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4.4. *Mare salis intellegere*. Knowing the salt of the oceans

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In 1987, Konstantin Fedorov, a prominent Soviet oceanographer of the time, dedicated one of his popular science talks to the salinity of the ocean and called it "The Cinderella of Dynamic Oceanology". Fedorov said that "The fate of salinity as a physical parameter is closely related to the dynamics of ocean waters and is very similar to the fate of poor Cinderella in Charles Perrault's fairy tale. And, like the fate of poor Cinderella, salinity has long cried out for justice".

In fact, historically, salinity observations have been less valued than other physical parameters of the ocean, such as temperature, currents, waves or sea level.

Salinity has traditionally been measured by oceanographic surveys, starting with the Challenger Expedition between 1872 and 1876 and was later also measured from fixed stations. While, systematic measurement on a global scale began with the first Argo profilers in the 2000s and continued with the launch of the Soil Moisture and Ocean Salinity (SMOS) satellite dedicated to measuring surface salinity from space (Font *et al.* 2012).

Why is it necessary to measure salinity?

Salinity is a fundamental ocean variable. Together with temperature, it contributes to the determination of density, which modulates the intensity of mixing processes in the upper layer of the ocean and the formation of water masses and currents.

The main processes that influence salinity variability are related to water exchanges between the ocean and the atmosphere (evaporation and precipitation) and to advection. If we look at a map of surface salinity or a transect of the Atlantic Ocean from north to south, we see that salinity varies from one place to another (Figure 1), with values that are generally between 32 and 38 in the open ocean. However, it has been observed that the concentration of salt in the oceans does not show great changes on a climatic scale, and its average value is 35.

Surface salinity is influenced by runoff from rivers near the coast and by the mechanisms of formation and melting of sea ice in polar areas. This formation of sea ice contributes to the formation of deep waters, the main forcing of the general thermohaline circulation. All this, together with evaporation and precipitation, modify the surface salinity, which allows it to be used as a tracer of of the water cycle. Moreover, since salinity is only modified on the surface, it is used together with temperature as a tracer of water masses.

How to measure salinity?

One of the main observations of the first world oceanographic expedition, the Challenger Expedition of 1872–1876, was that "salinity varies from one sea to another, but the relative proportions of the salts that compose it are maintained". Thanks to this key observation, measuring the concentration of a single component of the salts contained in seawater

makes it possible to recover the concentration of the others, and therefore the salinity. And until the first part of the 20th century, salinity (expressed in parts per thousand: ppt or ‰) was estimated by chemical methods from the chloride content, the largest component of dissolved salts in seawater (Knudsen 1901).

In the 1940s, it was observed that, at a fixed temperature, the electrical conductivity of seawater depended on salinity, which is why the chemical method has been replaced by the measurement of conductivity at a fixed temperature. This method led to the arrival of new instruments: salinometers. From here, the salinity of a sample was set as the conductivity ratio at 15°C between the sample and a standard corresponding to a salinity of 35 ppt, so this new scale (practical salinity of 1978; PSS-78 o PSU for pratical salinity units) no longer has units. Finally, in 2010 the concept of concentration was returned with absolute salinity in g kg^{-1} (TEOS-10). What makes salinity in the literature found in the diverse units.

And for the late 1960s until today, instruments have been developed to include a temperature and pressure sensor together with the conductivity sensor. The famous conductivity-temperature-depth (CTD) is capable of continuously measuring vertical or horizontal temperature and salinity profiles. Based on this technology, thermosalinographs installed in ships were developed to provide continuous measurements of surface temperature and salinity during navigation. Most of these instruments have been commonly used during oceanographic surveys since the 1970s, but they are also used on moorings, fixed stations or drifting buoys, such as L'Estartit ICM mooring or the ICM buoy (Salvador *et al.* 2010) designed at the Institut de Ciències del Mar (ICM-CSIC).

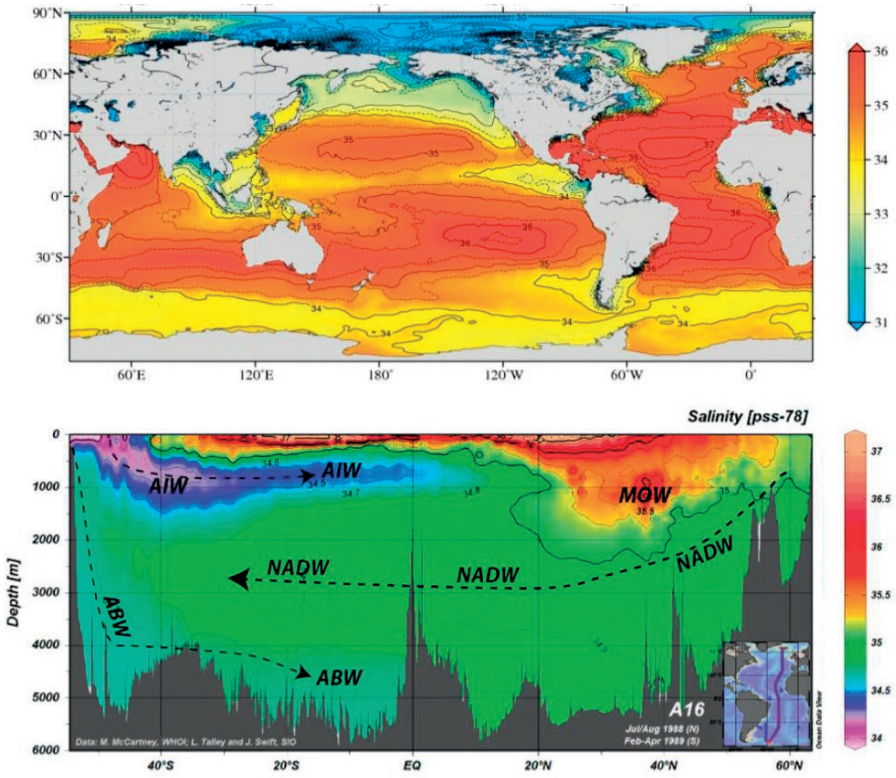

Figure 1. Above: annual mean surface salinity (World Ocean Atlas, 2018). Bottom, salinity transect in the Atlantic Ocean, indicating the main water masses: Antarctic Bottom Water (ABW), Antarctic Intermediate Water (AIW), North Atlantic Deep Water (NADW) and Mediterranean Outflow Water (MOW).

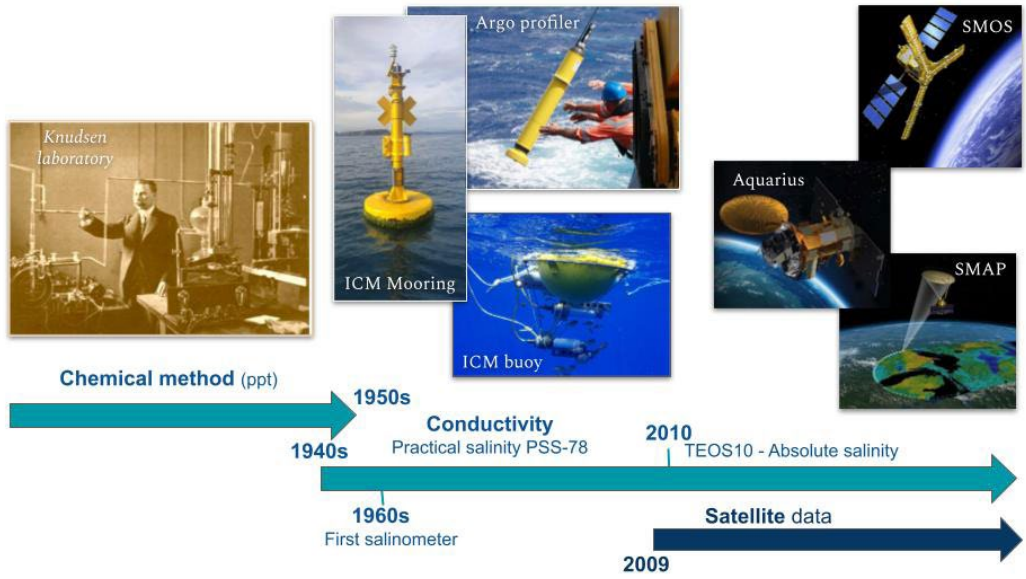

Figure 2. Chronology of sea salinity measurement methods. Photos from left to right: Martin Knudsen (1901); instruments based on CTD technology; the SMOS, Aquarius and SMAP satellites.

In order to measure salinity systematically all over the world, the scientific community started the international Argo programme in the early 2000s that performs routine measurements in the water column, providing continuous monitoring of the oceans through some 4000 active authomatic Argo profilers.

In parallel, techniques were also perfected for measuring surface salinity from space. A new generation of L-band (1.4 GHz) satellites arrived 40 years after the first oceanographic satellites (1970s). SMOS was the first satellite designed to measure surface salinity. It was launched by the European Space Agency in 2009, in collaboration with several European institutions, and the Barcelona Expert Centre of the ICM-CSIC led the scientific part. Today, with the subsequent arrival of NASA's Aquarius (2011–2015) and SMAP (2015) missions, more than ten years of surface salinity data are available.

At the end, thanks to the continuous efforts of the scientific community, the Cinderella of salinity has finally achieved its deserved importance, resulting in a wide range of instruments available to measure salinity at various scales (Figure 2). Today salinity observations continue to increase in all oceans including the polar areas, which despite their influence on the climate remain poorly studied.

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