potential applications exist for ground strengthening, mitigation of liquefaction, and seepage or erosion control. The new microbial technology provides a more cost-effective, sustainable, and environmentally friendly solution to ground improvement. However, a lot of research studies still need to be done before this new approach can be developed into common practice.

For background information *See* BACTERIA; CEMENT; ENGINEERING GEOLOGY; FOUNDATIONS; GROUT; MICROBIOLOGY; SAND; SOIL; SOIL MECHANICS in the McGraw-Hill Encyclopedia of Science & Technology. Jian Chu; Volodymyr Ivanov; Jia He

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Arctic Ocean freshwater balance

As part of the global hydrological cycle, the Arctic Ocean plays a central role by receiving, transforming, storing, and exporting freshwater (FW) from rivers, precipitation, sea-ice melt and growth, and from the Pacific and Atlantic oceans via straits. Changes in the FW balance influence the extent of the sea-ice cover, the surface albedo, the energy balance, the temperature and salinity structure of the water masses, and biological processes in the Arctic Ocean and high-latitude seas. Within the entire Arctic Ocean, the FW at the surface maintains a strong density stratification that prevents release of significant deep-ocean heat to the sea ice and atmosphere. Loss of this FW cap could have grave consequences for the climate, resulting in massive sea-ice melt. Subsequent reestablishment of the FW cap and strong stratification could then result in climate cooling as new sea-ice formation ensues.

Under stable climate conditions, a balance of FW sources and sinks is necessary to maintain unchanging ocean circulation, heat and salt fluxes, and ocean stratification. However, under natural climate variability from seasonal to decadal timescales, the Arctic Ocean can accumulate significant volumes of FW during several seasons or years and then release this water to the North Atlantic resulting in so-called "great salinity anomalies" that influence ocean circulation and climate conditions in the Northern Hemisphere.

Freshwater balance: sources and sinks. The total FW content of the Arctic Ocean varies from 85,000 to 95,000 km^3, depending on the study, and FW is unevenly distributed in the ocean due to influences of wind forcing and FW sources and sinks (**Fig. 1**). In the ocean, FW is a relative term, and is typically considered the salinity anomaly relative to a reference salinity of 34.8 g/kg, which corresponds to the mean salinity of the Arctic Ocean. Change in FW is thus a measure of how much liquid FW was accumulated or lost from the water column bounded by the 34.8 isohaline (constant salinity surface). Low salinity sources that make up the FW pool include river runoff, precipitation, sea-ice melt, and waters of Pacific origin that penetrate the Arctic through the Bering Strait. High salinity sources are saline waters of Atlantic Ocean origin that penetrate the Arctic via the Fram Strait and the Barents Sea. Very salty water (brine) rejected to the ocean during sea-ice formation is an additional source of high salinity.

Liquid FW and solid (sea ice) components leave the Arctic Ocean with the East Greenland current

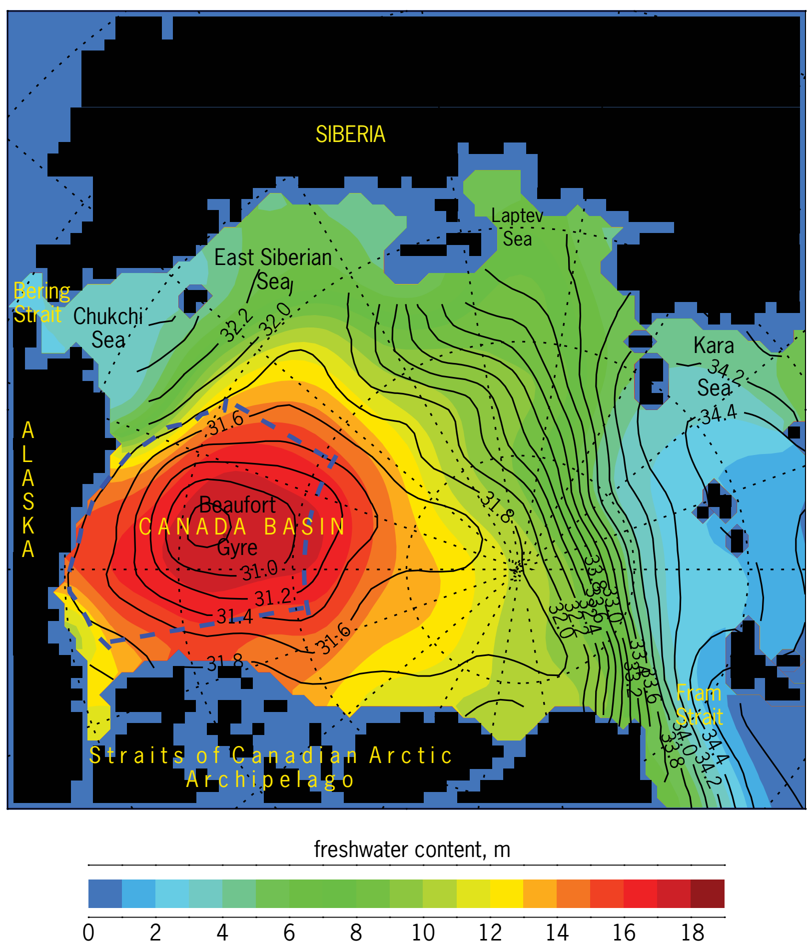

Fig. 1. Climatology of FW content in the Arctic Ocean (shown in colors). Solid lines depict mean 1950–1980 salinity at 50 g/kg. FW content is calculated relative to salinity 34.8 on the basis of 1950–1980 data. The Beaufort Gyre Region is bounded by thick dashed blue lines. (*From A. Proshutinsky et al., 2009*)

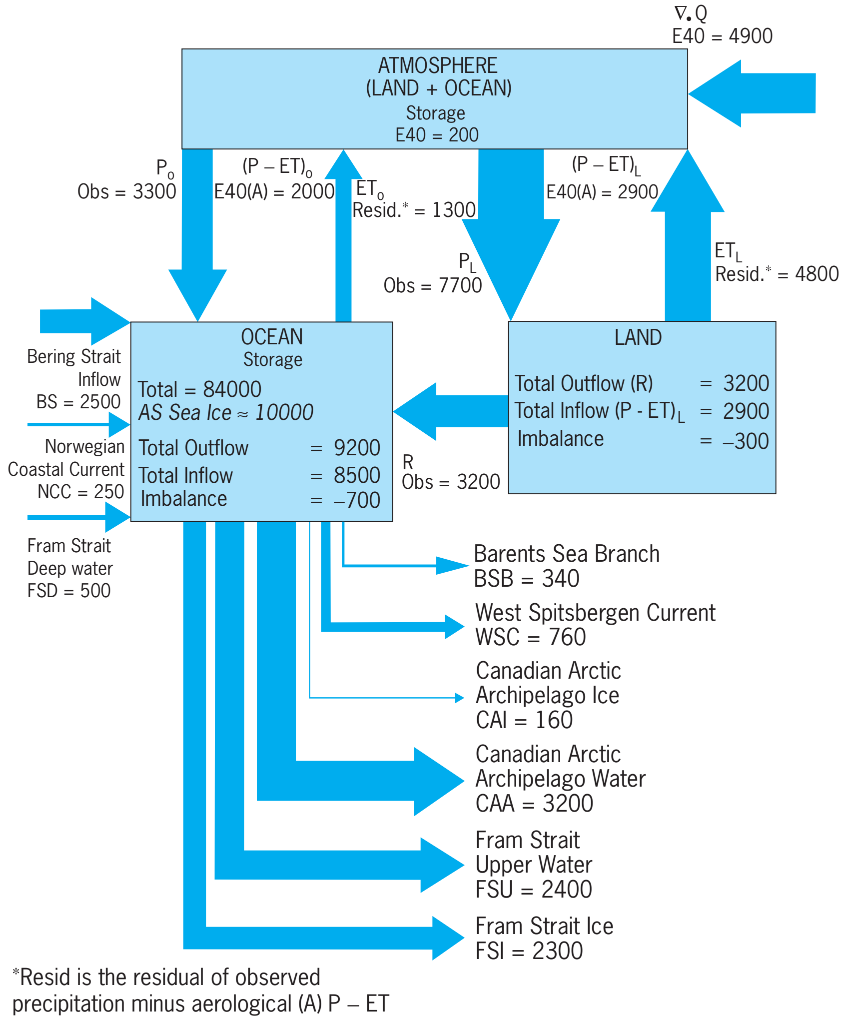

Fig. 2. Annual mean FW budget of the Arctic. The atmospheric box combines the land and ocean domains. The boxes for land and ocean are sized proportional to their areas. All transports are in units of km^3 per year. Stores are in km^3. The width of the arrows is proportional to the size of the transports. Subscripts L and O denote land and ocean, respectively. E40 (ERA-40) shows results obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-40 reanalysis. P and ET depict precipitation and evapotranspiration, respectively. The net precipitation (P-ET) represents water available for runoff (R). ∇Q is the divergence of the horizontal water vapor flux Q integrated from the surface to the top of the atmospheric column. (*From M. C. Serreze et al., 2006; panels are reproduced by permission of American Geophysical Union*)

via the Fram Strait and via the straits of the Canadian Archipelago. A smaller fraction of FW is evaporated (or sublimated) from liquid and solid components within the Arctic Ocean.

The annual cycle of FW and its variability from year to year and decade to decade are difficult to construct because of uncertainties in the various sources and sinks due to a lack of observations (**Fig. 2**). M. C. Serreze and coworkers estimated that the annual mean FW input to the Arctic Ocean is dominated by river discharge (38%), inflow through the Bering Strait (30%), and net precipitation (24%). FW export from the Arctic Ocean to the North Atlantic is dominated by transports through the Canadian Arctic Archipelago (35%) and via the Fram Strait as liquid (26%) and sea ice (25%).

Beaufort Gyre freshwater reservoir. Within the Arctic Ocean, the largest volume of FW stored in the Canadian Basin with its Beaufort Gyre (BG) [Fig. 1] is roughly equal to that stored in all lakes and rivers of the world and is 10–15 times greater than the annual export of FW (including ice and water) from the Arctic Ocean. Since the 1950s, the BG region was recognized by oceanographers as a unique "reservoir" containing more than 20,000 km^3 of FW or approximately half of the FW stored in the Canadian Basin (Fig. 1). Historical observations between 1950 and 1990 showed that the BG FW reservoir was a stable feature of the Arctic Ocean and could be considered as a flywheel of Arctic Ocean circulation. However, recent observations coordinated in the region under the umbrella of the Beaufort Gyre Observing System (BGOS), with support from the National Science Foundation (NSF) Office of Polar Programs Arctic Observing Network (AON), show an unprecedented increase (a gain of more than 25%) of FW in 2003–2011. An important scientific question is whether significant changes in the mechanics of the BG flywheel can be expected in the near future.

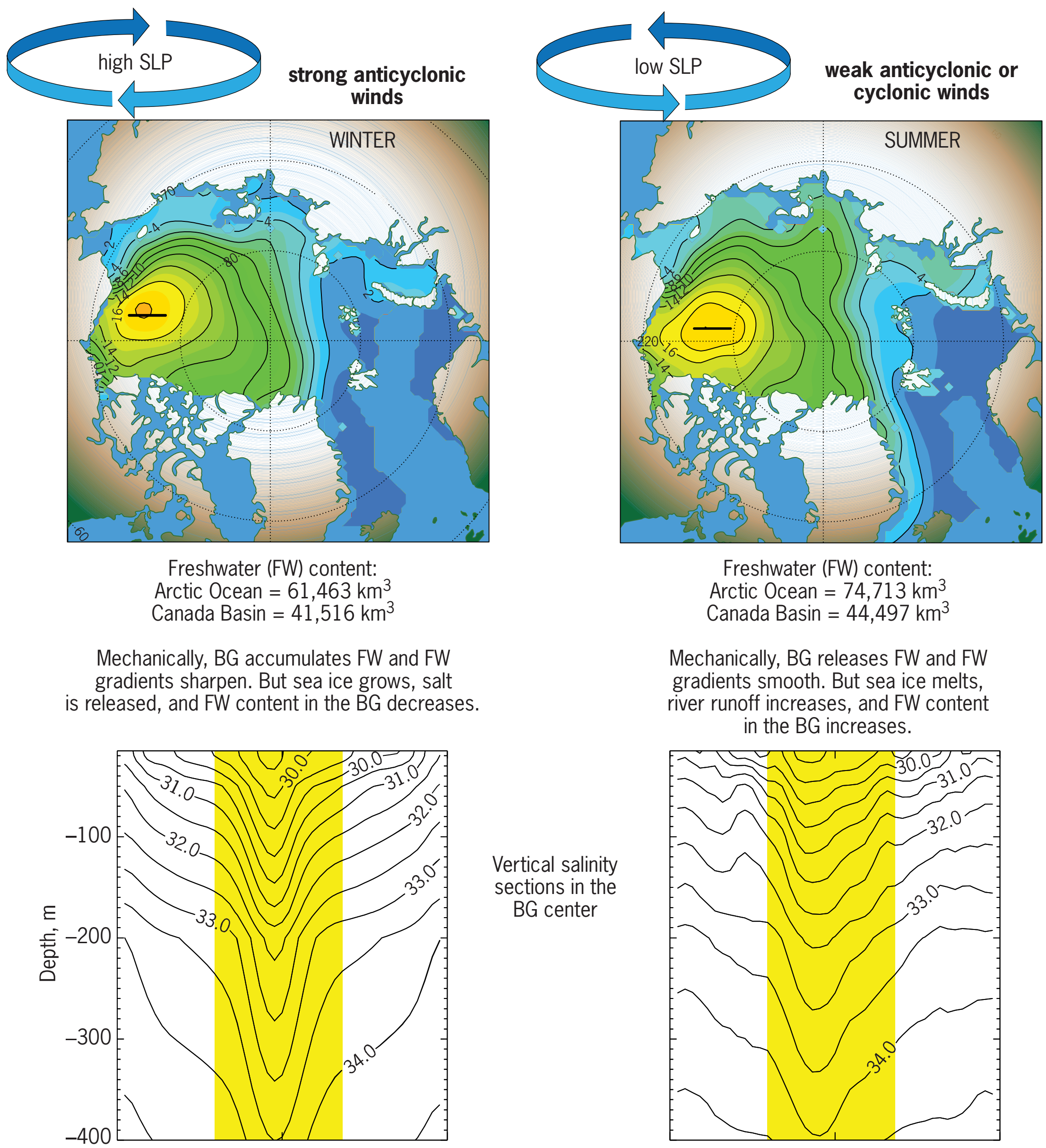

Fig. 3. Conceptual mechanisms of FW accumulation and release in the Beaufort Gyre during an annual cycle. FW content in summer and winter is shown in meters (isolines) calculated relative to salinity 34.8 g/kg. SLP = sea level atmospheric pressure. The bottom panels show salinity distribution along sections in the center of the Beaufort Gyre region. In winter, the wind drives the ice and ocean in an anticyclonic (clockwise) sense so that the Beaufort Gyre accumulates FW mechanically through deformation of the salinity field (Ekman convergence and subsequent downwelling; bottom left panel). In summer, anticyclonic winds are weaker (and may even reverse to be cyclonic). The resultant summer anomaly in Ekman convergence under cyclonic wind forcing releases FW or under weak anticyclonic winds accumulates less FW, thereby relaxing salinity gradients (bottom right panel) and reducing Beaufort Gyre FW content. (*From Proshutinsky et al., 2009; figure is modified by permission of American Geophysical Union*)

The fundamental dynamics governing the BG FW reservoir is that FW is accumulated in the region from different sources by anticyclonic (clockwise) winds dominating over the region as a result of water convergence in the surface ocean (**Fig. 3**). This FW can be released when the anticyclonic forcing weakens or changes sense of rotation to dominantly cyclonic (counterclockwise). FW release from the BG could significantly influence Arctic and global climate. It has been argued that FW release from the Arctic can influence global climate via reduction of the ocean meridional overturning circulation—a release of only 20% of FW from the BG is enough to cause a salinity anomaly in the North Atlantic with the magnitude of the Great Salinity Anomaly of the 1970s (M. B. Vellinga et al., 2008). In this sense, the BG FW reservoir is "a ticking time bomb" for climate.

Recent BGOS observations and climatological data allow for estimates of the magnitude of FW accumulation and release at seasonal to decadal time scales (**Fig. 4**). The strong FW accumulation trend in the center of the BG (Fig. 4) is linked to an increase in strength of the anticyclonic wind forcing. An atmospheric circulation regime with anticyclonic winds

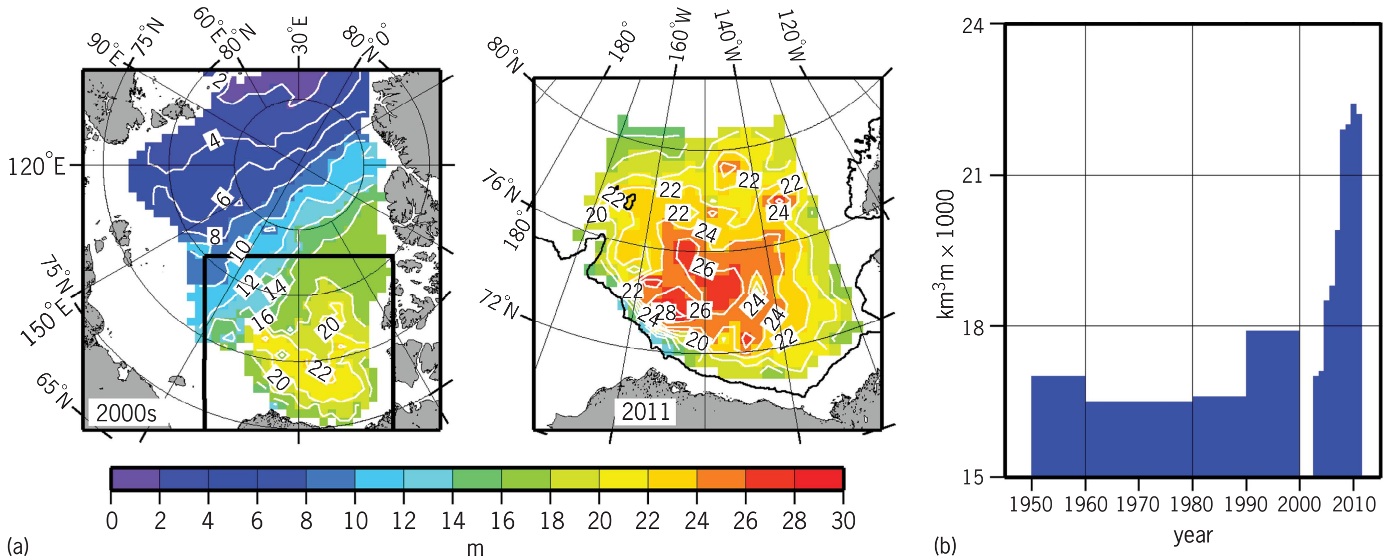

Fig. 4. FW in the BG region. (*a*) FW content (in m) in the Arctic Ocean based on all available ocean measurements from the 2000s. The BG region is delineated by the box. Right panel: FW content (m) in the BG region based on available measurements from 2011 (*b*) Decadal FW content (in thousands of km^3) in the BG region before 2000, and annual FW content after 2000. The unprecedented increase of FW content in the BG in 2003–2011 relative to previous decades manifests dramatic changes in the Arctic climate and warns that release of this FW may have significant consequences to Arctic and global climate.

has dominated over the Arctic for at least 14 years, instead of the typical 5–8 year pattern of alternation between anticyclonic and cyclonic regimes. It is to be expected from climatology that the present regime that drives FW accumulation soon will change to one that permits FW release. In fact, the magnitude of BG FW in 2011 is modestly less than 2010, so the change might have already begun.

For background information *see* ARCTIC OCEAN; ATLANTIC OCEAN; HYDROLOGY; PACIFIC OCEAN; SEA ICE; SEAWATER in the McGraw-Hill Encyclopedia of Science & Technology.

Andrey Proshutinsky; Richard Krishfield;
Mary-Louise Timmermans; John M. Toole

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Arthropod evolution and phylogeny

It is not an exaggeration to say that life on Earth is predominantly arthropodous. By any criteria, arthropods (members of the phylum Arthropoda) are the dominant metazoans (multicellular animals) on the planet, and this has been true for hundreds of millions of years. This dominance is evident in terms of the number of described species, global biomass, ecological importance, economic impact, and numerous other categories. Arthropods constitute more than 85% of all known species on Earth, and they have the richest fossil record of any animal group. Some typical arthropods are insects, spiders, ticks, and crustaceans. Of course, in additional to the numerous described species, the number of undescribed species of arthropods remains unknown. Arthropods dominate not only in number of species but in number of individual organisms: for example, who could begin to estimate the number of ants on the planet, or the number of copepods in the world's oceans?

Arthropoda. In terms of numbers of described species, the insects rule. Of the estimated 1.8 million described species on Earth, more than half are insects, with the vast majority of those being beetles. Insects are found on all continents and in nearly all habitats, and their diversity in form and function is astounding. However, arthropods also include other extremely significant groups. Foremost among these in terms of species numbers are the incredibly diverse chelicerate groups (including not only spiders, but ticks, mites, scorpions, xiphosurans, opilionids, and many other lesser-known groups) and the