospheric transport, and the chemical processes in the atmosphere which lead to elevated levels of O_3, CO, and other trace gases over the southern tropical Atlantic Ocean. The field campaigns conducted under STARE were TRACE-A, SAFARI, and SA'ARI. See Andreae et al. [1996].

stationarity The property requiring that certain statistical properties of a stochastic process be invariant with respect to time. As some have noted, the strict satisfaction of this requirement is impossible if one lends creedence to the Big Bang theory of universal origin, although inroads can be made towards satisfaction on less strict and more pragmatic grounds.

stationary planetary wave Departures of the time average of the atmospheric circulation from zonal symmetry. They result from east-west variations in surface elevation and temperature associated with the continents and oceans. See Hartmann [1994].

statistical downscaling A procedure wherein local or regional climate characteristics are inferred from the output of GCMs that don't explicitly resolve such scales. Statistical relationships between observed local climate variables, e.g. surface air temperature, precipitation, etc., and observed large-scale predictors are developed and then applied to the same large-scale predictors in the GCM output to predict the local climate variables. This method has been shown to produce local temperature and precipitation change fields that were significantly different and had a finer spatial scale structure than those generated by directly interpolating large-scale GCM fields. See Houghton and Filho [1995].

statistically robust Statistical results which are relatively insensitive to the presence of a moderate amount of bad data or to inadequacies in the statistical model being used, and that react gradually rather than abruptly to perturbations of either. See Chave et al. [1987] for a discussion of this in relation to geophysical data.

STC 1. See Subtropical Convergence. 2. See South Trench Current.

STD Abbreviation for Salinity-Temperature-Depth. See CTD.

STEP A temperature profiler for measuring the oceanic thermal boundary layer at the ocean–air interface. See Mammen and von Bosse [1990].

steric anomaly Another name for the specific volume anomaly.

steric height In oceanography, a quantity introduced to determine the distance or depth difference between two surfaces of constant pressure. The steric height h is defined by

$$h(z_1, z_2) = \int_{z_1}^{z_2} \delta(T, S, p)\, \rho_0 dz$$

where z_1 and z_2 are the depths of the pressure surfaces, δ the specific volume anomaly, T the temperature, S the salinity, p the pressure, and ρ_0 a reference density. It has the dimension of height and is expressed in meters.

STERNA Expedition A two–ship study carried out in the Bellingshausen Sea, Southern Ocean from October to December, 1992. The STERNA project, carried out aboard the Royal Research Ships *James Clark Ross* and *Discovery*, was the final field–work phase of the NERC–funded BOFS (the major U.K. contribution to the IGBP JGOFS over the period 1989–1993). The study was originally developed to also include an investigation of biogeochemical fluxes during the spring ice–melt in the Greenland Sea, and was named STERNA after the migrations carried out by the tern *Sterna paradisea*, during which individual commonly spend alternate summers in each polar region. The northern component was cancelled because of major refitting work on the research ships, but the name was retained.

The objectives of the STERNA Expedition were:

- to determine ocean–atmosphere exchanges of radiatively active gases, and the factors influencing such fluxes, over a wide latitudinal range;
- to investigate the interactions among the biological, chemical and physical processes that control carbon fluxes in the euphotic zone;
- to assess the impact of sea–ice on biogeochemical fluxes; and
- to determine the export of biogenic material from the upper ocean.

See Turner and Owens [1995].

STF Abbreviation for Subtropical Front.

STFZ Abbreviation for Subtropical Frontal Zone.

still water level The level of the sea with high frequency motions such as wind waves averaged out. See also mean sea level.

STMW Abbreviation for Subtropical Mode Water.

stochastic process A reasonably strict definition of this (also called a random process) is a family of random variables indexed by t, where t belongs to some index set T (which may denote time, space, or whatever else one wishes). A more intuitive definition might call this the set of all possible outcomes of an experiment (this set also being called the ensemble) inherently involving some degree of randomness along with the mechanism by which individual outcomes, or realizations, selected.

stochastic resonance Stochastic resonance (SR) is a resonance-like response of a dynamical system to stochastic forcing. This phenomenon was first introduced by as a possible explanation of long-term climatic variability, but has since been widely observed and studied in many different fields of science. According to Paldor and Dvorkin [2000]:

> The essence of the phenomenon of SR in a dynamical system is the detection of a signal only due to the presence of noise. There are two main types of dynamical systems where SR was studied. The paradigm of the first one is an overdamped particle in a bistable potential well, which is rocked by a subcritical periodic forcing. Subcritical here implies that this periodic forcing, in itself, is insufficient to cause a particle to overcome the potential barrier, so that no switching between the two steady states can occur. When a small noise is added, there arises a nonzero probability for the particle to cross the potential barrier from the basin of one steady state to the other. As the noise amplitude grows, so does the

> number of crossings in a given time interval, until the hopping over the potential barrier reaches a saturation level at which point it is entirely dominated by noise. The ratio of the crossing probability (which can be calculated in several ways) to the noise amplitude will exhibit a global maximum at the saturation noise level where any further increase of the noise amplitude is not accompanied by an increase in the hopping probability.
>
> The second type of dynamical systems where SR was demonstrated has no periodic forcing. Instead, the signal in these systems is a coherent motion, which can be quantified into a signal-to-noise ratio (SNR) by resorting to the spectral density function.

Paldor and Dvorkin [2000] investigate SR as a mechanism for allowing cross-equatorial flow. See Moss [1994] and Gammaitoni et al. [1998] for reviews.

STOIC Acronym for Study of Tropical Oceans in Coupled Models, a project for the intercomparison of tropical ocean behavior in coupled ocean–atmosphere models on seasonal and interannual scales. It focuses on the Atlantic and Indian Ocean regions and their relationship to the Pacific Ocean. This project is designed to be complementary with the ENSIP program.

[http://www1.imgw.gdynia.pl/lustro_dkrz/clivar/stoic.html]

Stokes drift A mean Lagrangian current that can be generated by surface gravity waves. This is caused when water particle orbits are not closed in surface gravity waves. A steady drift results even if no mean currents are present. See Stokes [1847] for the original work and McWilliams and Restrepo [1991] for a review of possible effects on ocean circulation. See also Ianniello and Garvine [1975].

Stokes' theorem A theorem of geophysical importance in that it enables one to calculate whether there is a tendency for a flow to be circulating around a curve C, e.g. the Earth. It is mathematically expressed as

$$\int\int_S \eta \cdot (\nabla \times v)\, d\sigma \;=\; \int_C \tau \cdot v\, ds$$

where η is the normal vector to a surface S, τ the tangent vector to the curve C bounding S, and v the velocity vector field. This theorem, dealing with the integration of the curl of the velocity field (or, equivalently, the vorticity vector), allows us to evaluate whether or not the fluid is circulating (as well as rotating or spinning via the calculation of the vorticity vector itself). See Dutton [1986].

Stokes velocity A velocity in fluids that derives from the wave Reynolds stresses. See the Stokes wave entry and compare to Lagrangian velocity and Eulerian velocity. See Wunsch [1981], p. 345.

Stokes wave A wave theory whose theoretical development is the same as that for Airy waves except that second and higher order terms involving the wave height are retained. The expression for the wave surface elevation includes the Airy wave expression as the first term and a number of additional terms (depending on the order of the theory) that modify the elevation profile. The added terms generally enhance the amplitude of the wave crest and detract from the trough amplitude such that the crests are steeper and the troughs flatter.

The particle orbits in Stokes theory, unlike those in Airy wave theory, are not closed. This leads to a nonperiodic drift or mass transport in the direction of wave advance with an associated speed called the Stokes velocity. Stokes wave theory is generally limited in applicability to waves with steepness (i.e. H/L where H is the wave height and L the length) less than 1/100 in deep water, with even more severe restrictions in shallow water. See Komar [1976] and LeMehaute [1976].

Stommel, Henry Melson (1920-1992) A physical oceanographer who has been called "the most significant scientific contributor to the development of oceanography", Stommel's long and distinguished career was marked not only by many significant scientific contributions to his field but also by his unsurpassed ability to help others in their research efforts and to catalyze the development of major research programs.

His scientific contributions included proposing the use of T-S correlations to estimate missing salinity values from measured temperatures in order to calculate dynamic heights, the beta spiral method for determining absolute geostrophic circulation fields, the initiation of studies of double diffusion, and the development in the early 1960s (along with Arnold Arons) of a model of abyssal circulation that still serves as the fundamental basis for further investigations today. His most famous contribution was his 1947 paper in which he developed an analytical model showing how the westward intensification of ocean currents is caused by the variation of the Coriolis parameter with latitude (i.e. the beta effect).

His efforts to foster research programs included the genesis of the long-term measurements of the deep waters off Bermuda in 1953, the planning (with K. Yoshida) of a survey of the Kuroshio Current in the late 1960s, the proposal of a dense network of oceanographic stations off the coast of Bermuda that resulted in the Mid-Ocean Dynamics Experiment (MODE), and the motivation of the geochemistry community to carry out the GEOSECS program.

His work led to hundreds of publications under his name and with dozens of collaborators. His books included Science of the Seven Seas (1945), The Gulf Stream (1966), Kuroshio (co-edited with K. Yoshida in 1972), Volcano Weather (co-written with his wife Elizabeth in 1983), Lost Islands (1984), A View of the Sea (1987) and Introduction to the Coriolis Force (co-written with Dennis Moore in 1989). He inspired the 1981 festschrift entitled Evolution of Physical Oceanography: Scientific Surveys in Honor of Henry Stommel (edited by B. Warren and C. Wunsch). The Collected Works of Henry M. Stommel (edited by N. Hogg and R. Huang) were published in three volumes in 1995. This set includes introductory essays for each chapter written by his many colleagues as well as previously unpublished material, e.g. about a hundred pages from his unpublished autobiography. See Veronis [1992], Warren and Wunsch [1981], and Hogg and Huang [1995].

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

Stommel-Arons thermohaline circulation A model of global thermohaline circulation developed by Henry Stommel and Arnold Arons in a series of papers starting in 1961. This model combines sources of abyssal water at either pole, the turbulent mixing of warm surface water downward, the broad and slow upward flow of cold deep water, and deep western boundary currents in a dynamically consistent manner to provide a first-order explanation for that part of the general ocean circulation driven by spatial differences in the salinity, temperature and, therefore, density of sea water.

Stommel's demon In the theory of the ventilated thermocline, a deepening mixing layer allows only a narrow range of density to subduct at any geographical location. Only water of a particular density class is able to enter the thermocline at a given position. Stommel likened the process to the role of the demons in Maxwell's theory of gases. This has led to referring to the selection process of subducted density as Stommel's demon. See Stommel [1979], Williams et al. [1995] and Pedlosky [1996].

Stommel transitions A transition in which the state of a shallow coastal basin, or estuary, in an arid climate, switches suddenly between classical and inverse states. In the classical state the basin has a lower density than the ocean, while in the inverse state the reverse is true. The classical state is due to heating (no river flow is assumed), and the inverse state is hypersaline. A classical, well-mixed basin features gravitational circulation that flows from the basin to the ocean at the surface, and from the ocean to the basin at the bottom. In a Stommel transition these flow directions are reversed, as is the sign of the density gradient from oceean to basin. The possibilities were originally discovered by Stommel [1961]. After Hearn and Sidhu [2003].

storm surge A phenomena wherein sea level rises above the normal tide level when hurricanes or tropical storms move from the ocean along or across a coastal region. Technically, this is defined as the difference between the actual sea (tide) level under the influence of a meteorological disturbance (storm tide) and the level which would have been reached in the absence of the meteorological disturbance. This sea level rise can consists of three components, the first of which results from low barometric pressure, i.e. the so-called inverse barometer effect, where lower atmospheric pressure on the surface of the water allows it to rise. The second component is wind set-up where the winds drag surface water to the shore where it piles up. The third component of the rise is due to coupled long waves where the peak of the wave coincides with the shoreline. See Wiegel [1964] and Heaps [1967].

Strait of Gibraltar A shallow strait that separates the eastern Atlantic Ocean from the Mediterranean Sea. See Gascard and Richez [1985].

Strait of Hormuz A strait joining the Persian Gulf to the west and the Gulf of Oman to the east. It is located at about 56° E and 27° N.

Strait of Magellan According to Strub et al. [1998], "Despite the strong southwesterly winds characteristic of the area, tides are the dominant forcing function for the currents, especially on the Atlantic side." See Medeiros and Kjerfve [1988] and Panella et al. [1991].

Strait of Messina A narrow strait between between the southwestern tip of Italy and Sicily that connects the Tyrrhenian Sea in the north with the Ionian Sea to the south. It is a narrow channel whose smallest cross–sectional area is 0.3 km^2 in the sill region where the mean water depth is 80 m. The depth increases more rapidly in the southern than in the northern part, with the depths 15 km from the sill to the north and south being 400 m and 800 m, respectively. Both Tyrrhenian Surface Water (TSW) and Levantine Intermediate Water (LIW) are present year–round, separated at a depth of around 150 m. A seasonal thermocline is also present for most of the year with the difference across this interface generally much larger than than across the TSW/LIW boundary. Large gradients of tidal displacements are present despite generally small tides in the Mediterranean since the predominantly diurnal tides to the north and south are approximately in phase opposition. The tides combine with the topographic restrictions to allow current velocities to reach as high as 3.0 m s^{-1} in the sill region. There is also a weak mean exchange flow directed toward the Ionian Sea with a velocity of about 0.10 m s^{-1} in the surface layer, and toward the Tyrrhenian Sea at about 0.13 m s^{-1} in the lower layer. See Bignami and Salusti [1990].

Straits of Sicily A strait located at around 12° E in the Mediterranean Sea that separates the eastern and western basins. Its shallow sill separates the deep waters of the Tyrrhenian Sea to the northwest from those of the Ionian Sea to the southeast. See Fairbridge [1966].

stratification In oceanography, the vertical density structure resulting from a balance among atmospheric heating, surface water exchange, freezing, stirring and diffusion of heat, and the horizontal and vertical motion (advection) of waters with different temperature and salinity characteristics.

stratified estuary One of four principal types of estuaries as distinguished by prevailing flow conditions. This type is stratified with a halocline between the upper and lower portions of the water column of nearly constant salinity. The James and Mersey estuaries are examples of this type.

stratified fluid See Fernando [1991].

stream function wave theory A surface gravity wave theory wherein the wavelength L, coefficients $X(n)$, and the the value of the stream function on the free surface ψ_η are numerically determined given the wave height z, the water depth h and the wave period T. The expression for the stream function ψ in a reference frame moving with the speed of the wave C is

$$\psi = \left(\frac{L}{T} - U\right) z + \sigma_{n=1}^{NN} X(n) \sinh\left[\frac{2\pi n}{L}(h + z)\right] \cos\left(\frac{2\pi n x}{L}\right).$$

The unknowns are determined to best satisfy the dynamic free surface boundary condition in the least squares sense.

The advantages of this wave theory are that it is one theory that can be applied to the full range from shallow to deep water and from small to breaking wave heights, and that fairly comprehensive tables are available for design purposes (and, more recently, computer programs). The original irrotational version of the theory has been extended to some rotational flows. Other representations in terms of the stream function or velocity potential have also been developed since the stream function theory was first described in 1965. See Dean [1990].

streaming velocity A small first–order mean velocity near the bottom in the direction of wave motion that occurs in the presence of the vortical bottom boundary layer in water of finite depth. See Phillips [1977] and Longuet-Higgins [1986].

strength of ebb In the description of tides, the magnitude of the ebb current at the time of maximum speed. This is usually associated with lunar tide phases at spring tides near perigee or with maximum river discharge. This is also known as ebb strength.

STRESS Acronym for Sediment Transport Events over Shelves and Slopes. See Sherwood et al. [1994].

STREX Acronym for Storm Transfer and Response Experiment, a joint meteorological–oceanographic experiment carried out in the northwestern Pacific Ocean during November and December 1980. The purpose was to examine the response of the atmospheric and oceanic boundary layers to the passage of storms. See Fleagle et al. [1982], Paduan and DeSzoeke [1986] and Geernaert [1990].

Strouhal number A dimensionless number or parameter proportional to the reciprocal of vortex spacing. It is expressed as a number of obstacle parameters and generally used in momentum transfer calculations, e.g. Von Karman vortex street and unsteady flow calculations. It is expressed as:

$$S_r = \frac{f\,L}{V}$$

where f is a frequency, L a characteristic length scale, and V a characteristic velocity.

SUAVE Acronym for Submersible System Used to Assess Vented Emissions, an integrated instrument system consisting of an advanced chemical analyzer and an array of physical property sensors. SUAVE is used to investigate the chemical properties of hydrothermal vents. The chemical analyzer is based on the principles of flow analysis and colorimetric detection, and its main components include:

- a 12–channel peristaltic pump allowing the simultaneous operation of up to four of the chemical methods employed;
- three miniature 3–way pinch valves to allow selection between sample intake and up to three *in situ* standards;
- 8 reagent reservoirs and 4 standard reservoirs, with an auxiliary bin with a 12 bottle capacity for extended deployments;

- an intake filter to prevent clogging of the sample intake, and manifolds for mixing samples before testing; and
- six LED–photodiode detector channels.

The auxiliary sensors include:

- a CTD including an SBE 4 conductivity sensor and an SBE 3 temperature sensor;
- a Sea Tech 25 cm transmissometer and a Sea Tech LS6000 Light Scattering Sensor; and
- glass enscapsulated thermisters.

SUAVE was built in 1991 and has been deployed over 200 times to date, accumulating more than 1500 hours of in situ analysis time, all directed toward hydrothermal vent research. Over 1000 km of ridgecrest with hydrothermal plumes have been investigated, with the thermochemical attributes determined with spatial detail seldom achieved anywhere on the sea floor. See Massoth et al. [1992].

`[http://www.pmel.noaa.gov/vents/geochem/suave/about_suave.html]`

Subantarctic Front In physical oceanography, a region of rapid transition in the Southern Ocean (S)) between the Polar Frontal Zone (PFZ) to the south and the Subantarctic Zone (SAZ) to the north. Its position is generally identified by the rapid northward sinking of the salinity minimum associated with the Antarctic Intermediate Water (AAIW) from near the surface in the PFZ (S $<$ 34) to depths greater than 400 m in the SAZ (S $<$ 34.30). The property indicators within the front are S $<$ 34.20 at Z $<$ 300 m, $\theta >$ 4-5° at 400 m, and $O_2 >$ 7 ml/l at Z $<$ 200 m. The SAF is one of three distinct fronts in the Antarctic Circumpolar Current (ACC), the others being (to the south) the Polar Front (PF) and the Southern ACC Front (SACCF). This has also been called the sf Australasian Subantarctic Front. See Orsi et al. [1995].

Subantarctic Mode Water (SAMW) In physical oceanography, a water mass in the Subantarctic Zone of the Southern Ocean. This is one type of Subpolar Mode Water. The SAMW is the deep surface layer of water with uniform temperature and salinity created by convective processes in the winter. It can by identified by a temperature of around -1.8° C and a salinity of around 34.4 and is separated from the overlying surface water by a halocline at around 50 m in the summer. Although it is not considered to be a water mass, it contributes to the Central Water of the southern hemisphere, and is additionally responsible for the formation of AAIW in the eastern part of the south Pacific Ocean. This has also previously been called Winter Water. See McCartney [1977], Piola and Georgi [1981] and Tomczak and Godfrey [1994].

Subantarctic Surface Water (SSW) A water mass found in the Southern Ocean between the Subtropical Front (STF) and the Subantarctic Front (SAF) and above the salinity minimum of the Antarctic Intermediate Water (AAIW). At the surface the SSW is fresher than the surface waters of the Polar Frontal Zone (PFZ) in the Drake Passage, although by the time it reaches the Greenwich Meridian surface salinities are 0.3–0.4 higher than in the Drake Passage and more saline than those in the PFZ. Below the surface the SSW shows monotonically decreasing temperature as well as a maximum in salinity and a minimum in oxygen, both of the latter induced by the underlying AAIW. See Whitworth and Jr. [1987].

Subantarctic Upper Water (SAUW) In physical oceanography, a water mass located in the Subantarctic Zone of the Southern Ocean. It is characterized hydrographically by temperatures ranging from 4-10° C in the winter and 4-14° C in summer, with salinities between 33.9 and 34.9 and reaching as low as 33.0 in the summer as the ice melts. See Tomczak and Godfrey [1994], p. 82.

Subantarctic Zone The name given to the region in the Southern Ocean between the Subantarctic Front to the south and the Subtropical Front to the north. This zone is characterized by the presence of SAUW at and near the surface. The SAZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being (to the south) the Polar Frontal Zone (PFZ), the Antarctic Zone (AZ) and the Continental Zone (CZ). See Tomczak and Godfrey [1994] and Orsi et al. [1995].

Subarctic Intermediate Water (SIW) In physical oceanography, this is a water mass which originates from the Polar Front formed between the Kuroshio and the Oyashio in the western North Pacific Ocean. It is formed chiefly by the process of mixing of surface and deeper waters and subducted into the subtropical gyre, filling the northern Pacific south of 40° N from the east. This is one of the few water masses whose formation process has little to do with atmosphere-ocean interaction. It is characterized by a salinity minimum ranging from about 300-1000 m depth and a large east-west salinity gradient in the South Pacific. See Tomczak and Godfrey [1994] (p. 161) and Ahran [1990].

subduction In physical oceanography, a process whereby Ekman pumping injects surface water into intermediate depths along isopycnal surfaces. This process is responsible for the formation of the water masses in the permanent thermocline. Although it is a permanent process, water mass formation occurs only in late autumn and winter due to variations in the seasonal thermocline. See Tomczak and Godfrey [1994].

Subduction Experiment An experiment that took place in the subtropical North Atlantic near the eastern flank of the Bermuda/Azores atmospheric high pressure system from June 1991 to June 1993. That region is a preferred one for convergence of the wind–driven or Ekman circulation which leads to subduction, the process by which mixed layer water is injected into the main thermocline. See Spall et al. [2000].

`[http://uop.whoi.edu/data/subduction/subduction.html]`

subjective analysis In meteorology, the name given to synoptic weather charts prepared by hand since the resulting diagnosis or analysis relied extensively on the subjective judgment of the preparer. Compare to objective analysis. See Daley [1991].

submarine valley See valley.

Subpolar Mode Water (SMW) See McCartney and Talley [1982].

subsurface countercurrent (SSCC) Another name for the Tsuchiya jets found in the equatorial Pacific Ocean.

subtropical Of the subtropics.

Subtropical Convergence The name given by Deacon (Deacon [1933], Deacon [1937]) to the hydrographic boundary between the Southern Ocean and subtropical waters to the north. This was replaced by the term Subtropical Front (STF) in the mid-1980s.

Subtropical Countercurrent An eastward flowing current found in the region from 20-26° N. In geostrophic current calculations these currents extend to the bottom of the thermocline and occasionally to 1500 m, while they've been identified in ship drift data with speeds reaching 0.15 m/s. They do not exist east of Hawaii and, given also the fact that they are in the middle of the subtropical gyre, are thought to be caused by a modification of the Sverdrup circulation by those islands. No satisfactory explanation has as yet been advanced. See Tomczak and Godfrey [1994] and Kubokawa and Inui [1999].

Subtropical Front (STF) In physical oceanography, a region of pronounced meridional gradients in surface properties that serves as the boundary between the Southern Ocean and the waters of the subtropical regime to the north. This was originally called the Subtropical Convergence (DTC) by Deacon but the newer terminology arose in the mid-1980s. This is generally a subduction region for various types of Central Water.

The STF separates the Subantarctic Surface Water (SASW) to the south from the Subtropical Surface Water to the north. The surface hydrographic properties of the STF include a rapid salinity change from 35.0 to 34.5 and a strong temperature gradient (from 14-10° C in winter and 18-14° C in summer) as one crosses from north to south. At 100 m its approximate location is within a band across which temperatures increase northward from 10 to 12° C and salinities from 34.6 to 35.0, with the salinity gradient usually the more reliable indicator. The position as well as the intensity of sinking or rising motion in the STF is more variable than in any other front or divergence in the Southern Ocean. See Tomczak and Godfrey [1994], Tchernia [1980] and Orsi et al. [1995].

Subtropical Frontal Zone (STFZ) A broad zone up to 4°–5° latitude wide consisting of several cores or fronts interspersed by zones of relatively homogeneous waters. The STFZ is thought to be a more accurate desciption of what was formerly thought to be single front called the Subtropical Front, with the STFZ boundaries being the North Subtropical Front (NSTF) and the South Subtropical Front (SSTF). See Belkin and Gordon [1996].

subtropical gyre A clockwise/counterclockwise circulation in the northern/southern hemisphere that is forced by the wind and features western intensification in the form of a western boundary current. In the northern hemisphere the gyres span the width of the oceans and extend from about 10 to 40 °N with the boundary currents in the Atlantic and Pacific called, respectively, the Gulf Stream and the Kuroshio. There are analogous features in the southern hemisphere. The polar boundaries between these and the subpolar gyres coincide with the latitude at which the curl of the wind stress vanishes, the latter being largely the mechanism of causation. See Schmitz and McCartney [1993].

Subtropical Mode Water (STMW) A type of water mass found along the equatorward side of the separated western boundary currents of each of the subtropical gyres. They are identified as a layer of reduced stratification found below the seasonal thermocline and above the main thermocline. They are formed by winter mixing and cooling, with restratification occurring in the surface layer during summer. The STMW thermostads can be traced for a considerable distance away from the formation regions following the equatorward flow of the gyre interiors.

In the North Pacific, deep convection occurs offshore of both the Kuroshio and the Kuroshio Extension in winter. Vertically homogeneous water is formed in the deep convective mixed layer which remains as a pycnostad between the seasonal and main thermoclines through the succeeding surface warming. This pycnostad is found over a much wider region in the western subtropical North Pacific than its formation area, and the water therein is the North Pacific STMW.

According to Suga and Hanawa [1995]:

> The Kuroshio Countercurrent composing the Kuroshio recirculation system advects STMW formed in the wintertime thick mixed layer immediately off the Kuroshio Current and the Kuroshio Extension. During the non–large–meander period, the recirculation system has a single anticyclonic gyre centered near 30°N, 137°E and advects STMW formed off the Kuroshio Extension, or east of 140°E, to the meridian of 137°E south of Honshu within a few months. Heavier STMW formed farther eat is advected along an outer path, taking several months longer. During the large–meander period, the recirculation system is separated into two anticyclonic gyres west and east of 140°E, and no substantial westward advection of

> STMW across the 140°E meridian occurs, while minor advectionof STMW along the outer path can occur. The climatological hydrography also suggests that the STMW formed in one winter will be dissipated considerably within a year or so.

In the South Pacific, the STMW thermostad is less pronounced than in either the North Pacific or North Atlantic. According to Roemmich and Cornuelle [1992], the South Pacific STMW ...

> ... is a thermostad, or minimum in stratification, having temperatures of about 15–19°C and vertical temperature gradient less than about 2°C per 100 m. Typical salinity is 35.5 psu at 16.5°C. The STMW layer is formed by deep mixing and cooling in the eastward–flowing waters of the separated East Australia Current (EAC). Surface mixed layers are observed as deep as 300 m north of New Zealand in winter, in the center of a recurring anticyclonic eddy.

See Masuzawa [1969], McCartney [1982], Bingham [1992], Roemmich and Cornuelle [1992], Hanawa and Suga [1995], Suga and Hanawa [1995] and Hautala and Roemmich [1998].

subtropics Generally the part of the Earth's surface between the tropics and the temperate regions, or between about 40° N and S.

Sulawesi Sea Part of the Australasian Mediterranean Sea centered at approximately 122° E and 3° N. It is surrounded by the Sulu Archipelago and Mindinao to the north, Kalimantan to the west, the Makassar Strait and Sulawesi to the south, and the north part of the Moluccan Sea to the west. It covers about 280,000 sq. km with the deepest part being around 6200 m just southwest of Mindanao. The entire Sulawesi is mostly a deep, flat (4600-5200 m deep) plain with steep sides.

The deep water Pacific Ocean water that passes through the northern Molucca Sea and enters the Sulawesi over a 1400 m deep sill. This water eventually passes through the Makassar Strait and on into the Flores Sea to the south. The surface temperatures range between 28° C in April and 27° C in February, and the salinities range through four patterns during the year (i.e. 31-34 from SW to NE during Dec.-Feb., 32.8-33.9 from SW to NE during Mar.-May, 34 from Jun.-Aug., and 33.5-34.1 from NW to SE during Sep.-Nov.).

The monsoon pattern dominates the wind forcing, with the winds blowing from the north to northeast during the northern winter and more weakly from the south and southwest during the summer. This creates a surface current directed from Mindanao towards the Makassar Strait during the summer. This regime is largely maintained through the winter although westward currents are additionally found along Sulawesi. See Fairbridge [1966].

Sulu Sea A regional sea contained within the Australasian Mediterranean Sea at the southwestern edge of the Pacific Ocean. It is centered at about 120° E and 8° N and connected to the Sulawesi Sea to the southeast via many passages through the Sulu Archipelago, the Bohol Sea to the east, and the South China Sea to the west and northwest chiefly via the Mindoro, Linapacan, North Balabac, and Balabac Straits. It borders the Philippine islands of Mindanao, Negros, and Panay to the east, Mindoro and the Calamin Group to the north, Palawan to the west, and the aforementioned Sulu Archipelago to the southeast. The Malaysian portion of the island of Borneo lies to the southwest.

sumatra A squall that occurs in the Malacca Strait, blowing from between southwest and northwest. These usually occur at night and are most frequent between April and November. They are generally accompanied by thunder and lightning and torrential rain, and their arrival is accompanied by a sudden fall of temperature.

Sunda Sea A marginal sea in the southwest Pacific Ocean. This is a name sometimes given to the combined areas of the Java Sea and the shelf sector of the South China Sea.

Sunda Shelf One of the largest continental shelves in the world. It covers around 1,800,000 km^2, is centered around 108° E and 2° N, and occupies the regions of the Java Sea, the southern parts of the South China Sea, and the Gulf of Thailand. See Fairbridge [1966].

SUPER Acronym for Subarctic Pacific Ecosystem Research, a research program in the north Pacific. See Miller [1993].

SURATLANT A French project to make systematic hydrographic observations in the North Atlantic subpolar gyre. Observations are made with the merchant ships Godafoss (between Iceland and the U.S. sine 1993) and Nuka Arctica (between Denmark and Greenland since May 1997). The sampling is mostly for temperature with XBTs and for sea surface salinity.

[http://www.obs-mip.fr/omp/legos/english/rech/var/var4.htm]

surf beat The rising and falling of the water level in the surf zone at intervals in the vicinity of 2 to 5 minutes, especially noticeable on a flat beach. This is caused by the pattern of incoming waves being such that groups of high waves and low waves follow each other at the same intervals. This is in turn due to the interaction of wave groups with slightly different frequencies, a process that leads to a much longer envelope or beat frequency modulated the short wavelength waves. See Wiegel [1964].

surf zone The portion of the nearshore zone in which borelike translation waves occur following wave breaking. It extends from the inner breakers shoreward to the swash zone. See Komar [1976].

surface energy balance The balance of energy terms at the ocean surface in a climate model. The terms are the absorbed solar flux (S), the downward infrared flux (Sd), the upward infrared flux (Su), the sensible heat flux (H), and the latent heat flux (LE). The balance can be expressed as

$$S + Sd - Su - H - HE = 0.$$

surface renewal theory A method for evaluating turbulent fluxes at the ocean surface. See Clayson et al. [1996].

surface Reynolds number See Kagan [1995].

surface scattering layer A group of marine organisms in the surface layers of the ocean which scatters sound. The layer may extend from the surface to depths as great as 600 feet, and several layers or patches may comprise the layer. There are also shallow and deep scattering layers.

surface tension More later.

SURVOSTRAL A French project started in the austral summer of 1992/1993 for monitoring climate variability at high latitudes. The objective of the program is to monitor the seasonal and interannual changes in upper ocean thermal content and salinity, as well as changes in the position, structure and transport of the polar fronts between Tasmania and Antarctica. SURVOSTRAL uses the French Antarctic supply ship Astrolabe to make measurements between Hobart, Tasmania and the French base Durmont D'Urville. Sampling is performed with XBTs and XCTDs to obtain vertical profiles of temperature and salinity, and a thermosalinograph is used to obtain continuous measurements of surface salinity and temperature.

[http://www.obs-mip.fr/omp/legos/english/rech/var/var4.htm]

SUW Abbreviation for Subarctic Upper Water.

Sverdrup, Harald Ulrik (1888–1957) Sverdrup started his scientific career by enrolling as a student in "physical oceanography and astronomy" at the University of Oslo, where his early interests leaned towards the latter. This changed when he received an assistantship to study under Professor V. Bjerknes, under whom he published twenty papers and a dissertation entitled Der nordatlantische Passat (in which he calculated energy and momentum budgets for the North Atlantic trade winds) over the next six years.

He took charge of scientific work on Roald Amundsen's North Polar expedition at the age of 29 in 1918. He did not return until late in 1925 as the expedition ship Maud attempted to duplicate the voyage (and ice drift) of the Fram. At one point during the seven years of this expedition Sverdrup left the ship to spend eight months with the nomadic Chukchi tribe of northeastern Siberia, an experience he later recounted in a book (which has never been translated into English). The collected observations of the expedition were a notable achievement, with Sverdrup's most significant contribution being a paper entitled "Dynamics of tides on the North Siberian Shelf."

Sverdrup succeeded V. Bjerknes as the Chair of Meteorology at the Geophysical Institute in Bergen, Norway upon his return, and he additionally became a research professor at the Christian Michelson Institute in Bergen in 1931. The ten years following his return from the Maud expedition were the most productive of his career, with his accomplishments including publishing over fifty papers on results from the expedition, spending two half-year periods in Washington, D.C. to help analyze the results from a cruise of the Carnegie, taking charge of the scientific work on the Wilkins Ellsworth North Polar Expedition aboard the submarine Nautilus in 1931, and spending two months in the snow fields of Spitzbergen which resulted in the first quantitative heat budget of glaciers.

In 1936 he accepted the Directorship of the Scripps Institution of Oceanography in La Jolla, California, leaving the Michelsen Institute for three years, although the war resulted in his not returning to Norway until 1948. At Scripps Sverdrup initiated the Marine Life Research Program (still ongoing today), organized the first systematic course in oceanography given in the United States, and taught and collaborated such future reknowned scientists as Gifford Ewing, Donald Pritchard, Roger Revelle, Robert Reid and Walter Munk. He spent a great deal of time and effort during the pre-war years collaborating with Martin Johnson and Richard Fleming to write the classic text The Oceans, with his chapter on the water masses and currents of the oceans still one of the best reviews of the subject available.

He returned to Norway in 1948 at the age of sixty and retired from research, dividing his time variously as Director of the Norsk Polar Institut, the President of the ICES, Prorector and Director of the Summer School for foreign students at the University of Oslo, and as Chairman of a committee for reorganizing the Norwegian educational system. He continued in these activities until a stroke weakened him and led to his death in 1957.

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

Sverdrup A unit of transport used in oceanography equivalent to 10^6 m^3s^{-1} and abbreviated as Sv.

Sverdrup balance A vorticity balance in which meridional advection in the presence of the planetary vorticity gradient is balanced by the stretching of fluid columns. It is most simply stated as

$$\beta v = f\frac{\partial w}{\partial z}$$

where β is the meridional gradient of the Coriolis parameter f, v the meridional velocity, and w the vertical velocity. This indicates that the stiffness imparted to a large scale fluid by planetary rotation leads to the conservation of the separation of marked fluid surfaces measured parallel with the rotation vector.

Sverdrup transport The net meridional flow of mass in the interior of the ocean gyres away from the lateral boundaries.

SVP Abbreviation for Surface Velocity Program, a WOCE project.

Swallow float A neutrally buoyant float used as a subsurface drifter to study mesoscale circulation and small-scale motions in the oceans. Swallow floats approximately track isobaric surfaces, and as such are not strictly Lagrangian followers of water parcels.

Rossby et al. [1985] describe a modified version of the float that follows isopycnal rather than isobaric surfaces, and thus better approximates Lagrangian motion. This is accomplished by the addition of a compressor within the float that adjusts its effective compressibility to approximate that of seawater. See Swallow [1955] and Rossby et al. [1985].

swamp ocean The simplest ocean model used in coupled model simulations. SSTs are computed but from surface energy balance (local effects) only, i.e. there is no accounting for heat storage (temporal) or ocean current (nonlocal) effects. Only mean annual forcing can be applied when a swamp ocean is used since the lack of the capability to store heat in the oceans would allow sea ice to freeze into the mid-latitudes in the winter hemisphere. On the plus side, the dominant equilibration time is that of the atmosphere since the ocean surface response time is almost instantaneous.

SWADE Acronym for Surface WAve Dynamics Experiment, an experiment performed in the fall of 1990 off the coast of Virginia which was primarily concerned with the evolution of the directional wave spectrum, wind forcing and wave dissipation, the effect of waves on air-sea coupling mechanisms, and the microwave radar response of the ocean surface. The scientific goals were to understand the dynamics of the evolution of the wave field in the open ocean; to determine the effect of waves on the air-sea transfers of momentum, heat and mass; to explore the response of the upper mixed layer to atmospheric forcing; to investigate the effect of waves on the response of various airborne microwave systems; and to improve numerical wave modeling. See Weller et al. [1991] and Willemsen [1995].

SWAMP 1. Acronym for Sea Wave Modeling Project. See group [1985]. 2. Acronym for Southwest Area Monsoon Project.

SWAN Acronym for Simulating WAves Nearshore, a third–generation wave model that computes random, short–crested, wind–generated waves in coastal regions and inland waters. The physics accounted for in the SWAN model includes:

- wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents, and nonstationary depth;
- wave generation by wind;
- three– and four–wave interactions;
- whitecapping, bottom friction, and depth–induced breaking;
- wave–induced setup;
- propagation from laboratory up to global scales; and
- transmission through and reflection from obstacles.

A copy of the FORTRAN code is available upon registration. See Booij et al. [1999].

`[http://swan.ct.tudelft.nl/home.htm]`

SWAPP Acronym for Surface WAve Processes Program, an experiment conducted off the coast of California in 1990 and concerned with wave breaking and the interaction between surface waves and upper ocean boundary layer dynamics. The scientific goals were to improve the understanding of processes involved in wave breaking (e.g. what determines the occurrence of breaking in space and time, the processes of bubble and fluid injection, the generation of turbulence in the upper layer of the ocean by waves) and in determining the structure of the upper ocean (e.g. the role of surface waves in air-sea transfers and in mixed layer dynamics, with particular emphasis on the structure and dynamics of Langmuir circulation. See Weller et al. [1991].

SWARM95 Acronym for Shallow Water Acoustic Random Media 1995 experiment, an ONR sponsored joint operation between the NRL Acoustic Signal Processing Branch and Woods Hole. The goal is to explore the effects on acoustic propagation of random ocean environments in the water column and the bottom sediments. The experiment was performed on the continental shelf about 100 miles of the coast of New Jersey in the Hudson Canyon area in July–August 1995, and deployed a significant number of acoustic and oceanographic equipment to characterize the acoustic propagation environment. See apel:1997.

[http://www.oal.whoi.edu/swarm.html]

swash zone The portion of the nearshore zone in which the beach face is alternately covered by the uprush of wave swash and exposed by the backwash. See Komar [1976].

Swedish Deep Sea Expedition A research cruise taking place from 1947–1948 aboard the vessel "Albatross," The expedition was headed by Hans Pettersson who also edited the ten–volume series of research reports published starting in 1957. The contents of the reports were:

1. The ship, its equipment, and the voyage
2. Zoology
3. Physics and chemistry
4. Bottom investigations
5. Sediment cores from the East Pacific
6. Sediment cores from the West Pacific
7. Sediment cores from the North Atlantic Ocean
8. Sediment cores from the Mediterranean Sea and the Red Sea
9. Sediment cores from the Indian Ocean
10. Special investigations

See Guberlet [1964].

SWIM Acronym for Shallow Water Intercomparison of wave prediction Models, and extension of the SWAMP project to shallow water. See group [1985].

SWIMS Acronym for Shallow Water Integrated Mapping System, an instrument developed by the APL.

SWIMSAT Acronym for Surface Waves Investigation and Monitoring from SATellite, a project to design, develop and use systems to measure directional wave spectra from satellites using the real–aperture technique rather than the traditional SAR technique. The system is a dual–beam radar (capable of nadir viewing and off–nadir viewing at an angle of 10°) operating in the K_μ frequency band (13.565 GHz) and flying on a polar–orbiting satellite at an altitude of 450–600 km. The nadir beam is operated to measure significant wave height and wind speed in the same way as spaceborne altimeters. An innovative feature is its operation in off–nadir viewing mode by tilting the radar beam to measure wave spectral characteristics. The principle is based on measuring modulations of the radar backscatter coefficient inside the swatch covered by the tilted beam. The tilted beam is rotated to perform a conical scan around the vertical axis to acquire measurements in all directions of wave propagation. SWIMSAT should be capable of measuring wave spectral properties under wind–sea (provided the dominant wavelength is greater than about 70 m) and swell conditions (provided the significant wave height is greater than 1.5–2 m, depending on wind). See Hauser et al. [2001].

SWODDY Acronym for Slope Water Oceanic eDDY, a term coined in Pingree and LeCann [1992] to describe jet–like extensions of the slope current off northern Spain and France in the southern Bay of Biscay in the winter that develop into anticyclonic eddies with an upper core of slope water. A typical SWODDY has a lifetime of about a year and, if not trapped by topography, propagates or advects westwards out of the Bay of Biscay at typical speeds of about 2 cm s^{-1}.

SWT Abbreviation for southern warm tongue, a tongue of relatively warm water located at the eastern boundary of the WPWP. It is located at around 10 ° S. See Ho et al. [1995].

SYMPLEX An experiment (also called ERS–SYMPLEX) carried out in the Sicily Channel during April–May 1996 to compare sea level anomalies obtained from ERS–1/2 and TOPEX/POSEIDON altimeters with in situ data. A dense network (about 5 km spacing) of XBT and CTD casts were made along all ERS–1/2 and TOPEX/POSEIDON tracks at the same time of each satellite pass.

`[http://earth.esa.int/symposia/data/santoleri2/]`

SYNOP Acronym for the SYNoptic Ocean Prediction experiment, an observational and modeling experiment designed to understand the physics governing large amplitude meandering of the Gulf Stream and the shedding and interactions of rings east of Cape Hatteras to the Grand Banks. The moored instrument program consisted of four arrays:

- the Inlet Array near Cape Hatteras, consisting of 9 inverted echo sounders (IES) and 5 deep current meters, and designed to monitor the inflow conditions as the Gulf Stream leaves the continental margin;
- the Central Array near 68°W, consisting of 24 IESs (12 with bottom pressure gauges) and 12 tall current moorings, each with four levels (400, 700, 1000 and 3500 m) instrumented, with three having upward–looking ADCPs above the topmost current meter;
- the East Array near 55°W; and
- the 50°W array.

Observations were made between 1987 and 1990.

A significant finding of SYNOP was the presence of strong, deep cyclones and anticyclones beneath the Gulf Stream, with the spin–up of the deep flow field occuring during the passage of the steep meander crests and troughs of the Stream. Velocities at 3500 m were observed to be as high as 35-40 cm s^{-1} during the strong events. See Tracey and Watts [1991].

`[http://mail.po.gso.uri.edu/dynamics/SYNOP/]`

synoptic Descriptive of data simultaneously obtained over a large area.

synoptic mean circulation In oceanography, the time-averaged flow field obtained in a coordinate system whose axes are parallel and perpendicular to the instantaneous axis of a particular strong current such as the Gulf Stream. This coordinate system can and does change with time. Compare to Eulerian mean circulation. See Schmitz and McCartney [1993].

systematic errors Stable errors in model simulations that result from model deficiencies in the component (e.g ocean and atmosphere) models alone, additive errors from the component models after they are coupled, or errors that are produced by the coupled interactions between imperfect component models. Sometimes called climate drift. See Meehl [1992].