

Chemical fronts of the Antarctic Circumpolar Current, the Southern Ocean

Evgeny V. Dafner

Freelancer, 436-3-B201 Sano, Susono, Shizuoka, 410-1118 Japan

Research over the past three decades in the Southern Ocean has identified three frontal zones associated with the Antarctic Circumpolar Current (ACC): the Subtropical Frontal Zone (STFZ), the Antarctic Polar Frontal Zone (APFZ) and the Southern ACC Front (SACCF). Each of these frontal zones is limited by two fronts, convergent in nature (Belkin and Gordon, 1996, and references hereafter), consists of continuous circumpolar circulation (except the STFZ; Orsi et al., 1995), and borders geographical and biological zonation of the Southern Ocean (Deacon, 1982). Along the almost zonal flow of the ACC, water mass properties between fronts, limited these frontal zones, are relatively constant, but across fronts all properties abruptly change producing sharp lateral gradients. The various criteria are proposed for characterization of the ACC fronts: some are based on particular surface or subsurface property values, while others use phenomenological definitions.

The fronts bordered the STFZ and PFZ are not always distinguishable by the lateral gradients of both temperature (T) and salinity (S): some fronts are characterized by the gradient of T, while other by the gradient of S, but all fronts are traceable in the density field. The thermohaline structure of the surface mixed layer of the ocean is characterized by thermohaline alignment and density compensation, and, as a result, T and S gradients tend to be parallel, and in some cases to oppose each other in their effect on density creating a two-stepped character of gradients across frontal zones. A term “stepped” is used here because if T, S or any other surface water mass property is continuously measured or analyzed in storage bottles collected across a front, results of measurements will produce a step in the distribution of this property. Such steps, generated by various properties when crossing the same frontal structure, do not always coincide.

In the Southern Ocean, it is common to apply dissolved oxygen (DO) and nutrients (hereafter chemical properties) as tracers of deep water masses, and, prior to phytoplankton bloom, chemical properties can be also used for the ACC surface fronts identification. A little chemical properties data exist on fronts' characterization at meso- or smaller scales as most of observations are conducted at synoptic or larger scales. This presentation focuses on the meso-scales nature of chemical properties in the STFZ, PFZ, SACCF and a multi-stepped character of fronts associated with the STFZ in the Atlantic Sector (Dafner *et al.*, 2003).

The results of a few available studies in the STFZ indicate that lateral surface gradients of DO ($\sim 5 \mu\text{mol kg}^{-1}$ per km) and phosphate (concentration changes from 0.4 to 0.7 μM) coincide with T, S and two axes of high-speed flows corresponding to the North and South Subtropical Fronts (NSTF and SSTF). As a rule, coincidence of gradients of T, S and DO characterize both the NSTF and SSTF. The gradient of phosphate is commonly observed further south at a distance of about 60 km from the gradient of DO. The SSTF is characterized by a large variability in nitrate concentrations (0.5–6.5 μM), and the gradient of nitrate is registered at the same distance (60 km) from the gradient of phosphate. Nitrate is the best circumpolar chemical marker of the SSTF, where concentration can vary in factor of 100 depending from season and location.

The APFZ is bordered by the Subantarctic and Antarctic Polar Fronts (SAF and APF), and there is a good agreement in distributions of T, S, and chemical properties along both fronts. Chemical properties within the PFZ reflect the patchiness in the distributions of T and S as a result of cross-frontal mixing caused by the spatial and temporal variability of the flow configuration affected by bottom topography and the injection of the Subantarctic and Antarctic Surface Waters (SAW and AASW) into the PFZ. The surface gradient of DO is a good chemical indicator of the SAF, while the latitudinal gradient of silicate is a good tracer for the APF. The magnitude of these gradients depend on the season and hydrological conditions, and can reach 0.5 to 4 $\mu\text{mol kg}^{-1}$ per km and 0.6 to 2.8 μM per km, respectively. The identification of the SAF by gradients of DO is possible due to the interaction of waters with different DO content on either side of the PFZ: the cold AASW with high DO content sinks under the warmer SAW with considerably lower DO content. The identification of fronts by phosphate and nitrate might have two scenarios: 1) both these

nutrients can be good indicators of the SAF and APF, and 2) concentrations of both chemical properties increase within the PFZ, as it was observed in the Atlantic Sector by 8.0 and 0.42–0.64 μM , respectively (Dafner et al., 2003).

The SACCF vertical structure is very different than those of the STFZ and PFZ because it separates not water masses of different origin, but two modification of the same AASW; therefore, the SAACF is not recognizable by the gradients of T and S, but by the gradients of chemical properties only. The permanent year-round criterion for the SACCF identification is the surface lateral gradient of silicate-to-phosphate atomic ratio which ranges from 25 to 35 (Arzhanova, 1982). This ratio is the most conservative index of this front due to the physiological features of prevailing at these latitudes diatom phytoplankton which consume silicate and phosphate in the ratio corresponding to that in its cells. The ratio is lower than 35 in the ACC waters, while in the high-latitude modification water, it is higher than is necessary for phytoplankton uptake. Within the SACCF values of silicate-to-phosphate atomic ratio vary insignificantly over the year, irrespective of the changes in silicate and phosphate concentrations. In the SACCF, the silicate gradient itself is also sharpest due to the silicate concentration contrast from both side of the front: 5 to 40 μM in the ACC and 60–120 μM in the high-latitude modification waters. Other chemical markers of the SACCF are: DO content at the upper boundary of the Circumpolar Deep Water and depths of its location.

The meso-scale observations show that lateral gradients of chemical properties not only do not always coincide with T and S, but between themselves as well, *e.g.*, different ACC fronts can be identified by different horizontal gradients of chemical properties. Phytoplankton releases DO and consumes nutrients sharpening lateral gradients of these properties, delineating the “patchiness” of phytoplankton distribution on a scale from a few to 100 km and changing relation of isopleths between physical and chemical properties from quasi-zonal to meridional. In the most distinct of these “biological” fronts, the lateral silicate gradient can reach 7.22 μM per km (Dafner et al., 2003). The chemical gradient zones associated with the phytoplankton activity are less distinct by the spring-summer period, *i.e.*, because of the duration of the bloom season and the intensity of wind mixing.

At first it seems that chemical properties are distributed homogeneously in a water mass adjacent to one side of the STFZ, but this is not the case. It is still unclear what causes the gradients of chemical properties along the SSTF to show the multi-stepped character of distributions, whether this is a result of different rates of mineralization of organic matter, mineralization in accordance with the Redfield ratio or non-periodic nutrients replenishment of the surface layer due to the wind mixing. To better understand the behavior of chemical properties along ACC fronts and their multi-stepped character, there is a need to obtain more data at smaller spacio-temporal scales (km and days) ideally applying a strategy of superposition of surveys of different scales. First, to conduct observation at synoptic scale to identify position of fronts and properties distribution, as a background before development of phytoplankton. Second, to follow the “patchiness” of phytoplankton development at meso scale to understand how it affects the chemical structure of fronts.

References

- Arzhanova, N.V., The ratio of silicate and phosphate contents (Si/P) as an index of water mixture zone in the region of the Southern Orkney Islands and the Antarctic Peninsula (in Russian), *Antarctika*, 21, 95-100, 1982.
- Belkin, I.M. and A.L. Gordon, Southern Ocean fronts from Greenwich meridian to Tasmania, *J. Geophys. Res.*, 101, 3675– 3696, 1996.
- Dafner, E.V., N. Mordasova, Yu. Mikhailovsky, P. Selin, V. Zubarevich, V. Maslennikov and N. Arzhanova, Major nutrients and oxygen as indicators of frontal zones in the Atlantic sector of the Southern Ocean, *J. Geophys. Res.*, 108 (C7), 3227-3242, 2003.
- Deacon, G.E.R., Physical and biological zonation in the Southern Ocean, *Deep Sea Res.*, 29, 1– 15, 1982.
- Orsi, A.H., T. Whitworth III, and W.D. Nowlin, On the meridional extend and fronts of the Antarctic Circumpolar Current, *Deep Sea Res. I*, 42, 641-673, 1995.