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Bio-optical Properties in the Southern Ocean in Support of Ocean Color Remote Sensing

University of Louisiana

Year 3 (2016) Report

Bio-optical Properties in the Southern Ocean in Support of Ocean Color Remote Sensing

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Introduction

The Southern Ocean due to its unique geography connects the various ocean basins and plays a critical role in the global ocean circulation, biogeochemical cycles and climate. This region is sensitive to climatic variations with changes in precipitation and ice melt influencing salinity, carbon uptake and the ecosystem that could influence the primary productivity, phytoplankton species and biomass, and dissolved organic matter content in the Southern Ocean (Arrigo et al. 2000; Sabine et al. 2004; Arrigo et al. 2008; Smith et al. 2012). The Southern Ocean contributes more than any other latitude band to the ocean storage of excess heat and carbon due to anthropogenic activities (Sabine et al. 2004; Levitus et al. 2005). The Antarctic Circumpolar Current (ACC), the planet's largest current that connects the ocean basins, and isolates the cold polar region from the warmer subtropics, plays an important role in regulating the Earth's climate. Future climate predictions indicate that the Southern Ocean air-sea heat balance and carbon system will account for most of the response of the ocean to climate change. The strengthening of the circumpolar westerly winds (IPCC, 2007) for example have been attributed to changes in temperature patterns caused by stratospheric ozone depletion and increases in greenhouse gases linked to anthropogenic influences (Fyfe et al. 2007; Marshall et al. 2004). The increase in winds in the region could result in the weakening of the Southern Ocean sink for anthropogenic CO_2 due to increases in upwelling and associated carbon from the deep ocean (Le Quere et al. 2007). Although there is much uncertainty about the extent of the changes on the ocean environment in the Southern Ocean, climate change effects have been reported or likely to impact among others, the ocean temperature, ocean acidification, melting ice, carbon uptake, and primary productivity.

Satellite ocean color remote sensing with its synoptic and frequent monitoring capability has improved our understanding of the oceanic biogeochemical processes. However, at high latitude polar regions such as the Southern Ocean, satellite estimates of seawater constituents such as phytoplankton chlorophyll are not very accurate as the standard ocean color algorithms were developed using field data obtained at lower latitudes (Dierssen and Smith 2000). A combination of field and improved satellite observations will thus provide a better understanding of the Southern Ocean biogeochemical processes. As part of this collaborative project with KOPRI, field bio-optical data (e.g., spectral absorption of dissolved and particulate matter) were obtained during field campaigns to the Southern Ocean. The combination of field and satellite studies will provide a better understanding of the biogeochemical processes in the New Zealand sector of the Southern Ocean.

Absorption properties of dissolved and particulate matter (phytoplankton and nonalgal particles) directly influence the water leaving radiance and thus the remote sensing reflectance. Spectral absorption properties of phytoplankton can reveal information on phytoplankton species while the colored dissolved organic matter (CDOM) optical properties of absorption and fluorescence provides useful information on CDOM source and water-mass mixing in the oceans (Stedmon et al. 2003; D'Sa and DiMarco 2009; Nelson et al. 2013). Fluorescence spectroscopy by means of excitation-emission matrices (EEMs) has also been widely used to characterize CDOM in various water masses over the globe (D'Sa et al. 2014 and references therein). The goal of this proposed collaborative research is to obtain a better understanding of the optical properties (e.g., absorption properties of the particulate and dissolved organic matter) and to assess ocean color data of the study area.

Key activities conducted during the study period

1. Analysis of bio-optical properties along the ARAON tract in the Southern Ocean from field measurements supported by satellite remote sensing data for the 2014 austral summer

Bio-optical measurements (CDOM and particulate absorption, DOC and chlorophyll concentrations, CDOM fluorescence) obtained during the *Araon* cruise of summer 2014 along the New Zealand sector of the Southern Ocean were analyzed. Synthesis of the results comprising of field measurements and satellite data have been conducted and a paper has been published in the Journal *Frontiers in Marine Science* (D'Sa, and Kim, 2017). An abstract of the work and selected figures are shown below:

Surface Gradients in Dissolved Organic Matter Absorption and Fluorescence Properties along the New Zealand Sector of the Southern Ocean (E. J. D'Sa and H-C. Kim. Frontiers in Marine Science. doi: 10.3389/fmars.2017.00021

The Southern Ocean plays a critical role in the global carbon cycling, the dissolved organic matter (DOM) component of which can be characterized optically. Sea surface chromophoric dissolved organic matter (CDOM) absorption and fluorescence properties were examined in the New Zealand sector of the Southern Ocean (NZSSO) along a transect encompassing various hydrographic fronts associated with the Antarctic Circumpolar Current (ACC) during summer (Figures 1 and 2). Phytoplankton chlorophyll, dissolved organic carbon (DOC) and CDOM absorption were observed to be most elevated off New Zealand shore that decreased to low values (chlorophyll: 0.21±0.06 mg m^{-3}; DOC: 54.19±4.02 μM; and CDOM absorption coefficient at 325 nm (a_g325): 0.097 ± 0.061 m^{-1}) between the Subtropical (STF) and Antarctic Polar (APF) Fronts (Figures 3, 4). Increases in phytoplankton biomass and DOC concentrations between the fronts were associated with meanders or eddies observed in satellite sea surface salinity and chlorophyll imagery. Overall, CDOM absorption was the dominant contributor to total absorption at 443 nm as indicated by the absorption of CDOM, phytoplankton and nonalgal particles along the transect and the ternary plot at 443 nm (Figure 5A, B), with implications for ocean color. Beyond the APF in the Antarctic Zone, an elevated chlorophyll band likely associated with upwelled waters transitioned to low chlorophyll in the summer ice edge zone that influenced DOM optical properties. A latitudinal increase in a_g325 and corresponding decrease in spectral slope S (μm^{-1}) poleward from the STF could be due to the combined effects of CDOM photooxidation, upwelling of high-CDOM waters or bacterial CDOM production in the Antarctic Zone (Figure 4). Parallel factor (PARAFAC) analysis of fluorescence spectra identified two protein-like (C1 and C2) and two humic-like (C3 and C4) components common in the global ocean (Figure 7). a_g325 and the humic-like C4 fluorescent component were positively correlated to chlorophyll indicating biological control. Surface distribution of the protein-like C1 and C2 and the marine humic-like C3 components showed patterns that appeared to be influenced by both physical and biological processes. This study provides insights into surface CDOM optical properties and its transformation along a complex topographically influenced sector of the Southern Ocean that could be used to trace changes linked to the meridional overturning circulation.

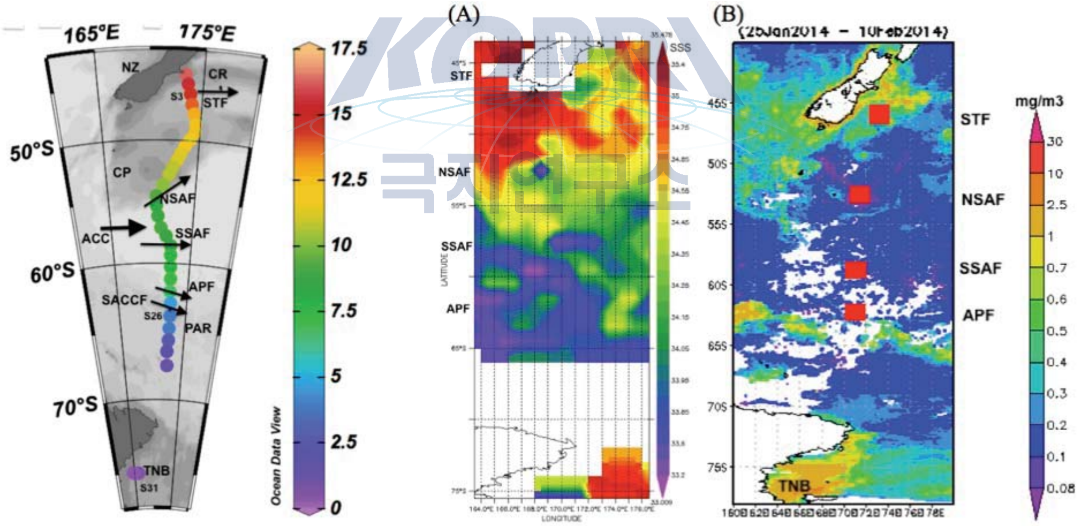

Figure 1. (Left) Sea surface temperature (SST) shown at sampling stations obtained between 30 Jan - 6 Feb, 2014 along a transect between Christchurch, New Zealand (NZ) and Terra Nova Bay (TNB) in the western Ross Sea. Thick arrow indicates the direction of the Antarctic Circumpolar Current (ACC) and the thinner arrows indicate the approximate locations of the Subtropical Front (STC), the Subantarctic Front (SAF), the Antarctic Polar Front (APF), and the Southern Antarctic Circumpolar Current Front (SACCF). CR and PAR indicate the locations of the Chatham Rise and the Pacific Australian Ridge, respectively.

Figure 2. (right). (A) Aquarius satellite-derived sea surface salinity for the period 29 Jan – 6 Feb, 2014 along the New Zealand sector of the Southern Ocean, and (B) MODIS-derived chlorophyll (25 Jan – 10 Feb, 2014) with locations of the Southern Ocean fronts (red squares).

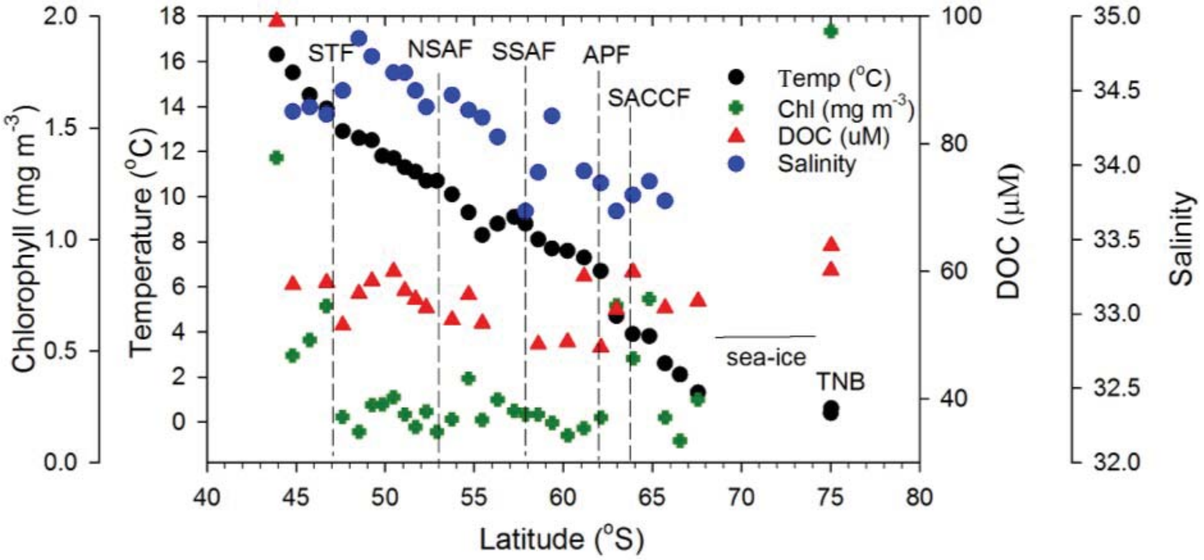

Figure 3. Sea surface temperature, satellite-derived salinity, chlorophyll, and DOC concentrations along the transect. Dashed vertical lines represent the locations of the Southern Ocean fronts.

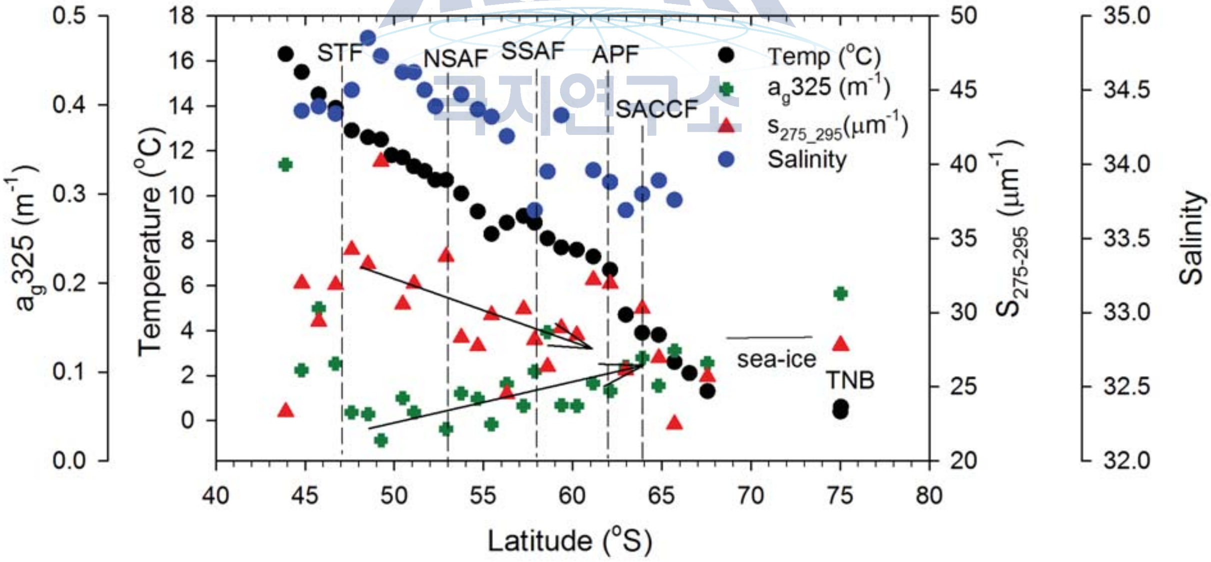

Figure 4. Sea surface temperature, Aquarius satellite-derived salinity, surface CDOM absorption at 325 nm, a_g325 (m^{-1}) and spectral slope $S_{275\text{-}295}$ (μm^{-1}) along the ship transect from NZ to TNB. Dashed vertical lines represent the location of the Southern Ocean fronts and the two arrows indicate trends in CDOM absorption and slope between the STF and APF.

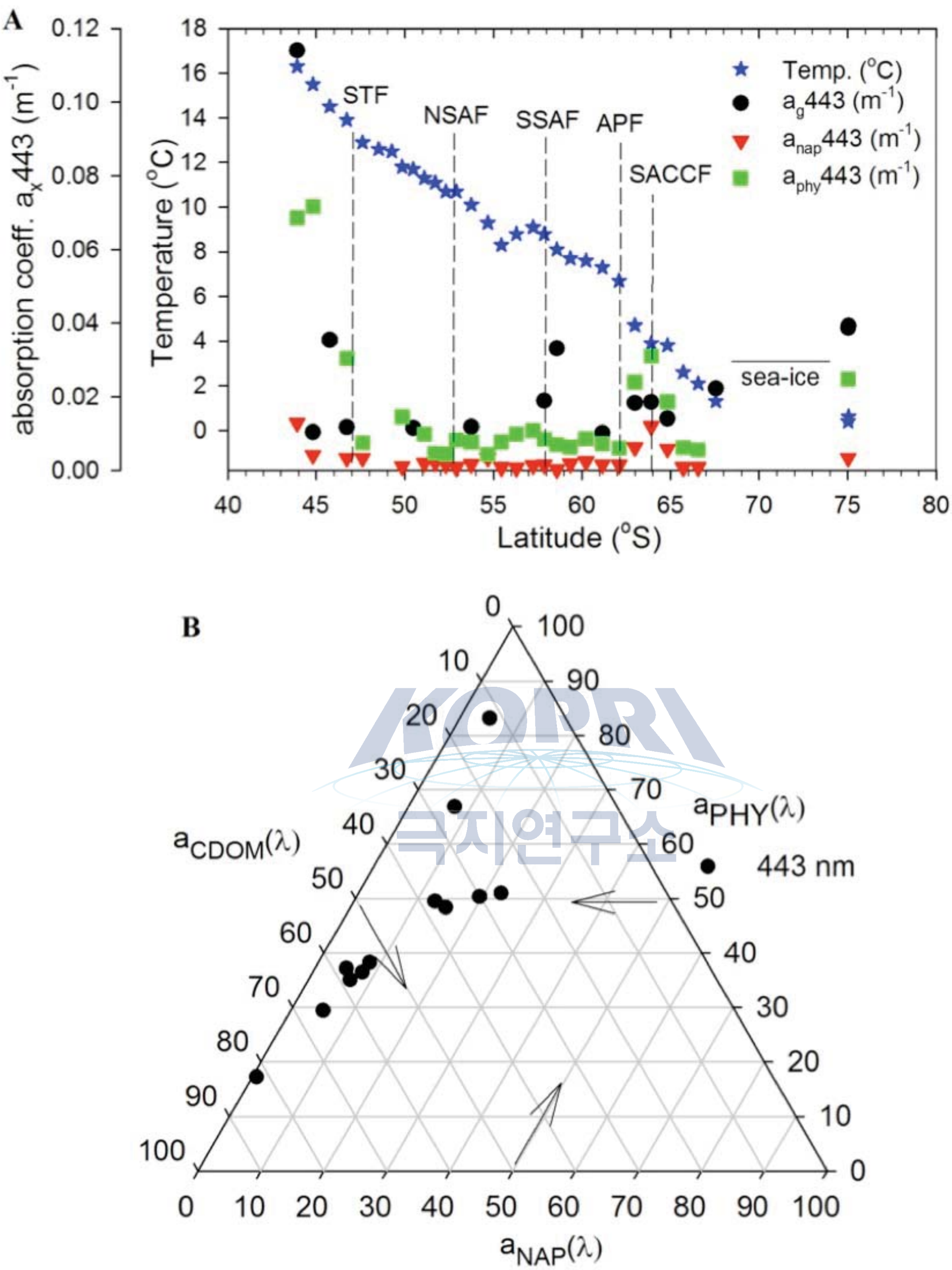

Figure 5. (A) Absorption coefficients at 443 nm of CDOM, phytoplankton and nonalgal particles along the transect. (B) ternary plot of absorption coefficient at 443 nm.

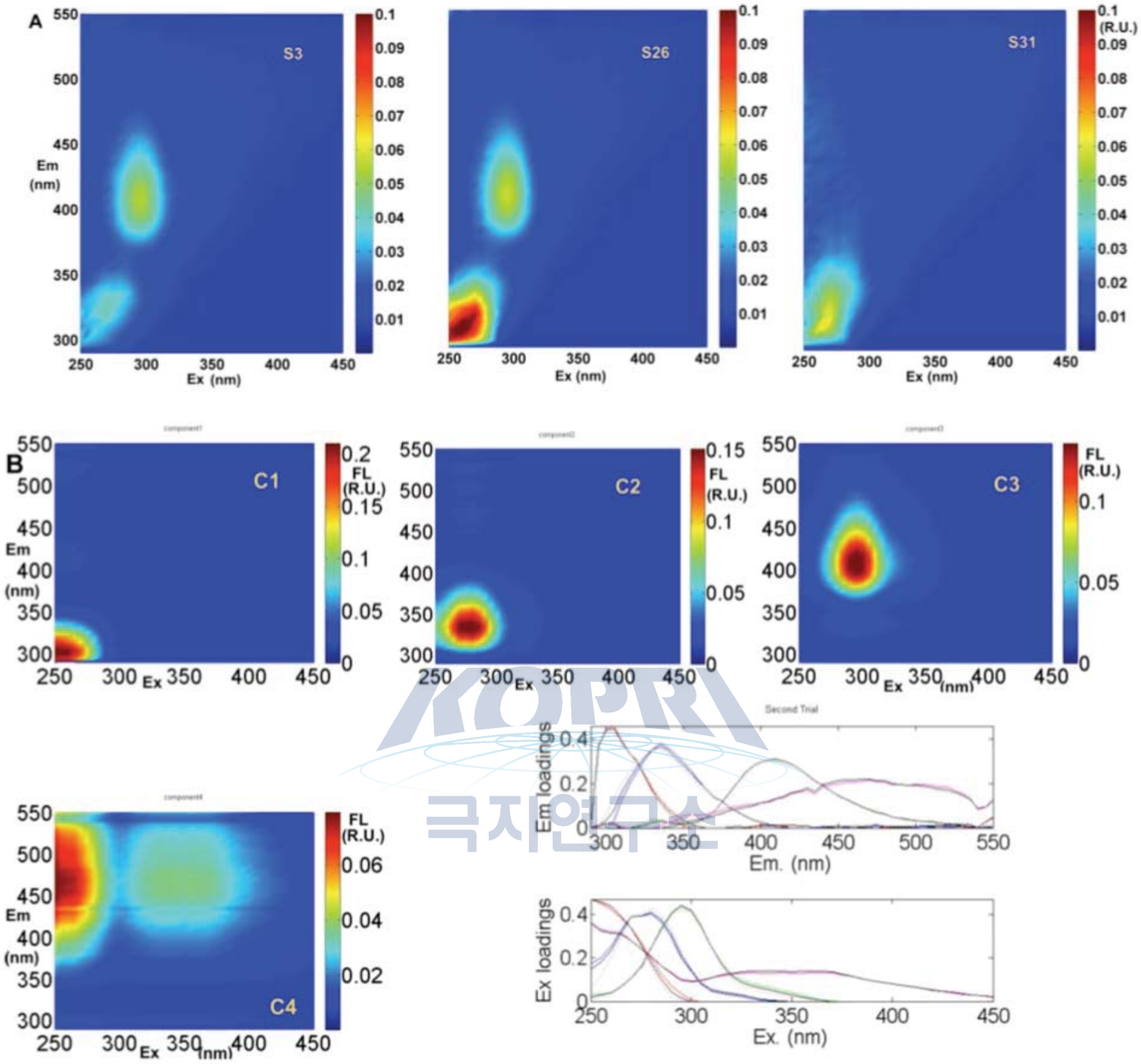

Figure 6. EEMs fluorescence spectra and PARAFAC analysis. **(A)** Example EEMs at three locations (S3, S26 and S31) along the transect. Spectral properties of four fluorescent components (C1, C2, C3, and C4) identified by PARAFAC in Raman Units (R.U.) of intensity. Excitation and emission loadings derived from the four-component PARAFAC model using split-half validation technique (bottom right).

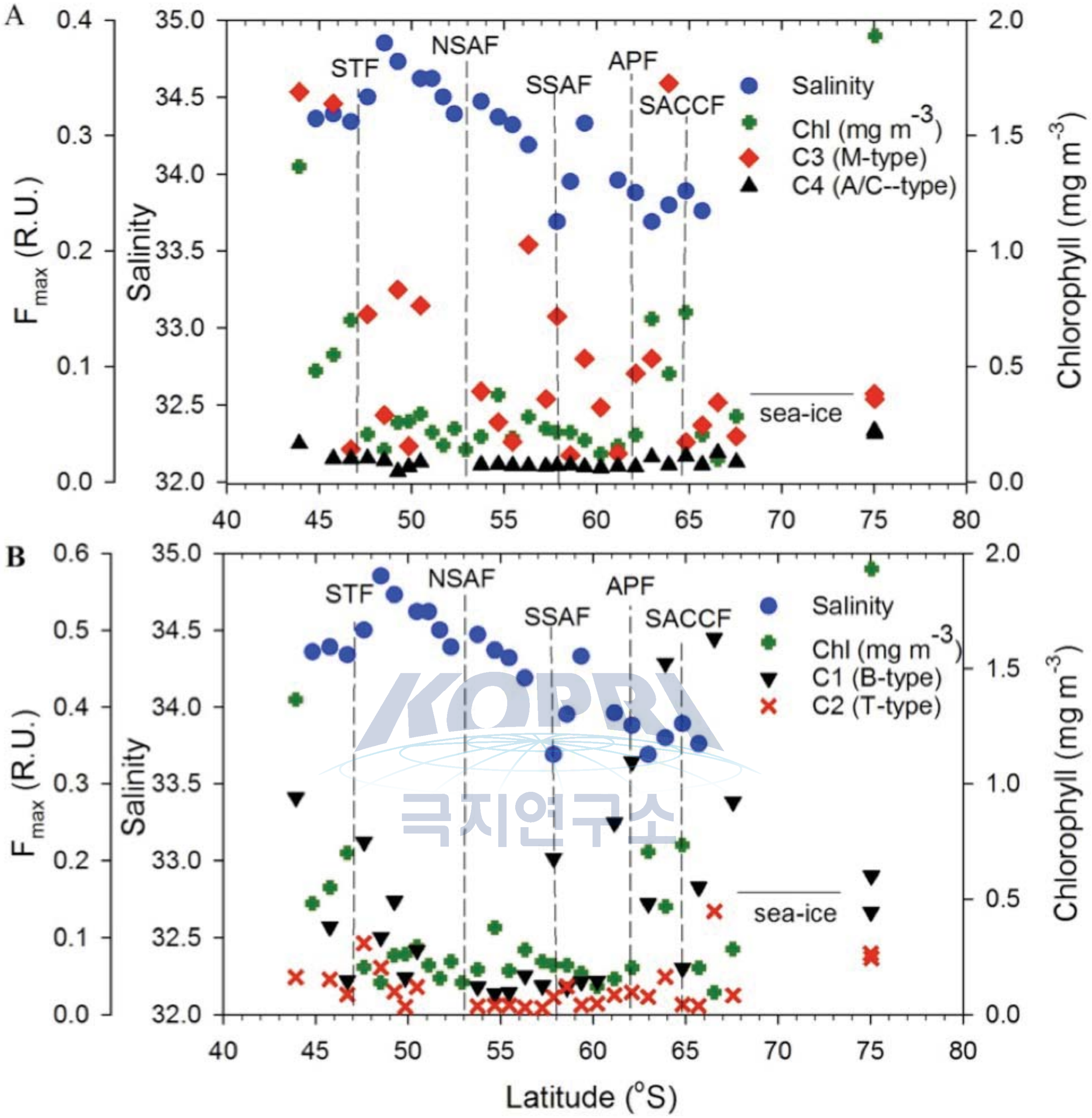

Figure 7. FDOM components. Meridional distribution of the (A) C3 and C4, (B) C1 and C2 FDOM components, sea surface salinity and chlorophyll along the transect. Dashed vertical lines show locations of the Southern Ocean fronts.

2. Analysis of bio-optical data obtained during the austral summer of 2015 along the New Zealand sector of the Southern Ocean and in the Ross Sea (manuscript in preparation)

During the 2015 austral summer, seawater samples were collected along the Araon transect as well as CTD stations in the Ross Sea (Figure 8-left) and processed in the laboratory. Measurements of CDOM spectral absorption, particulate (total, phytoplankton and non-algal) absorption coefficients, and EEMs fluorescence were then obtained on a spectrophotometer and a spectrofluorometer. DOC concentrations at these stations were also measured. These field bio-optical data were examined in conjunction with the physical properties in the Ross Sea (Figure 8 –right)

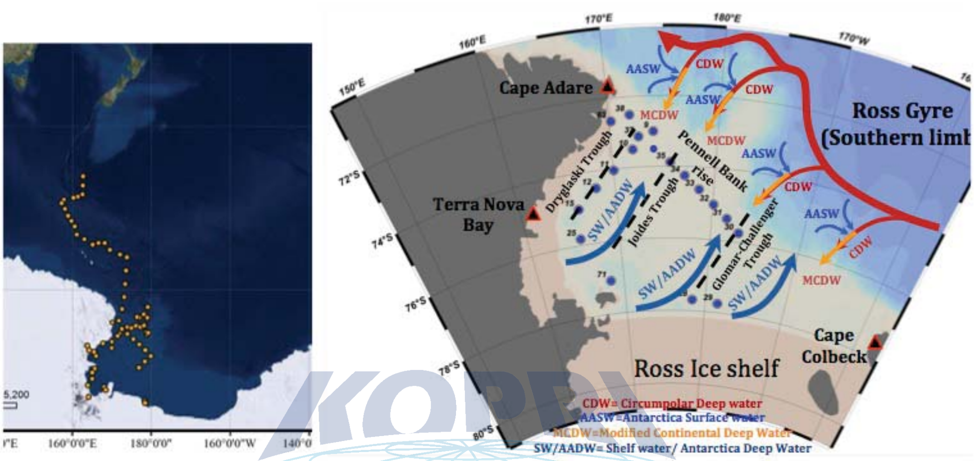

Figure 8. (Left) Sampling stations during the 2015 Araon cruise to the Southern Ocean. (Right) Location of sampling stations in the Ross Sea and physical regime corresponding to different water masses in the study area.

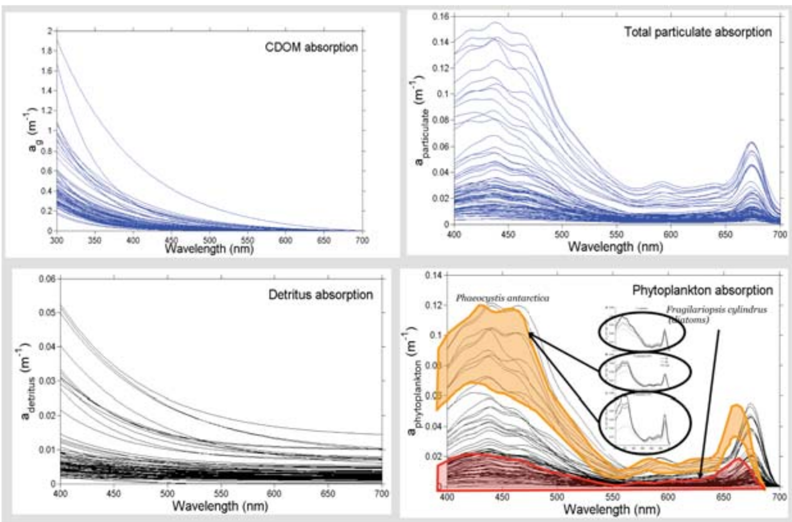

Figure 9. CDOM and particulate spectral absorption coefficients (total, non-algal, and phytoplankton) for all stations (at various depths – e.g., surface, mid-depth) in the Ross Sea.

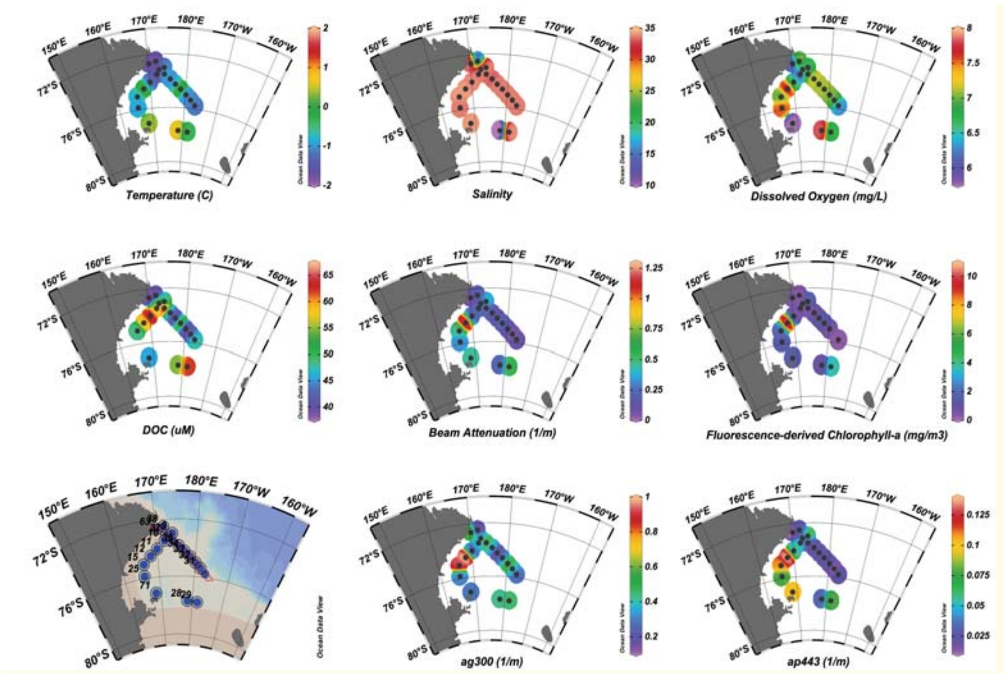

Figure 10. Surface hydrographic (temperature, salinity), and bio-optical (DOC, chlorophyll, absorption coefficients of CDOM, and particulate matter) properties along two transects in the Ross Sea.

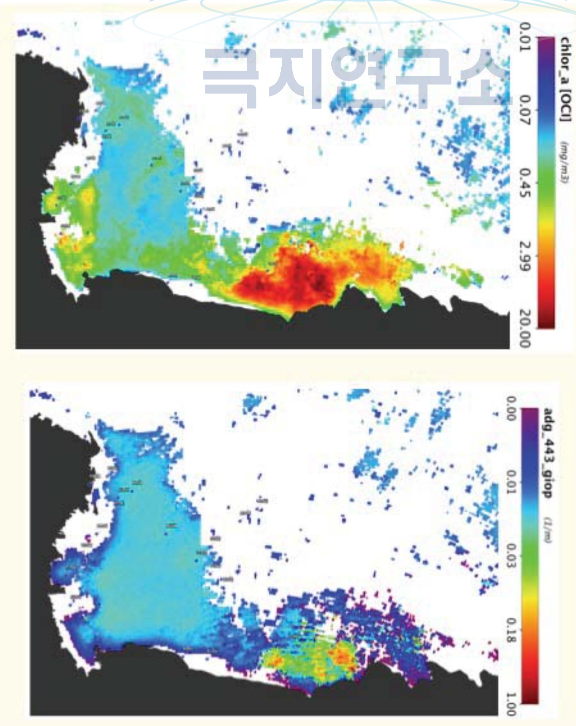

Figure 11. Satellite-derived (MODIS/Aqua) estimates of surface chlorophyll (mg m^{-3}) and cdm (CDOM + nonalgal particulate matter) absorption coefficient at 443 nm averaged for the sampling period during austral summer (January 2015) in the Ross Sea.

Summary results

Surface optical properties along the ARAON transect in the New Zealand sector of the Southern Ocean during 2014 cruise showed variability associated with different water masses. Both CDOM absorption and particulate matter absorption (indicative of CDOM, phytoplankton and non-algal matter concentrations) were generally higher off New Zealand coast and in the Terra Nova Bay, Ross Sea. However, along most of the transect that spanned the different water masses, CDOM and particulate absorption were very low, often close to the instrument detection limit. Satellite remote sensing data provided additional insights into the water masses present along the New Zealand Southern Ocean transect. Sea surface salinity from the new Aquarius satellite sensor provided important information on the frontal pattern (e.g., Subtropical Front (STF) which influenced the CDOM and chlorophyll distribution and further added to the understanding of the in situ bio-optical data. PARAFAC modeling of the fluorescence excitation-emission matrix (EEM) data revealed the presence of four fluorescence components in the CDOM pool of the Southern Ocean also common in the global ocean. Results of this study were presented at conferences and a paper has been published (D'Sa and Kim 2017-see reference list). Further, during the 2016 project year, a large number of seawater samples obtained during the Araon cruise to the Southern Ocean and the Ross Sea have been processed and analyzed in conjunction with hydrographic data. Work on a manuscript for submission to a peer-review journal has been initiated.

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