Hydrographic Atlas of the South Brazil Bight and the Southern Brazilian Shelf

Rodrigo Kerr, Rafael André Avila, Luísa de M. Garcia and Eduardo R. Secchi
Instituto de Oceanografia da Universidade Federal do Rio Grande - FURG

HYDROGRAPHIC ATLAS
OF THE SOUTH BRAZIL BIGHT
AND THE SOUTHERN BRAZILIAN SHELF

Editora da FURG
Campus Carreiros
CEP 96203 900 – Rio Grande – RS – Brasil
editora@furg.br

Rodrigo Kerr
Rafael André Avila
Luísa de M. Garcia
Eduardo R. Secchi

HYDROGRAPHIC ATLAS OF THE SOUTH BRAZIL BIGHT AND THE SOUTHERN BRAZILIAN SHELF

Rio Grande
2024

2024

Cover image: Rodrigo Genoves
Cover Layout: Rodrigo Kerr
Formatting and Layout: Rodrigo Kerr and Rafael André Avila

Ficha catalográfica

H995 Hydrographic atlas of the south Brazil bight and the southern Brazilian shelf [Recurso Eletrônico] / Rodrigo Kerr… [et al.]. – Rio Grande, RS : Ed. da FURG, 2024.
128 p. : il. color.

Outros autores: Rafael Avila, Luísa de M. Garcia, Eduardo R. Secchi.
Modo de acesso: http://repositorio.furg.br
ISBN 978-65-5754-245-3 (eletrônico)

1. Hidrografia 2. Oceanografia 3. Hidrologia 4. Brasil I. Kerr, Rodrigo II. Avila, Rafael III. Garcia, Luísa de M. IV. Secchi, Eduardo R. V. Título.

CDU 551.46(81)

Catalogação na Fonte: Bibliotecário José Paulo dos Santos – CRB10/2344

Hydrographic Atlas of the South Brazil Bight and the Southern Brazilian Shelf

Rodrigo Kerr, Rafael André Avila, Luísa de M. Garcia and Eduardo R. Secchi

FURG
UNIVERSIDADE FEDERAL
DO RIO GRANDE

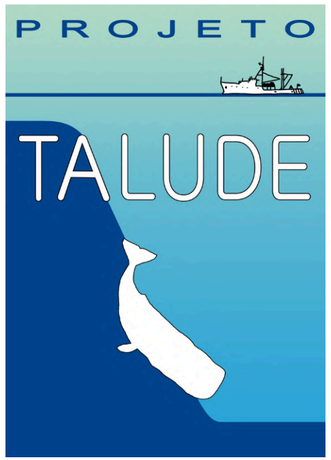
ECOMEGA
Laboratório de Ecologia e Conservação
da Megafauna Marinha

Laboratório de Estudos dos Oceanos e Clima
LEOC
IO-FURG

The CARBON Team
Laboratório de Estudos dos Oceanos e Clima
Instituto de Oceanografia - FURG

GOAL
Grupo de Oceanografia de Altas Latitudes

This Atlas was designed collaboratively by the projects led at FURG, i.e. Talude and MARES projects and the National Institute of Science and Technology on Biodiversity of the Blue Amazon (INCT-BAA), to contribute to the actions of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030)



INCT BIODIVERSIDADE
DA AMAZÔNIA AZUL

Acknowledgements

We would like to thank all the researchers, technicians, professors, students and ship crews involved in the planning, sampling and analysis of the data used in this Atlas, without whom this initiative would not be possible. Special thanks to those involved with Brazilian cruises.

We would also like to thank all the public and private agencies (and the people involved in their management) that financed the logistical activities, scholarships and conditions for the development of the Brazilian projects involved in this initiative.

We would like to thank the National Centers for Environmental Information (NCEI) of National Oceanic and Atmospheric Administration (NOAA) for keeping the World Ocean Database (WOD), which is world's largest collection of uniformly formatted, quality controlled, publicly available ocean profile data.

We also like to thank the Argo Program, as part of the Global Ocean Observing System. The Argo data were collected and made freely available by the International Argo Program and the national programs that contribute to it (https://argo.ucsd.edu, https://www.ocean-ops.org).

We would like to thank the GLobal Ocean Data Analysis Project for Carbon (GLODAP), which is a cooperative effort to coordinate global synthesis projects funded through NOAA, the U.S. Department of Energy, and the National Science Foundation as part of the Joint Global Ocean Flux Study - Synthesis and Modeling Project.

Datasets

The dataset from the World Ocean Database (WOD) is available at https://www.ncei.noaa.gov/. [Reference: Boyer, T.P., O.K. Baranova, C. Coleman, H.E. Garcia, A. Grodsky, R.A. Locarnini, A.V. Mishonov, C.R. Paver, J.R. Reagan, D. Seidov, I.V. Smolyar, K. Weathers, M.M. Zweng,(2018): World Ocean Database 2018. A.V. Mishonov, Technical Ed., NOAA Atlas NESDIS 87. https://www.ncei.noaa.gov/sites/default/files/2020-04/wod_intro_0.pdf]

The dataset from Argo float is available at https://argo.ucsd.edu/data/data-from-gdacs/. [Reference: Wong, A. P. S., et al. (2020), Argo Data 1999–2019: Two Million Temperature-Salinity Profiles and Subsurface Velocity Observations From a Global Array of Profiling Floats, Frontiers in Marine Science, 7 (700), doi: https://doi.org/10.3389/fmars.2020.00700]

The dataset from the Global Ocean Data Analysis Project (GLODAP) is available at https://glodap.info/. [Reference: Olsen, A., Lange, N., Key, R. M., Tanhua, T., Bittig, H. C., Kozyr, A., Àlvarez, M., Azetsu-Scott, K., Becker, S., Brown, P. J., Carter, B. R., Cotrim da Cunha, L., Feely, R. A., van Heuven, S., Hoppema, M., Ishii, M., Jeansson, E., Jutterström, S., Landa, C. S., Lauvset, S. K., Michaelis, P., Murata, A., Pérez, F. F., Pfeil, B., Schirnick, C., Steinfeldt, R., Suzuki, T., Tilbrook, B., Velo, A., Wanninkhof, R. and Woosley, R. J.(2020). GLODAPv2.2020 – the second update of GLODAPv2. https://doi:10.5194/essd-12-3653-2020]

The dataset from the Brazilian projects can be accessed upon request. Please e-mail carbonteam@furg.br. The interpolated data from this Atlas can be accessed through https://doi.org/10.5281/zenodo.13942335

Brazilian cruises, ships and PIs

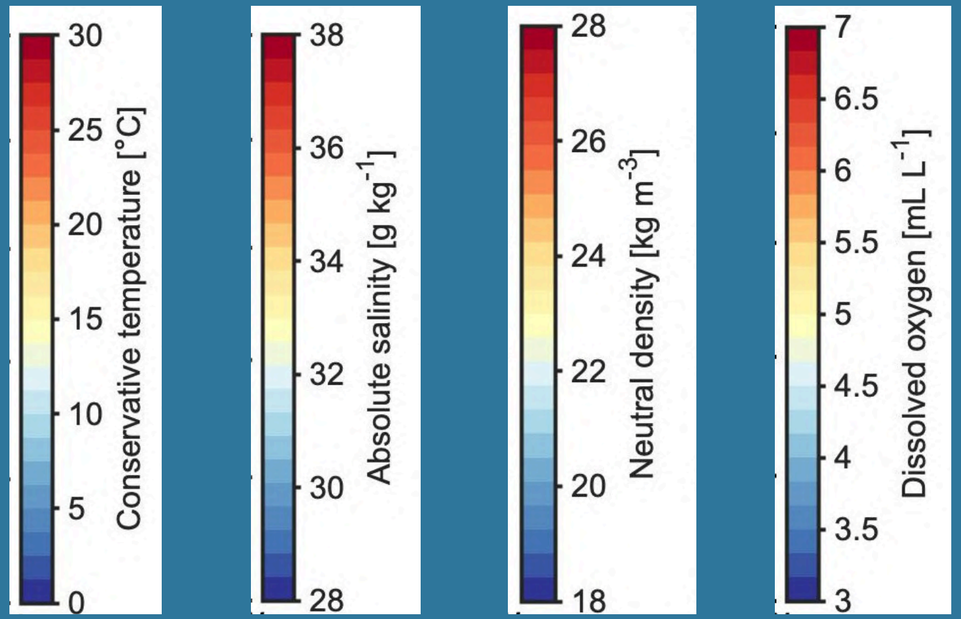
PROJECT

Cruise	Date (Month Year)	Chief Scientist (on board)	Principal Investigator	Research Vessel
TALUDE - more information at https://doi.org/10.5281/zenodo.14185604				
Talude I	Oct 2009	Eduardo Secchi	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude II	May 2010	Eduardo Secchi/Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude III	Nov 2010	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude IV	Apr 2011	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude V	Nov 2012	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude VI	May 2013	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude VII	May 2014	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude VIII	Nov 2014	Juliana di Tullio	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude IX	May 2015	Eduardo Secchi/Luciano Dalla Rosa	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude X	Nov 2015	Genyffer Troina	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude XI	Mar 2023	Stefan Weigert/Marcelo Pinho	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude XII	Aug 2023	Stefan Weigert/Marcelo Pinho	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)
Talude XIII	Mar 2024	Stefan Weigert/Marcelo Pinho	Eduardo R. Secchi	NOc. Atlântico Sul (FURG)

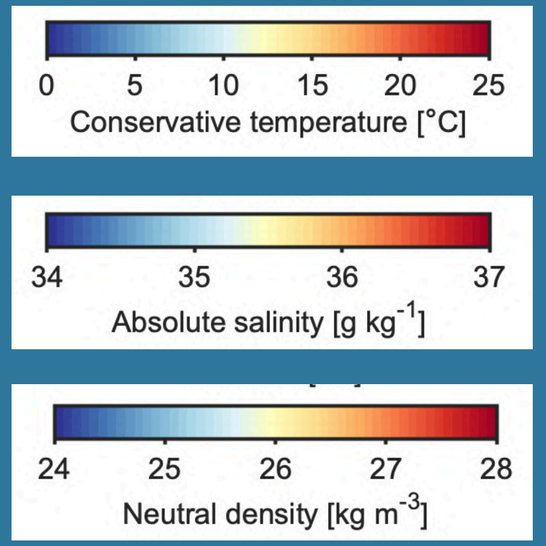
Brazilian cruises, ships and PIs

PROJECT Cruise	Date (Month Year)	Chief Scientist (on board)	Principal Investigator	Research Vessel
EstARte				
EstARte I	Oct 2014	Rodrigo Kerr	Rodrigo Kerr	NHo. Cruzeiro do Sul (H-38)
MOVAR				
MCT VI	Aug 2012	Carlos Fujita	Mauricio M. Mata	NHo. Cruzeiro do Sul (H-38)
CO_2 SSE				
MCT II leg I	Dec 2010	Rosane Ito	Carlos A. E. Garcia	NHo. Cruzeiro do Sul (H-38)
MCT II leg II	Jan 2011	Áurea Ciotti	Carlos A. E. Garcia	NHo. Cruzeiro do Sul (H-38)
Trans-Atlântico II				
Brazil to Africa	Oct/Dec 2011	Rosane Ito	Carlos A. E. Garcia	NHo. Cruzeiro do Sul (H-38)
Africa to Brazil	Dec 2011	Áurea Ciotti	Carlos A. E. Garcia	NHo. Cruzeiro do Sul (H-38)

Table of Atlas Plates (Climatological Maps and Hydrographic sections)

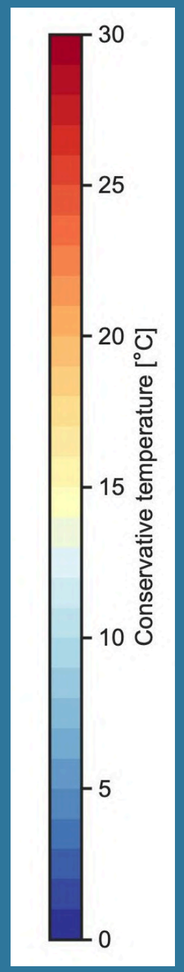


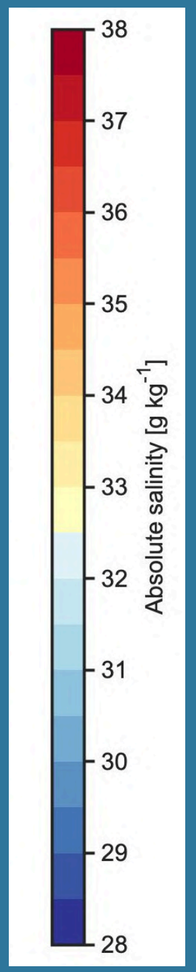
Section 03
page 28

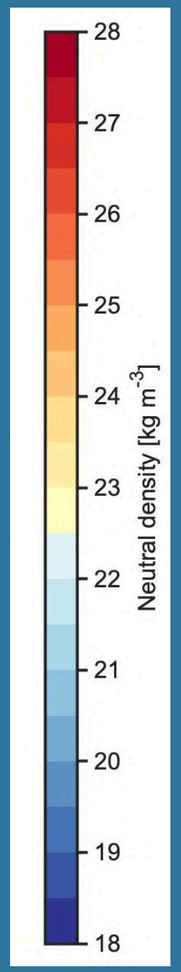


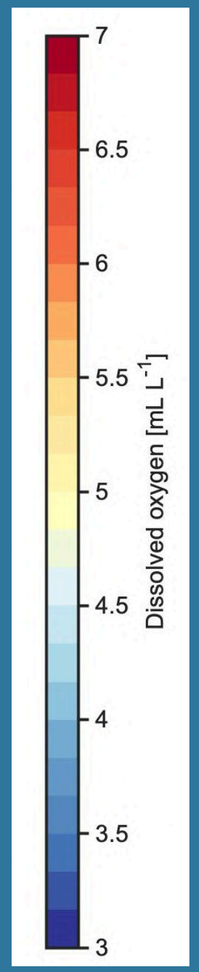
Section 05
page 129

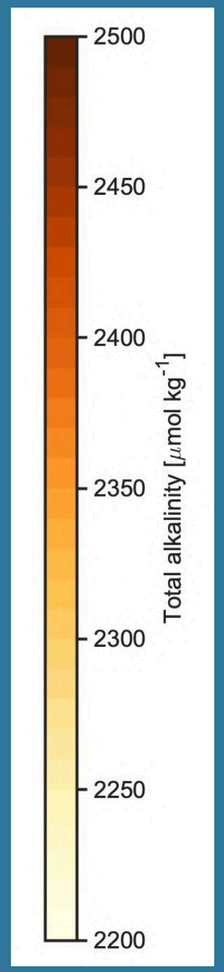
Table of Atlas Plates (Seasonal Maps)

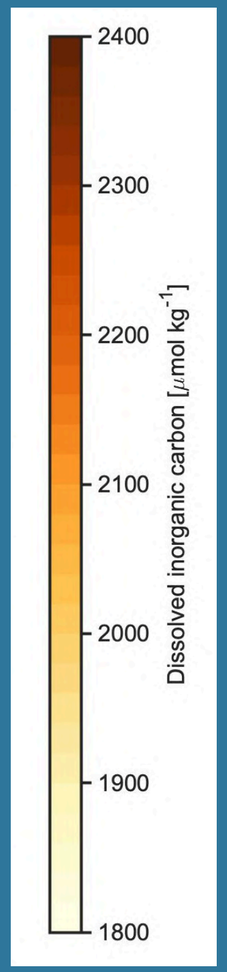


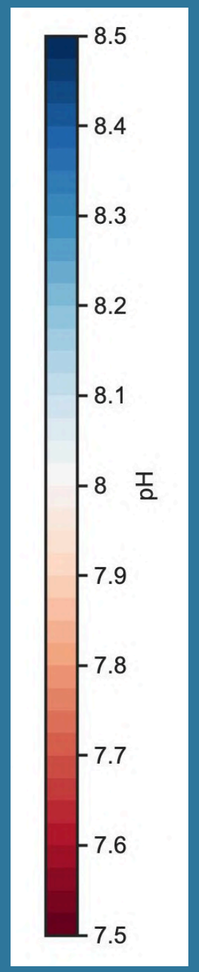


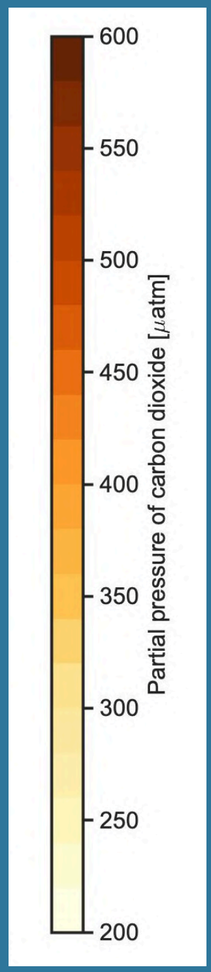


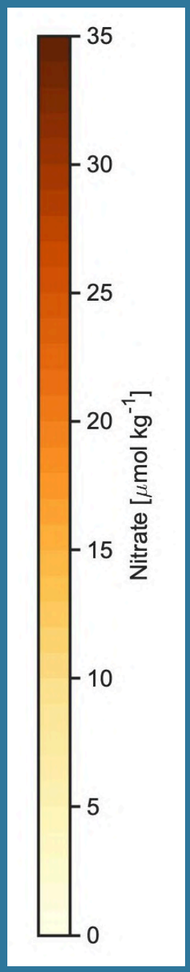


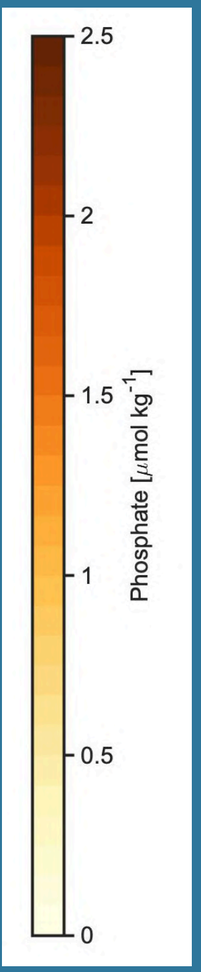






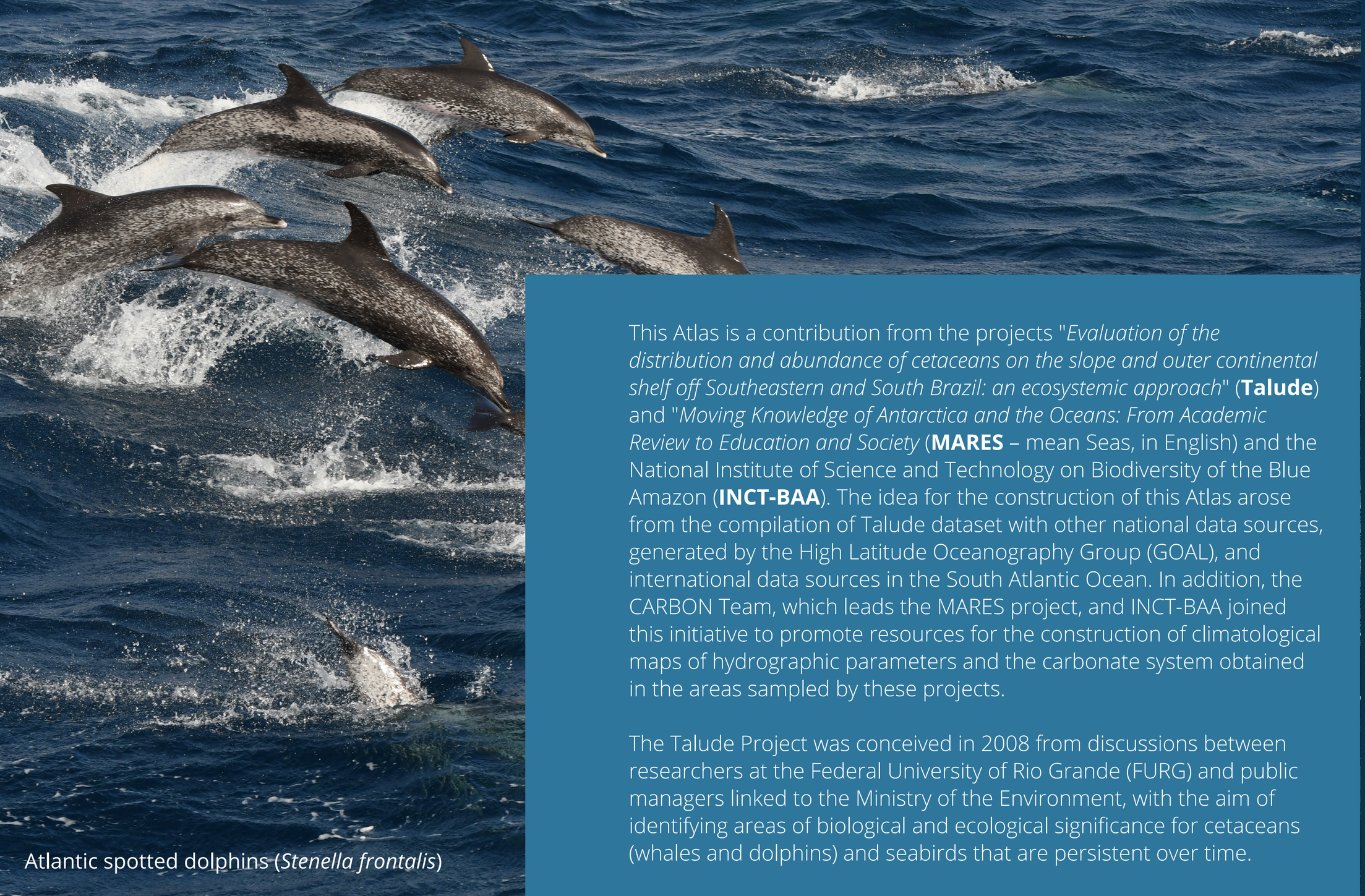






Contents

Rosette and Niskin bottles for seawater sampling

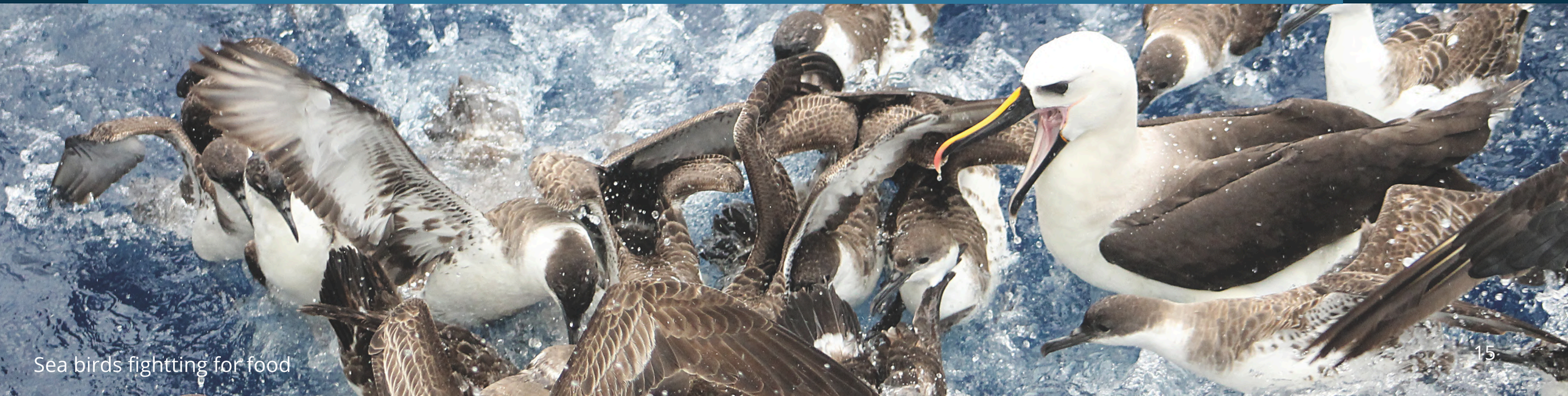


Atlantic spotted dolphins (*Stenella frontalis*)

This Atlas is a contribution from the projects "*Evaluation of the distribution and abundance of cetaceans on the slope and outer continental shelf off Southeastern and South Brazil: an ecosystemic approach*" (**Talude**) and "*Moving Knowledge of Antarctica and the Oceans: From Academic Review to Education and Society* (**MARES** – mean Seas, in English) and the National Institute of Science and Technology on Biodiversity of the Blue Amazon (**INCT-BAA**). The idea for the construction of this Atlas arose from the compilation of Talude dataset with other national data sources, generated by the High Latitude Oceanography Group (GOAL), and international data sources in the South Atlantic Ocean. In addition, the CARBON Team, which leads the MARES project, and INCT-BAA joined this initiative to promote resources for the construction of climatological maps of hydrographic parameters and the carbonate system obtained in the areas sampled by these projects.

The Talude Project was conceived in 2008 from discussions between researchers at the Federal University of Rio Grande (FURG) and public managers linked to the Ministry of the Environment, with the aim of identifying areas of biological and ecological significance for cetaceans (whales and dolphins) and seabirds that are persistent over time.

To achieve this, over 5 springs, 5 autumns, 2 summers, and 2 winters, the Talude project collected data on physical-chemical characteristics (temperature, salinity, nutrients, total alkalinity, dissolved inorganic carbon etc.), biological (primary and secondary production), and physiographic (bathymetry) to understand the variables and oceanographic processes that determine the distribution pattern of these marine megafauna animals along the slope and outer continental shelf, from Chuí (approximately 34°S), in the far South, to Cabo Frio in southeastern Brazil (22°S). The cruises were conducted aboard the Oceanographic Research Vessel "Atlântico Sul" of FURG. This study is of great importance as it pertains to an ecologically understudied area of economic interest for the country (mainly due to the fishing and oil and gas industries). Identifying areas of concentration for predators, such as birds and cetaceans, and their prey can assist in establishing critical areas for the conservation of these species and, therefore, contribute to programs for managing human activities and conserving marine biodiversity.



Sea birds fightting for food

01.2 MARES Project

The MARES Project is led by the CARBON Team (www.carbontean.furg.br) at the Laboratory of Ocean and Climate Studies (LEOC) and aims to connect society with scientific knowledge about the oceans and Antarctica, that play a crucial role in regulating the Earth's climate and are currently threatened by global climate change. MARES promotes a multidisciplinary collaboration among four higher education institutions across three regions of Brazil (Northeast, Southeast, and South), uniting researchers at various stages of their careers (early, mid, and established). The project intends to expand existing outreach and scientific communication efforts by establishing a specialized team focused on enhancing scientific messaging and developing accessible audiovisual resources, shared mainly through Instagram (@projmares). Additionally, MARES plans to produce materials such as new volumes of the CARBON Team News magazine, publish a Glossary of Marine and Antarctic Sciences, and contribute articles to journals aimed at young audiences.

Killer whale (*Orcinus orca*)

In addition, aiming to investigate and monitor the rich biodiversity of Brazil's Exclusive Economic Zone through an interdisciplinary and multidisciplinary approach, the INCT–BAA (www.bioamazoniaazul.com) brings together researchers from across Brazil, along with international collaborators from various fields of expertise, to conduct integrated studies of the oceans. Through oceanographic cruises, sample collection, and data analysis, the INCT–BAA seeks to enhance understanding and predictive capabilities regarding the impacts of climate change and human activities on marine biodiversity, with the goal of proposing mitigation strategies to preserve marine life, its biotechnological potential, and the essential ecosystem services it provides. The findings from these studies will form the basis for public policies that promote marine ecosystem conservation and the sustainable development ofuse of marine living resources.

Bottlenose dolphin (*Tursiops truncatus*)

01.4 SDGs contribution

The oceans play a vital role in regulating the climate, housing immense biodiversity that remains largely unmapped, unquantified, and, in many cases unsustainably explored. This biological diversity is crucial for ensuring ecosystem resilience and high-quality food security. It also represents significant biotechnological potential for addressing various contemporary challenges. A comprehensive understanding of this biodiversity and its dynamic interactions with the environment is essential for informing effective strategies for both its rational use and conservation, particularly in light of the human-related impacts and climate change.

Spinner dolphin (*Stenella longirostris*)

SDGs contribution

Given the vast scale and complexity of the oceans, the INCT−BAA, Talude and MARES projects have established a broad national research network, with international collaborators from various fields of expertise, all converging to investigate and monitor the oceans, especially the Brazilian continental shelf and beyond. Moreover, these projects aim to contribute for the achievement of the Sustainable Development Goals (SDGs) outlined by the United Nations as targets during the Decade of Ocean Science for Sustainable Development. The projects directly contribute to SDG 14, Life Below Water, by disseminating high-quality scientific information and making it accessible to all, thereby promoting the conservation and sustainable use of the oceans to meet the goals for the "Ocean We Want." Additionally, they indirectly support SDG 4, Quality Education, by fostering inclusive learning opportunities and contributing to target 4.7, which seeks to "ensure that by 2030, all learners acquire the knowledge and skills needed to promote sustainable development, including through education for sustainable development and sustainable lifestyles."

Bongo nets for zooplankton sampling

Bryde's whales (*Balaenoptera brydei*)

This Atlas is structured based on **(i) climatological maps** (1972-2024) of the essential properties of seawater (i.e. temperature, salinity, density and dissolved oxygen) in 8 horizontal strata of the water column, these being at 5, 10, 25, 50, 100, 200, 500 and 1000 dBar, **(ii) seasonal maps** of the same properties mentioned above, added some chemical variables of seawater (i.e. the four main parameters of the carbonate system - total alkalinity, dissolved inorganic carbon, pH and seawater partial pressure of CO_2 - and dissolved nutrients - nitrate and phosphate), which were reconstructed for the region, and **(iii) vertical hydrographic sections** of the physical properties measured by Talude project. Those maps are presented in Chapters 03, 04, and 05, respectively. All information related to the number of vertical profiles, interpolation methods and techniques used are indicated next to the maps presented. Additionally, to situate the reader, the following pages of this section introduce the reader to the main oceanic areas of this Atlas and indicate the aspects of the bathymetry and oceanic circulation of the region.

02.1 The South Brazil Bight

The South Brazil Bight (SBB), situated between Cabo Frio (23°S) and Cabo de Santa Marta Grande (28°40'S), is bordered by the Brazilian states of Rio de Janeiro, São Paulo, Paraná, and Santa Catarina, and is included in the South Brazil Shelf Large Marine Ecosystem (#15). Its circulation is influenced by low-amplitude tides, northeasterly winds, and the poleward flow of the Brazil Current (BC) along the shelf edge. A notable feature of circulation in the SBB is the intense mesoscale activity due to the occurrence of meanders and vortices (cyclonic and anti-cyclonic) associated with the BC.

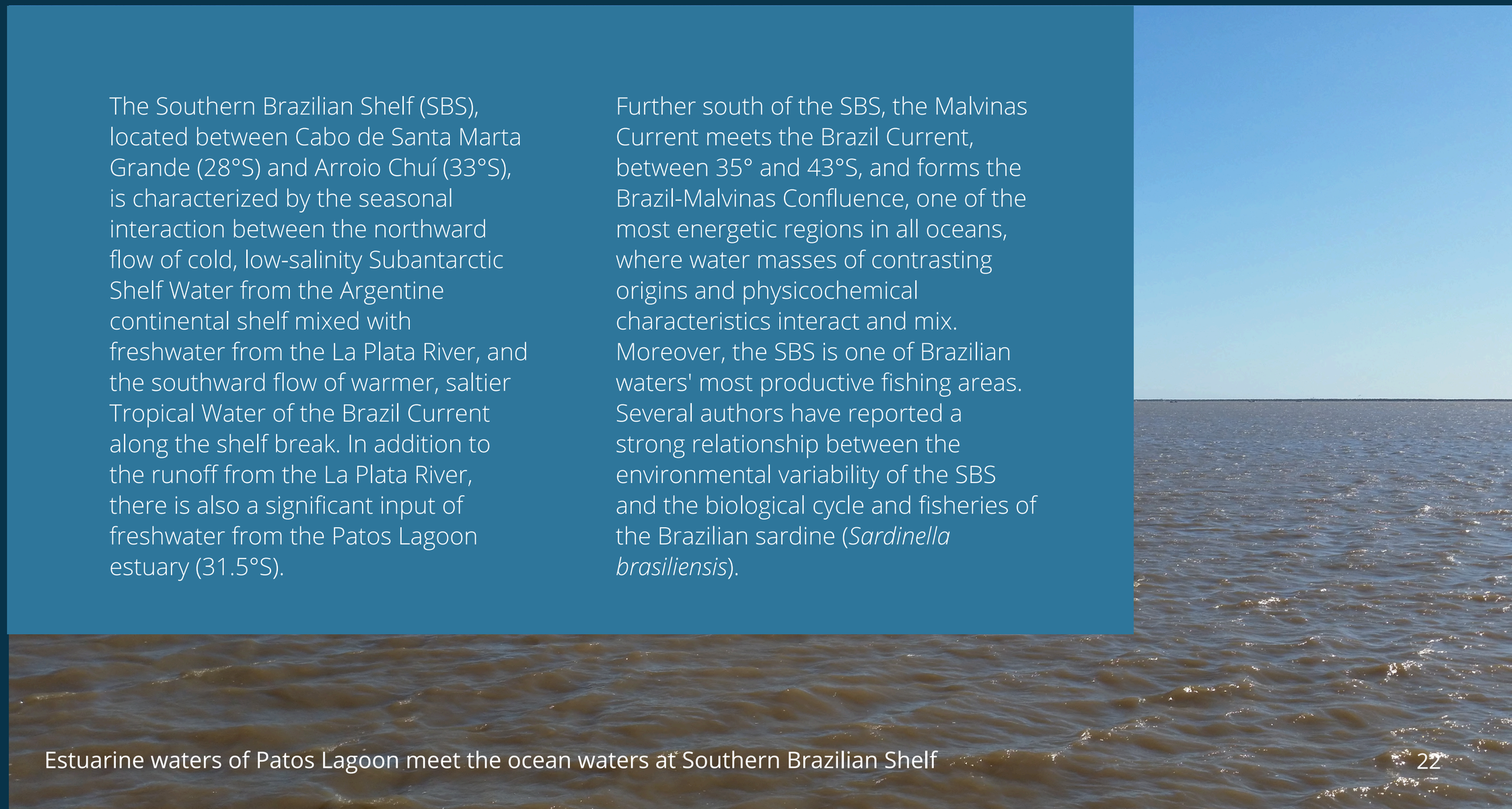
Additionally, the presence of shelf-break upwellings induced by cyclonic meanders promotes the intrusion of South Atlantic Central Water into the outer regions of the Santos Basin shelf. These upwellings on the slope have significant implications for primary production in the oceanic areas, where nutrient intrusion into the euphotic zone from deeper layers is typically constrained by a permanent thermocline. Thus, fertilization of the euphotic zone can lead to increased phytoplankton production, which is crucial for sustaining other trophic levels in the region.

Research Vessel "Atlântico Sul" surveying in the South Brazil Bight

02.2 The Southern Brazilian Shelf

The Southern Brazilian Shelf (SBS), located between Cabo de Santa Marta Grande (28°S) and Arroio Chuí (33°S), is characterized by the seasonal interaction between the northward flow of cold, low-salinity Subantarctic Shelf Water from the Argentine continental shelf mixed with freshwater from the La Plata River, and the southward flow of warmer, saltier Tropical Water of the Brazil Current along the shelf break. In addition to the runoff from the La Plata River, there is also a significant input of freshwater from the Patos Lagoon estuary (31.5°S).

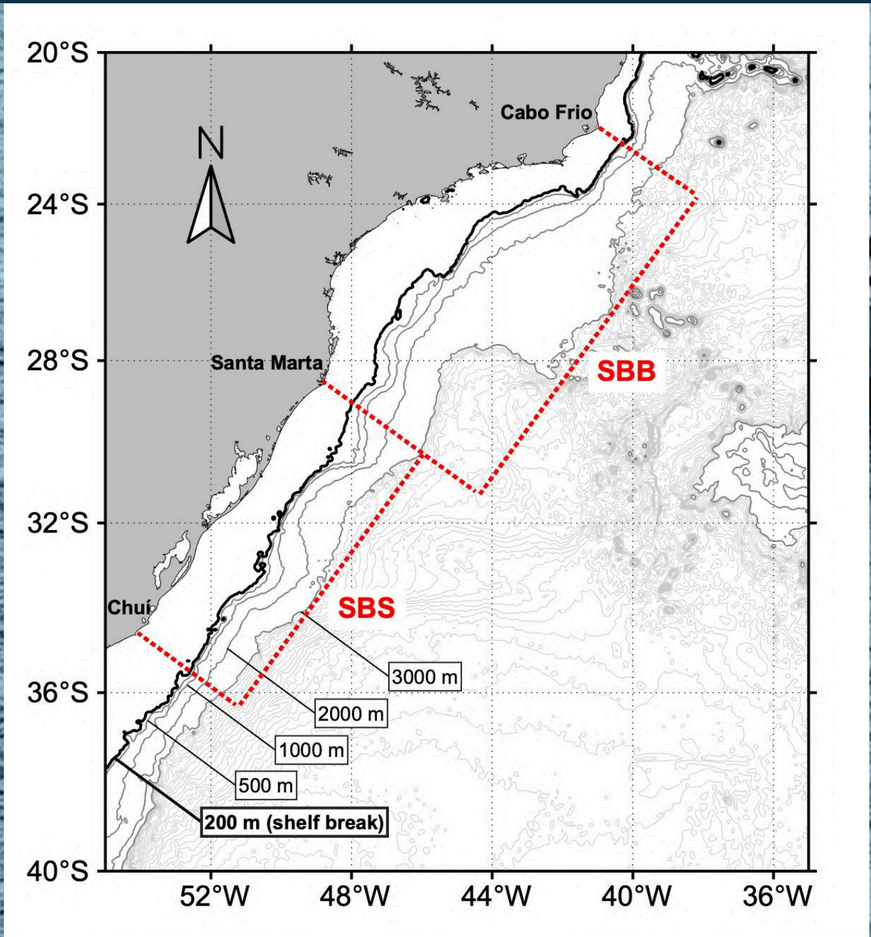
Further south of the SBS, the Malvinas Current meets the Brazil Current, between 35° and 43°S, and forms the Brazil-Malvinas Confluence, one of the most energetic regions in all oceans, where water masses of contrasting origins and physicochemical characteristics interact and mix. Moreover, the SBS is one of Brazilian waters' most productive fishing areas. Several authors have reported a strong relationship between the environmental variability of the SBS and the biological cycle and fisheries of the Brazilian sardine (*Sardinella brasiliensis*).



Estuarine waters of Patos Lagoon meet the ocean waters at Southern Brazilian Shelf

02.3 Bathymetry

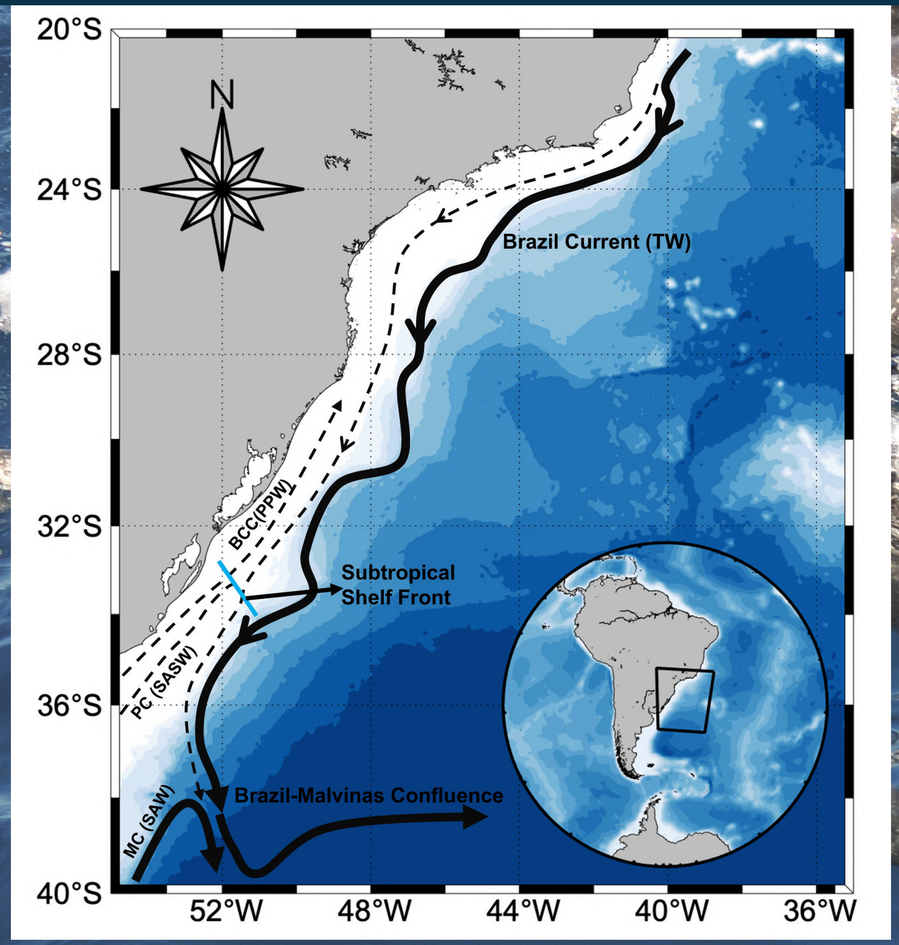
Both SBB and SBS have been systematically studied since the 1960s, focusing on bathymetric, seismic, and sedimentological research. Currently, it is known that the continental shelf covers an area around 267,000 km², with a width ranging from 50 to 230 km. It experiences a tidal range of less than 2 m and wave heights varying from 0 to 5 m. The inner continental shelf is primarily influenced by wave action, while currents dominate the outer continental shelf. The shelf break is located close to 200 m with the deepest portions of the continental slope extending beyond the 4000 m isobath. Along the continental shelf, the sedimentation is predominantly siliciclastic, accounting for 95% of the sediment. In terms of geological features, the continental shelf consists of both modern (50%) and relict/palimpsest (50%) characteristics.



Whale swimming by the Research Vessel "Atlântico Sul"

02.4 Ocean circulation

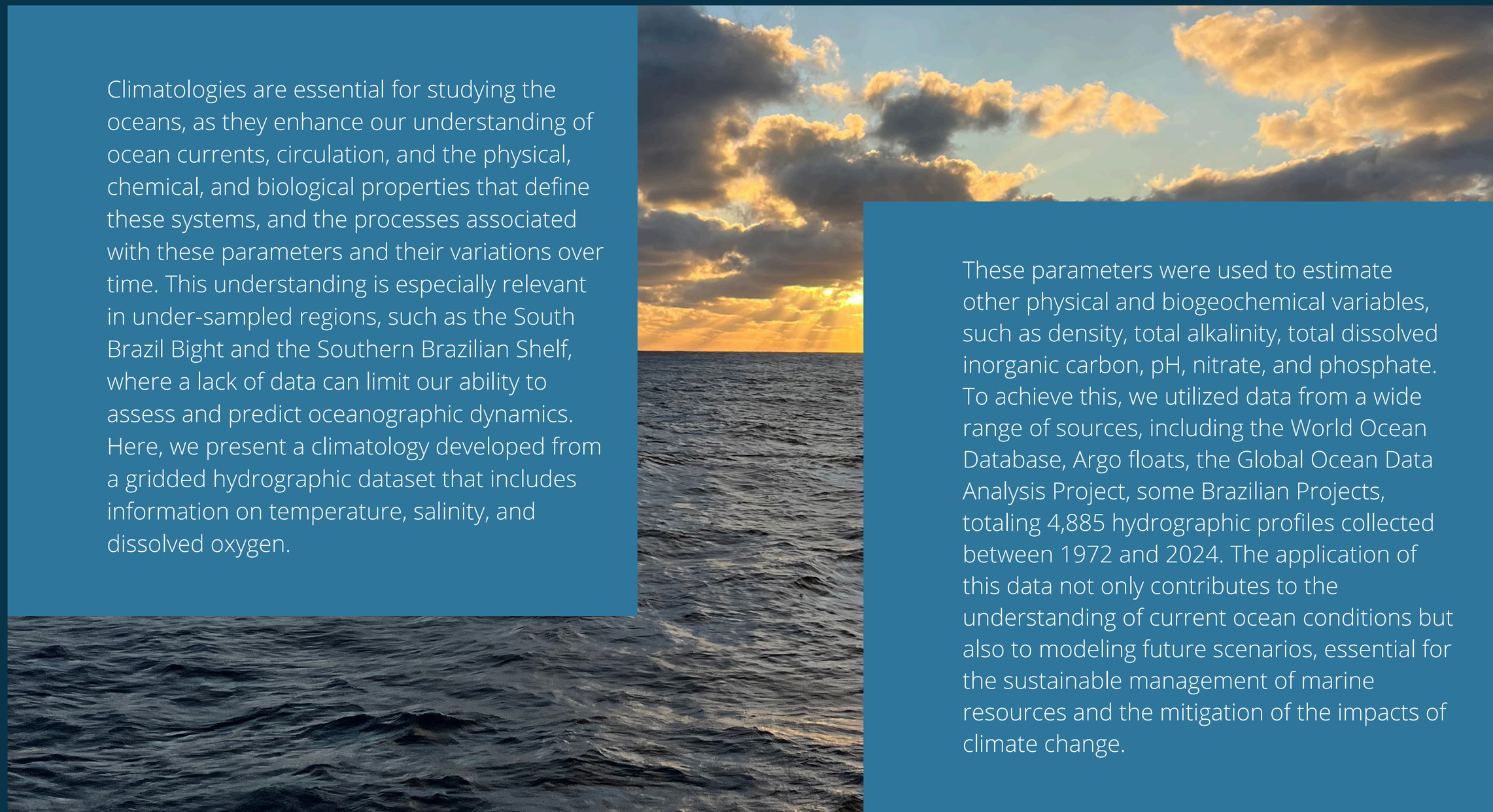
Schematic diagram of ocean currents and water masses in the Brazil's portion of the southwestern South Atlantic Ocean. Ocean currents: BCC = Brazilian Coastal Current, PC = Patagonian Current, and MC = Malvinas Current. Water masses: TW = Tropical Water, PPW = Plata Plume Water, SAW = Subantarctic Water, and SASW = Subantarctic Shelf Water. Solid lines indicate oceanic circulation, while dashed lines represent coastal circulation.



Atlantic spotted dolphins (*Stenella frontalis*)

03 Climatological Maps 1972-2024

Climatologies are essential for studying the oceans, as they enhance our understanding of ocean currents, circulation, and the physical, chemical, and biological properties that define these systems, and the processes associated with these parameters and their variations over time. This understanding is especially relevant in under-sampled regions, such as the South Brazil Bight and the Southern Brazilian Shelf, where a lack of data can limit our ability to assess and predict oceanographic dynamics. Here, we present a climatology developed from a gridded hydrographic dataset that includes information on temperature, salinity, and dissolved oxygen.



These parameters were used to estimate other physical and biogeochemical variables, such as density, total alkalinity, total dissolved inorganic carbon, pH, nitrate, and phosphate. To achieve this, we utilized data from a wide range of sources, including the World Ocean Database, Argo floats, the Global Ocean Data Analysis Project, some Brazilian Projects, totaling 4,885 hydrographic profiles collected between 1972 and 2024. The application of this data not only contributes to the understanding of current ocean conditions but also to modeling future scenarios, essential for the sustainable management of marine resources and the mitigation of the impacts of climate change.

Data availability

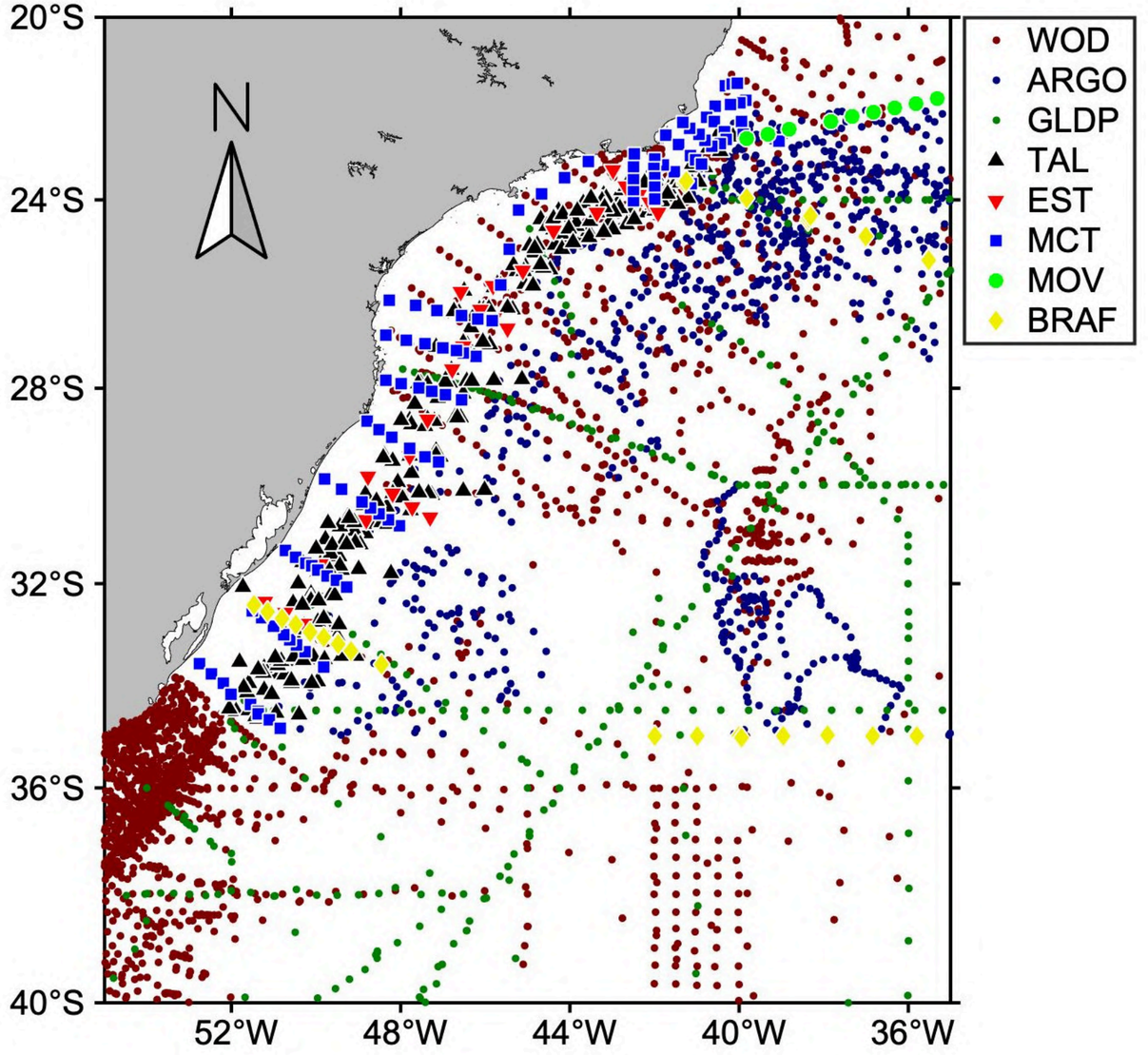
Temporal coverage:

- From 1972 to 2024

Spatial coverage:

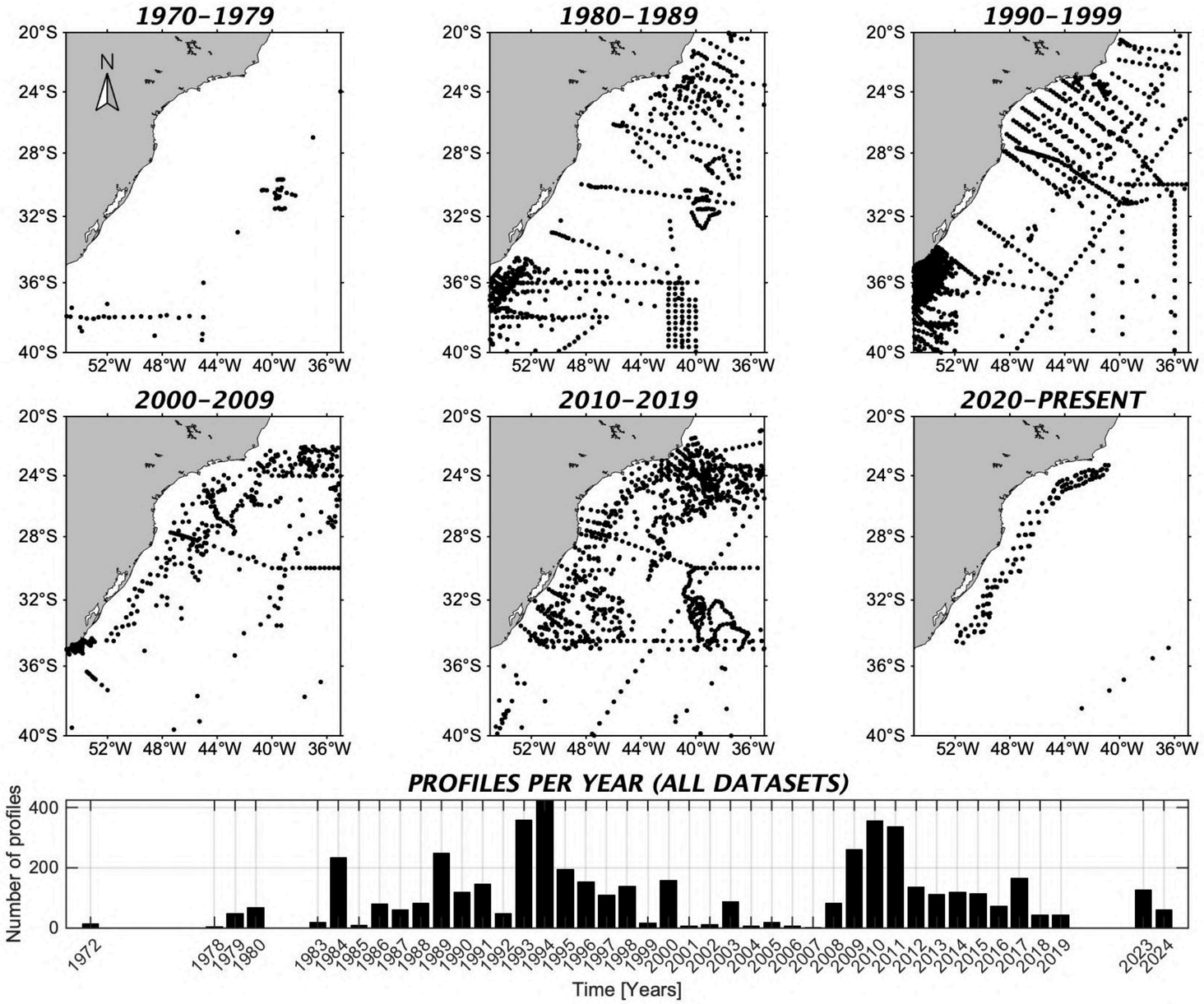
- *World Ocean Database* (WOD) - 2824 profiles
- *ARGO floats* (ARGO) - 795 profiles
- *Global Ocean Data Analysis Project* (GLDP) - 411 profiles
- *TALUDE* cruises (TAL) - 12 cruises, 665 profiles
- *ESTARTE SUL* cruise (EST) - 33 profiles
- *MOVAR* cruise (MOV) - 9 profiles
- *MCTI* cruise (MCT) - 113 profiles
- *BRASIL-AFRICA* cruise (BRAF) - 35 profiles

Total = 4885 profiles



Data availability per decade

- From 1970 to 1979 = 64 profiles
- From 1980 to 1989 = 798 profiles
- From 1990 to 1999 = 1704 profiles
- From 2000 to 2009 = 637 profiles
- From 2010 to 2019 = 1498 profiles
- From 2020 to present = 184 profiles



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

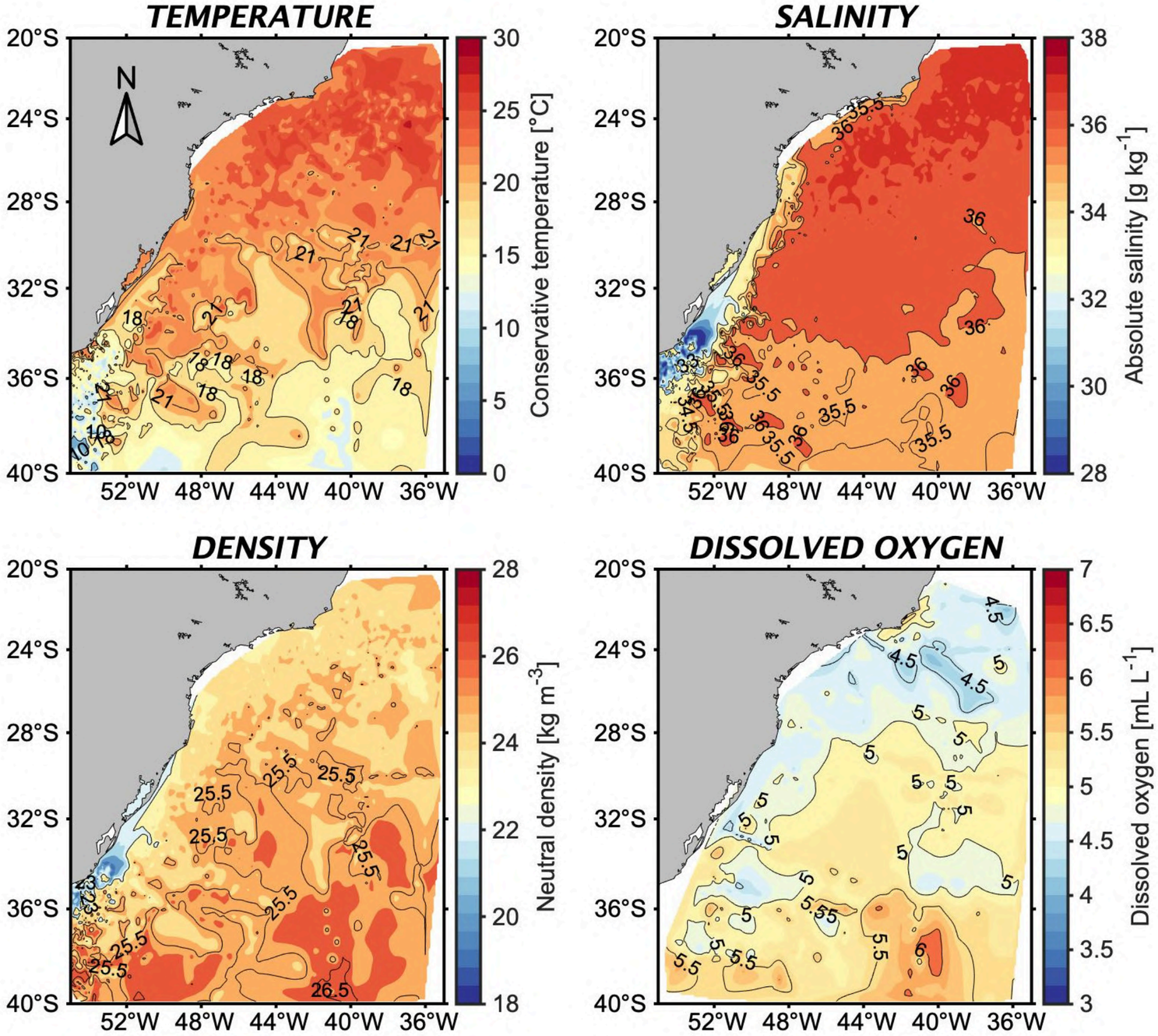
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 4136
- Salinity = 4136
- Dissolved oxygen = 963

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

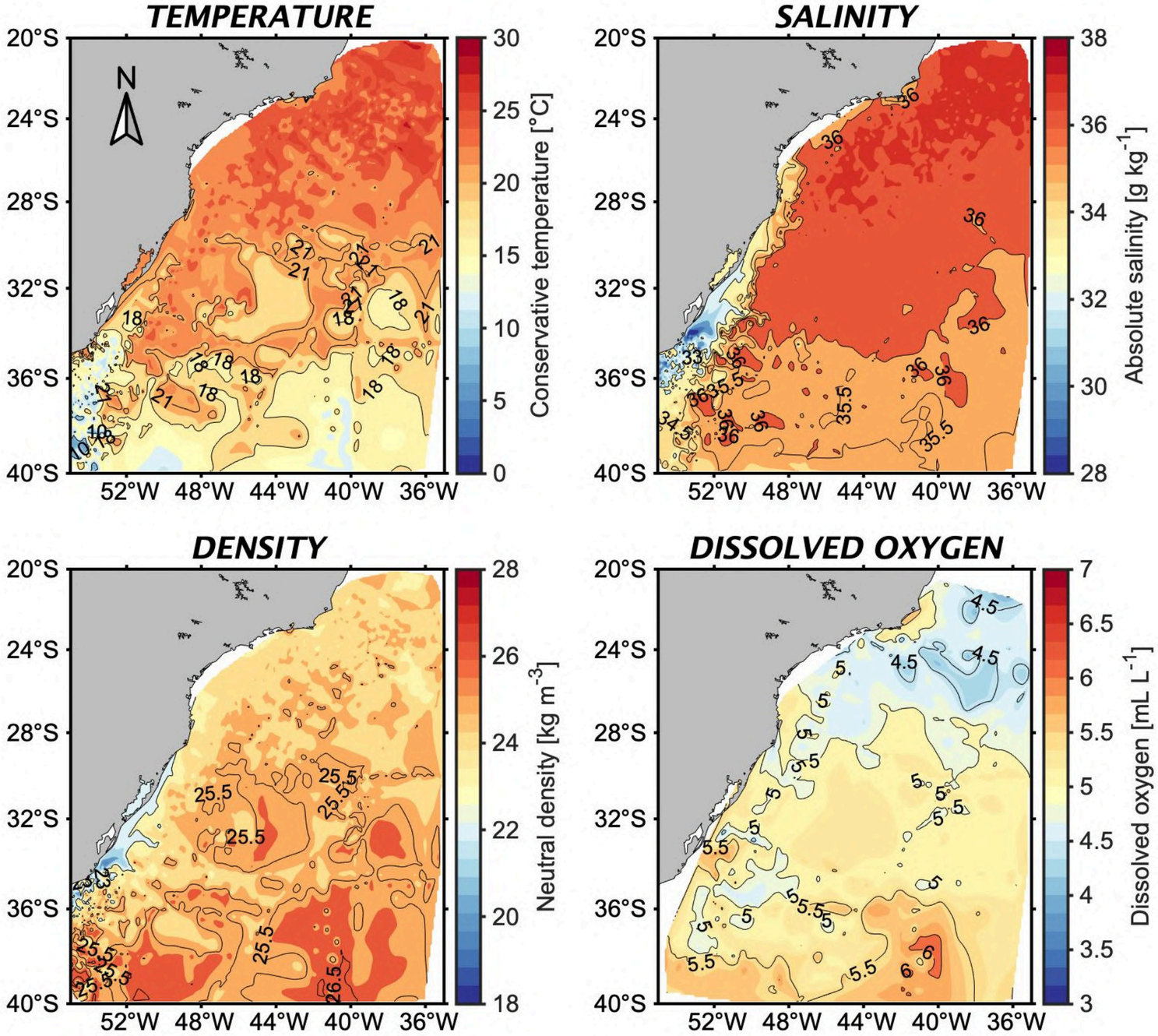
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 4618
- Salinity = 4618
- Dissolved oxygen = 1261

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

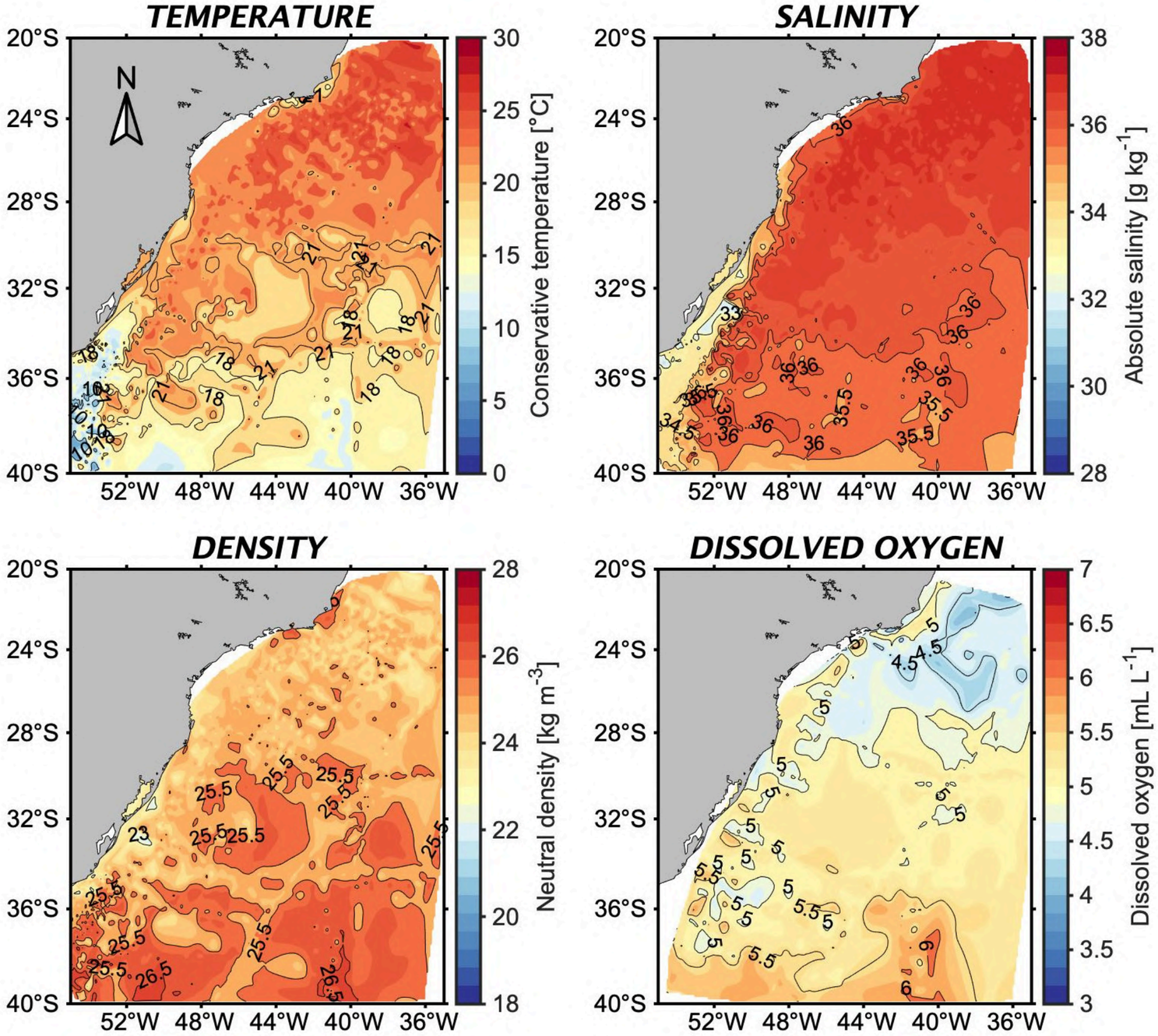
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 4619
- Salinity = 4619
- Dissolved oxygen = 1345

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

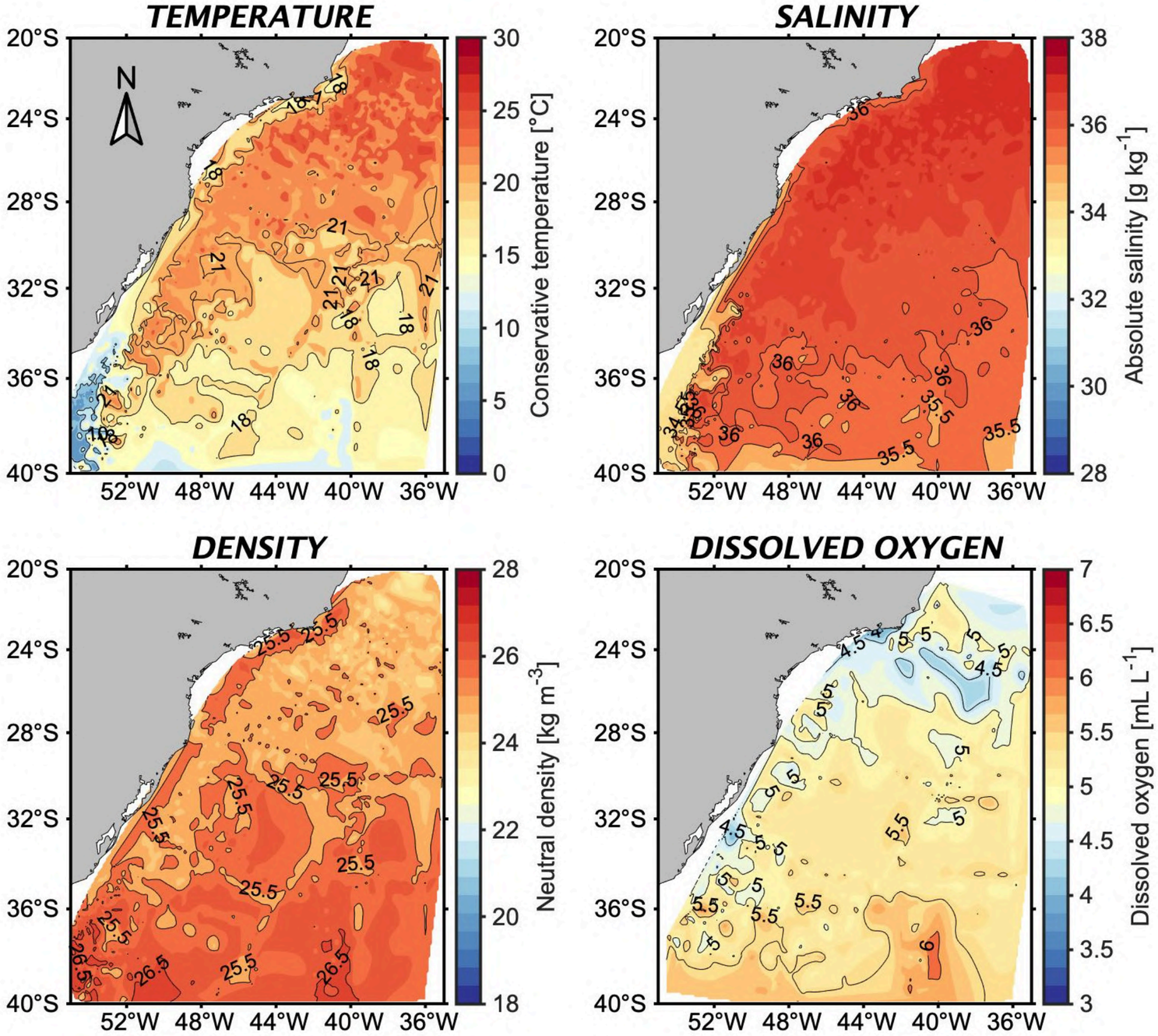
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 4262
- Salinity = 4262
- Dissolved oxygen = 1342

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

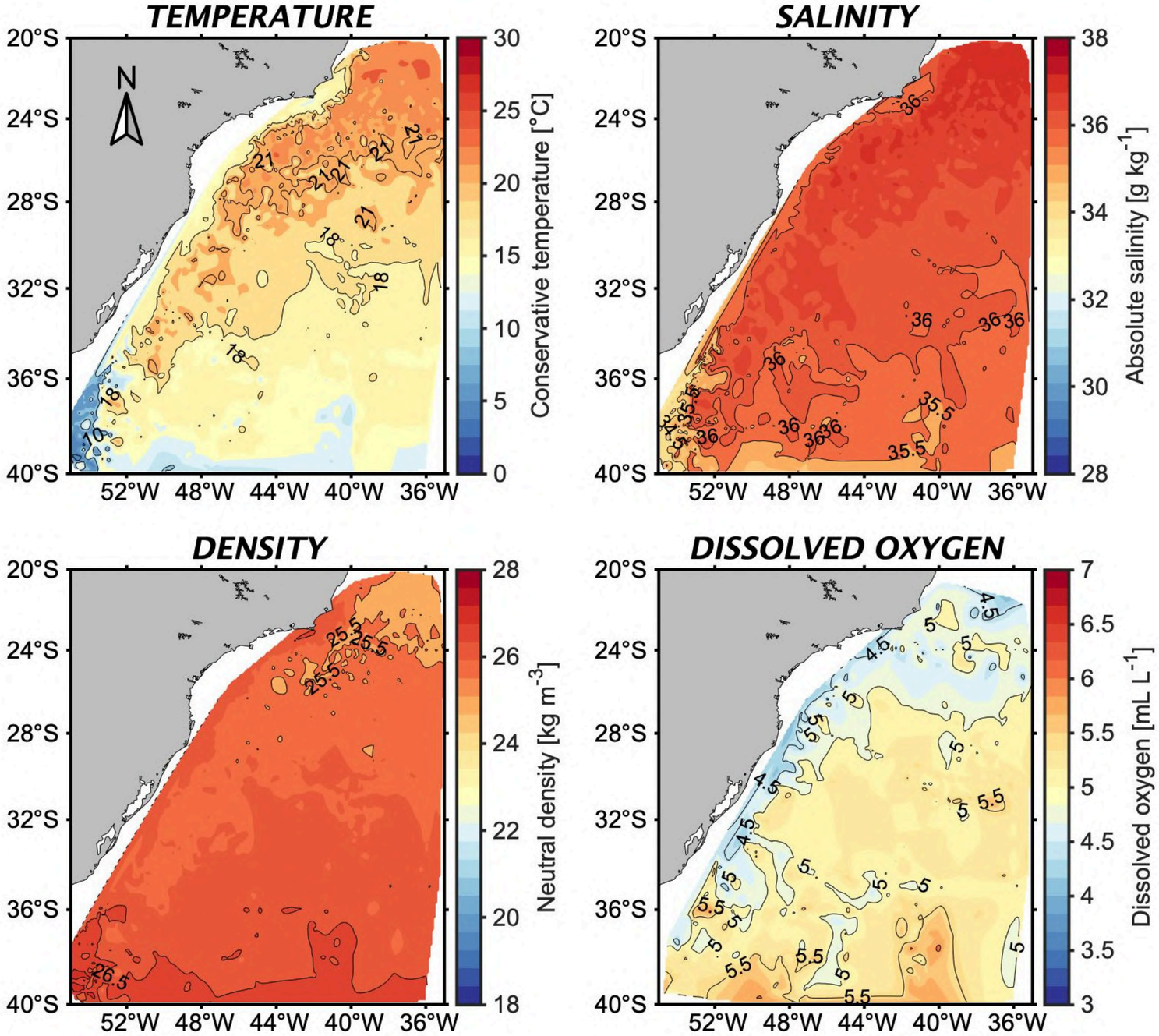
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 3839
- Salinity = 3839
- Dissolved oxygen = 1331

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

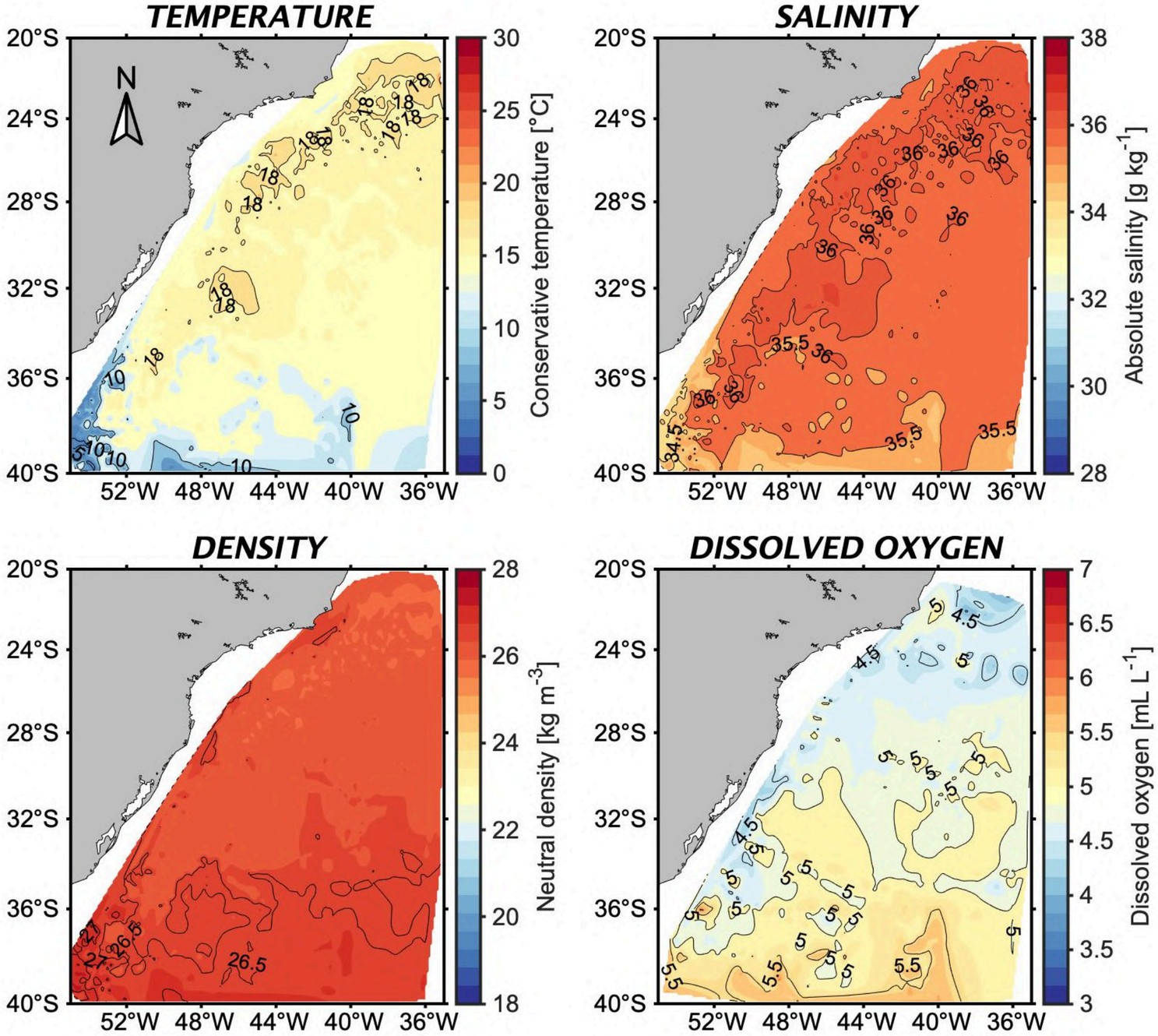
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 3178
- Salinity = 3178
- Dissolved oxygen = 1241

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

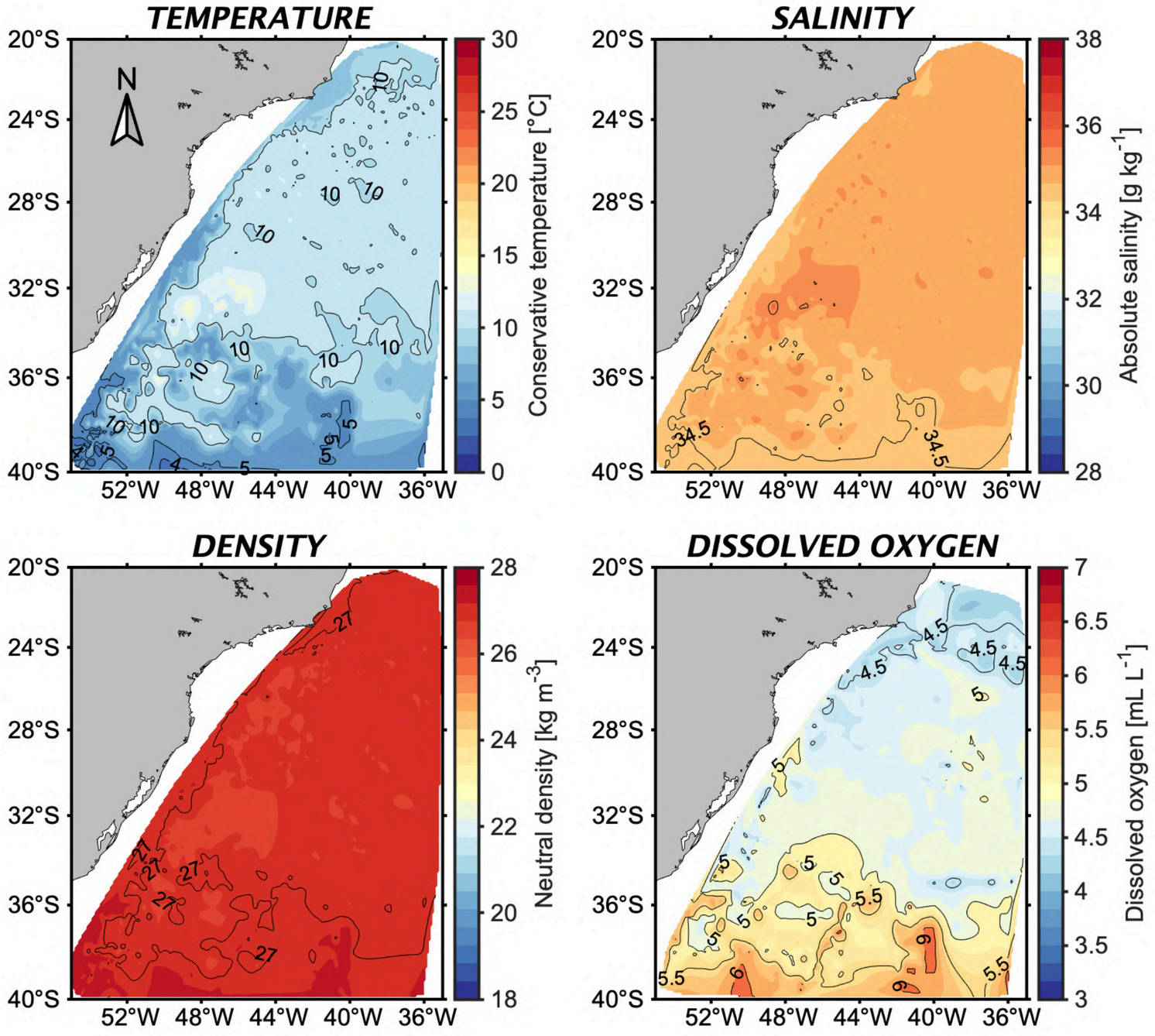
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 2890
- Salinity = 2890
- Dissolved oxygen = 1155

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



Data climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

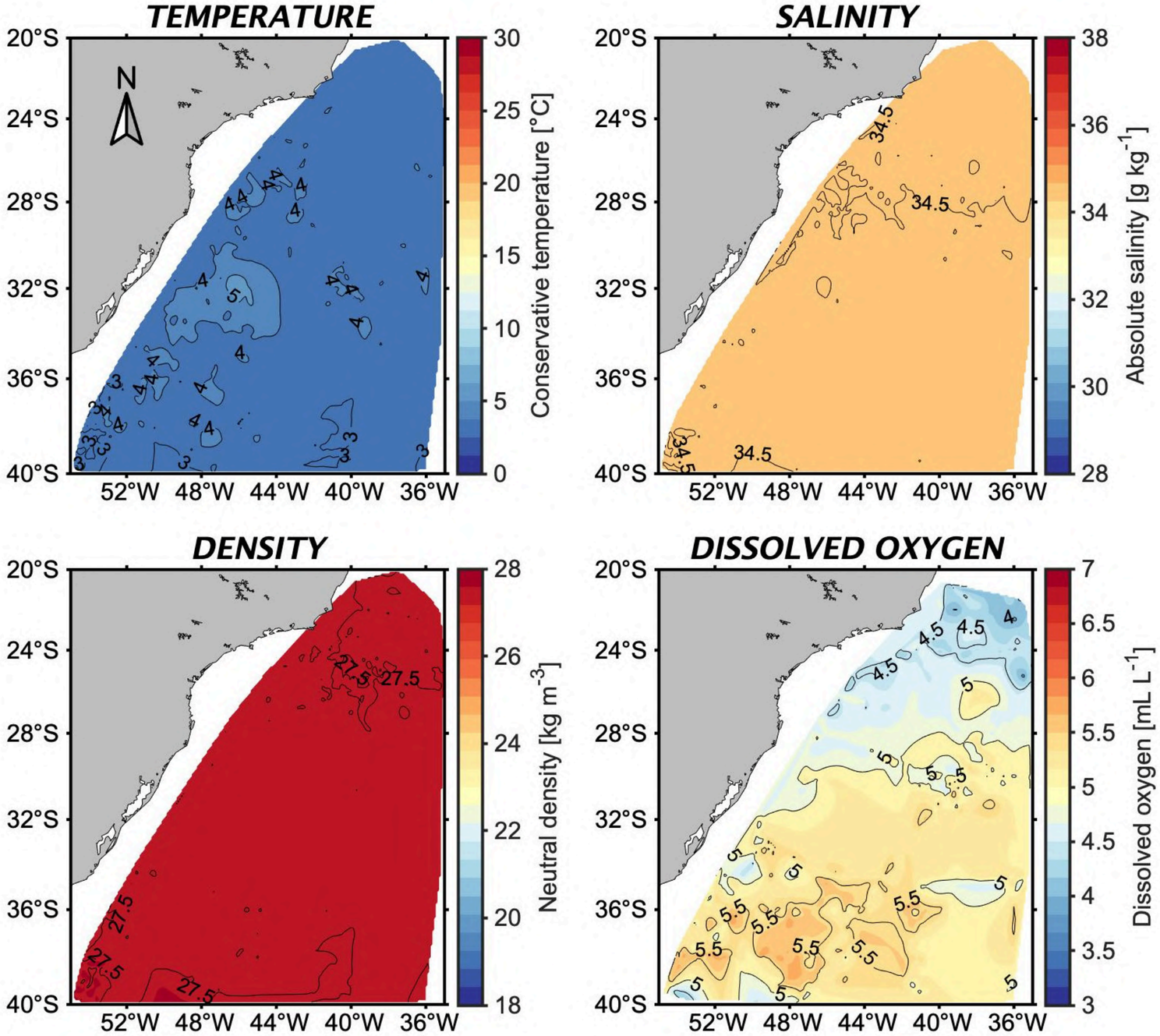
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation:

- Temperature = 2473
- Salinity = 2473
- Dissolved oxygen = 1118

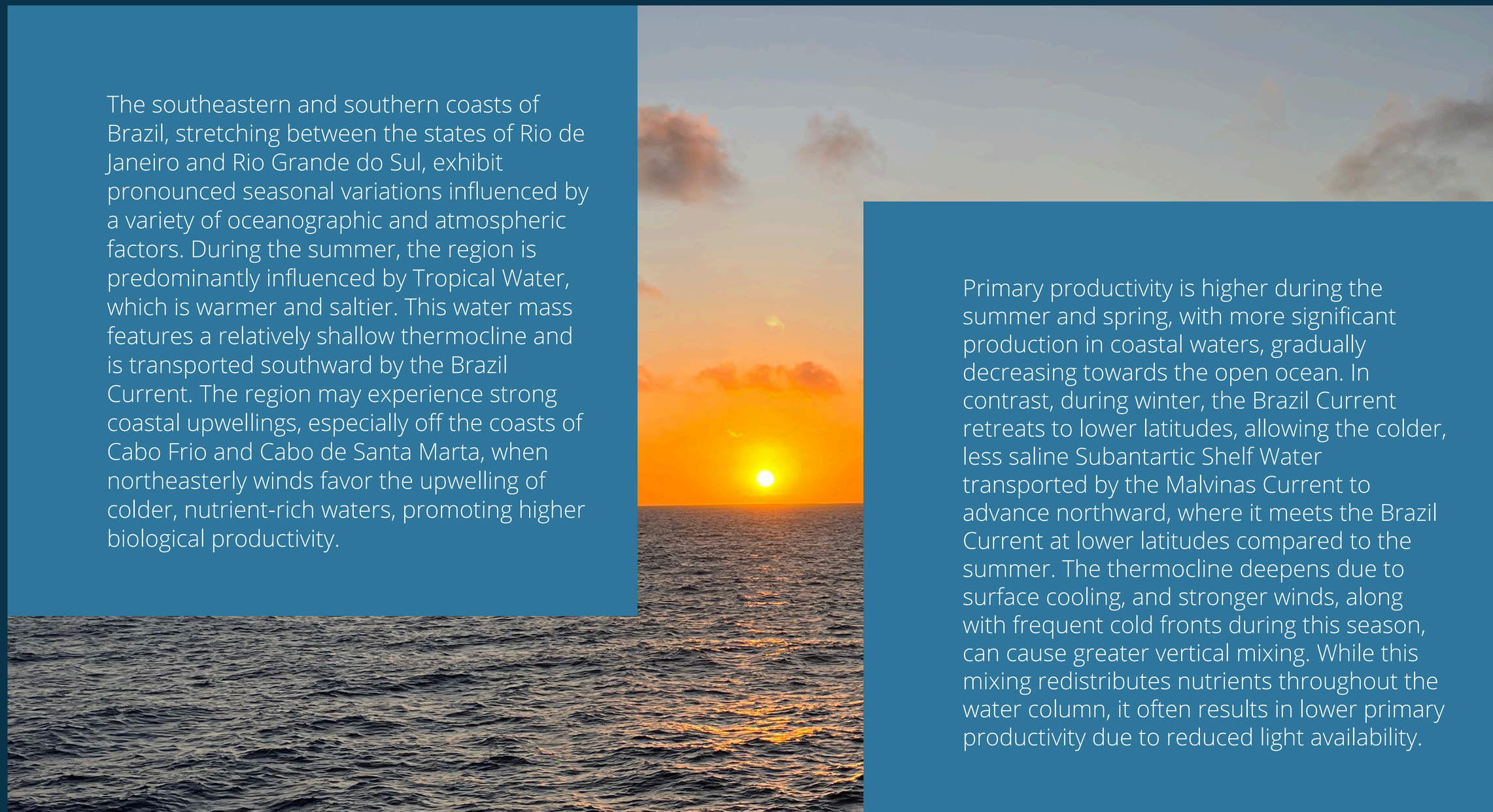
Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



04 Seasonal Maps

The southeastern and southern coasts of Brazil, stretching between the states of Rio de Janeiro and Rio Grande do Sul, exhibit pronounced seasonal variations influenced by a variety of oceanographic and atmospheric factors. During the summer, the region is predominantly influenced by Tropical Water, which is warmer and saltier. This water mass features a relatively shallow thermocline and is transported southward by the Brazil Current. The region may experience strong coastal upwellings, especially off the coasts of Cabo Frio and Cabo de Santa Marta, when northeasterly winds favor the upwelling of colder, nutrient-rich waters, promoting higher biological productivity.



Primary productivity is higher during the summer and spring, with more significant production in coastal waters, gradually decreasing towards the open ocean. In contrast, during winter, the Brazil Current retreats to lower latitudes, allowing the colder, less saline Subantartic Shelf Water transported by the Malvinas Current to advance northward, where it meets the Brazil Current at lower latitudes compared to the summer. The thermocline deepens due to surface cooling, and stronger winds, along with frequent cold fronts during this season, can cause greater vertical mixing. While this mixing redistributes nutrients throughout the water column, it often results in lower primary productivity due to reduced light availability.

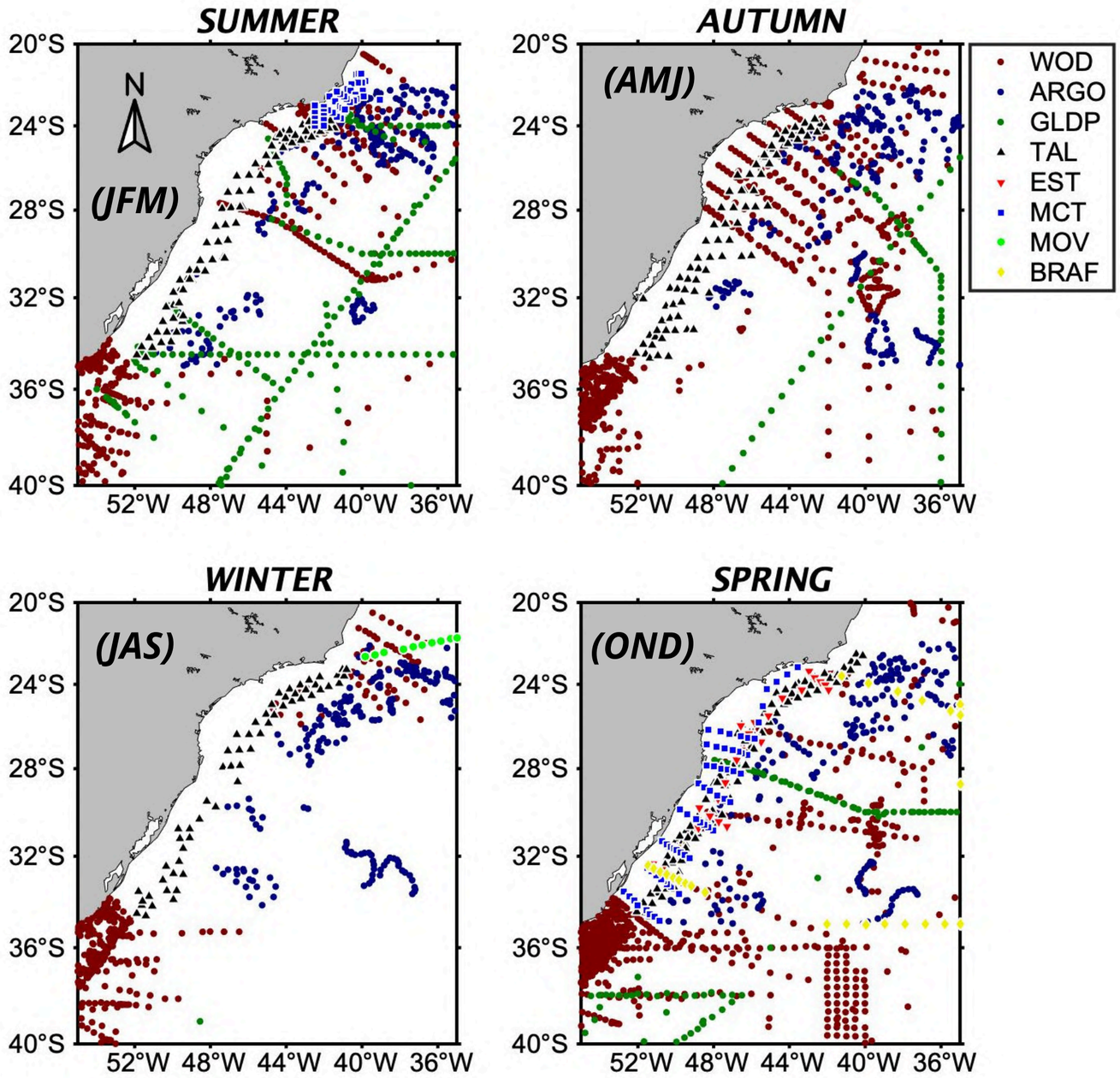
Data availability per season

SUMMER
- From January to March: 1251 profiles

AUTUMN
- From April to June: 1274 profiles

WINTER
- From July to September: 571 profiles

SPRING
- From October to December: 1652 profiles



Temperature-salinity-oxygen* diagram climatology - 5 to 1000 m

La Plata Plume Water (PPW) - low salinity waters (S < 33 g kg^{-1}) from the La Plata River discharge

Tropical Water (TW) - warm and salty (T > 18 °C, S > 36 g kg^{-1}) waters transported southward by the Brazil Current

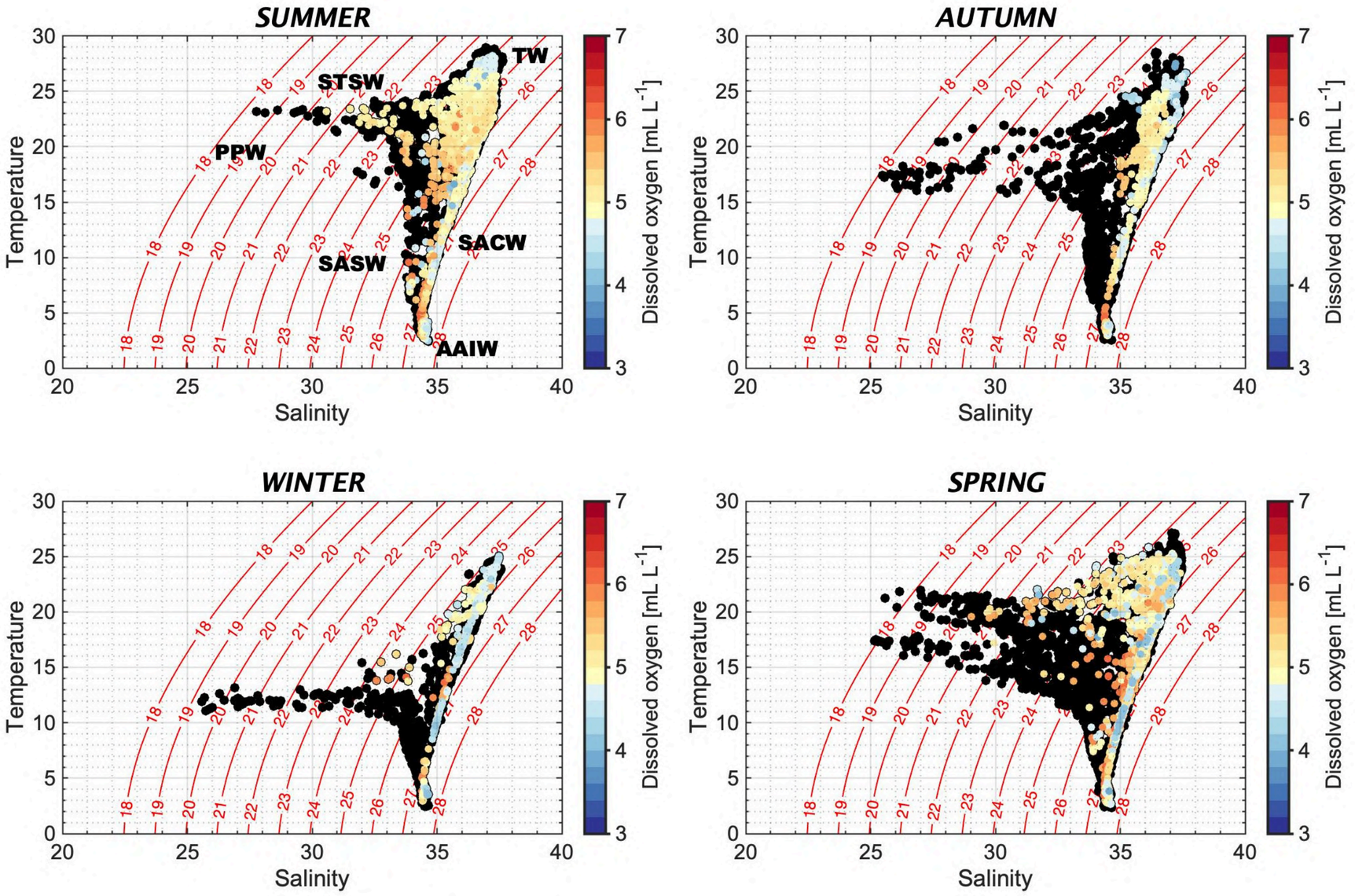
Subtropical Shelf Water (STSW) - mixing between TW and PPW onto the continental shelf

South Atlantic Central Water (SACW) - mildly cold and salty waters (T < 18 °C, S < 36 g kg^{-1}) located between 100 to 500 m

Antarctic intermediate Water (AAIW) - very cold and mildly salty waters (T < 5 °C, S ~ 34 g kg^{-1}) located below 500 m down to 1000 m

Subantarctic Shelf Water (SASW**) - cold and mildly salty waters (T < 14 °C, S ~ 34 g kg^{-1}) transported northward by the Malvinas Current onto the Patagonian shelf

*black dots do not have *in situ* measure of dissolved oxygen
**The SASW is derived from Subantarctic Water (SAW) intrusions over the Patagonian shelf. SASW and SAW have very similar indexes and are hardly distinguished in the diagram



04.1 Seawater Temperature

Atlantic spotted dolphins (*Stenella frontalis*)

The conservative temperature (Θ), similar to potential temperature (θ), is estimated from a seawater sample brought adiabatically to the surface. However, unlike θ, the calculation of Θ starts with potential enthalpy divided by the heat capacity of the physical system. This approach makes Θ a useful tool for analyzing water masses and understanding ocean circulation because it provides a more consistent method for comparing temperatures across different depths and locations, where Θ can differ from θ by up to 1.4°C, but in most cases the difference is around 0.1°C.

Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

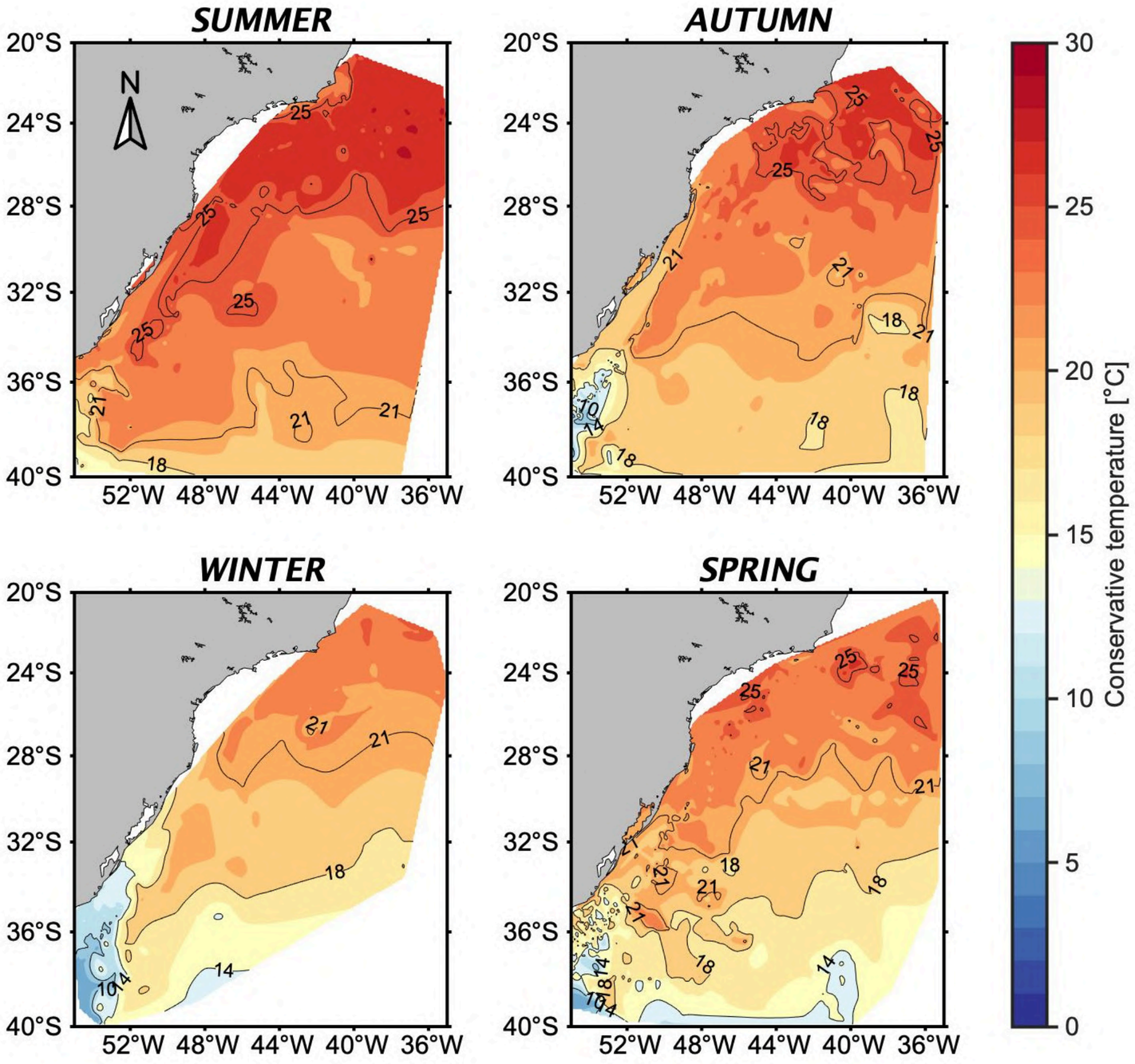
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1027
- Autumn = 1077
- Winter = 508
- Spring = 1524

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

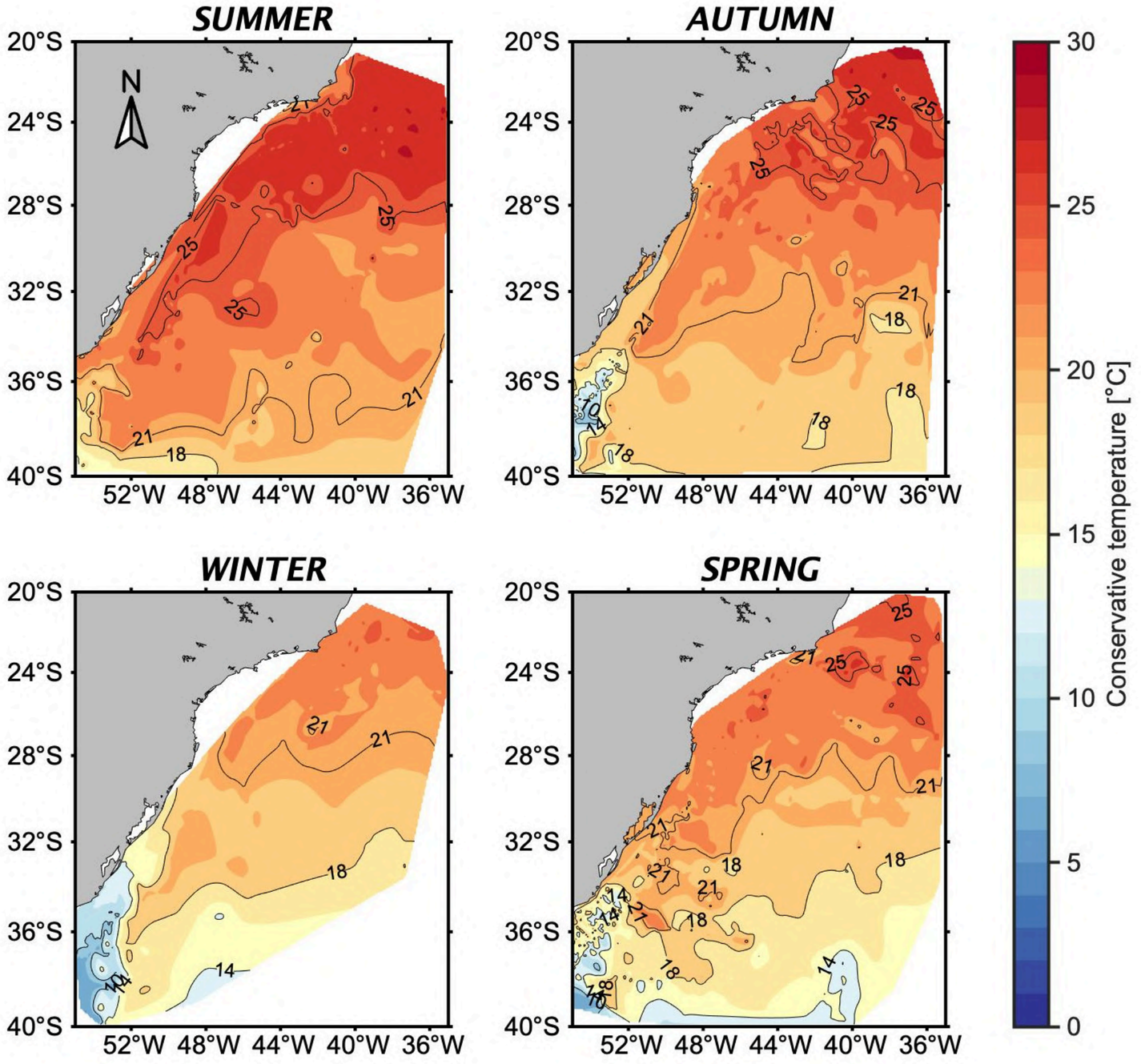
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1221
- Autumn = 1212
- Winter = 552
- Spring = 1633

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

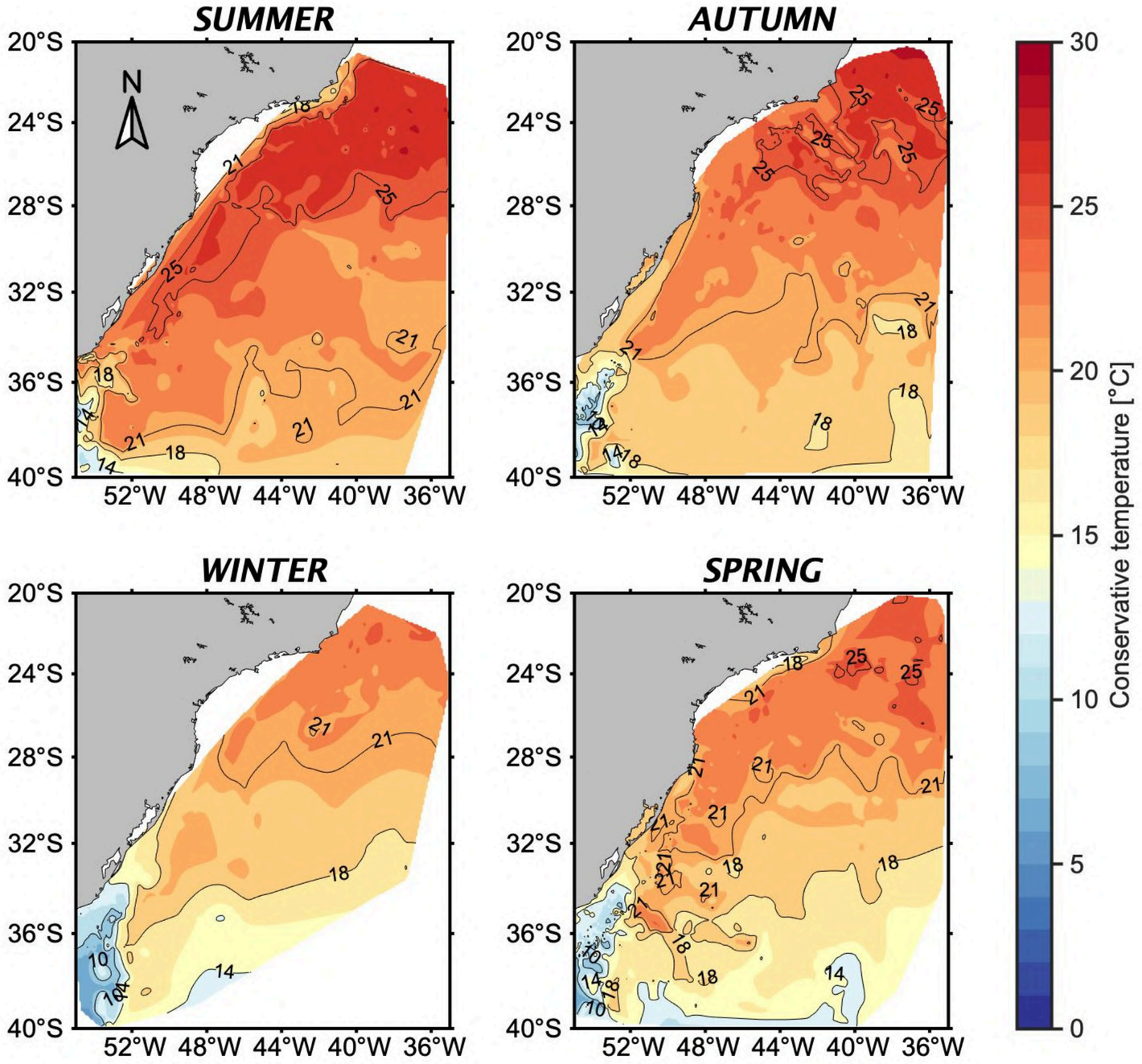
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1238
- Autumn = 1216
- Winter = 534
- Spring = 1631

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

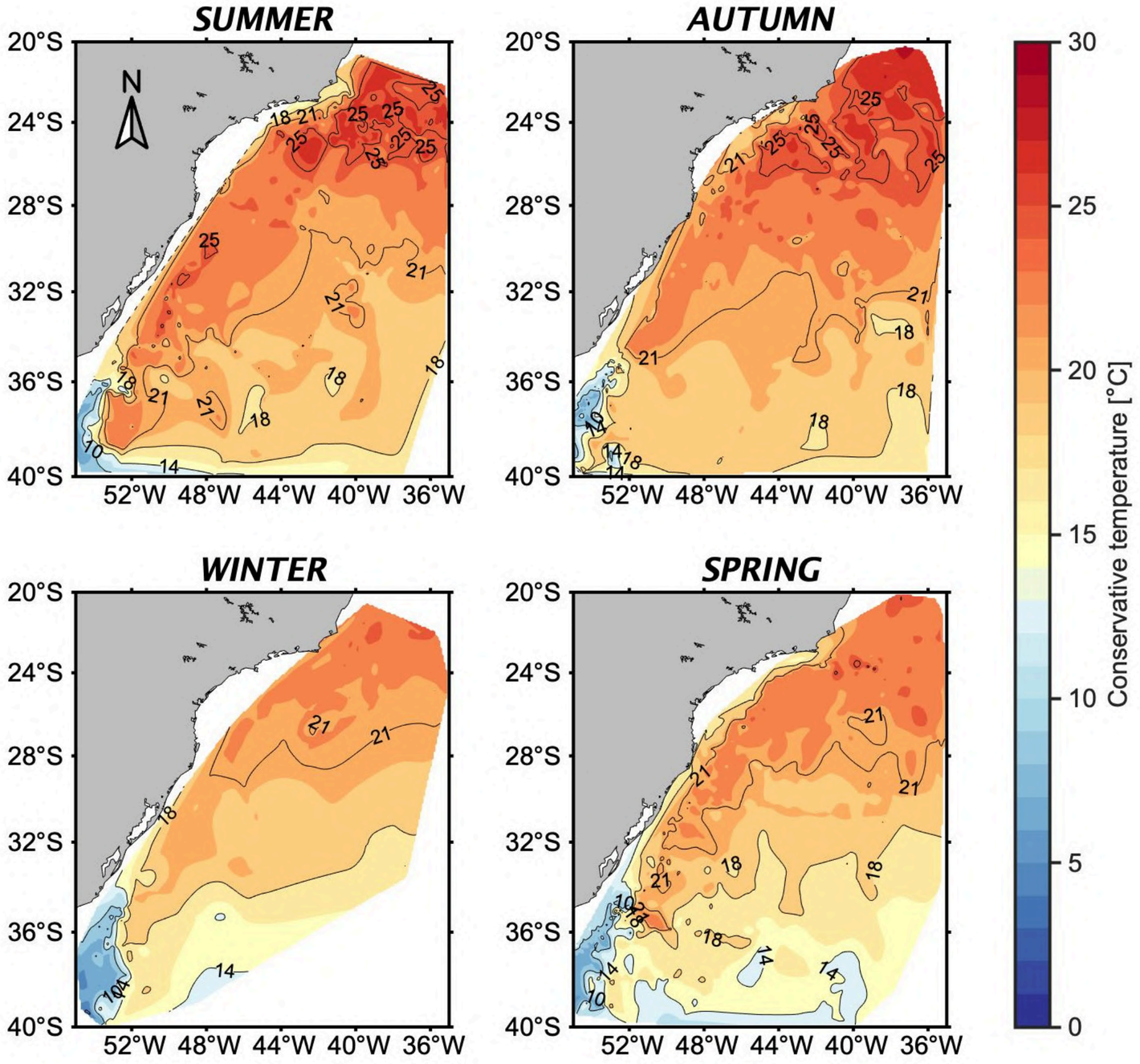
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1119
- Autumn = 1140
- Winter = 511
- Spring = 1492

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

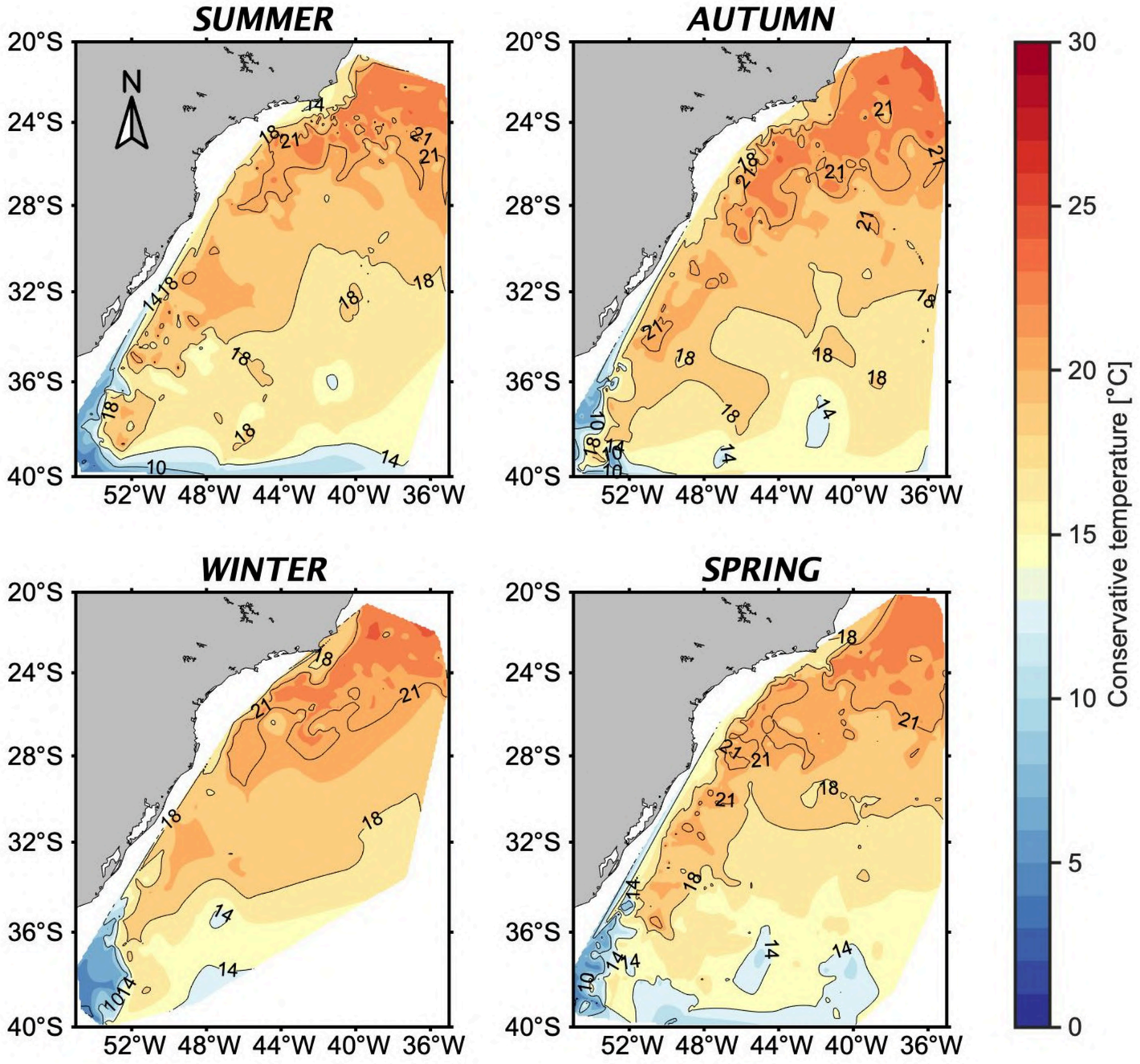
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1081
- Autumn = 998
- Winter = 459
- Spring = 1301

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

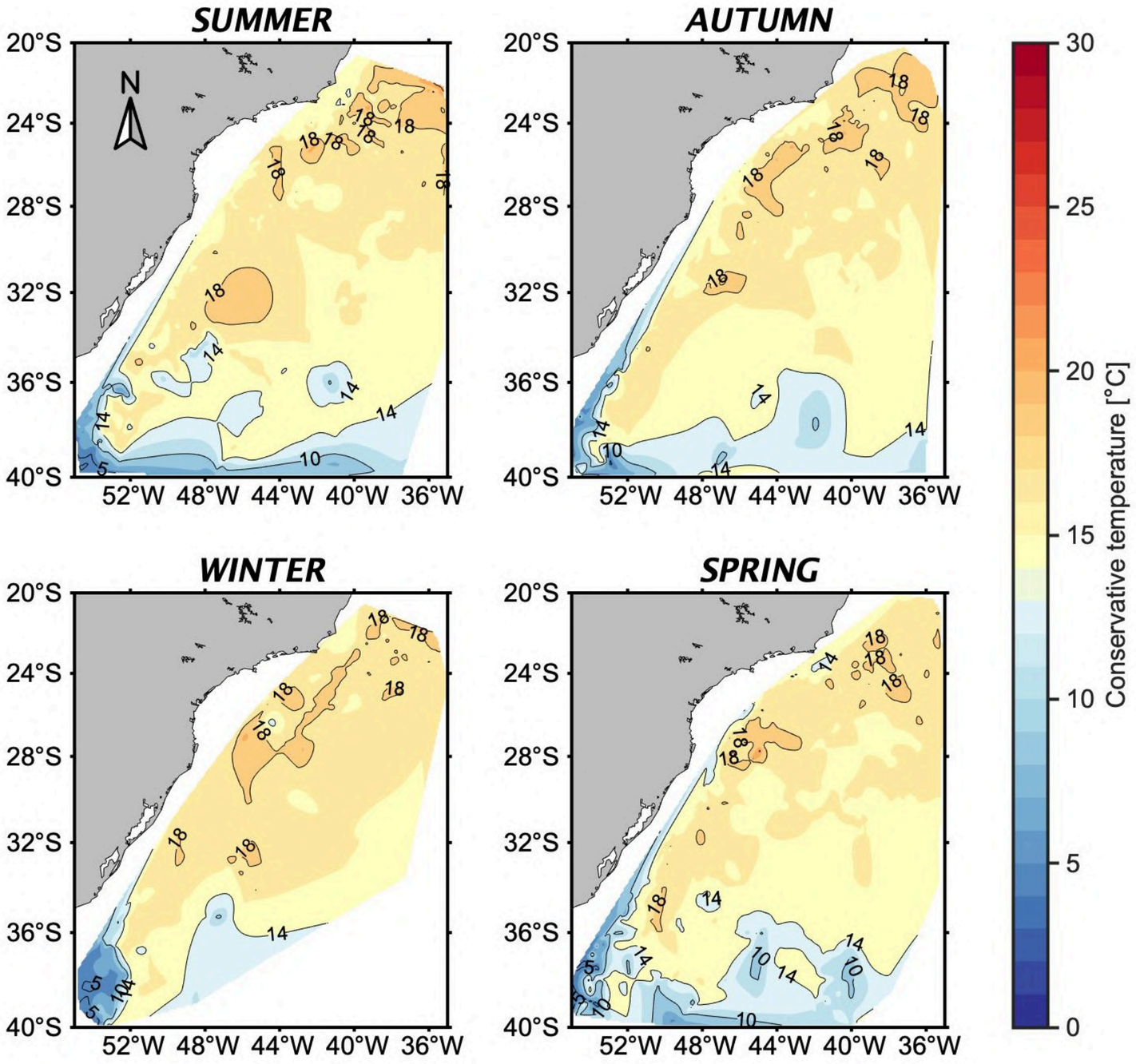
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 925
- Autumn = 825
- Winter = 385
- Spring = 1043

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

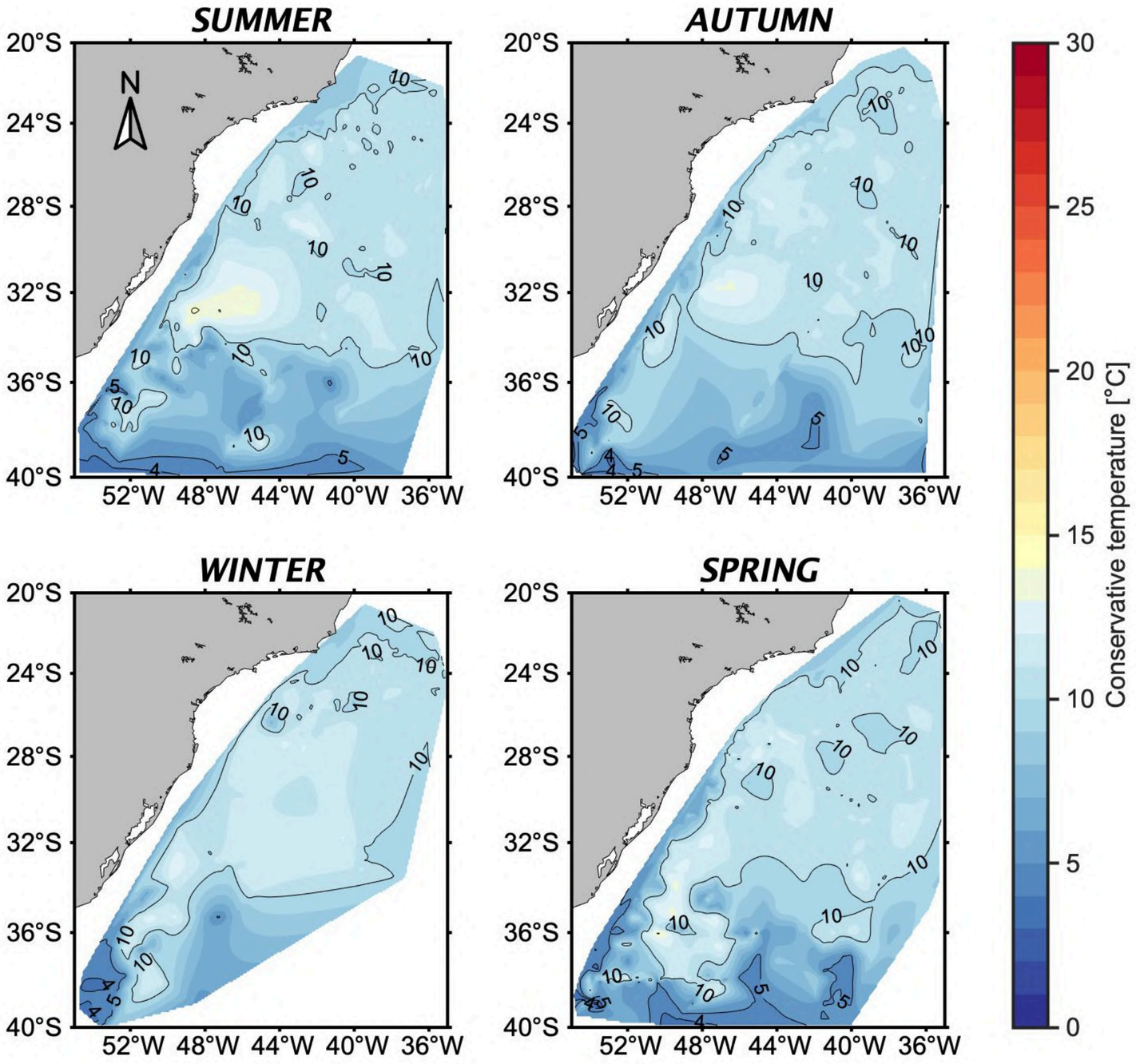
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 888
- Autumn = 759
- Winter = 362
- Spring = 881

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



Temperature climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

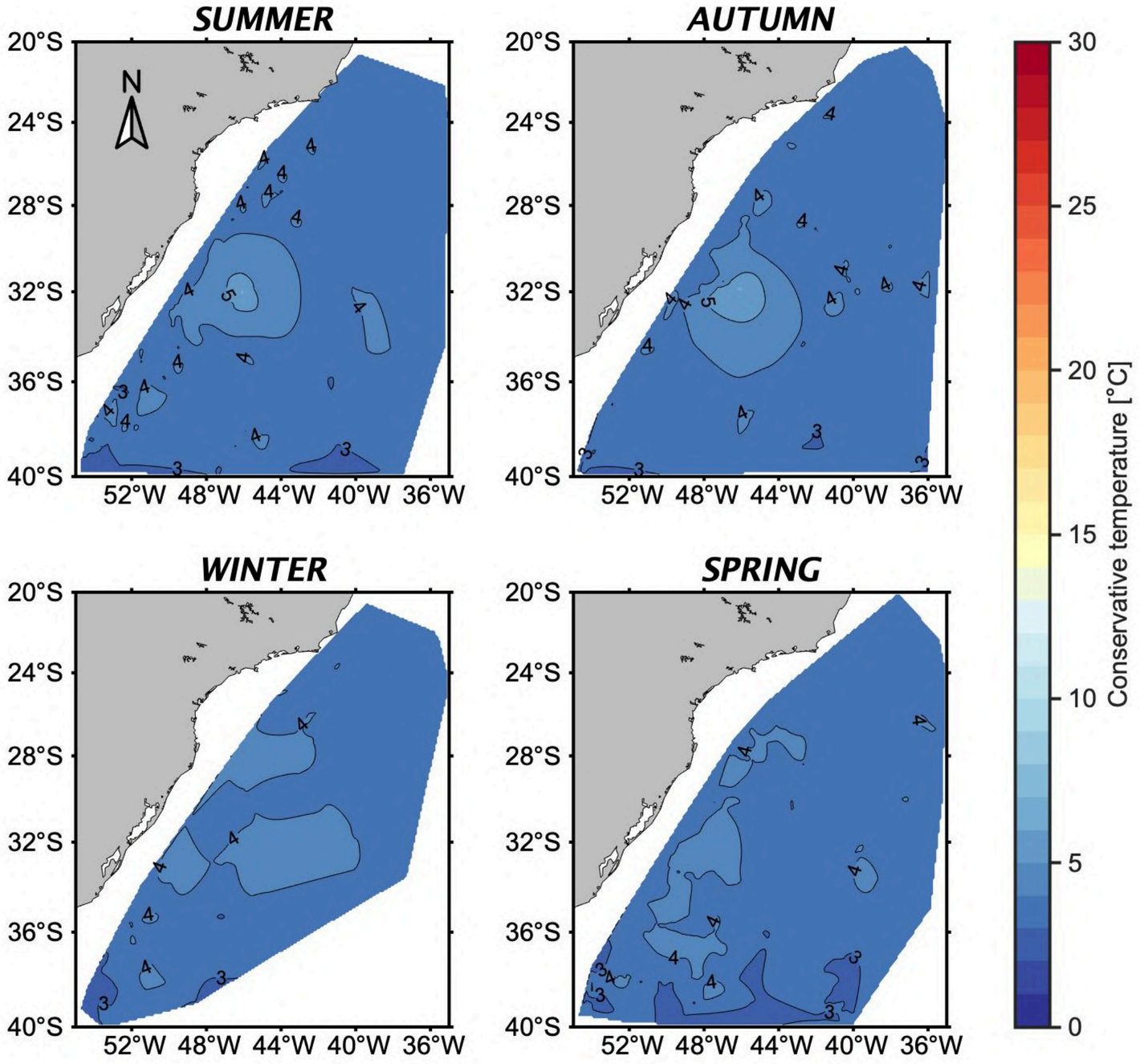
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 826
- Autumn = 596
- Winter = 321
- Spring = 730

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



04.2 Seawater Salinity

Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*)

The absolute salinity (SA), unlike practical salinity which is determined solely on the basis of conductivity, considers the impact of specific dissolved ions in seawater with low conductivity that still influence water density. These include ions resulting from the dissolution of calcium carbonates ($CaCO_3$), orthosilicic acid ($Si(OH)_4$), CO_2, and nutrients such as nitrate (NO^{3-}) and phosphate (PO_4^{3-}) from the oxidation of plant material.

Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

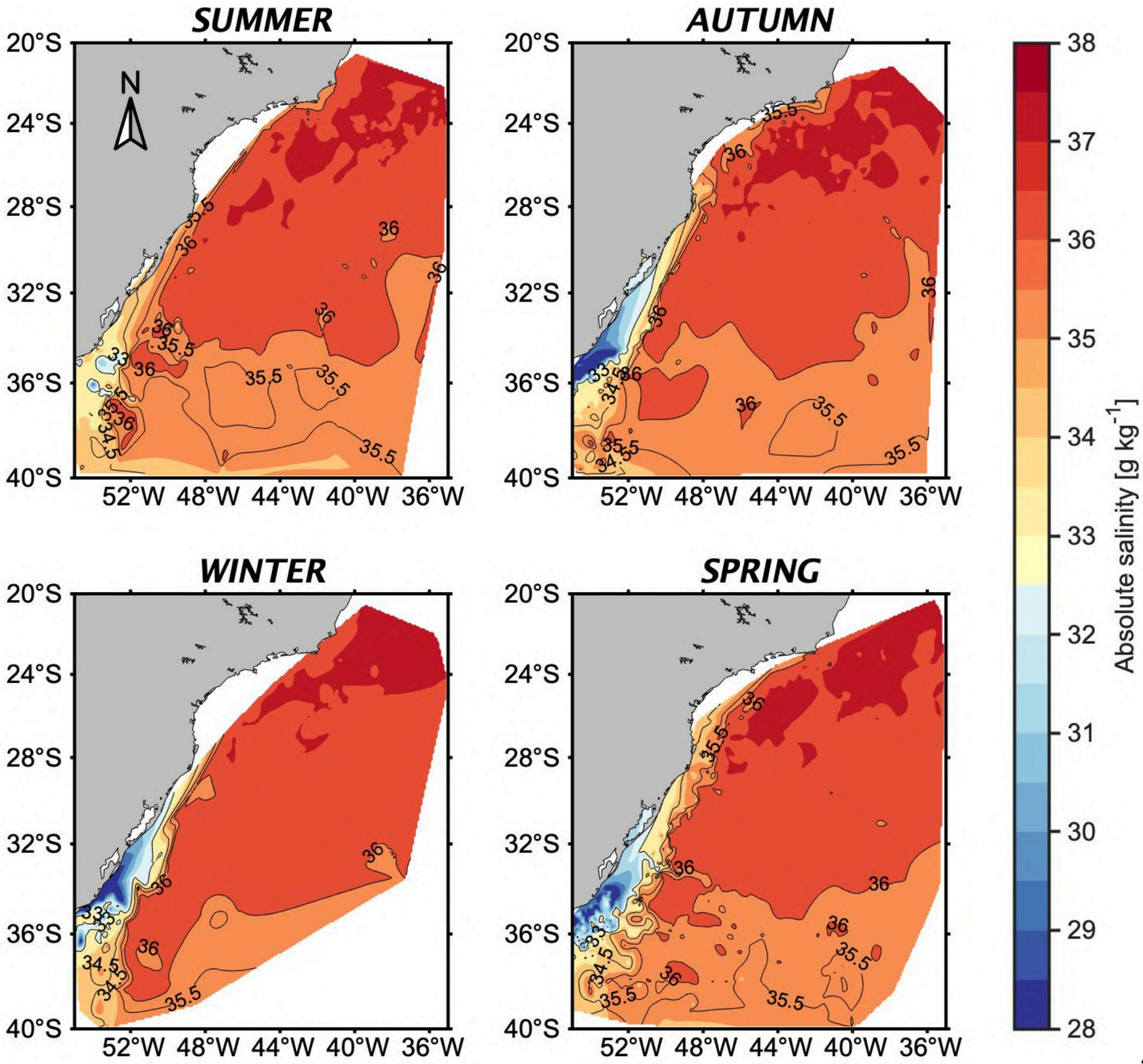
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1027
- Autumn = 1077
- Winter = 508
- Spring = 1524

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

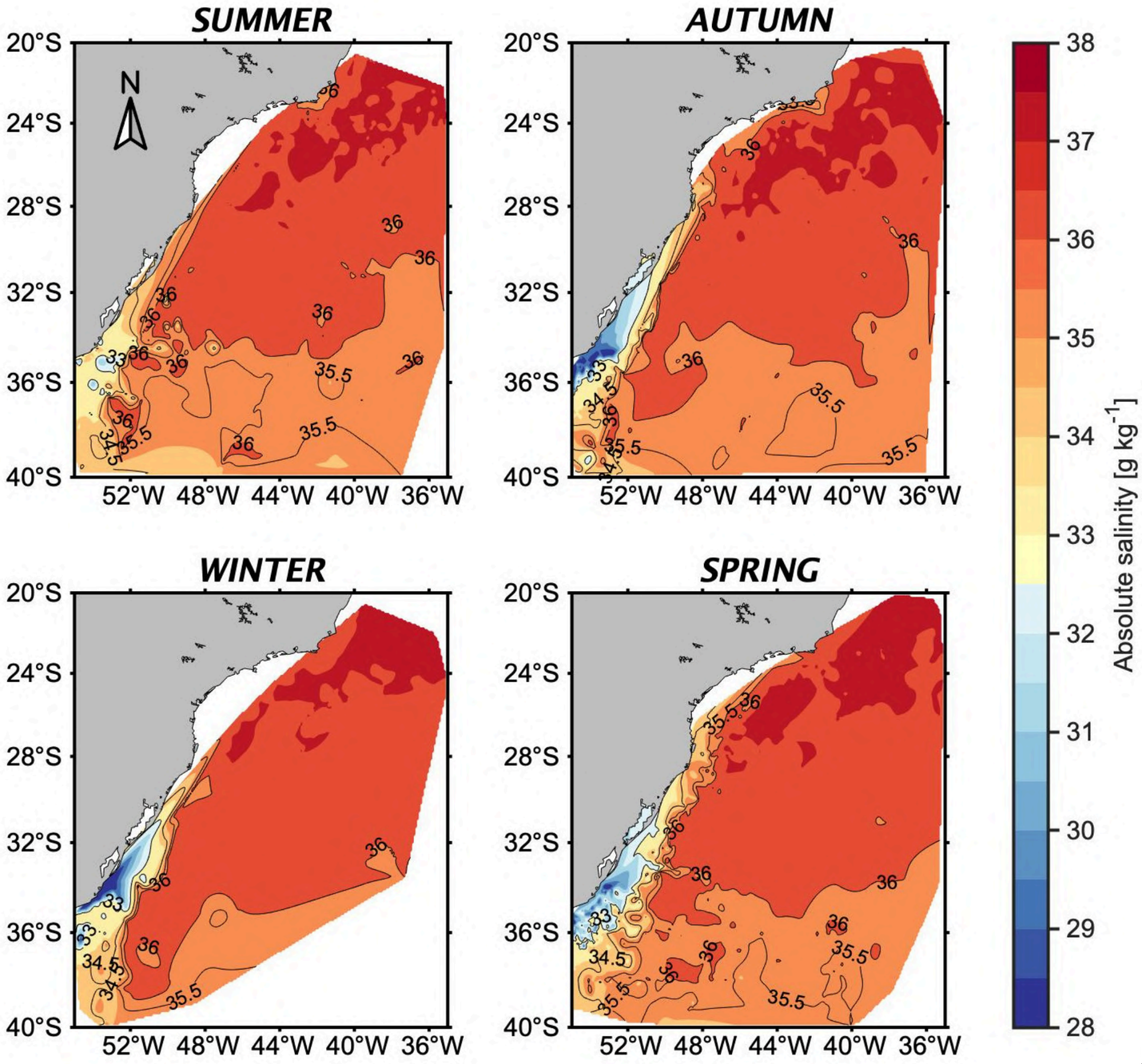
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1221
- Autumn = 1212
- Winter = 552
- Spring = 1633

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

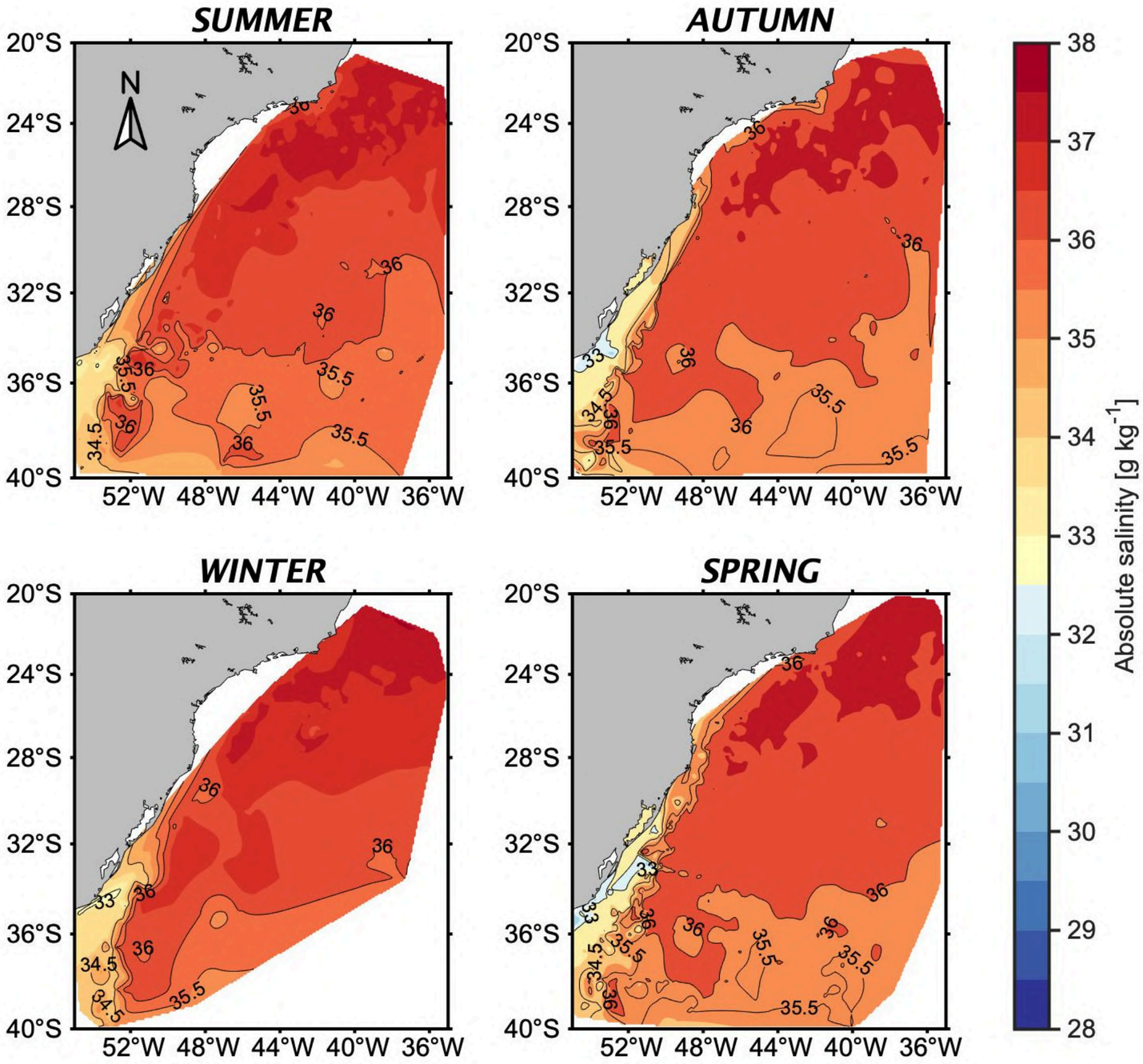
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1238
- Autumn = 1216
- Winter = 534
- Spring = 1631

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

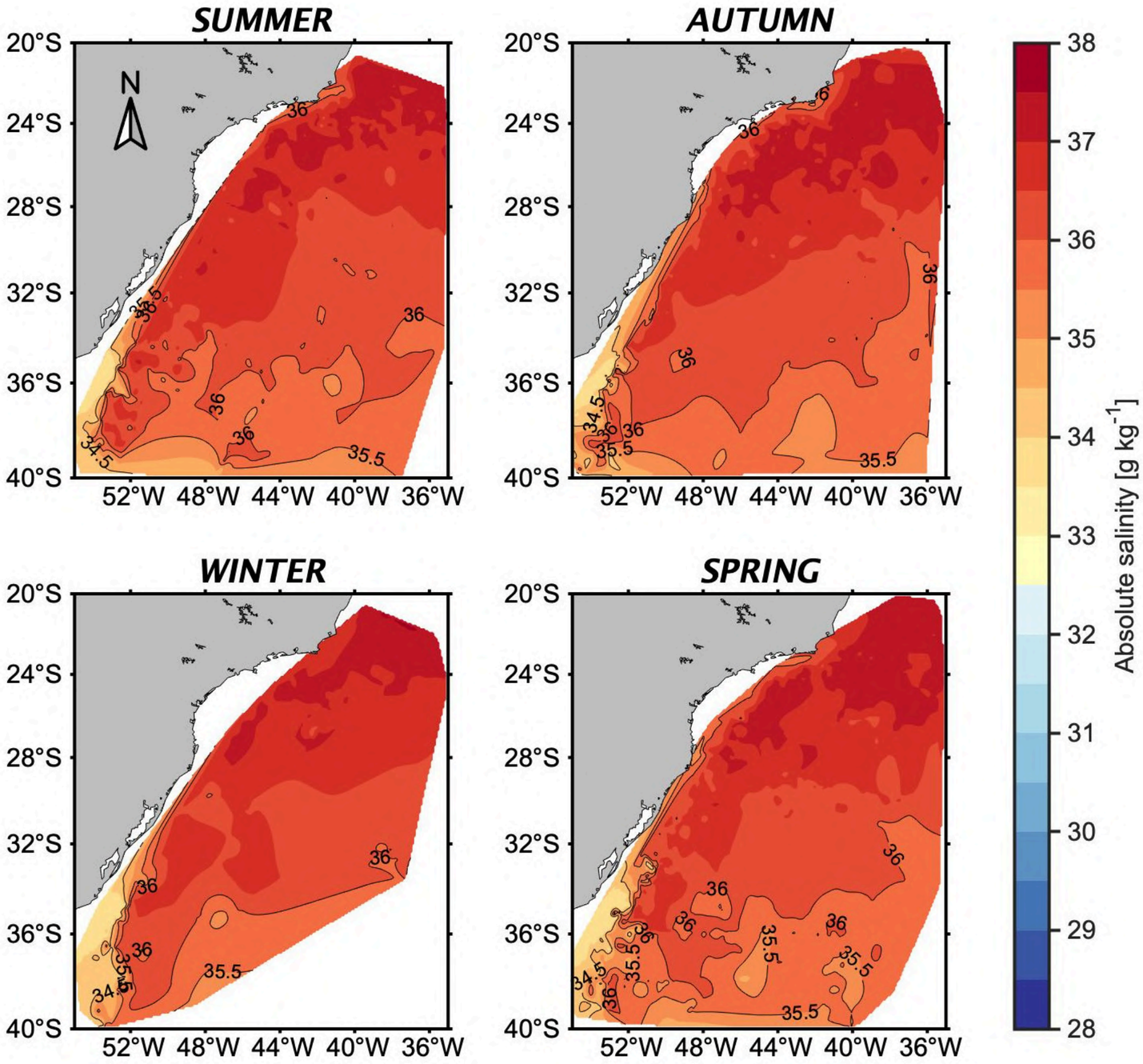
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1119
- Autumn = 1140
- Winter = 511
- Spring = 1492

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

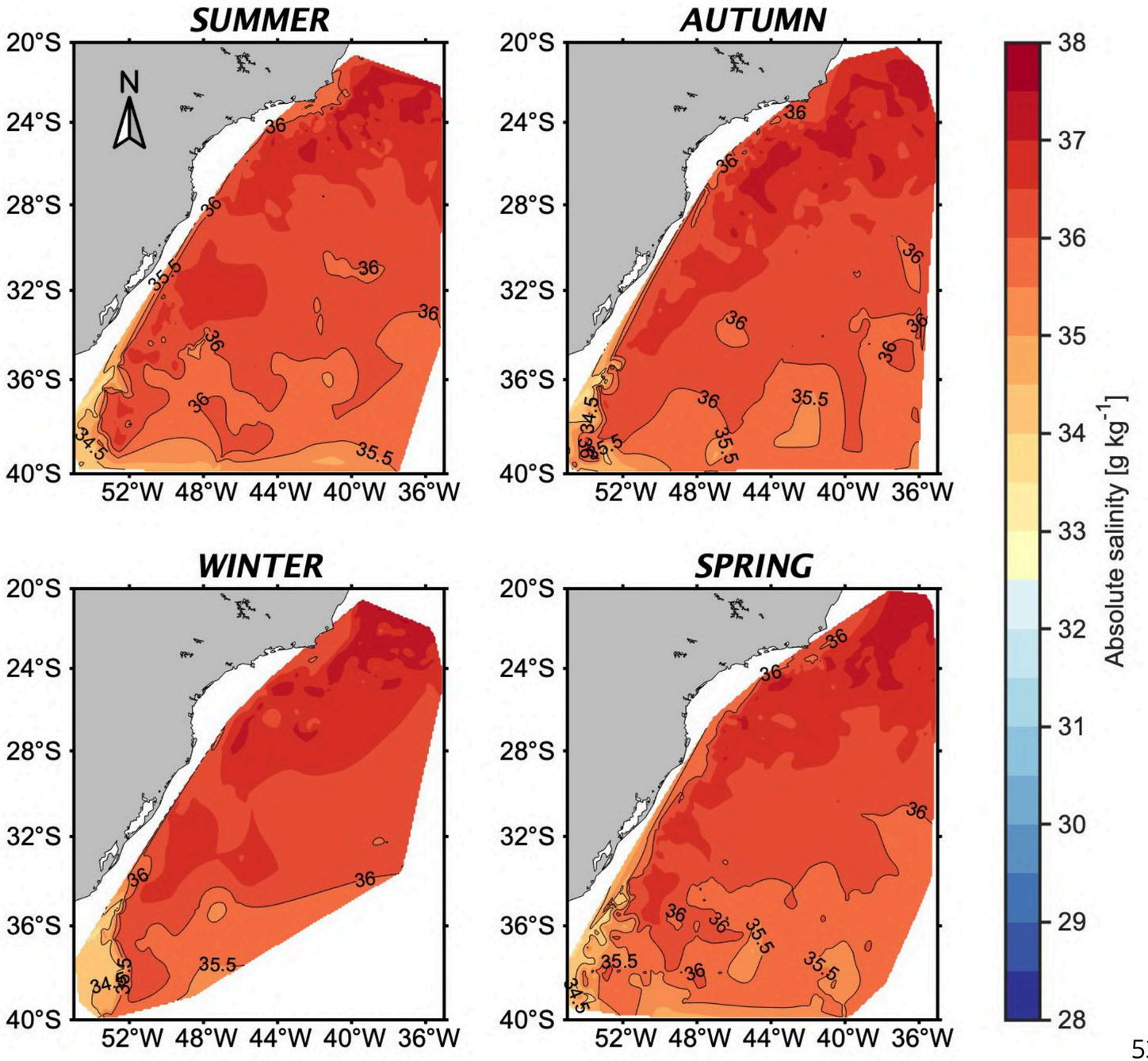
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 1081
- Autumn = 998
- Winter = 459
- Spring = 1301

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

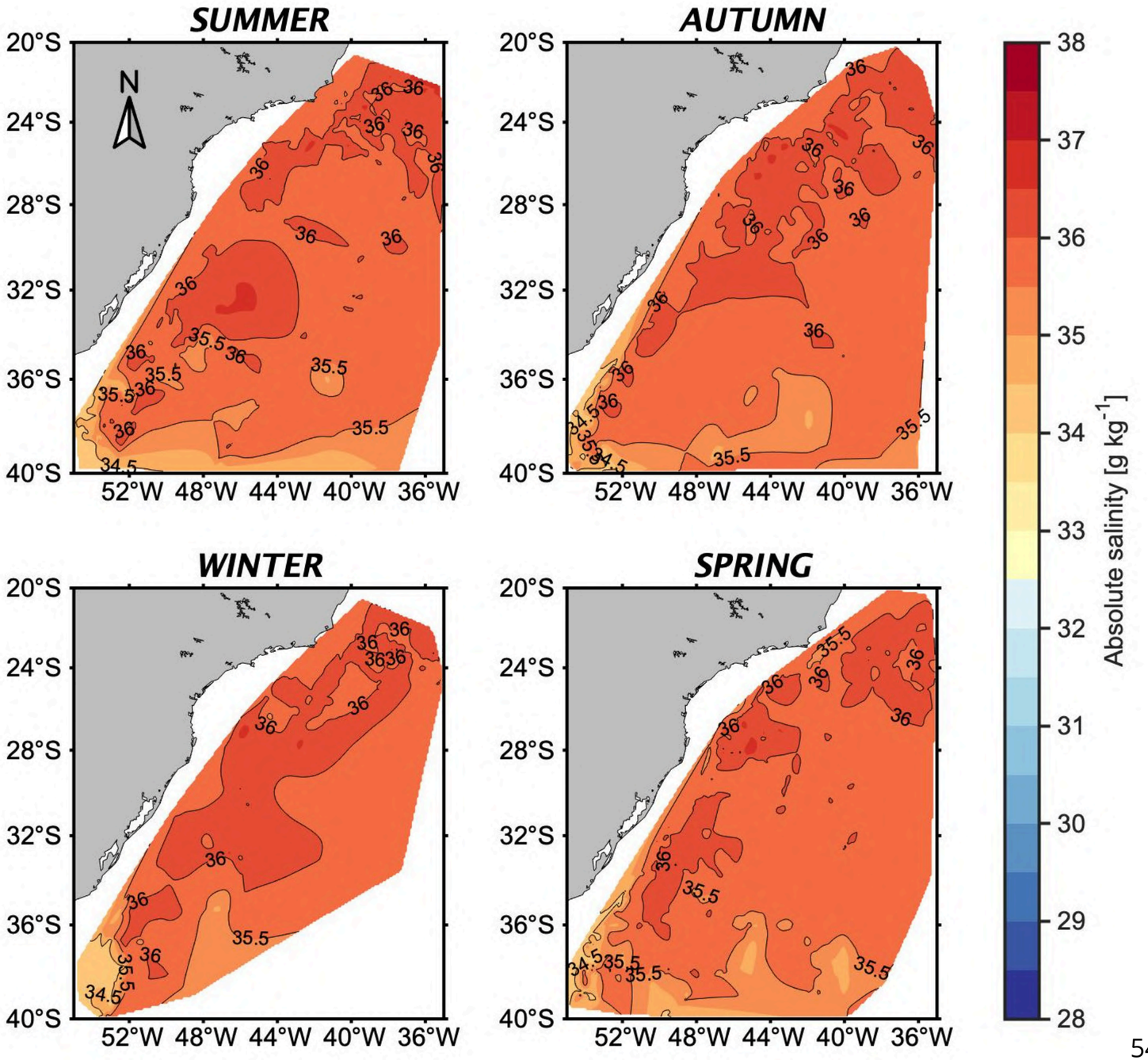
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 925
- Autumn = 825
- Winter = 385
- Spring = 1043

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

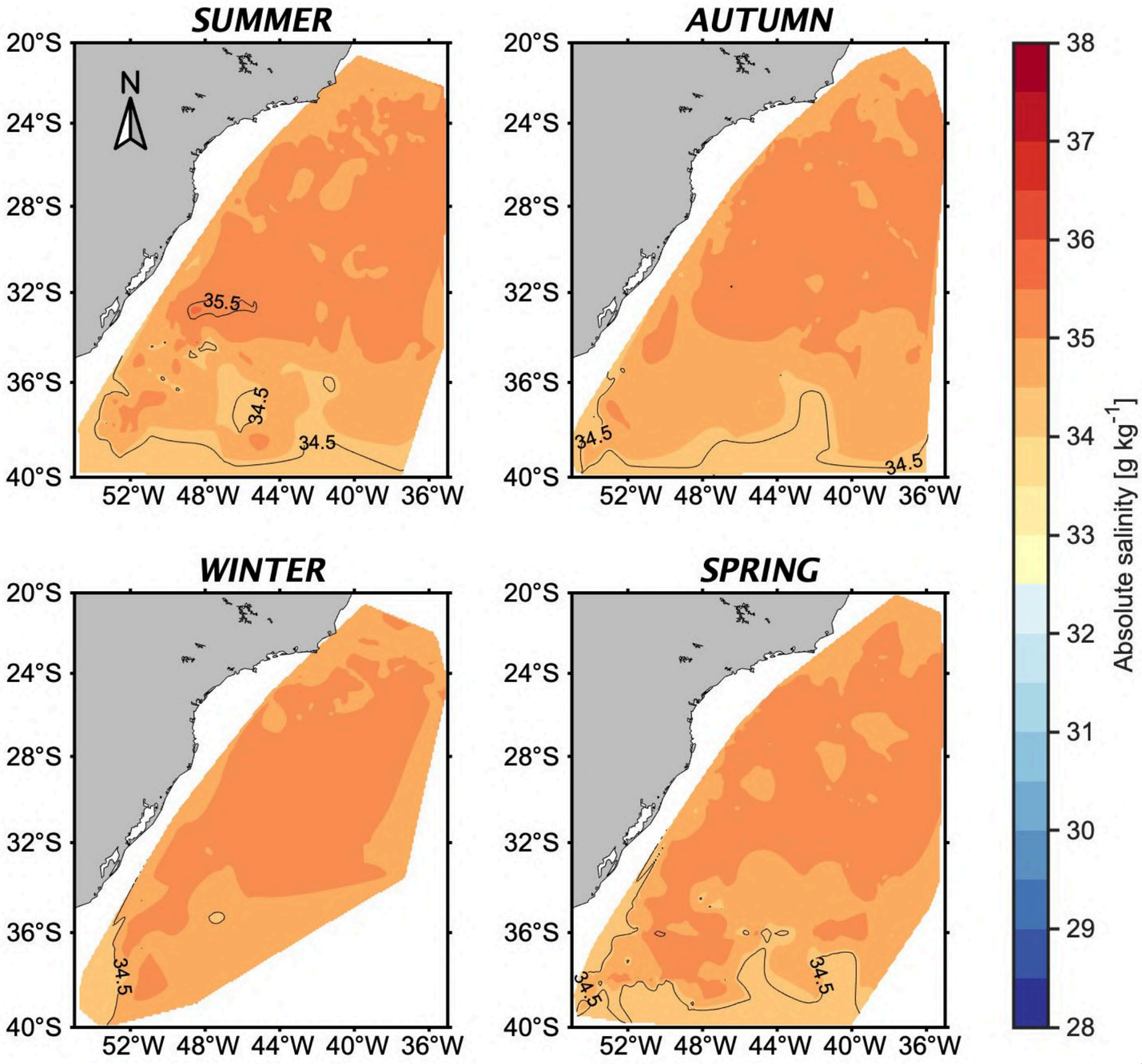
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 888
- Autumn = 759
- Winter = 362
- Spring = 881

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



Salinity climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

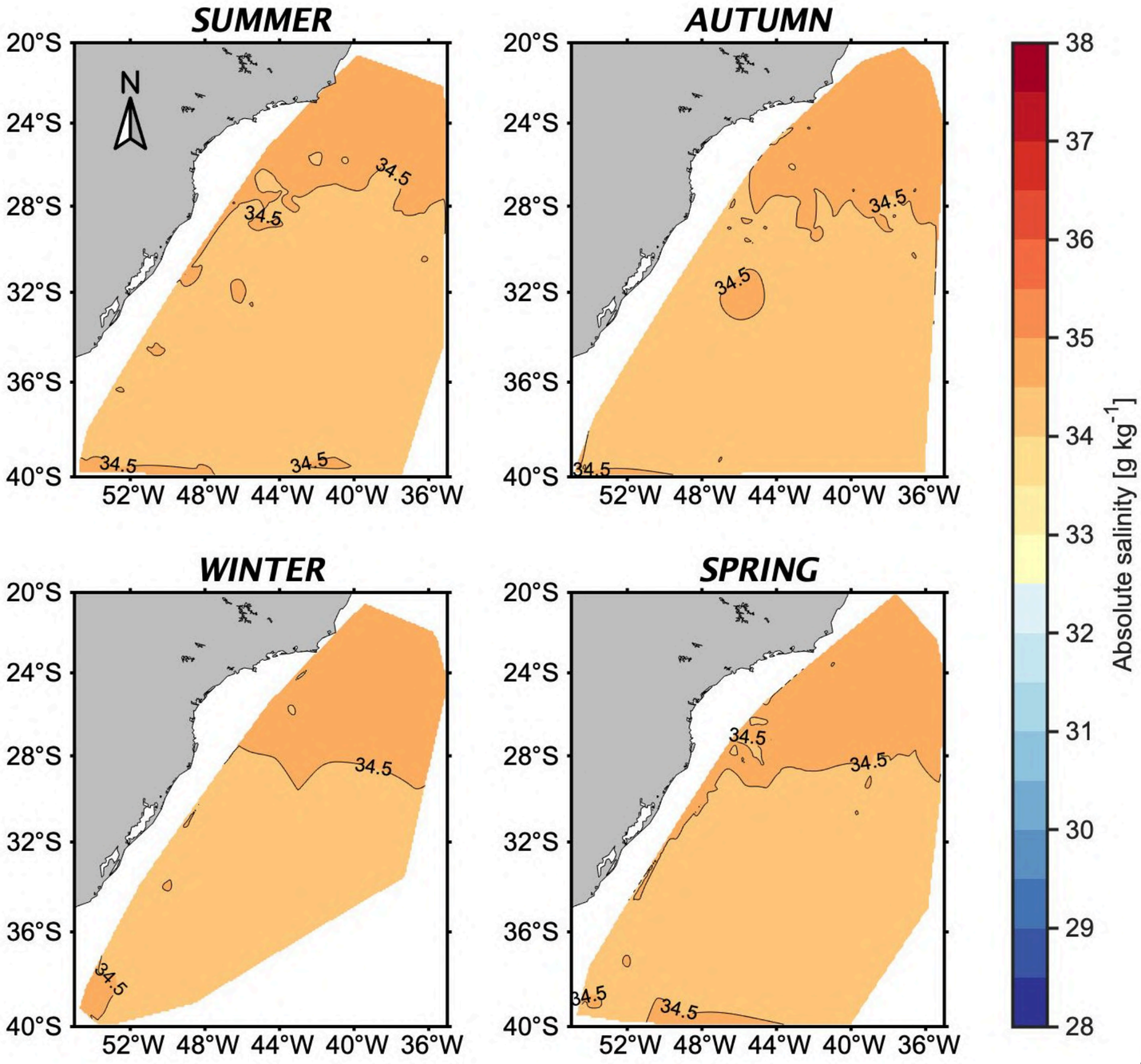
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

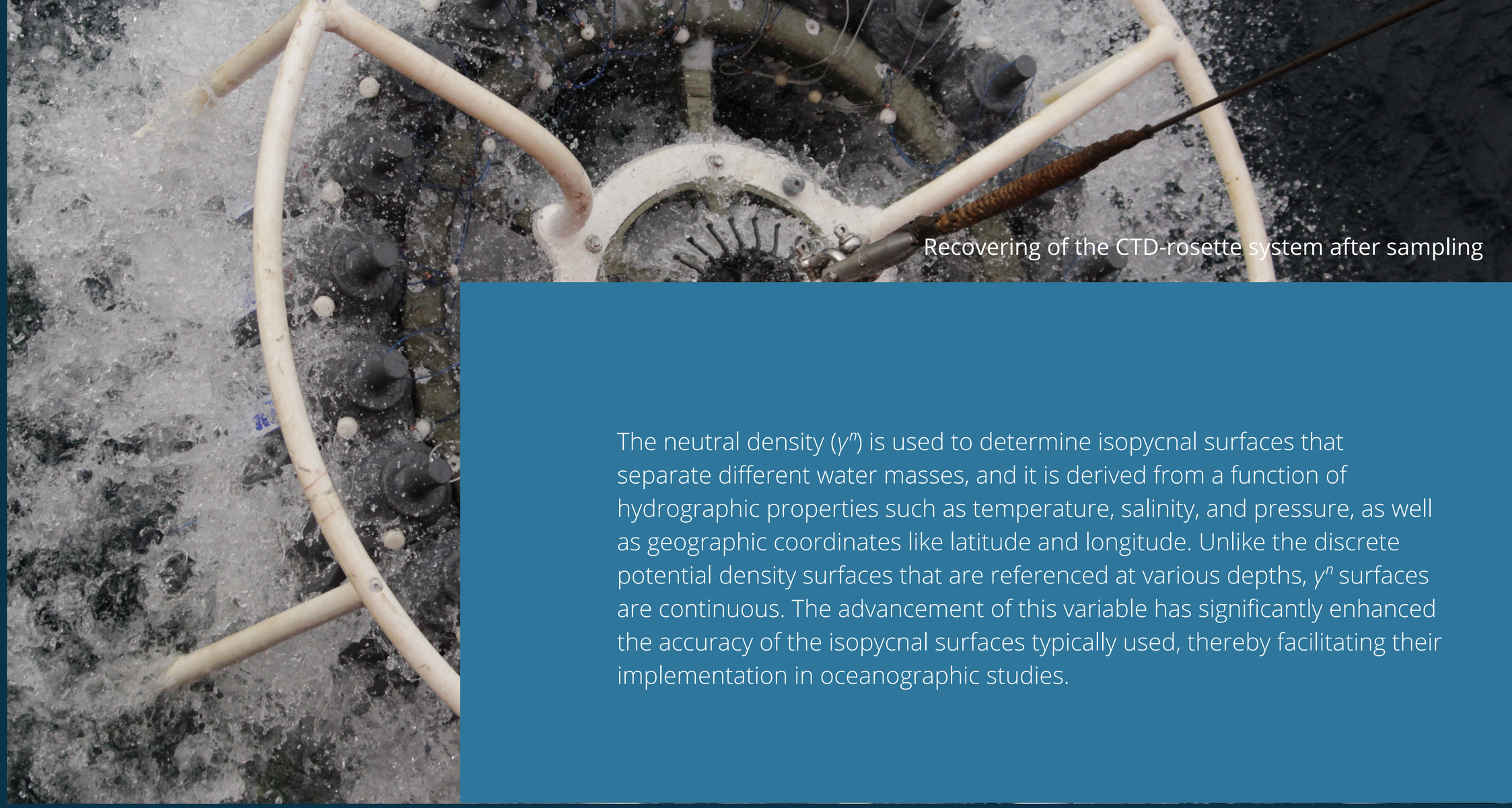
- Summer = 826
- Autumn = 596
- Winter = 321
- Spring = 730

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



04.3 Neutral Density



Recovering of the CTD-rosette system after sampling

The neutral density (γ^n) is used to determine isopycnal surfaces that separate different water masses, and it is derived from a function of hydrographic properties such as temperature, salinity, and pressure, as well as geographic coordinates like latitude and longitude. Unlike the discrete potential density surfaces that are referenced at various depths, γ^n surfaces are continuous. The advancement of this variable has significantly enhanced the accuracy of the isopycnal surfaces typically used, thereby facilitating their implementation in oceanographic studies.

Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

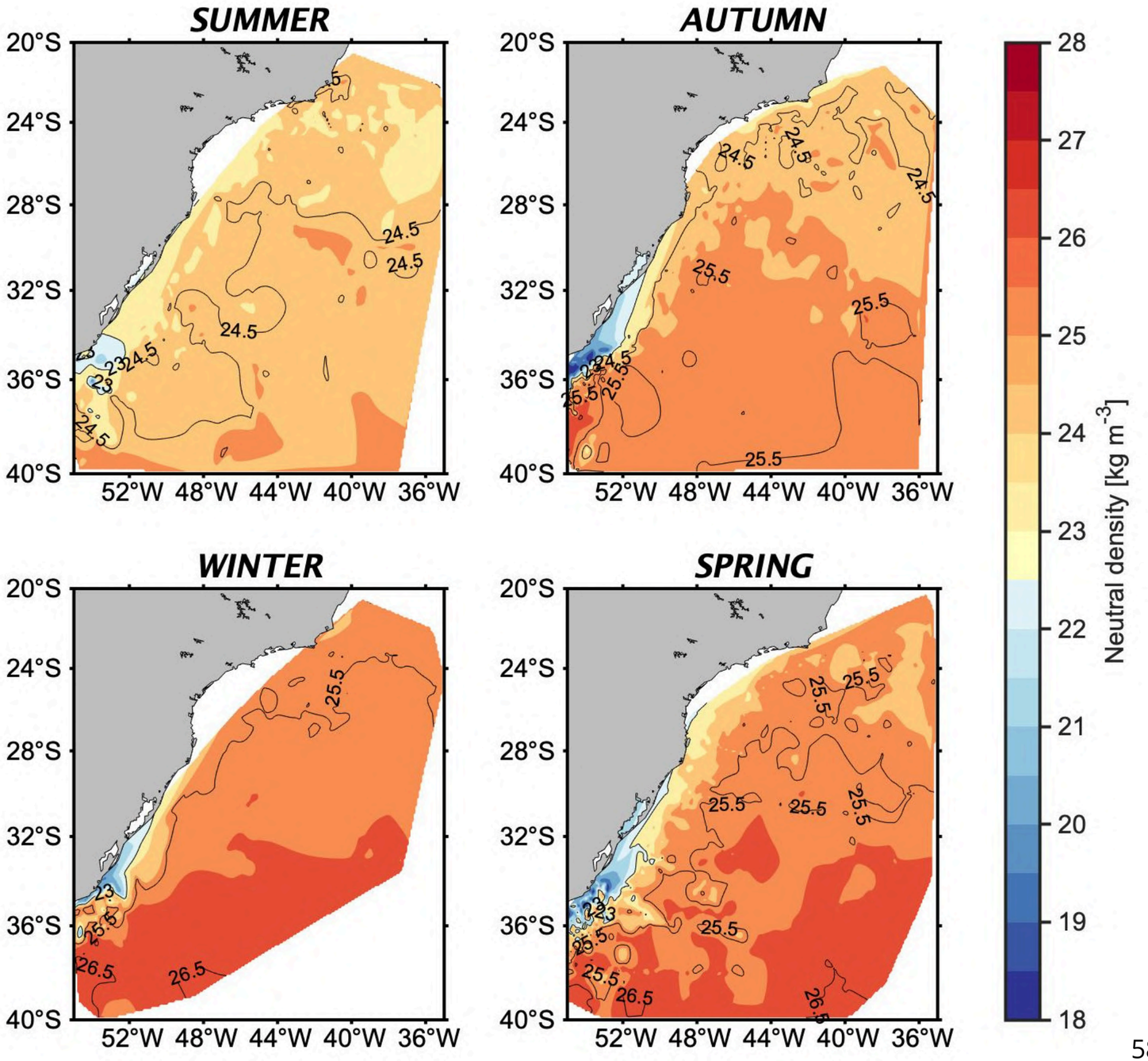
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 1027
- Autumn = 1077
- Winter = 508
- Spring = 1675

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

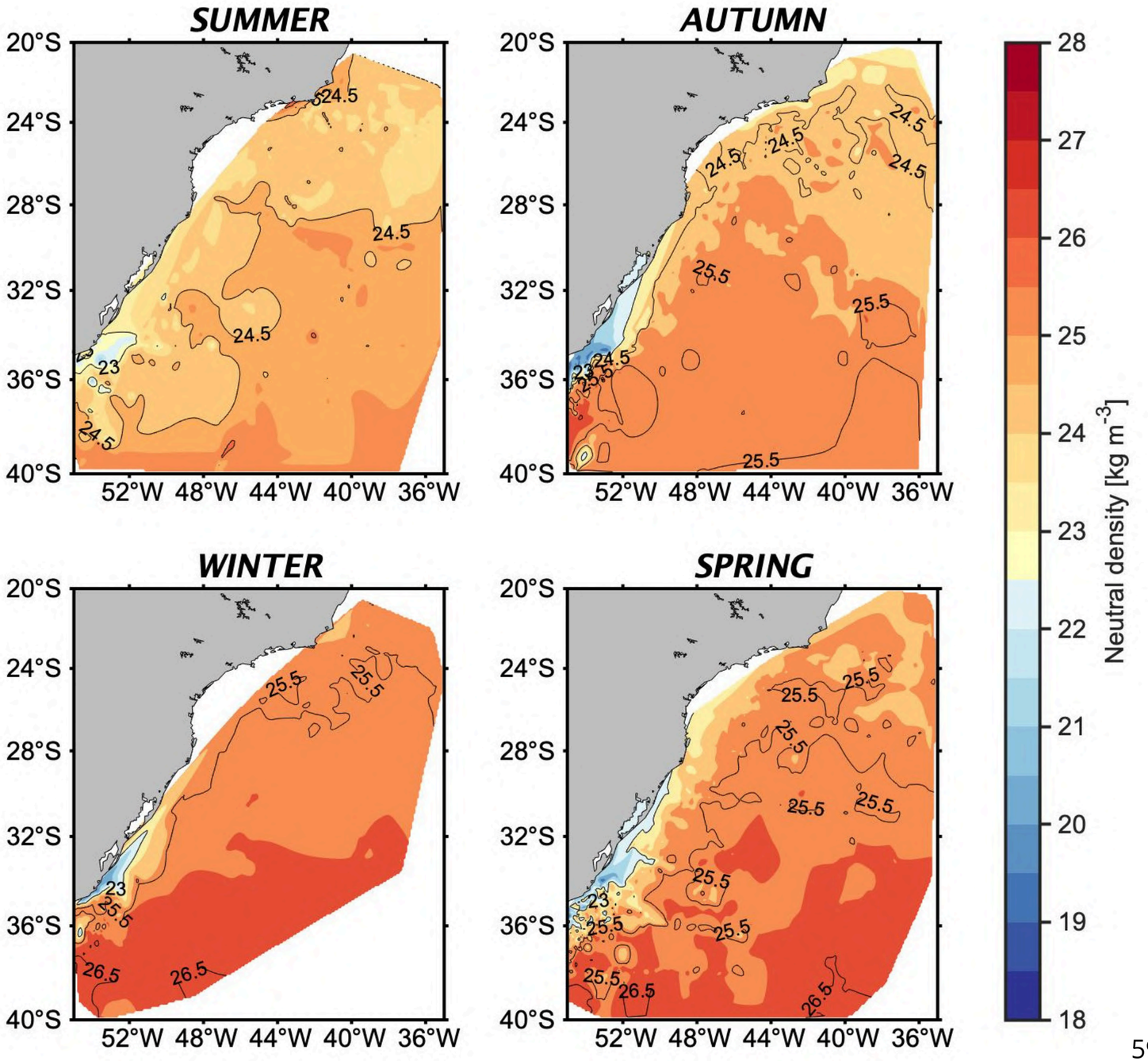
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 1221
- Autumn = 1212
- Winter = 552
- Spring = 1787

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

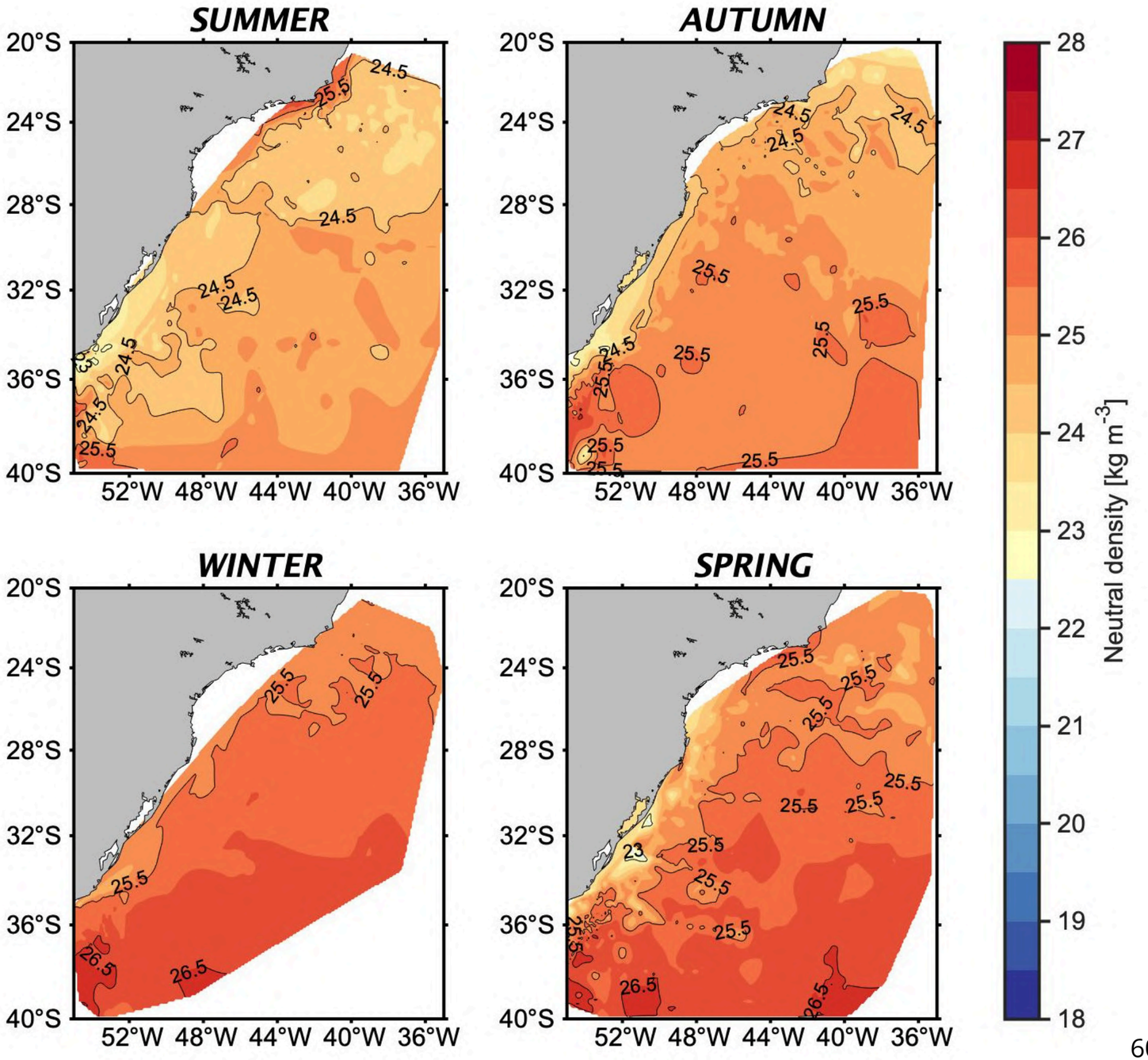
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 1238
- Autumn = 1216
- Winter = 534
- Spring = 1785

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

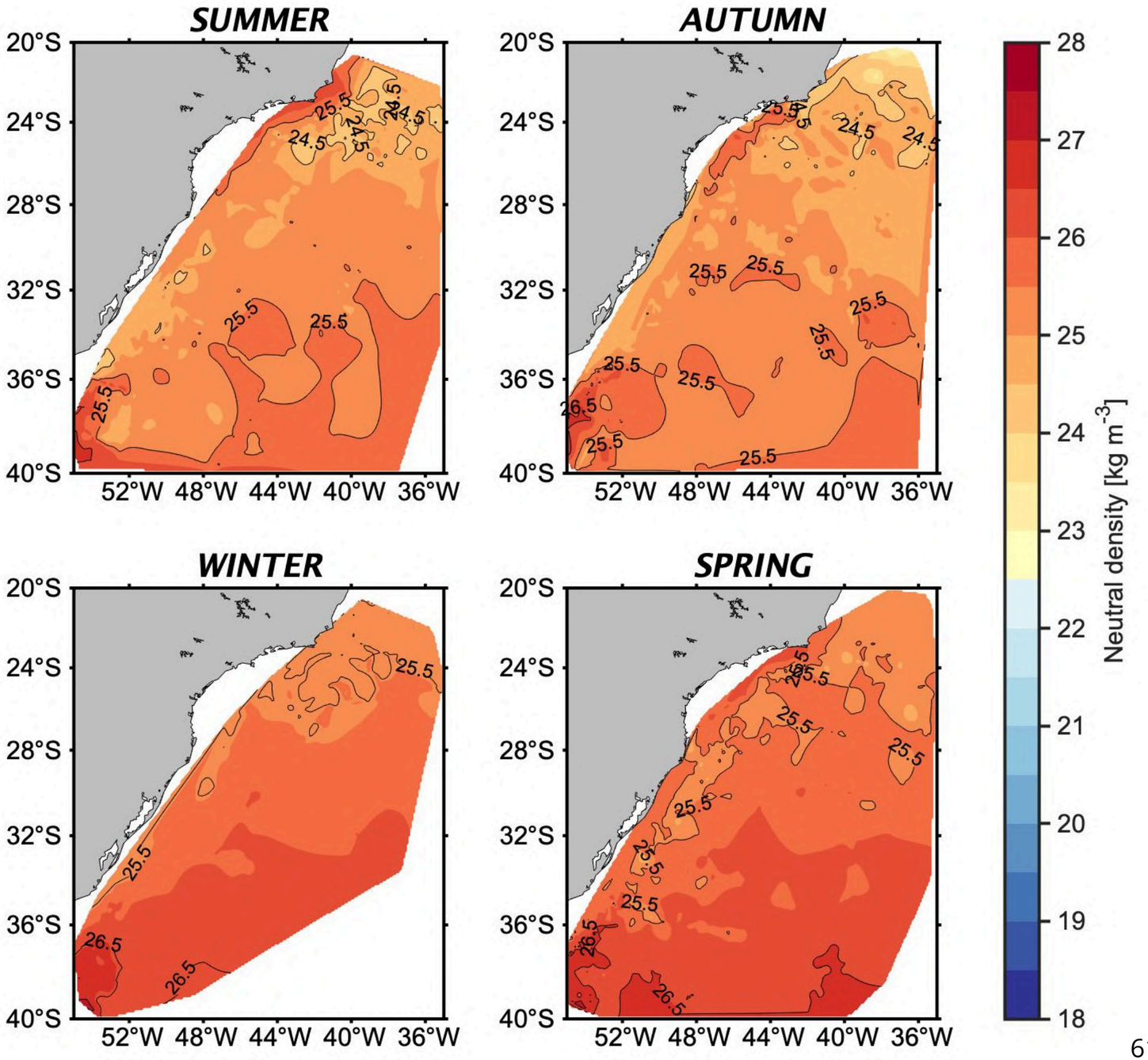
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 1119
- Autumn = 1140
- Winter = 511
- Spring = 1646

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

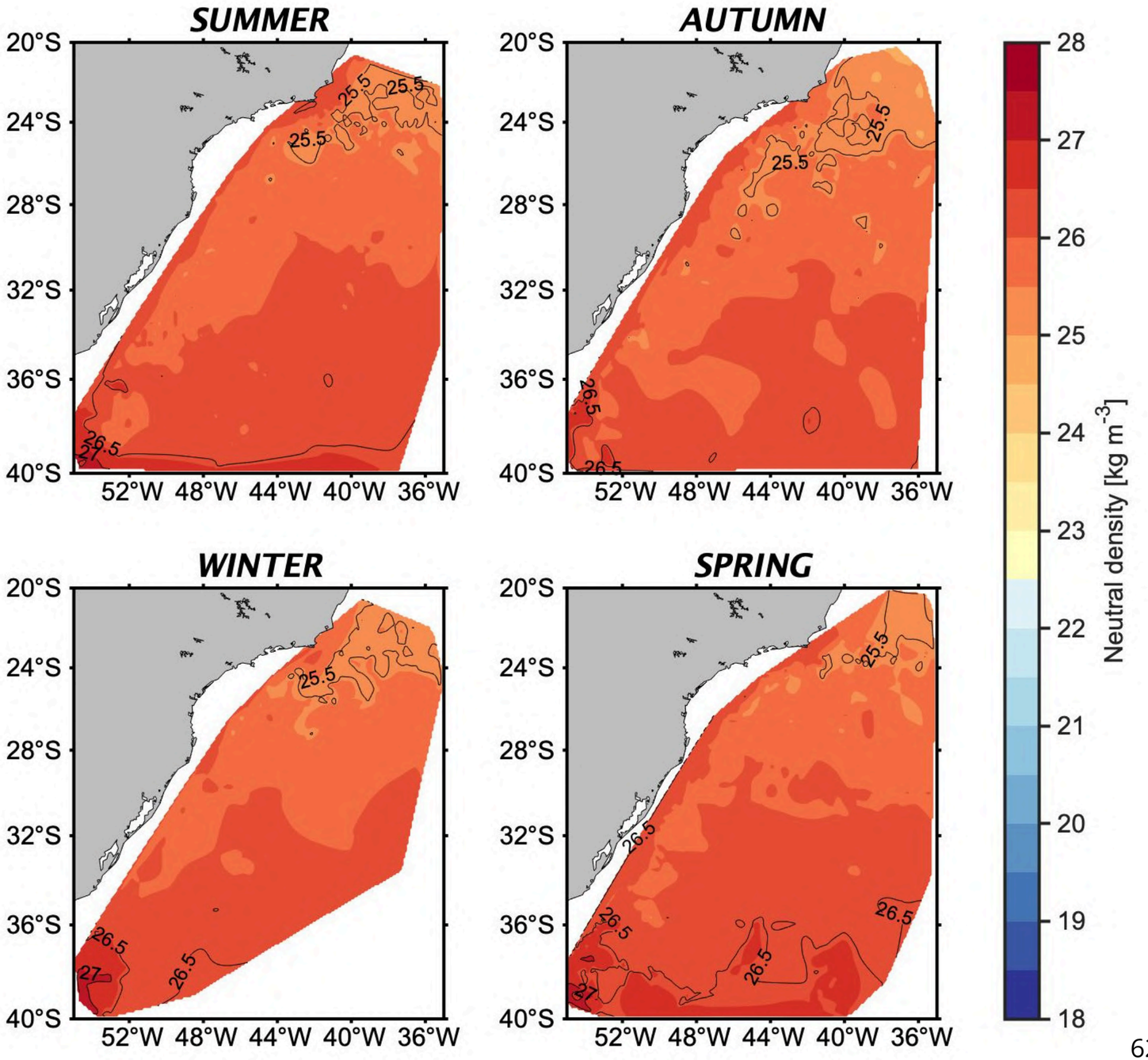
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 1081
- Autumn = 998
- Winter = 459
- Spring = 1450

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

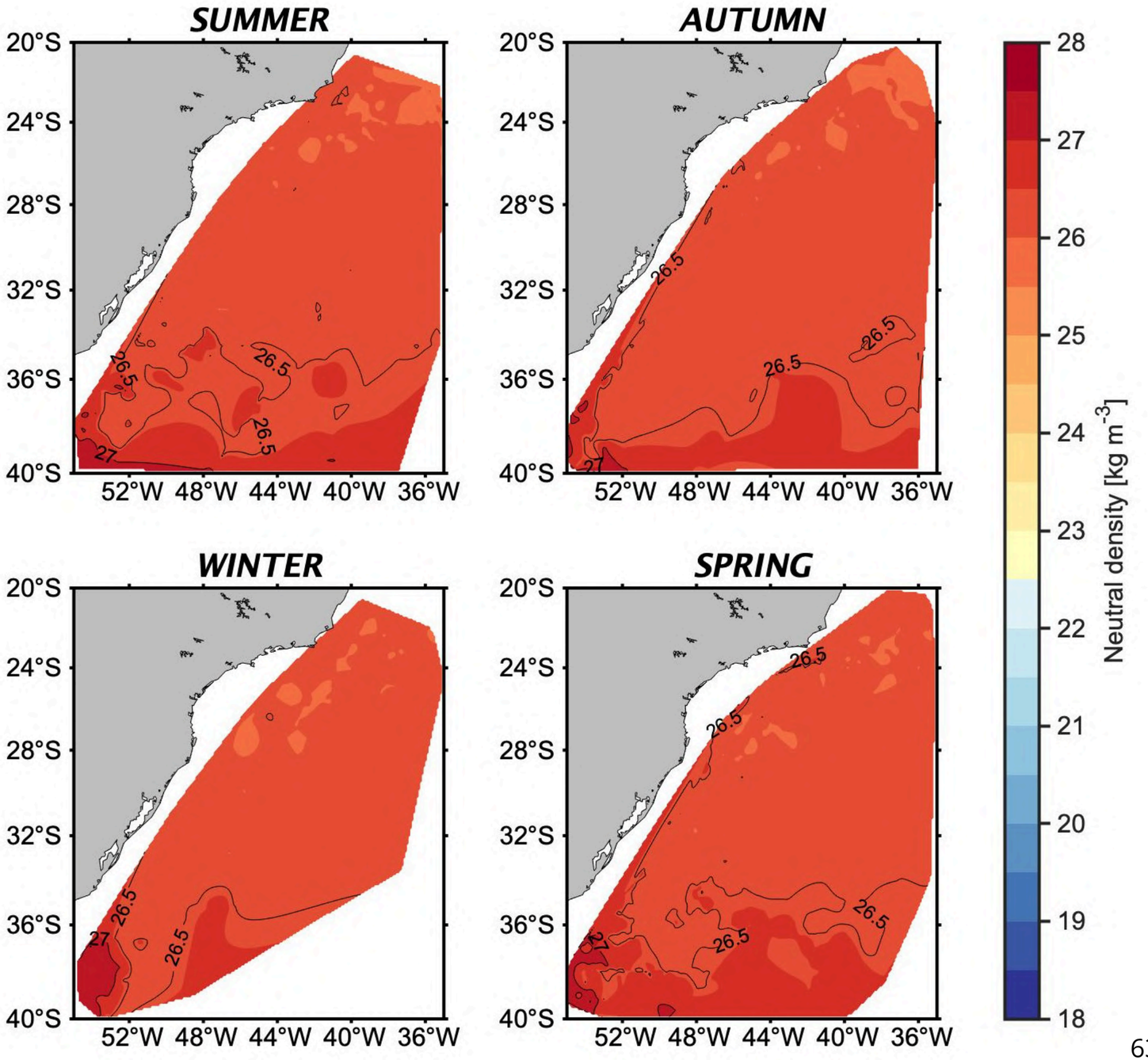
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 925
- Autumn = 825
- Winter = 385
- Spring = 1170

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

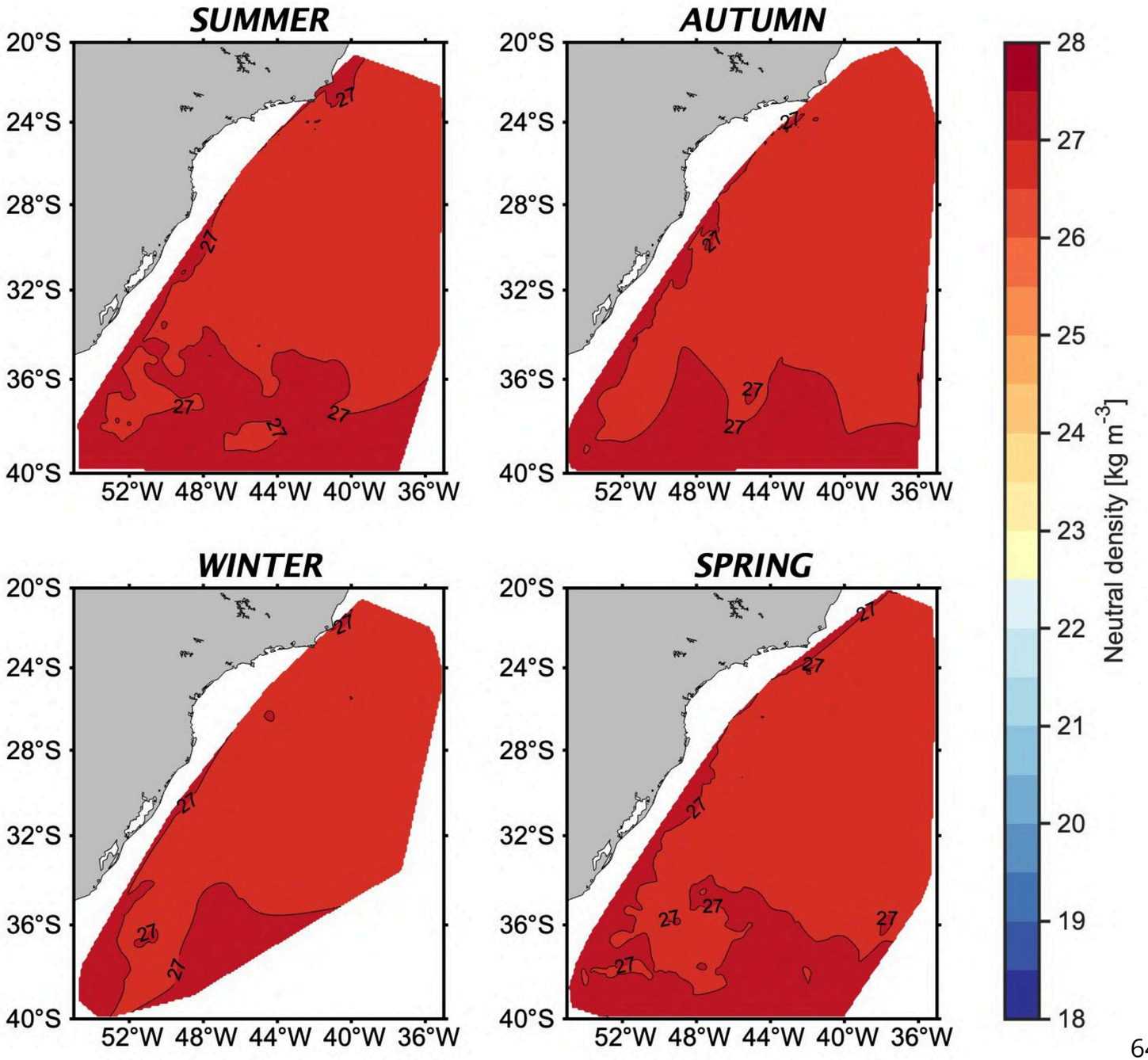
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

- Summer = 888
- Autumn = 759
- Winter = 362
- Spring = 1003

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



Density climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

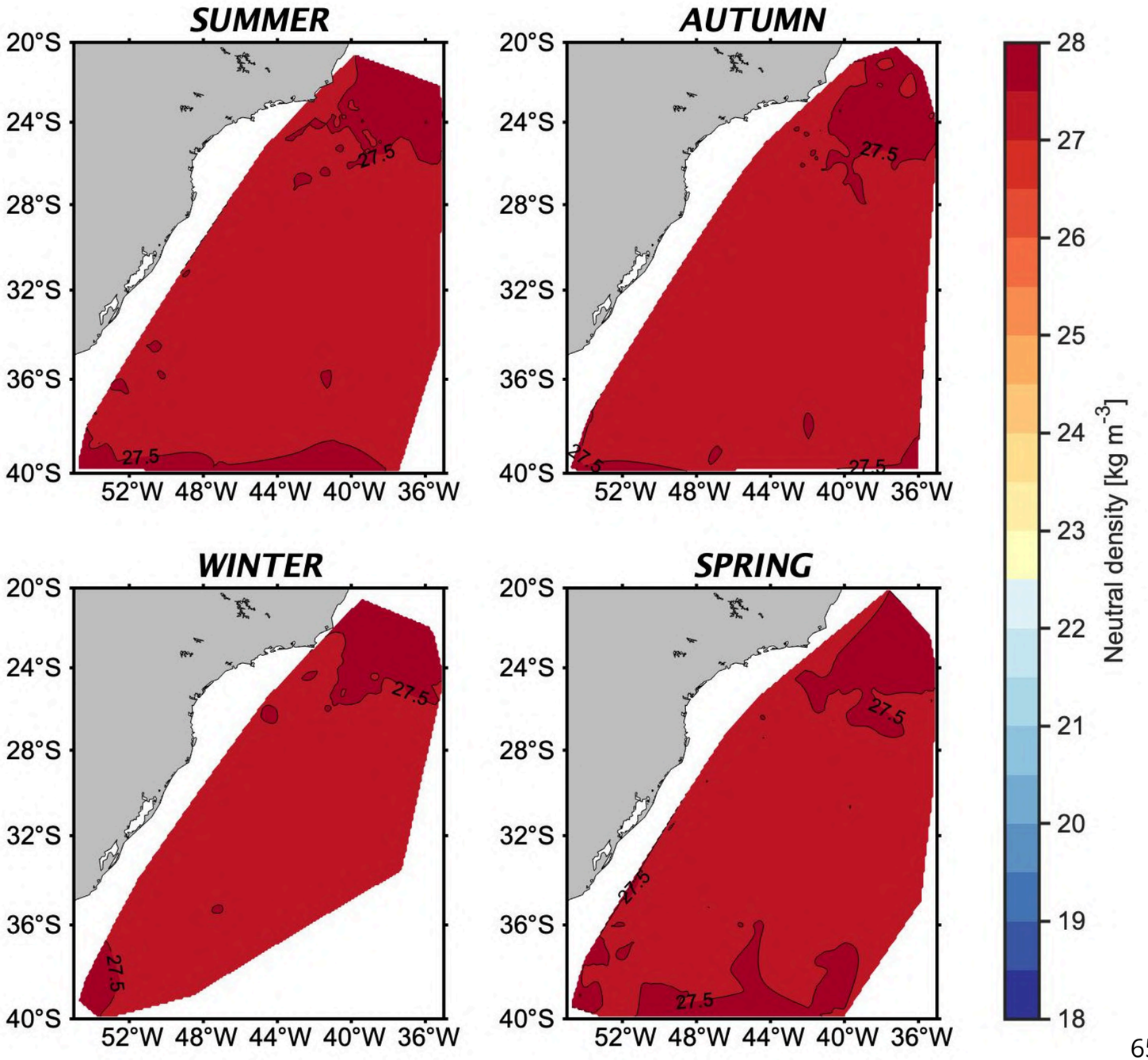
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T) used for interpolation per season:

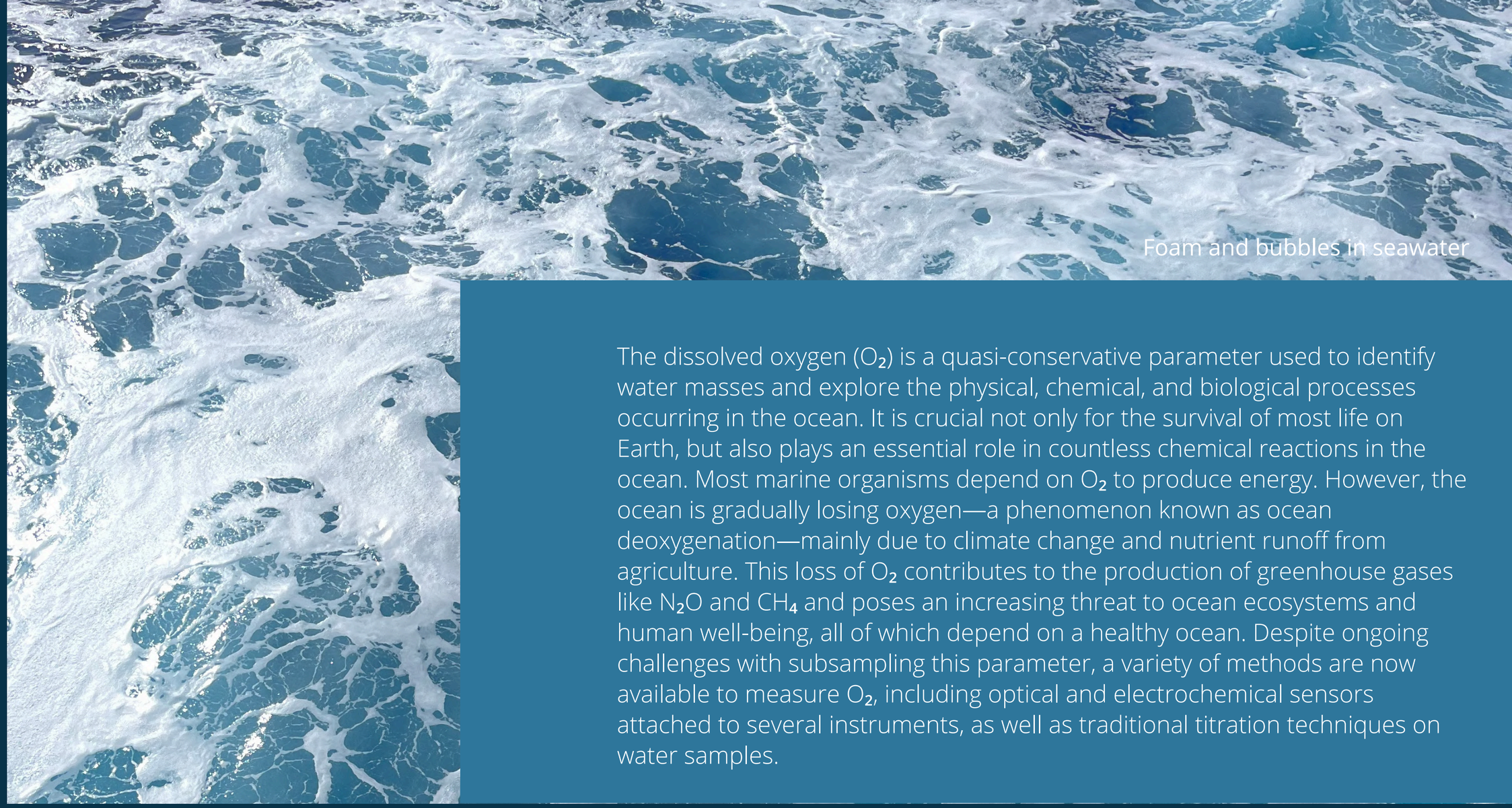
- Summer = 826
- Autumn = 596
- Winter = 321
- Spring = 833

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



04.4 Dissolved Oxygen



Foam and bubbles in seawater

The dissolved oxygen (O_2) is a quasi-conservative parameter used to identify water masses and explore the physical, chemical, and biological processes occurring in the ocean. It is crucial not only for the survival of most life on Earth, but also plays an essential role in countless chemical reactions in the ocean. Most marine organisms depend on O_2 to produce energy. However, the ocean is gradually losing oxygen—a phenomenon known as ocean deoxygenation—mainly due to climate change and nutrient runoff from agriculture. This loss of O_2 contributes to the production of greenhouse gases like N_2O and CH_4 and poses an increasing threat to ocean ecosystems and human well-being, all of which depend on a healthy ocean. Despite ongoing challenges with subsampling this parameter, a variety of methods are now available to measure O_2, including optical and electrochemical sensors attached to several instruments, as well as traditional titration techniques on water samples.

Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

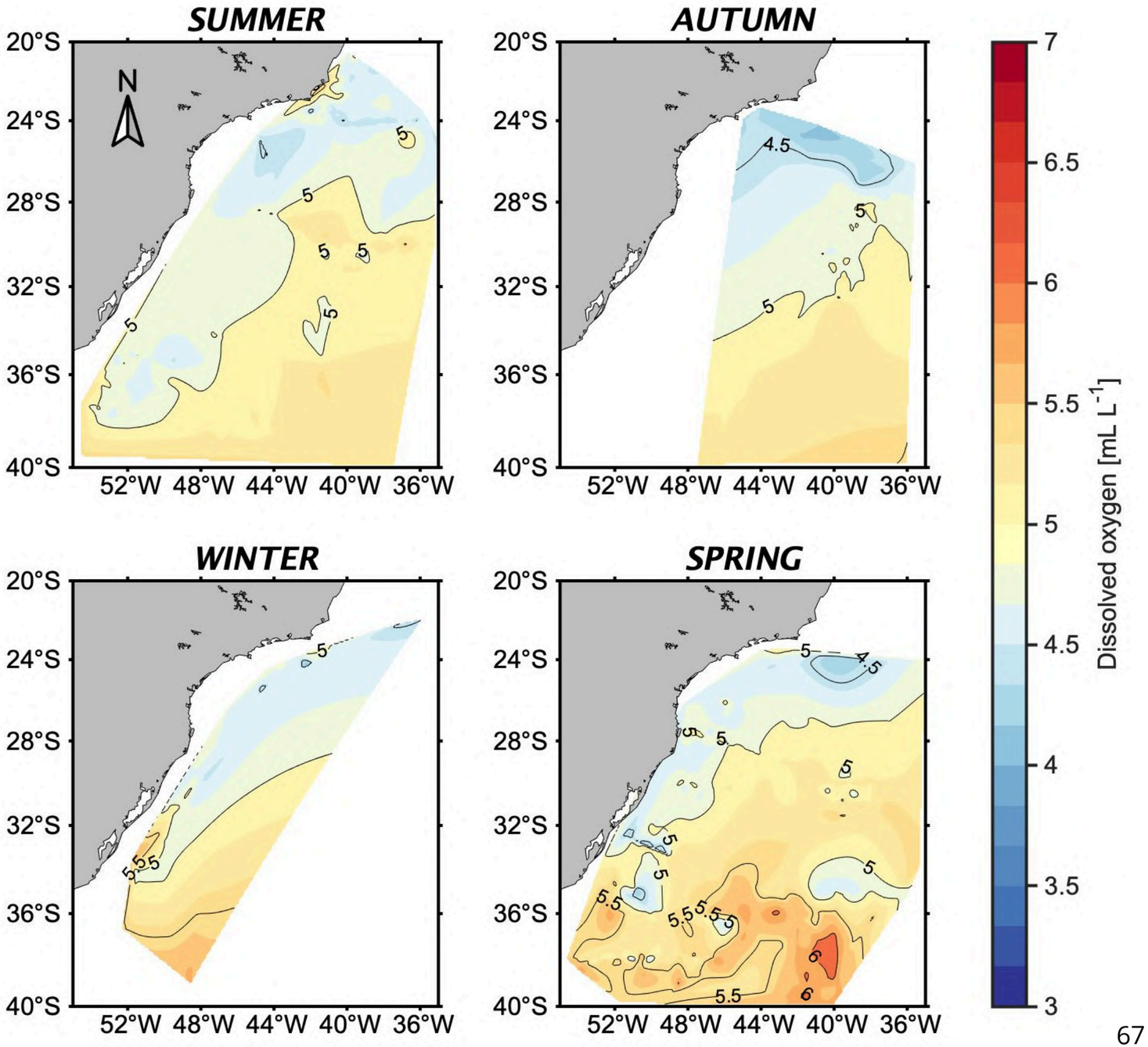
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 325
- Autumn = 123
- Winter = 64
- Spring = 451

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

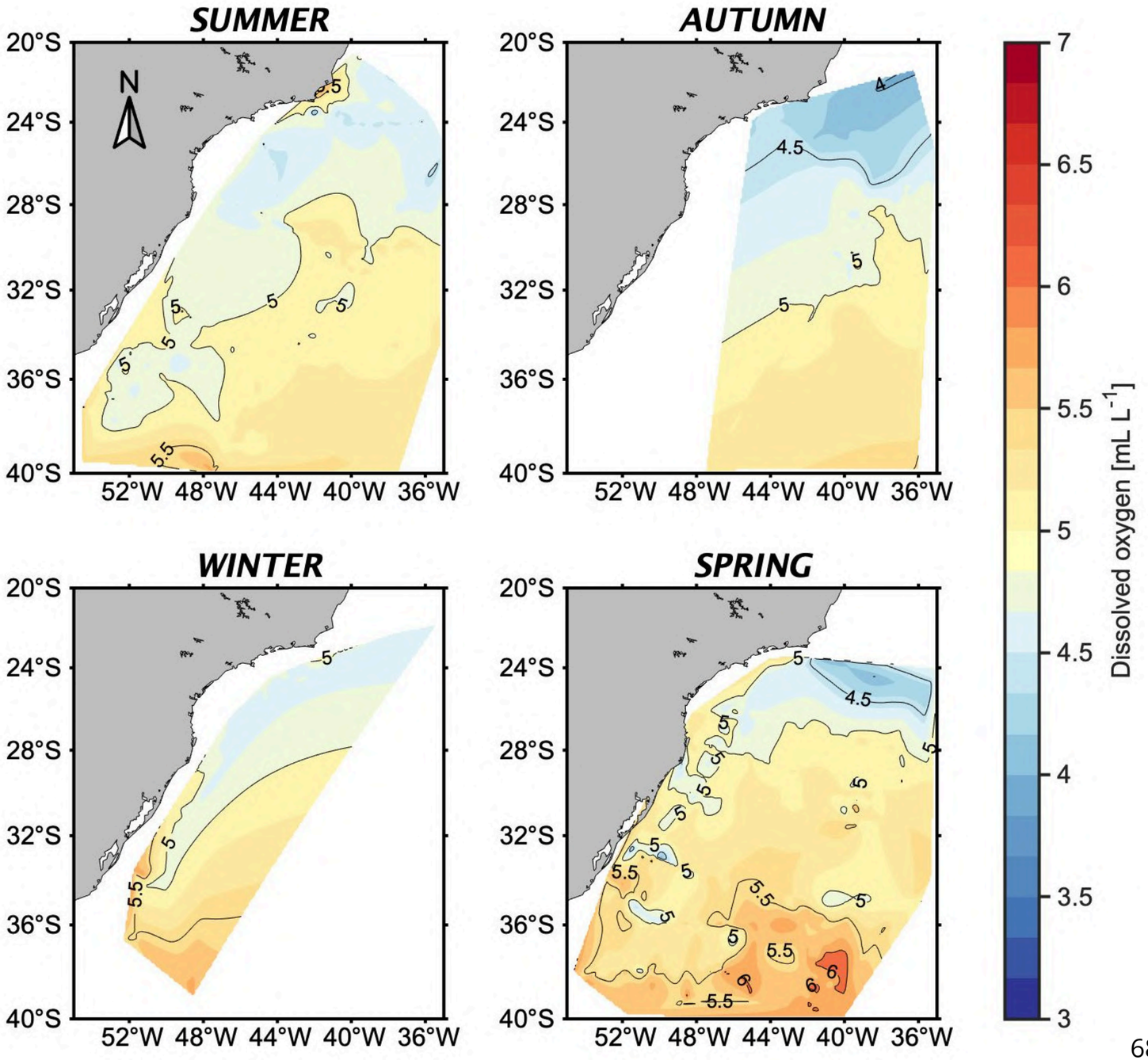
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 492
- Autumn = 176
- Winter = 70
- Spring = 523

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

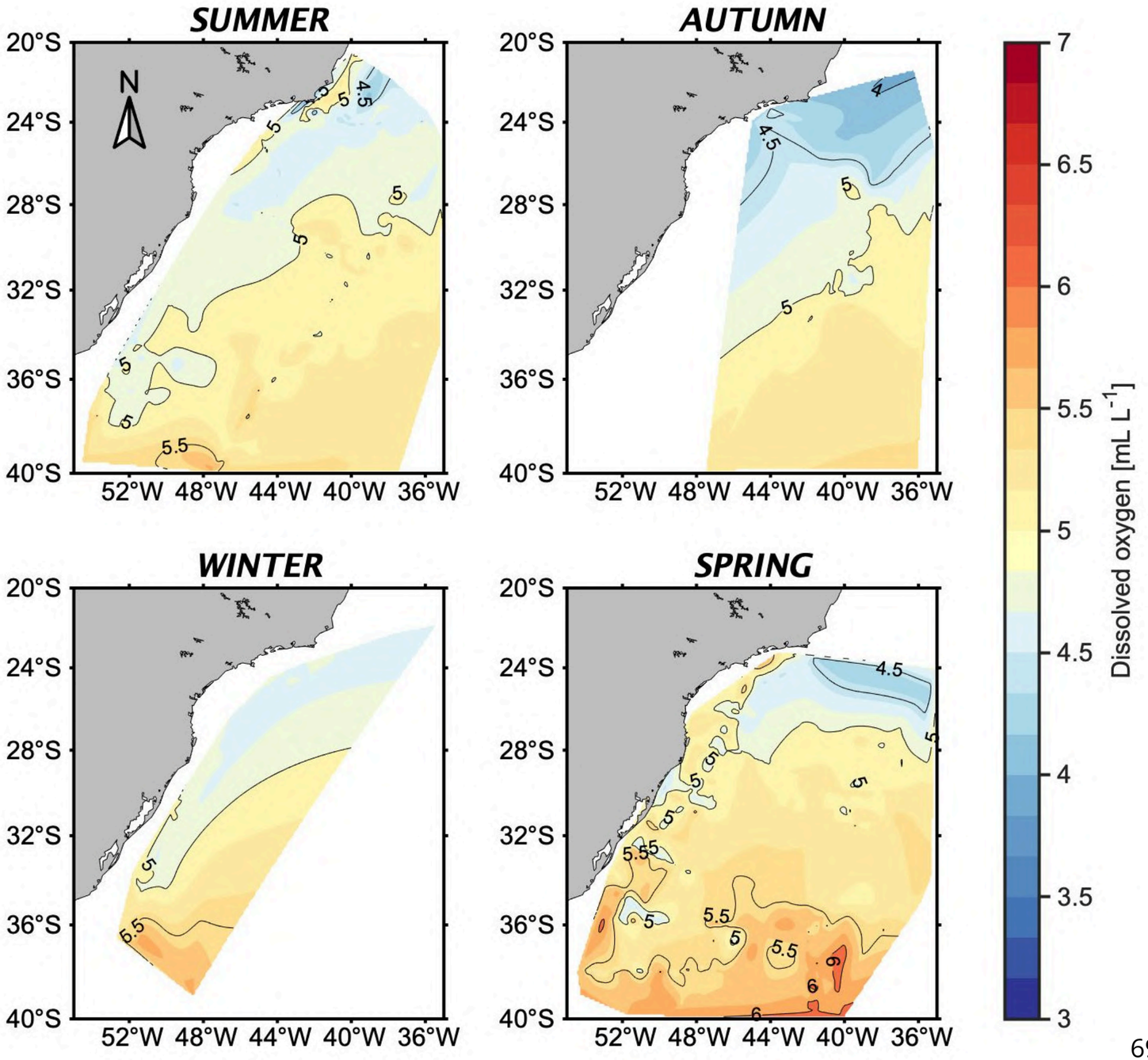
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 528
- Autumn = 182
- Winter = 71
- Spring = 564

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

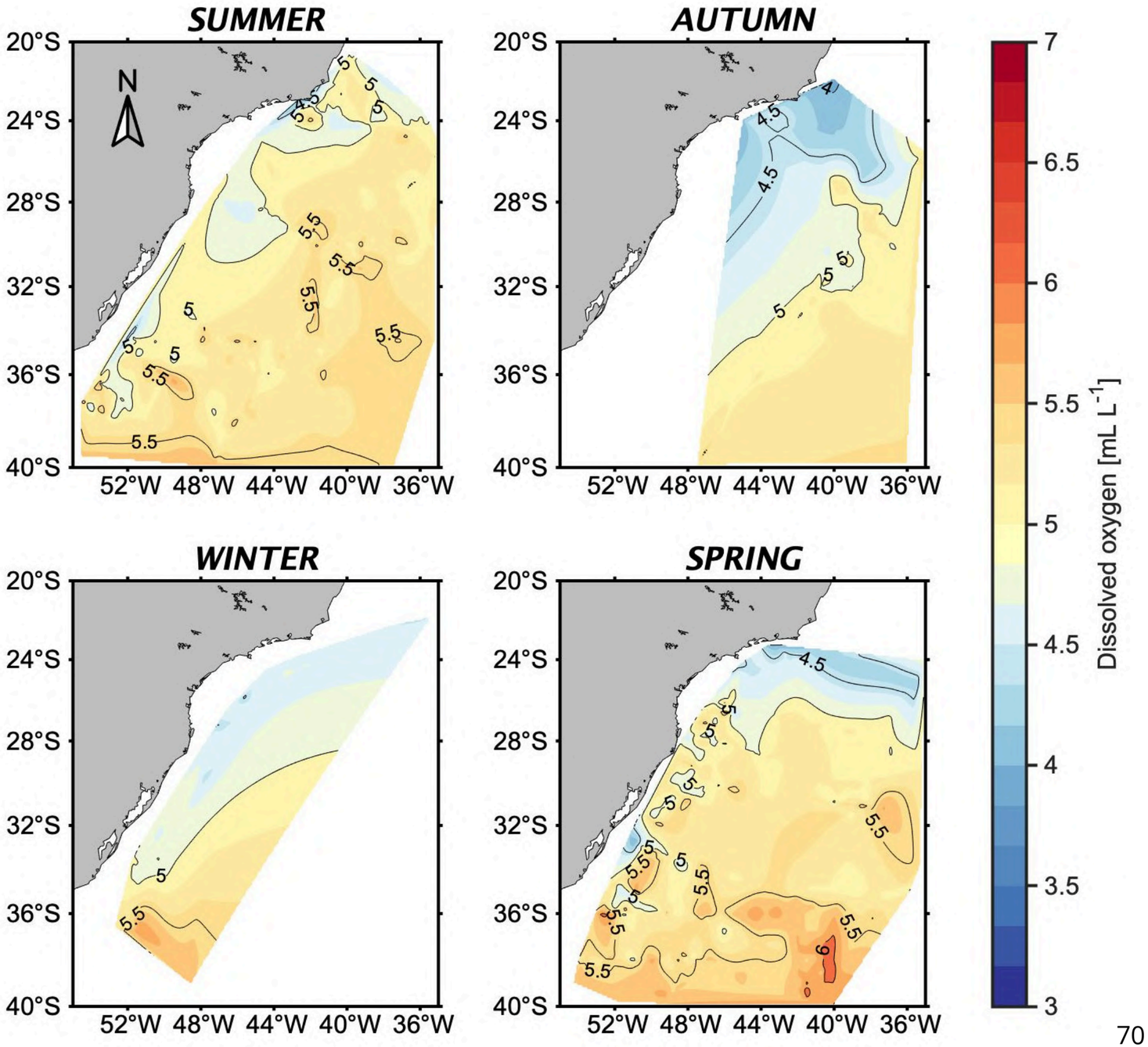
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 525
- Autumn = 180
- Winter = 71
- Spring = 566

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

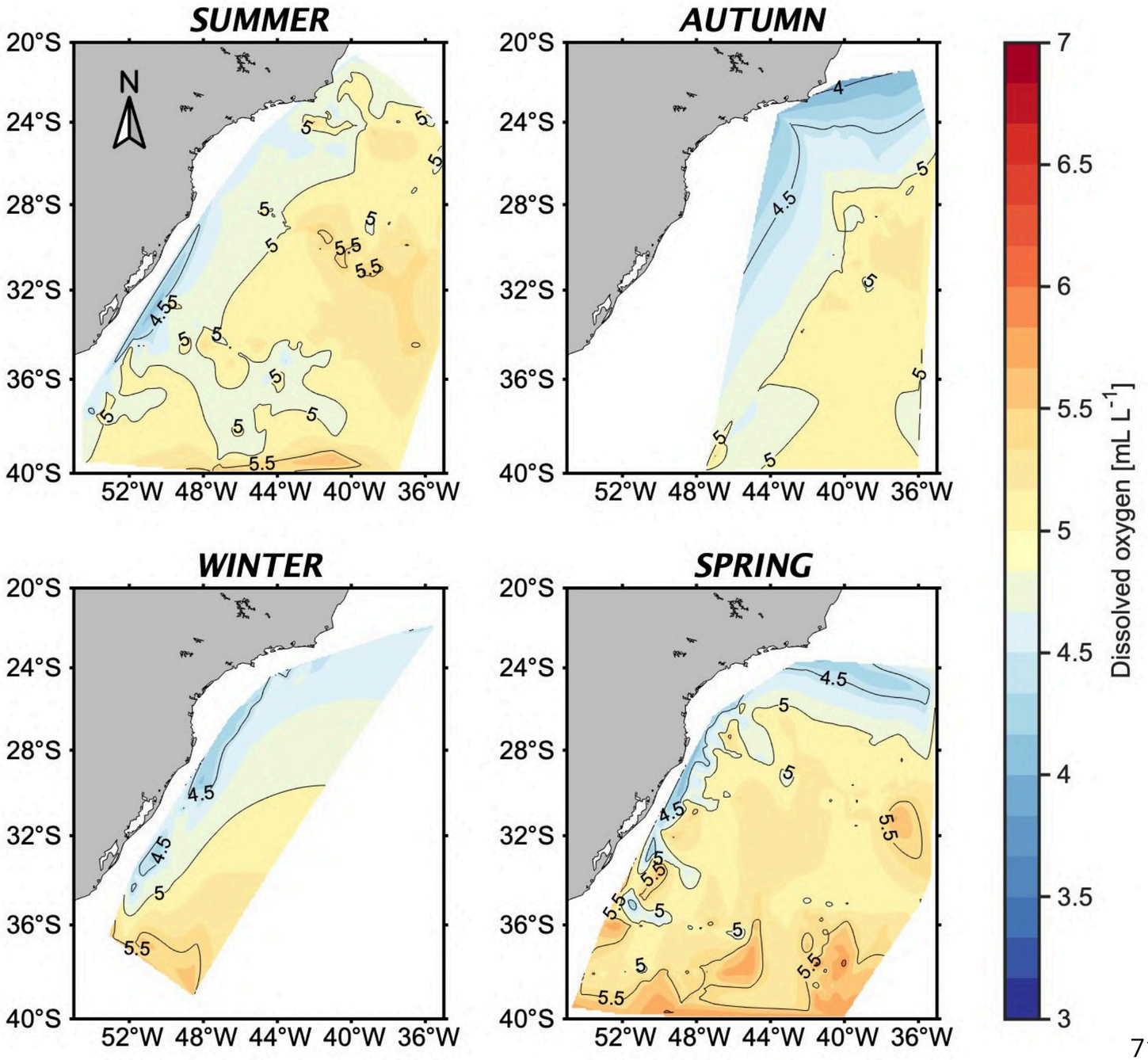
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 516
- Autumn = 182
- Winter = 72
- Spring = 561

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

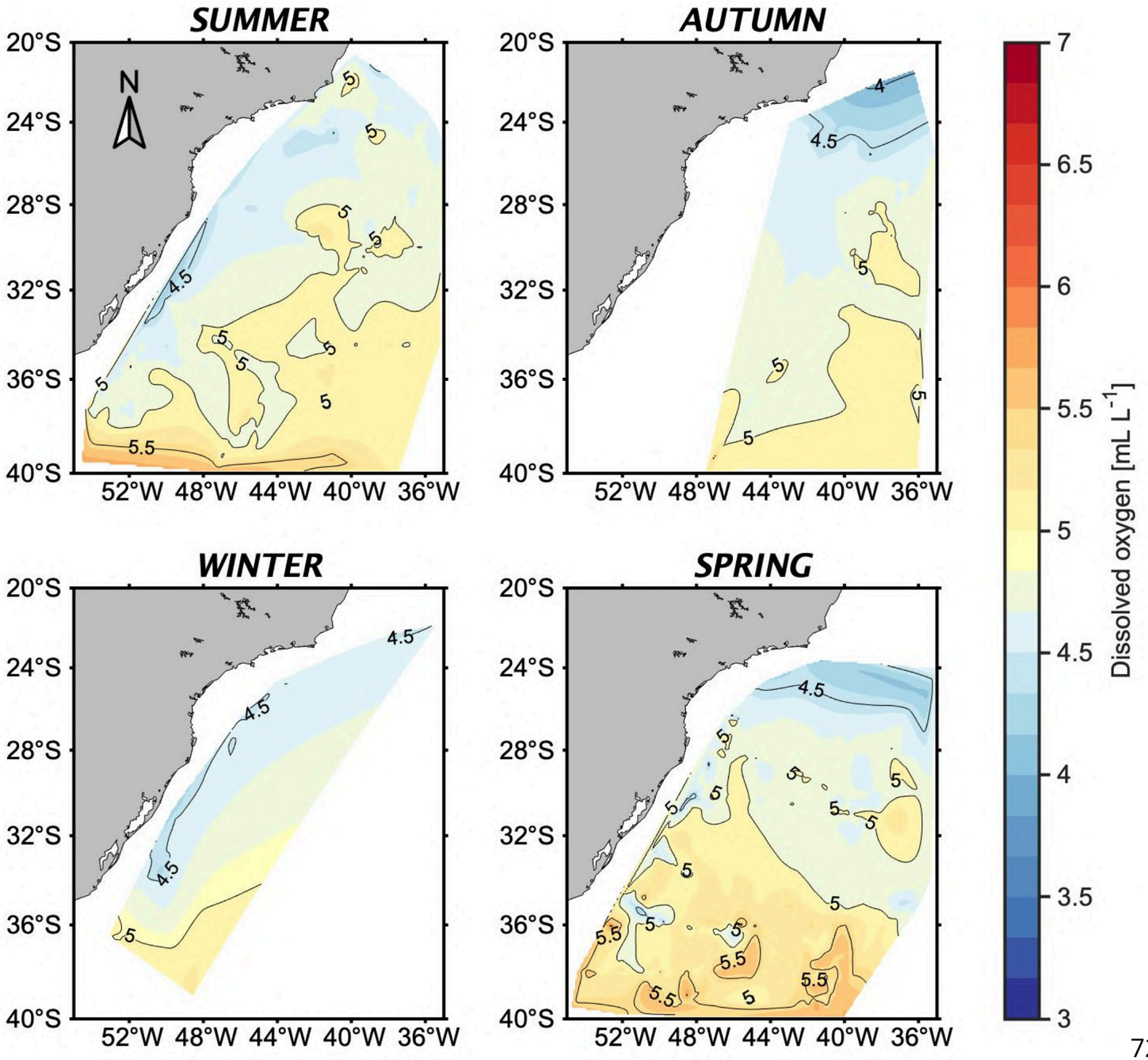
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 492
- Autumn = 179
- Winter = 47
- Spring = 523

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

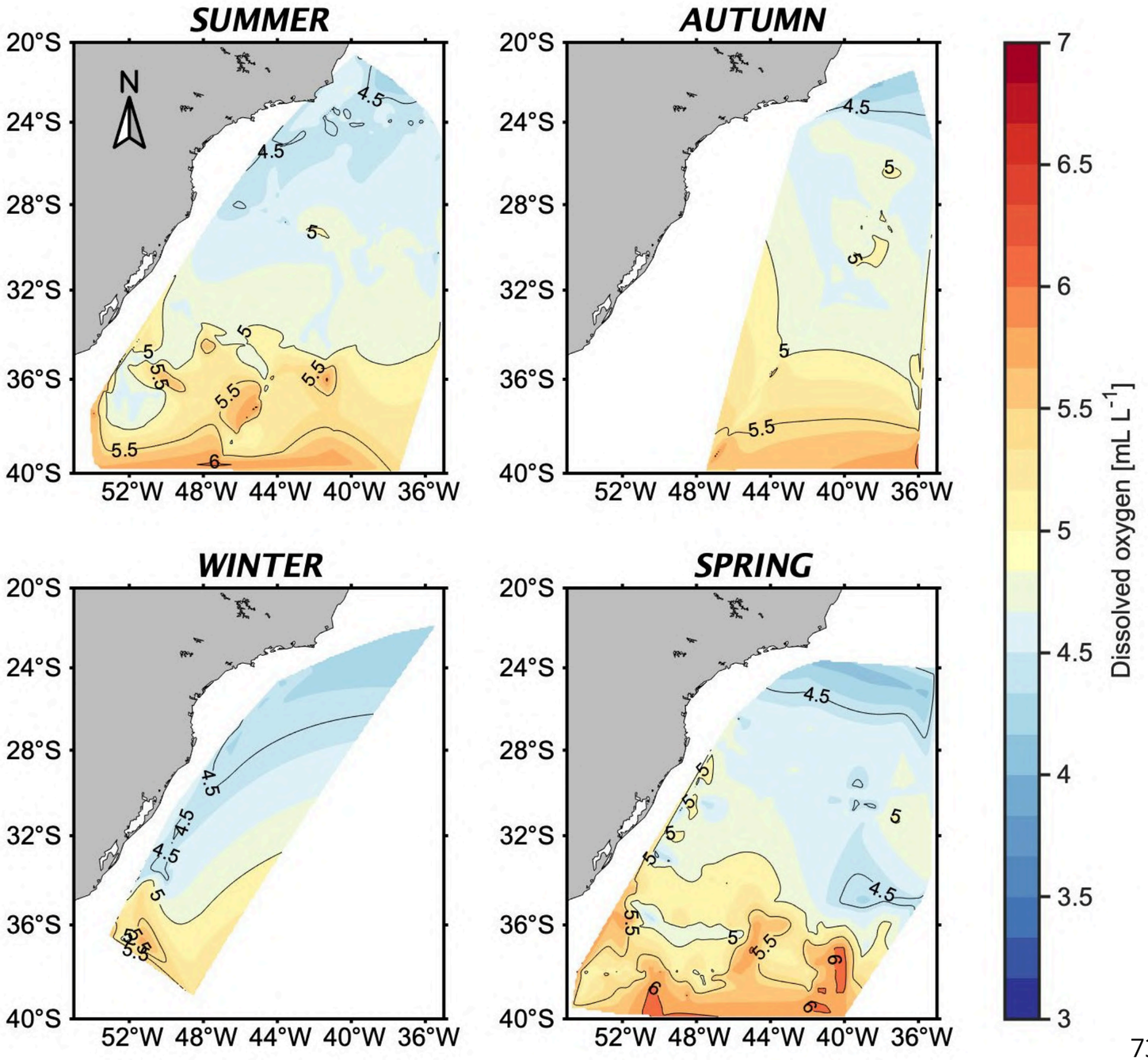
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

- Summer = 461
- Autumn = 179
- Winter = 46
- Spring = 469

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



Dissolved oxygen climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

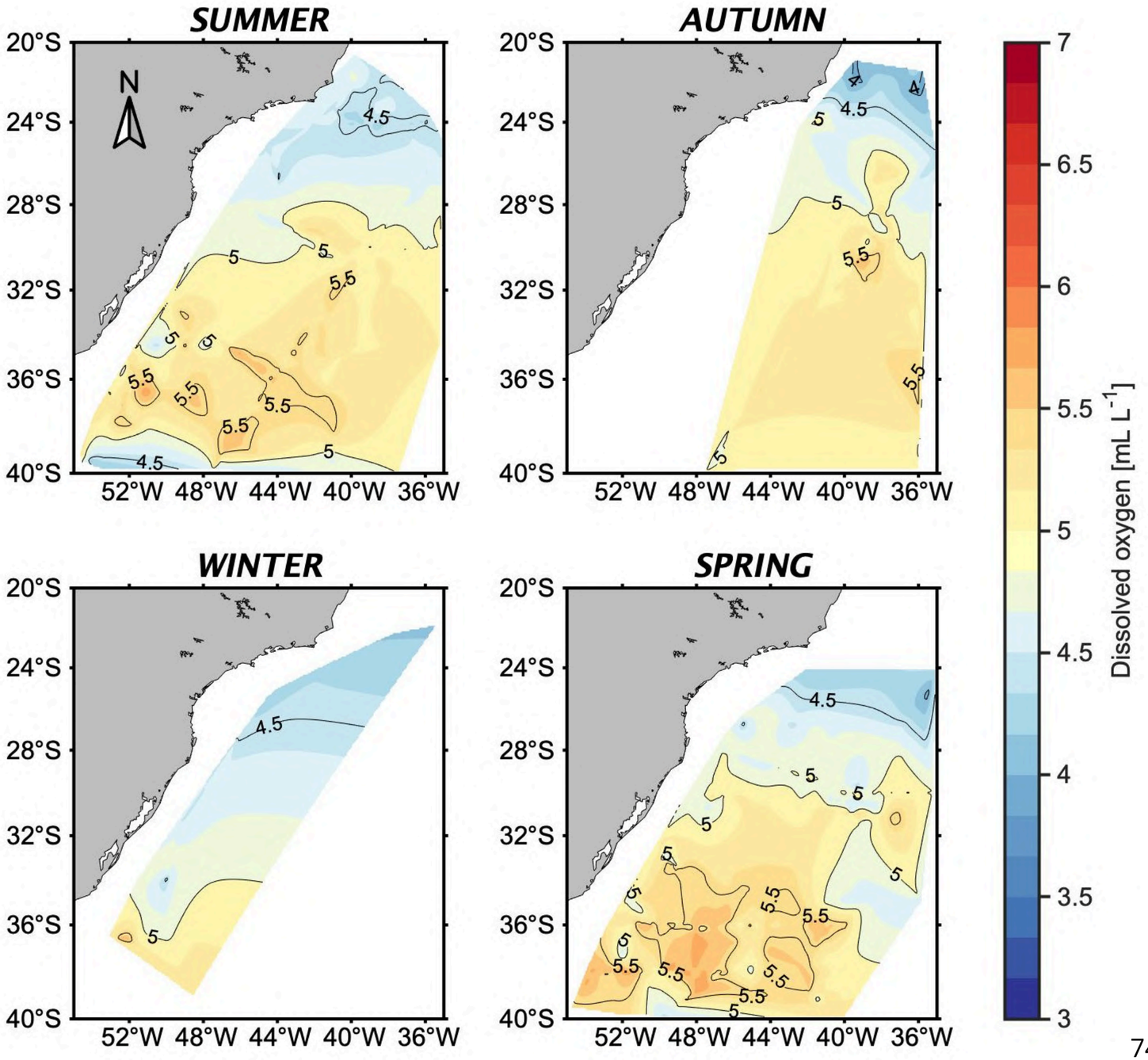
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations used for interpolation per season:

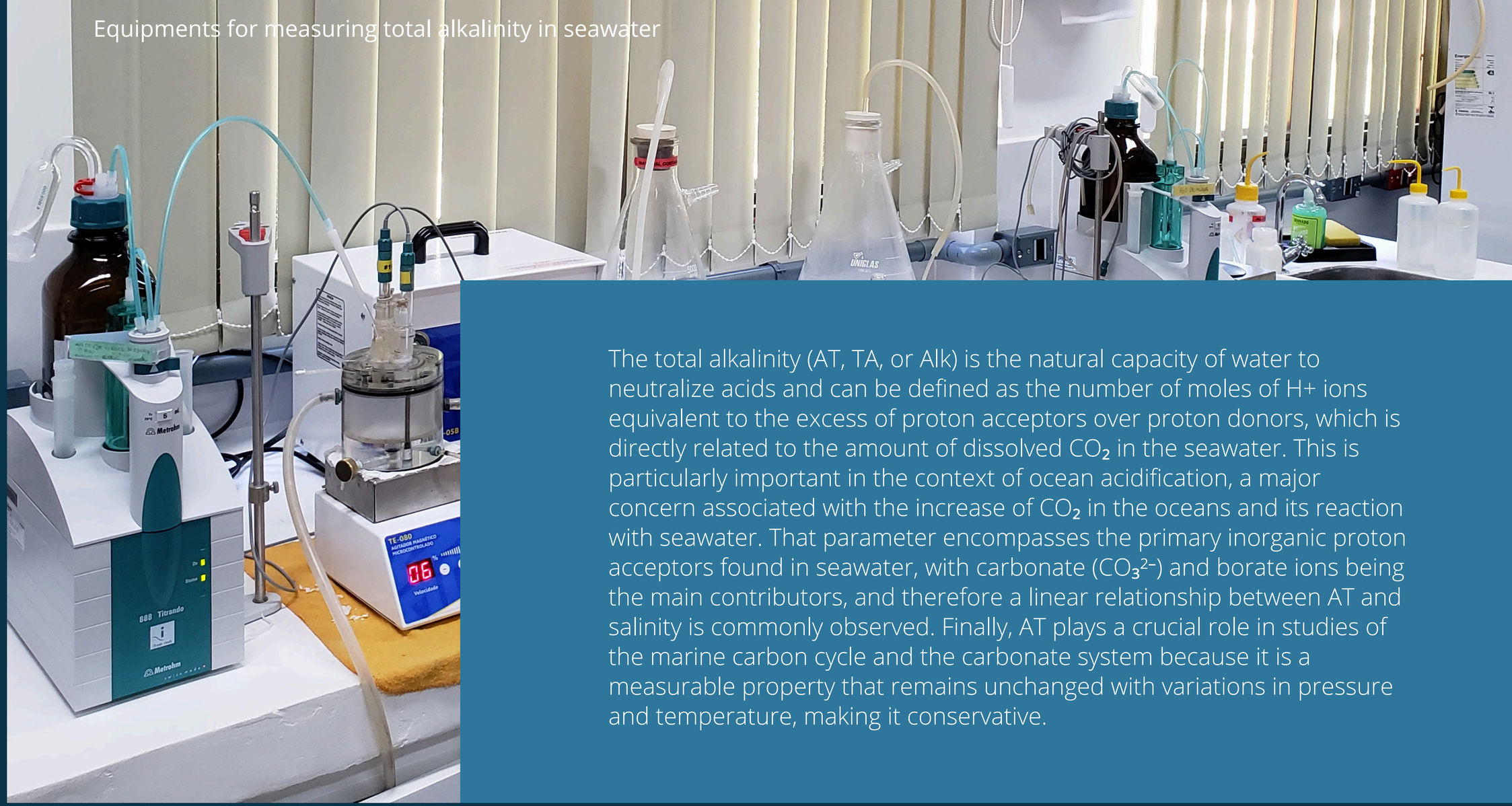
- Summer = 455
- Autumn = 189
- Winter = 36
- Spring = 438

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



04.5 Total Alkalinity



Equipments for measuring total alkalinity in seawater

The total alkalinity (AT, TA, or Alk) is the natural capacity of water to neutralize acids and can be defined as the number of moles of H+ ions equivalent to the excess of proton acceptors over proton donors, which is directly related to the amount of dissolved CO_2 in the seawater. This is particularly important in the context of ocean acidification, a major concern associated with the increase of CO_2 in the oceans and its reaction with seawater. That parameter encompasses the primary inorganic proton acceptors found in seawater, with carbonate (CO_3^{2-}) and borate ions being the main contributors, and therefore a linear relationship between AT and salinity is commonly observed. Finally, AT plays a crucial role in studies of the marine carbon cycle and the carbonate system because it is a measurable property that remains unchanged with variations in pressure and temperature, making it conservative.

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

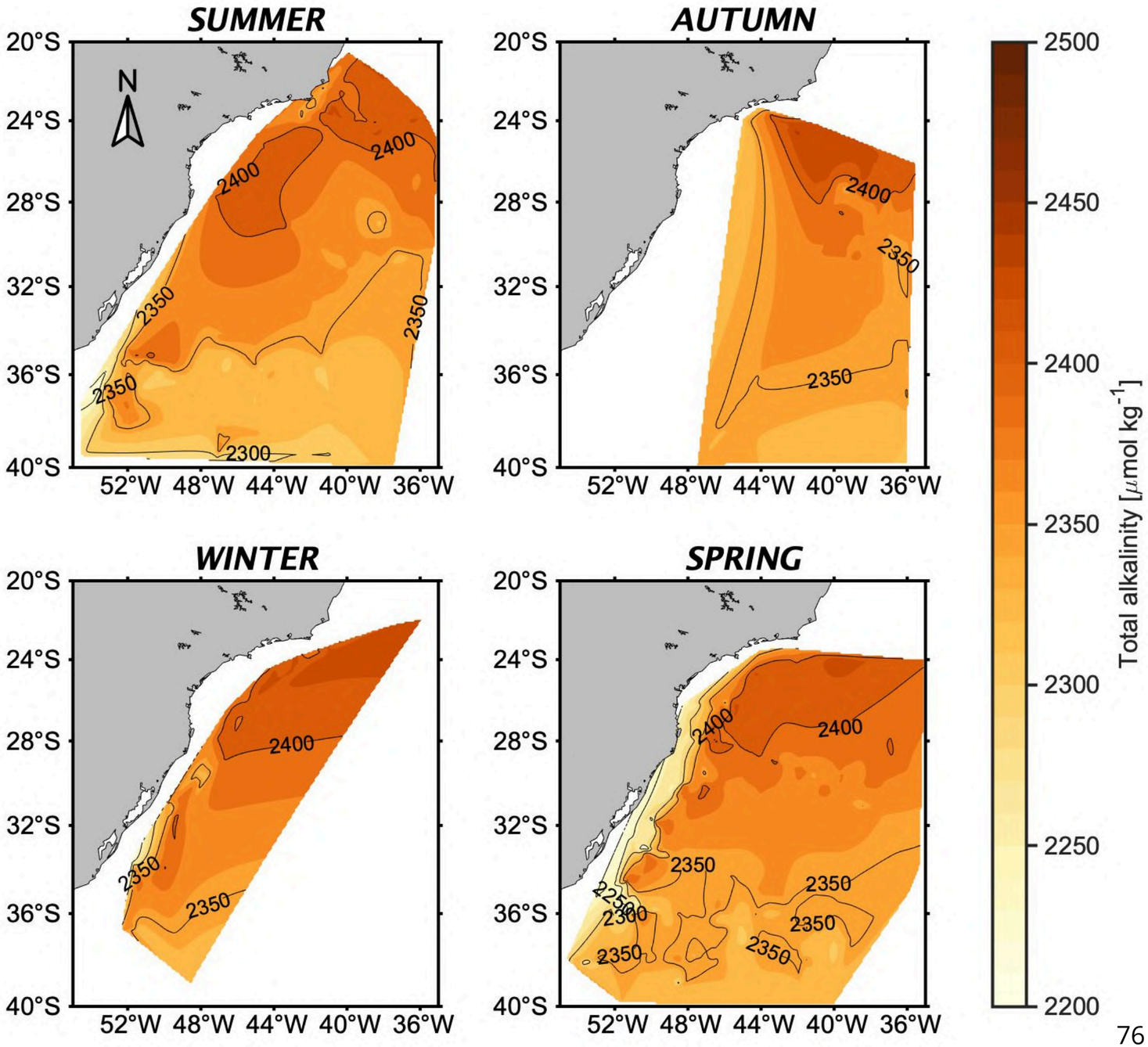
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 312
- Autumn = 123
- Winter = 62
- Spring = 437

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

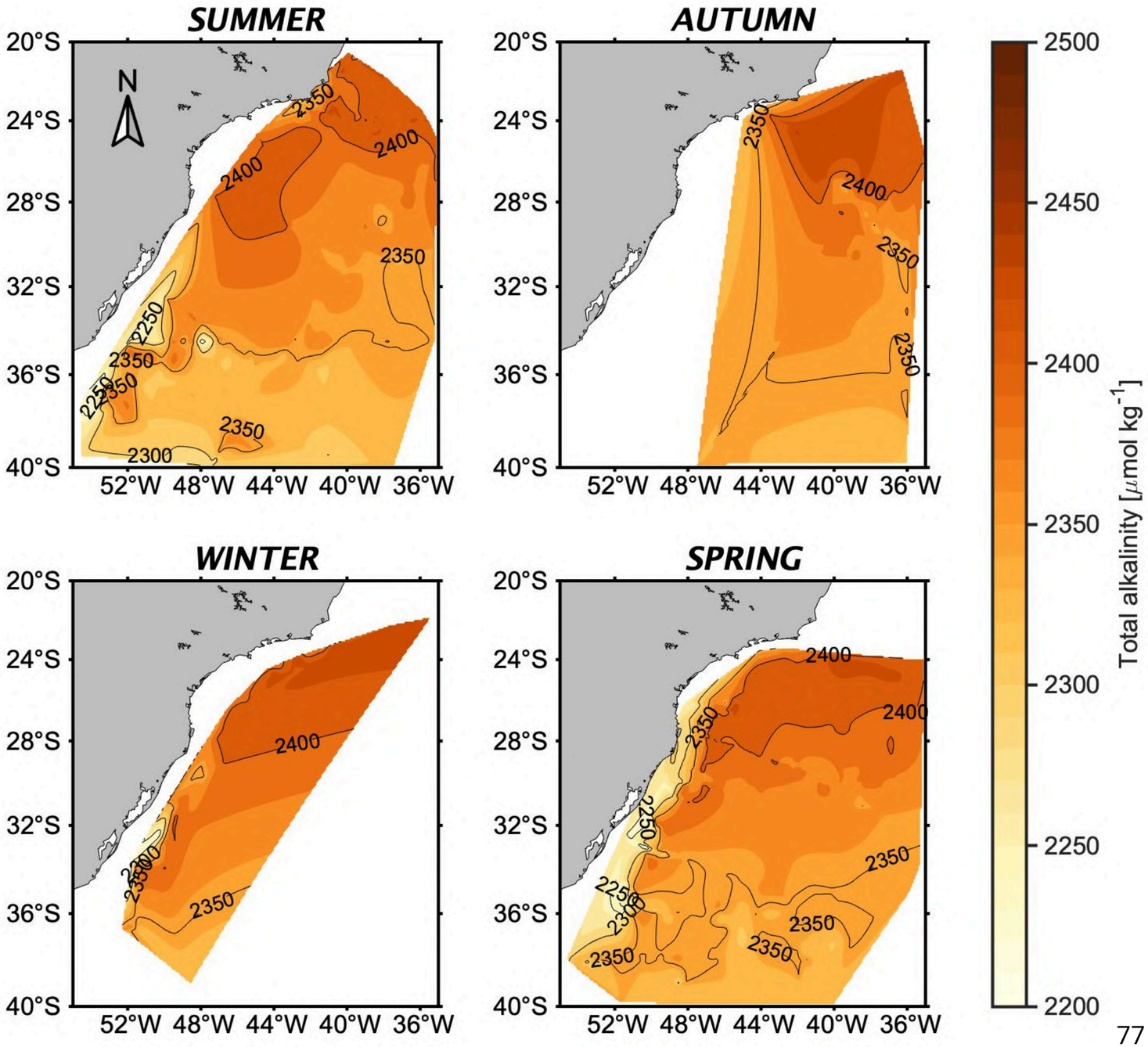
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 473
- Autumn = 176
- Winter = 69
- Spring = 504

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

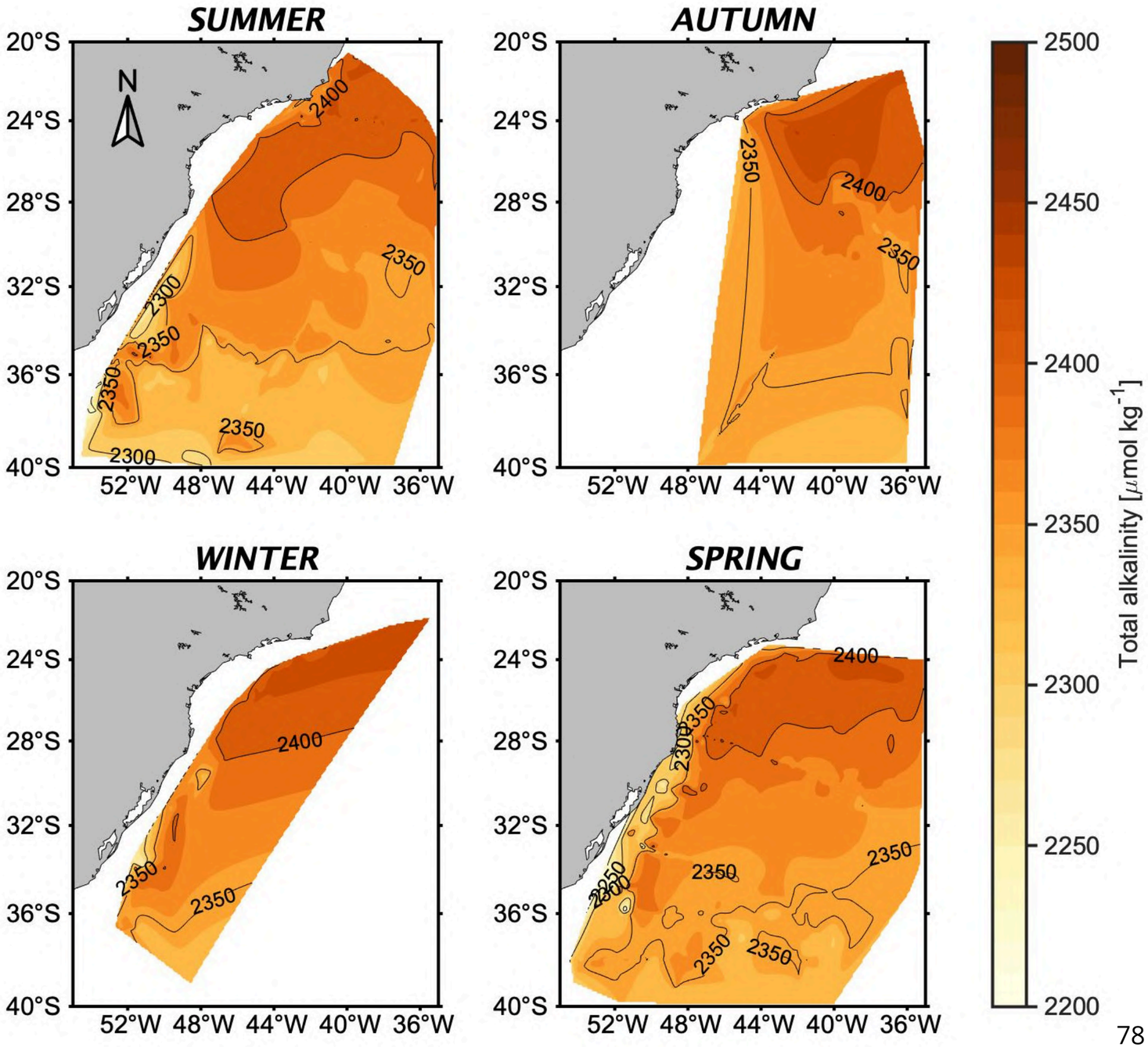
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 509
- Autumn = 182
- Winter = 71
- Spring = 543

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

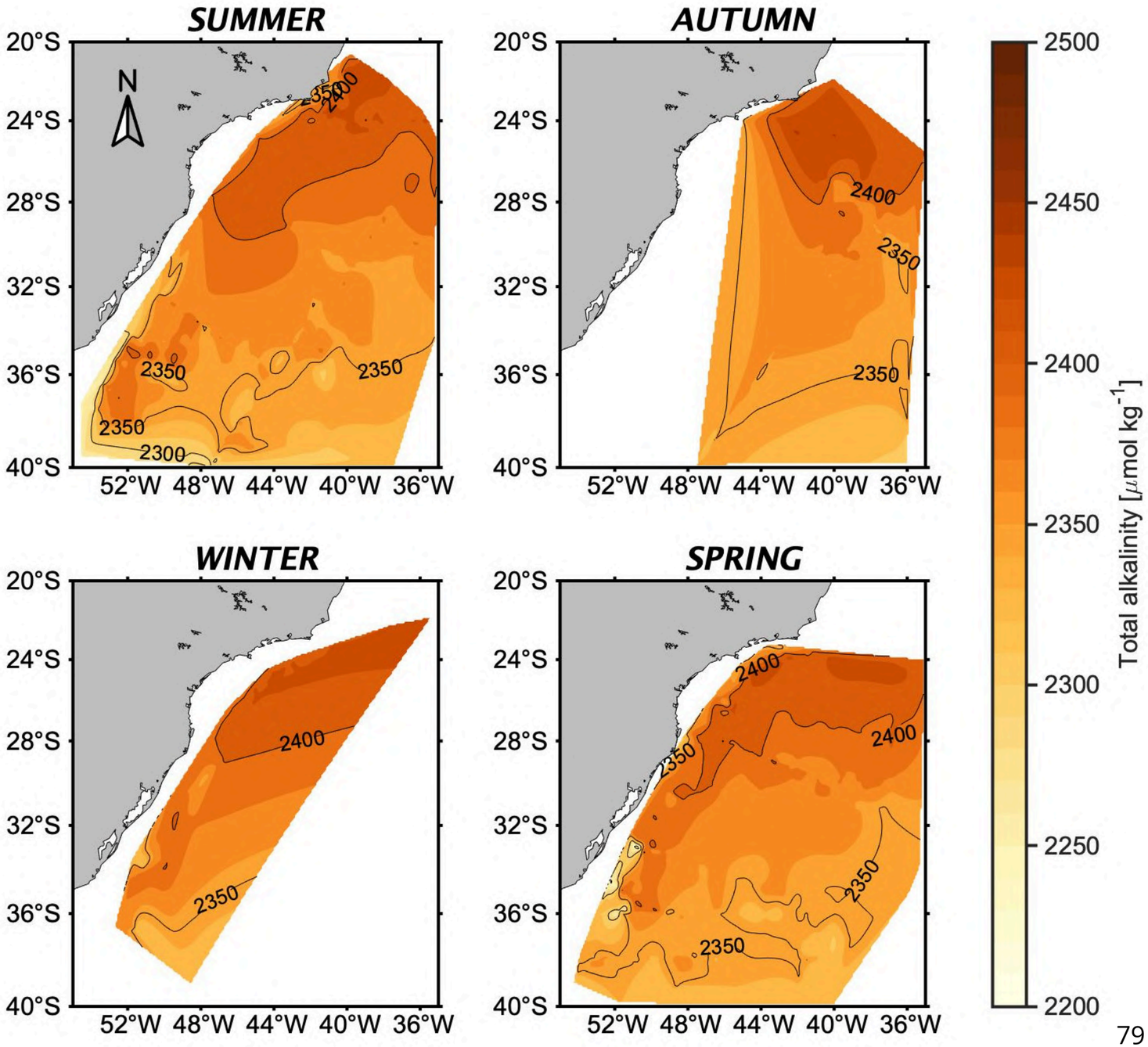
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 505
- Autumn = 180
- Winter = 71
- Spring = 554

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

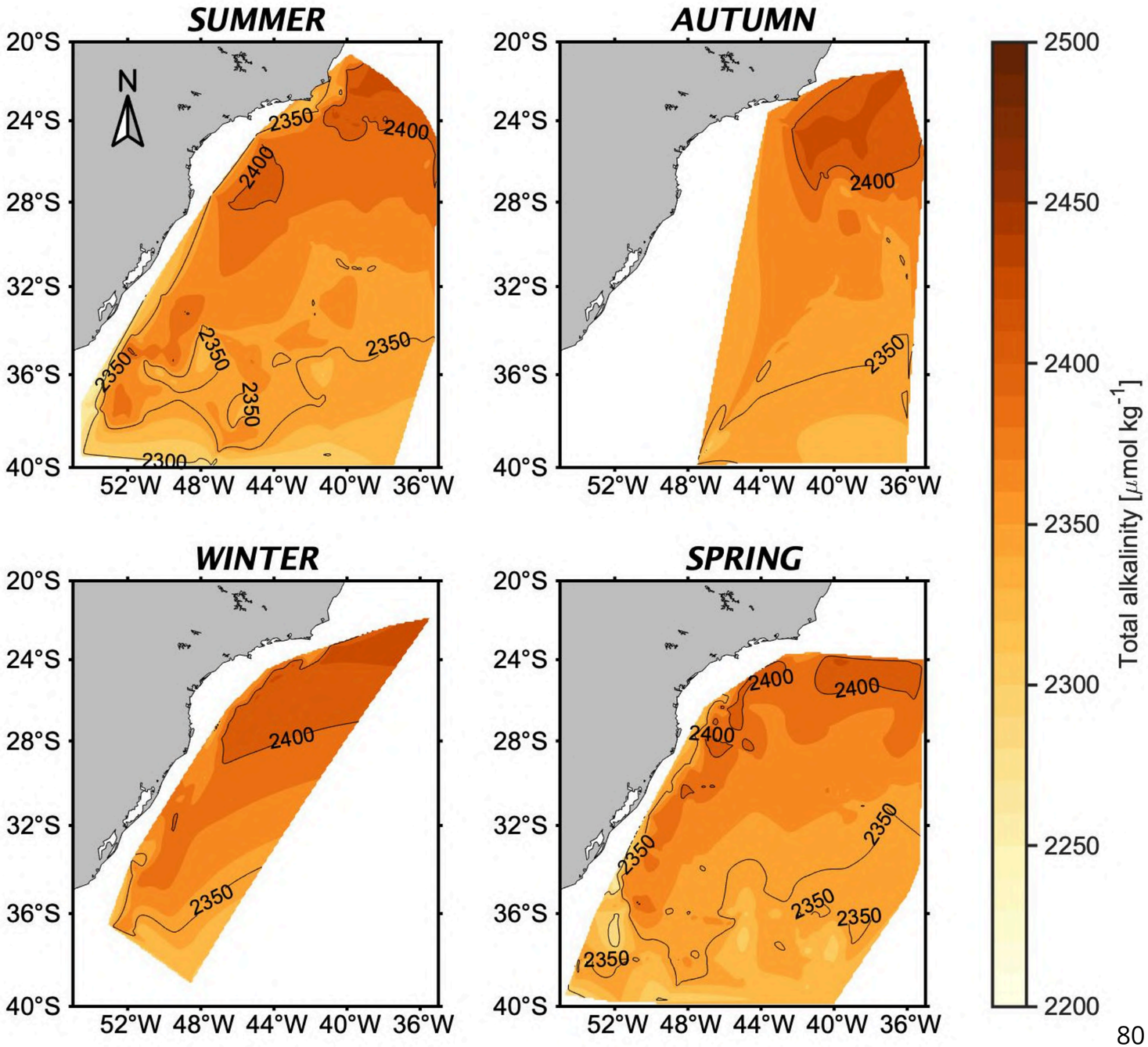
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 498
- Autumn = 182
- Winter = 72
- Spring = 551

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

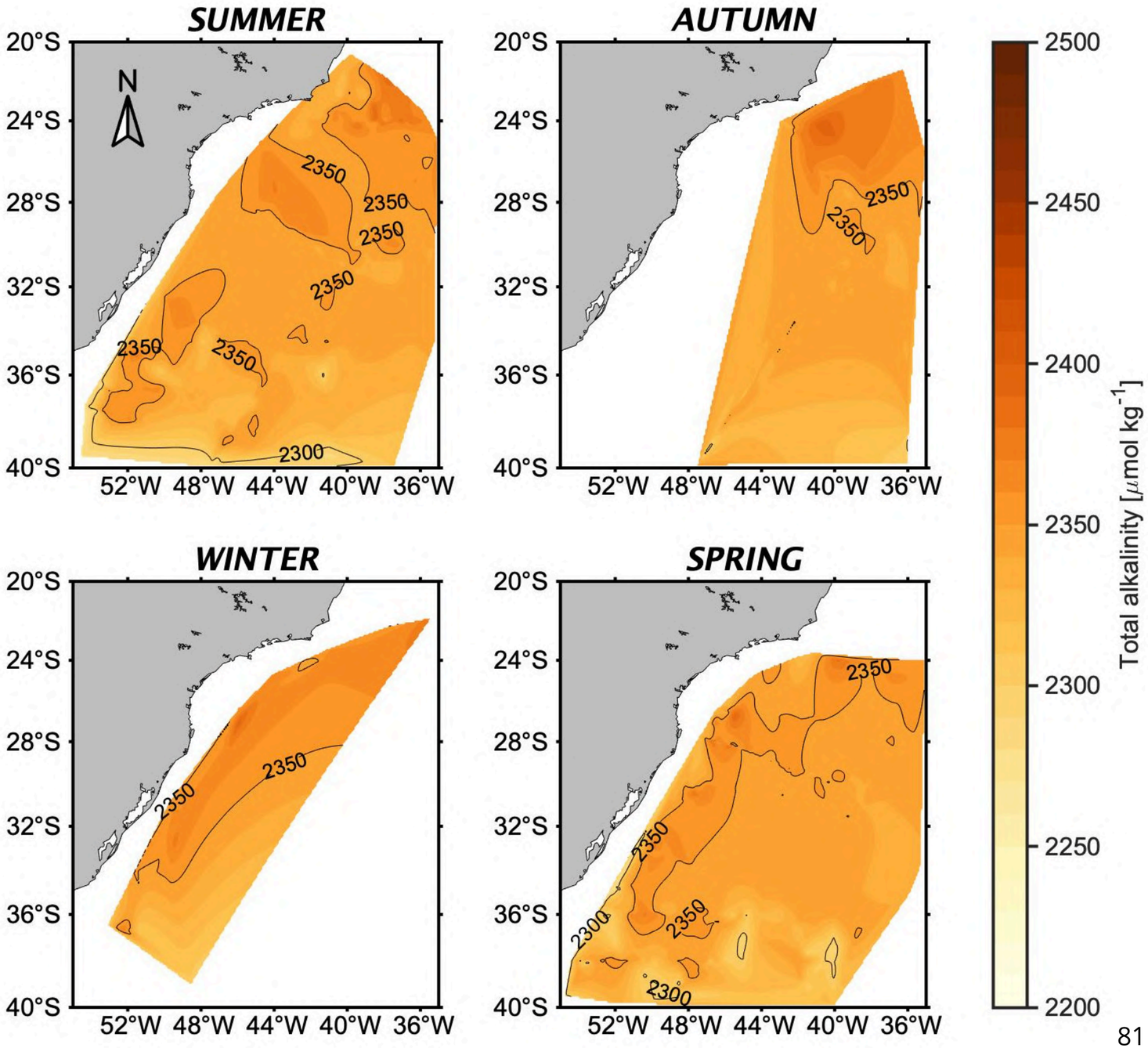
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

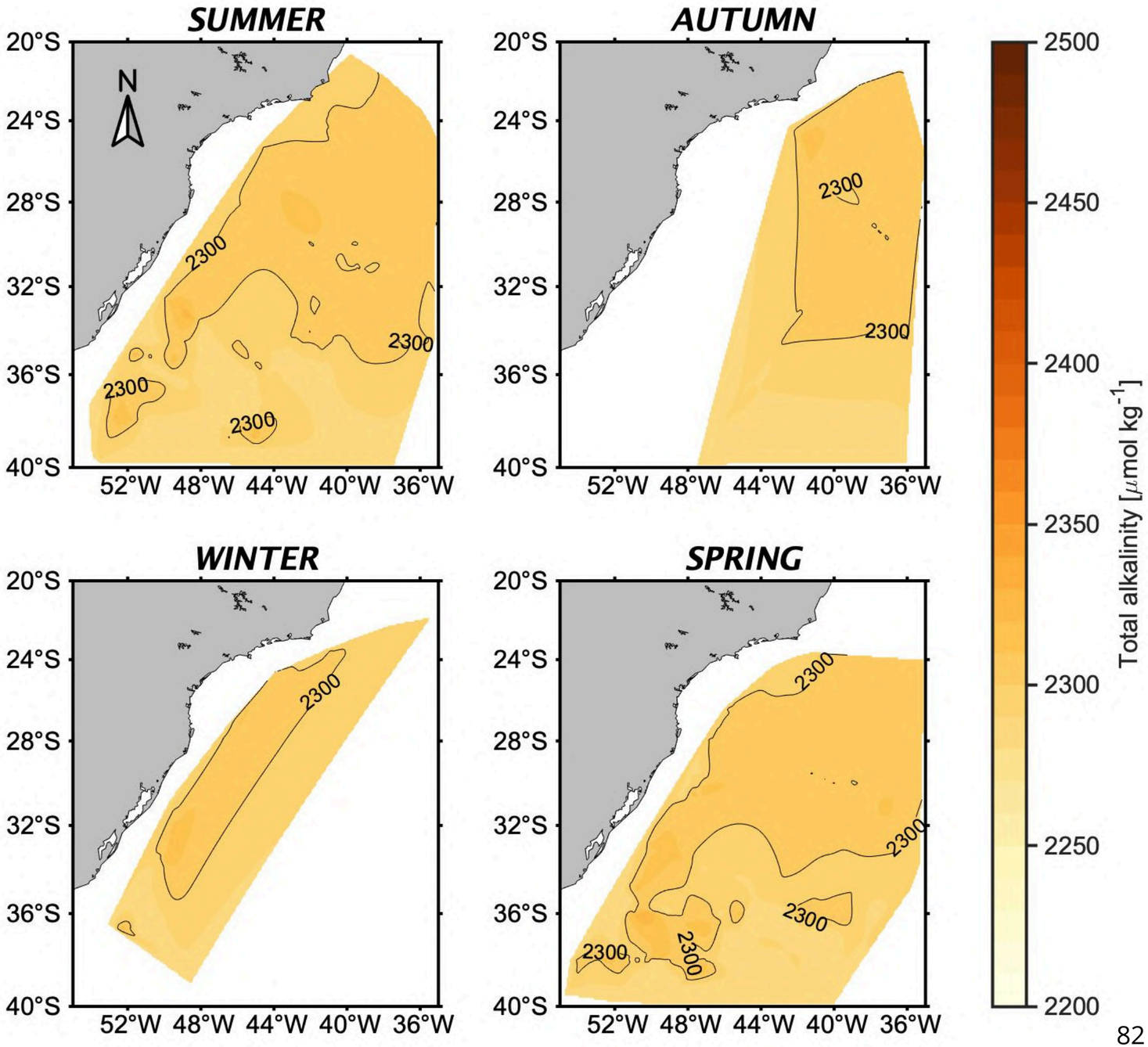
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

Total alkalinity* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

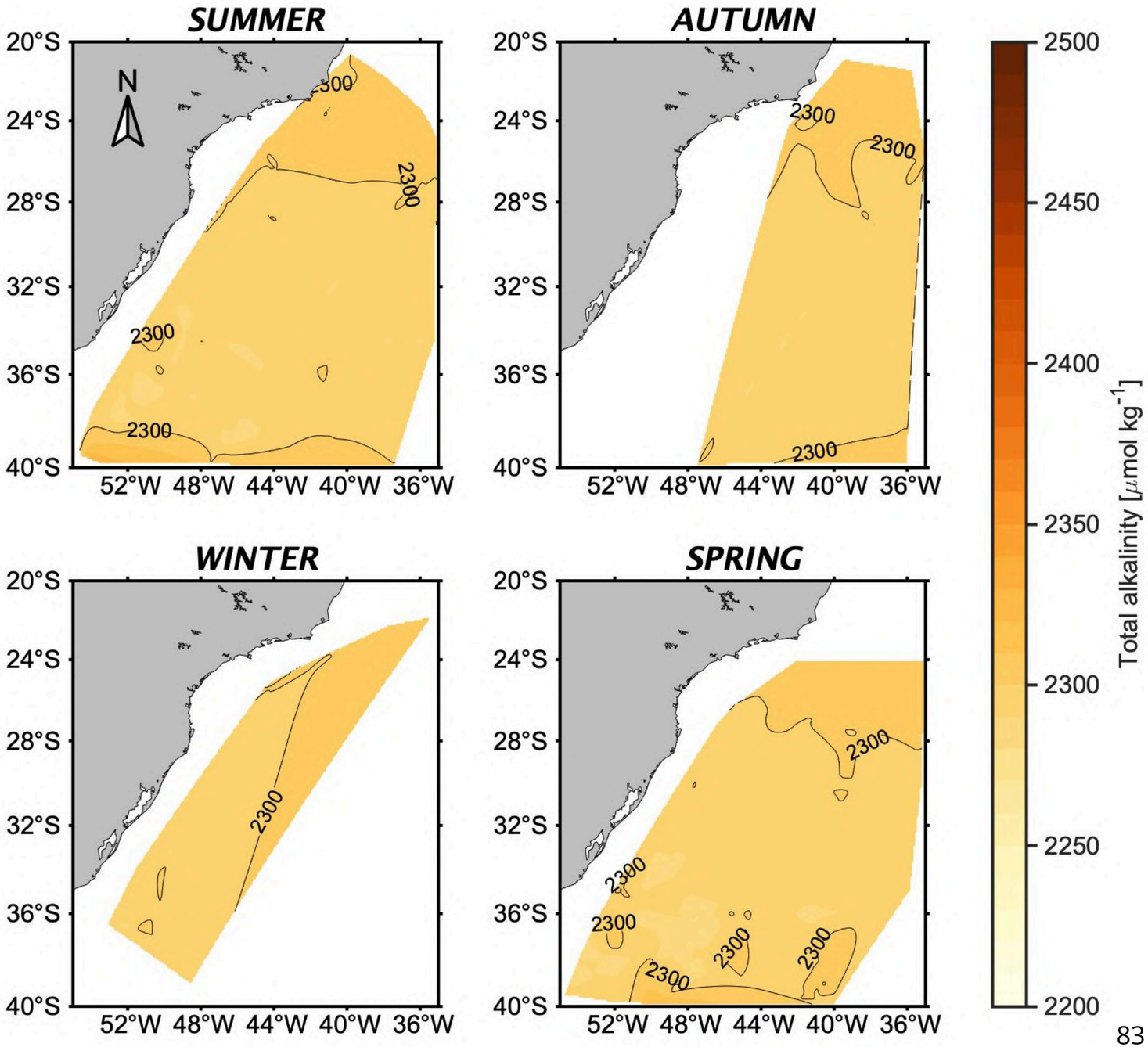
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

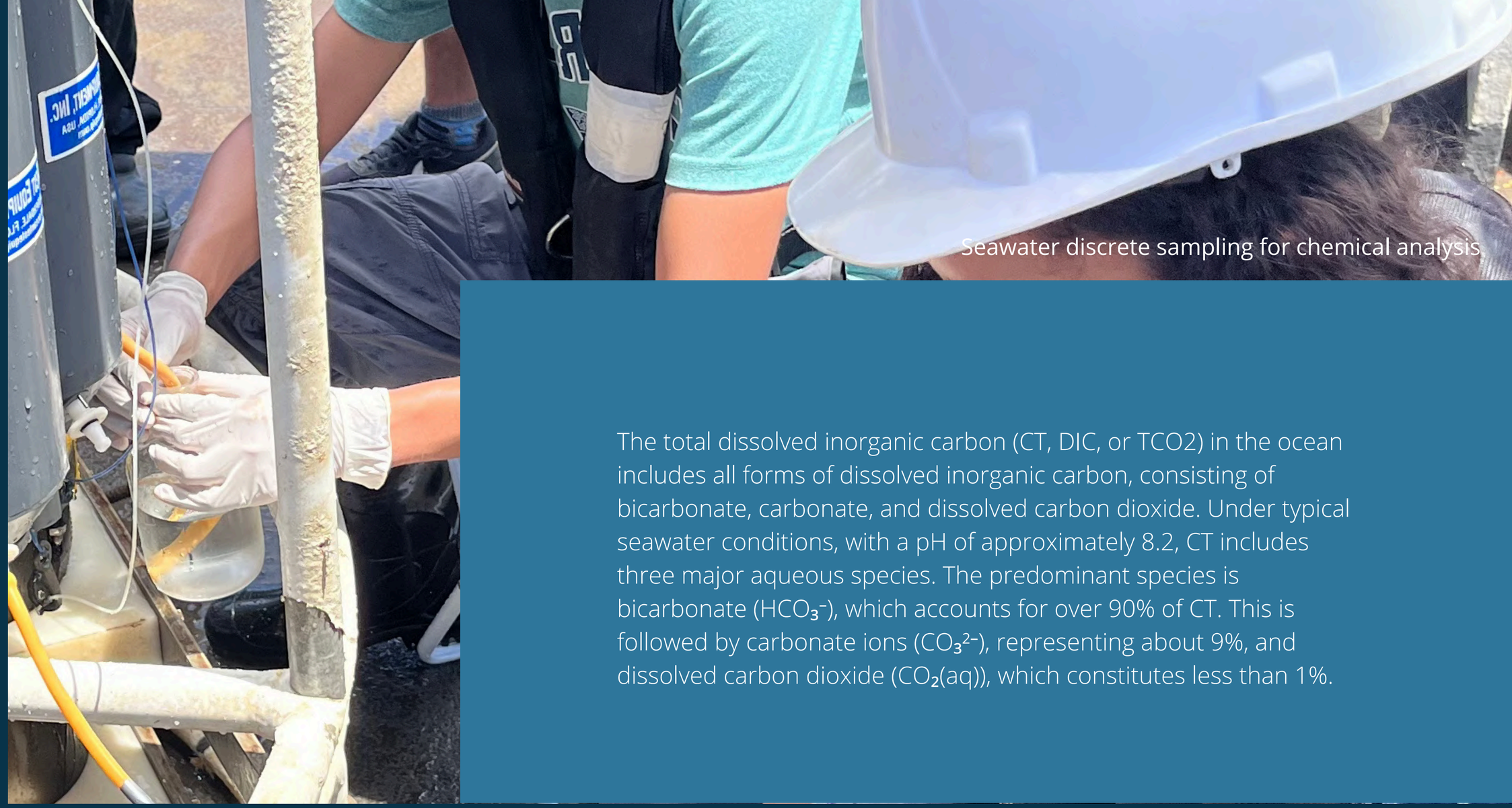
Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

04.6 Dissolved Inorganic Carbon



Seawater discrete sampling for chemical analysis

The total dissolved inorganic carbon (CT, DIC, or TCO2) in the ocean includes all forms of dissolved inorganic carbon, consisting of bicarbonate, carbonate, and dissolved carbon dioxide. Under typical seawater conditions, with a pH of approximately 8.2, CT includes three major aqueous species. The predominant species is bicarbonate (HCO_3^-), which accounts for over 90% of CT. This is followed by carbonate ions (CO_3^{2-}), representing about 9%, and dissolved carbon dioxide ($CO_2(aq)$), which constitutes less than 1%.

Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

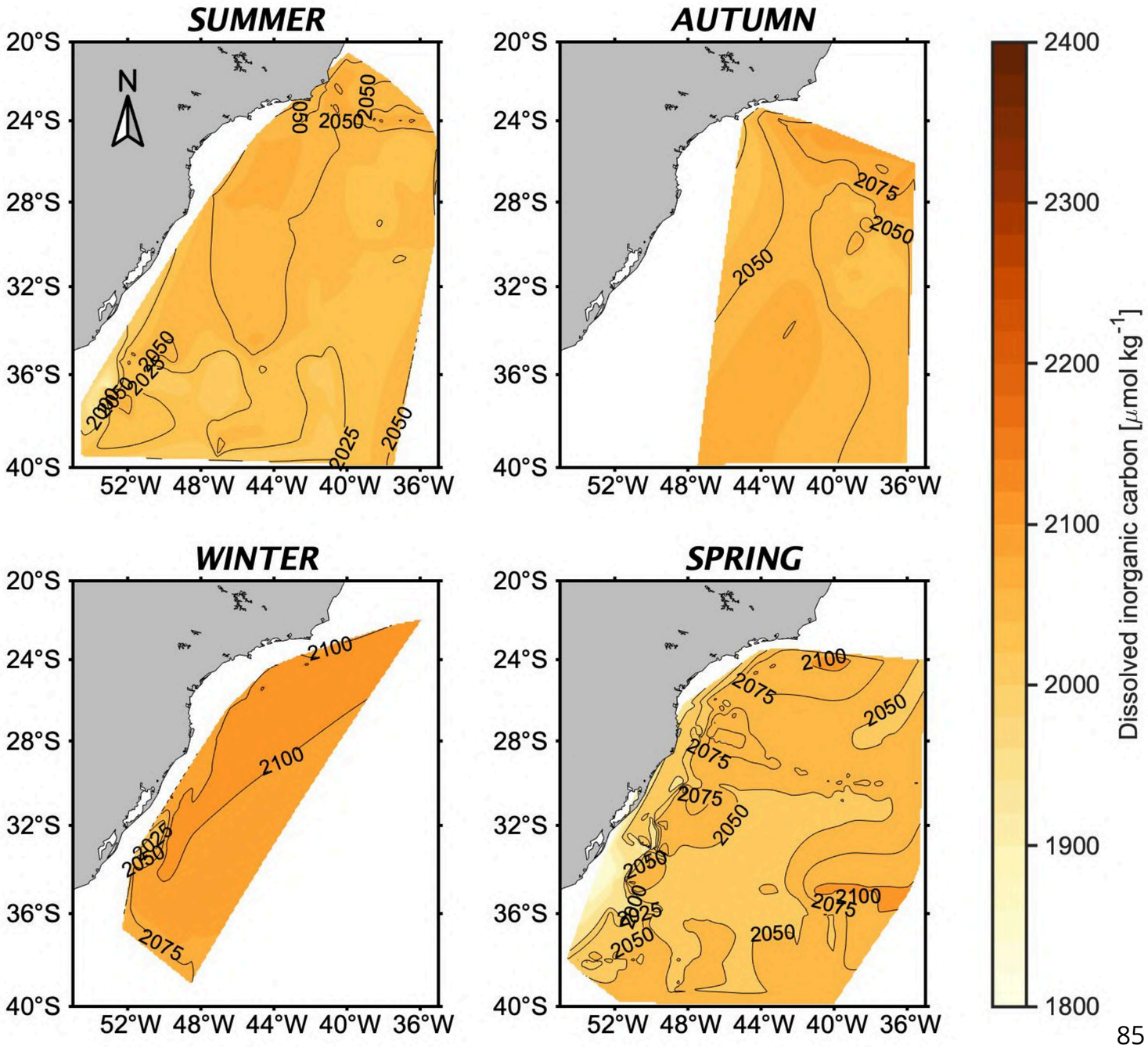
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 320
- Autumn = 123
- Winter = 63
- Spring = 450

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

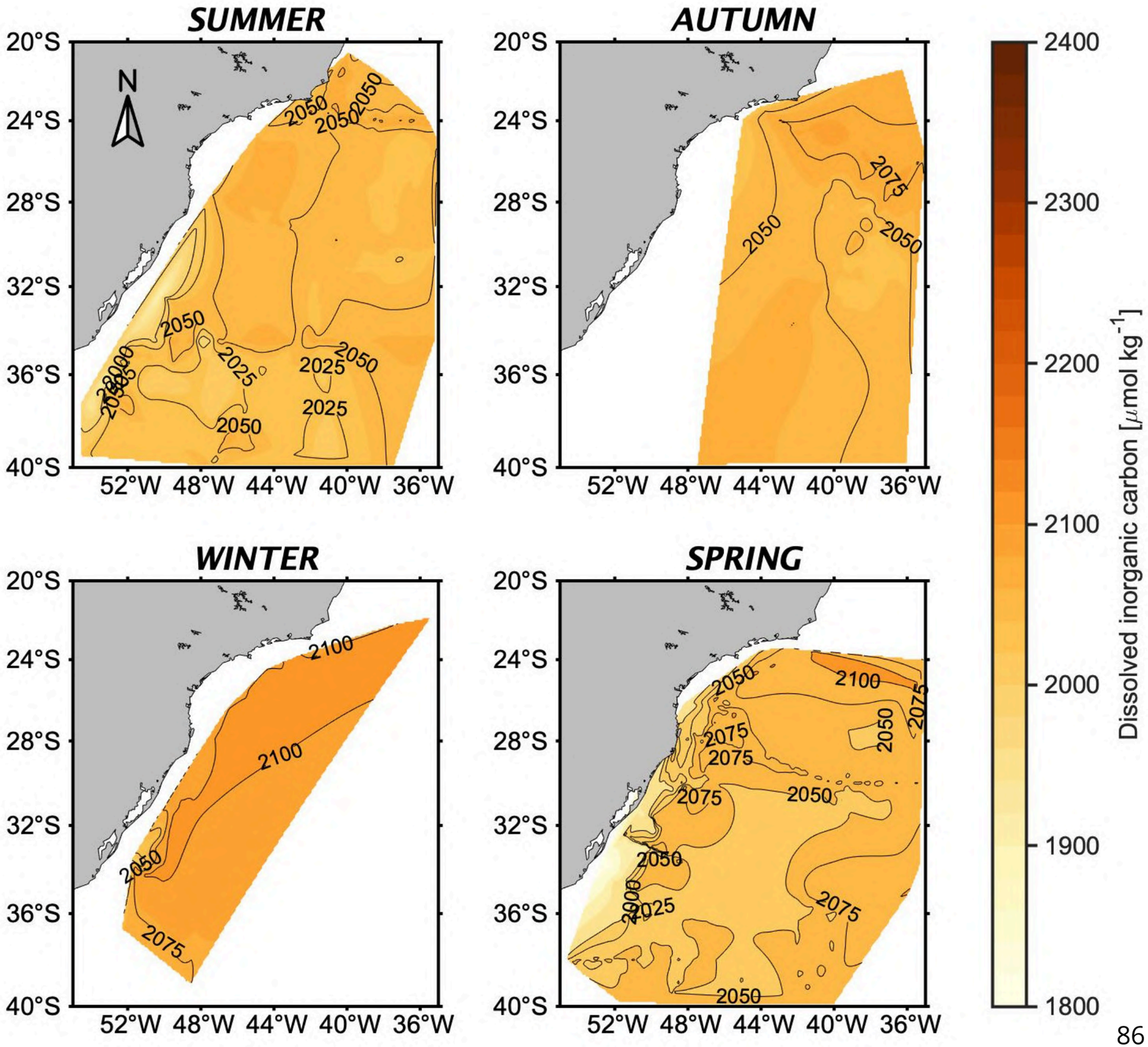
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 485
- Autumn = 176
- Winter = 70
- Spring = 518

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

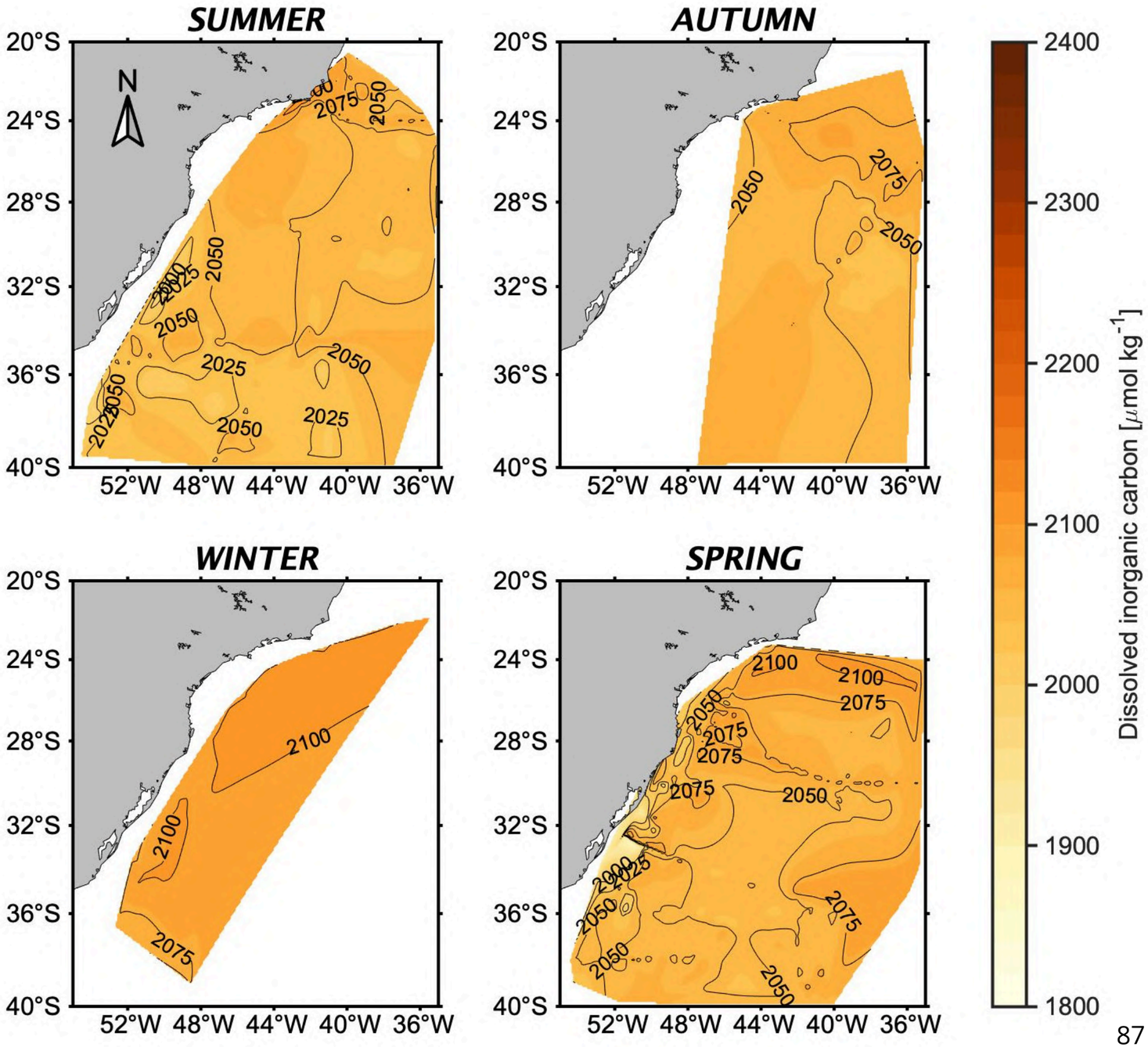
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 509
- Autumn = 182
- Winter = 71
- Spring = 553

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

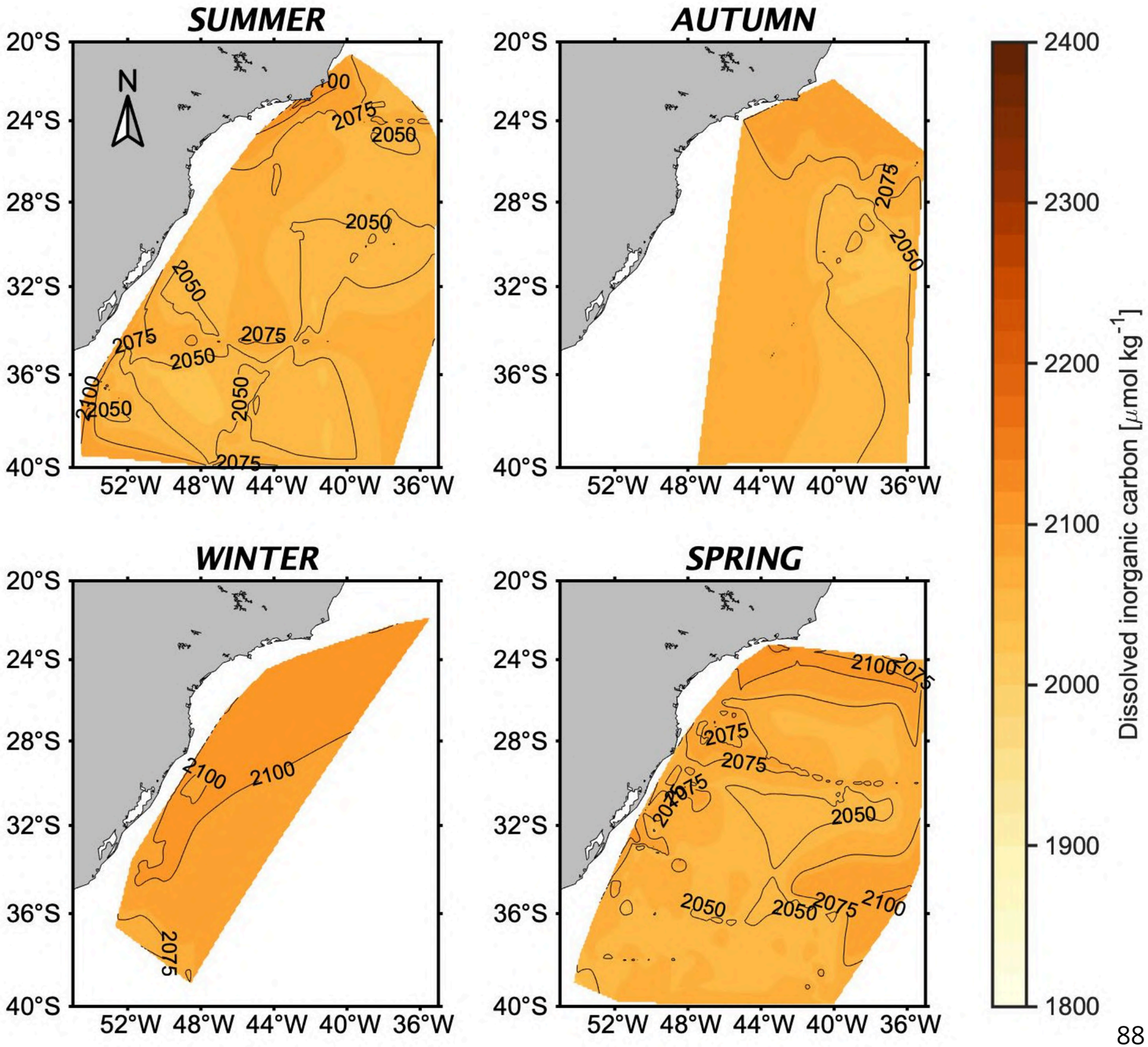
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 505
- Autumn = 180
- Winter = 71
- Spring = 554

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

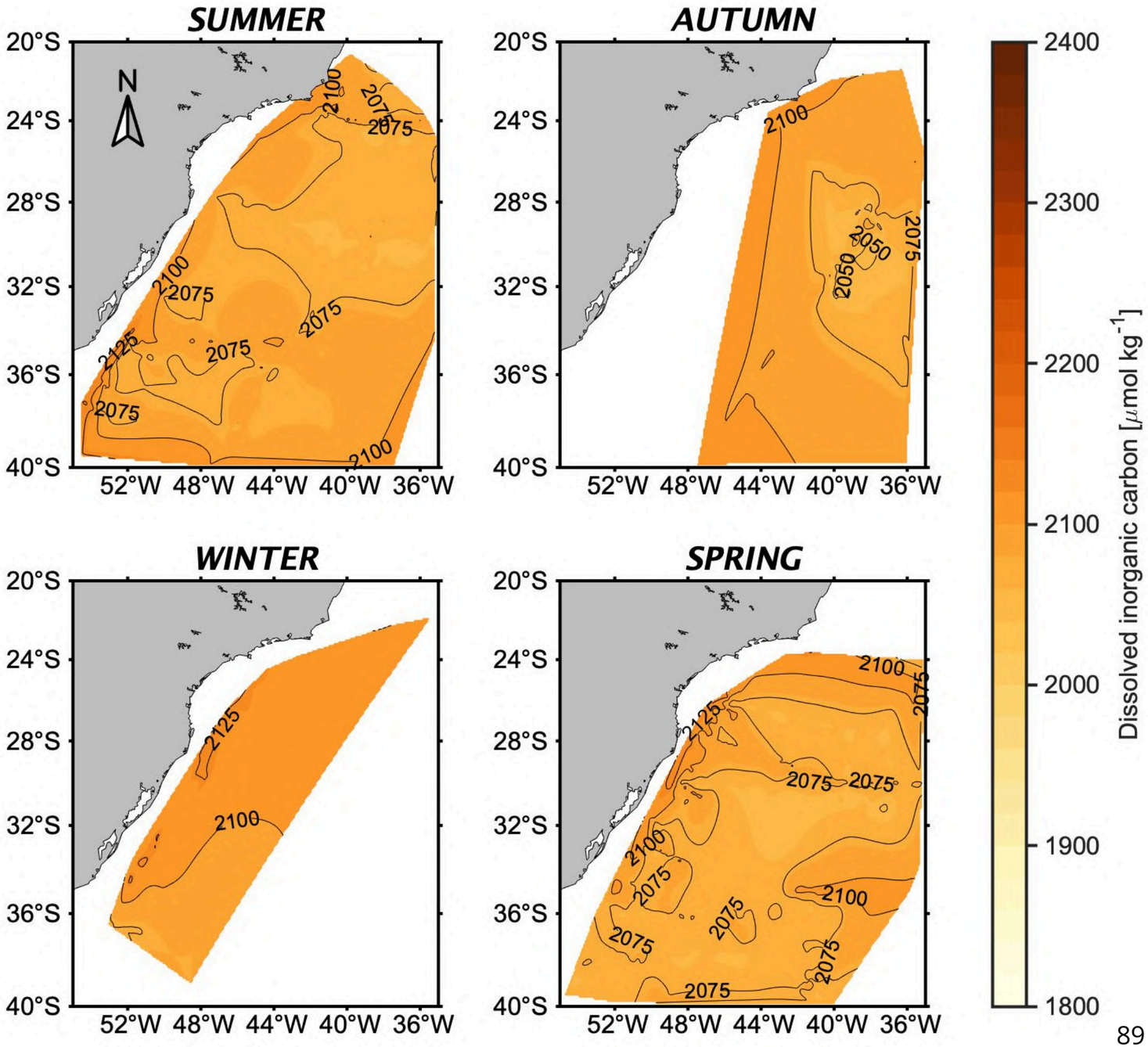
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 498
- Autumn = 182
- Winter = 72
- Spring = 551

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

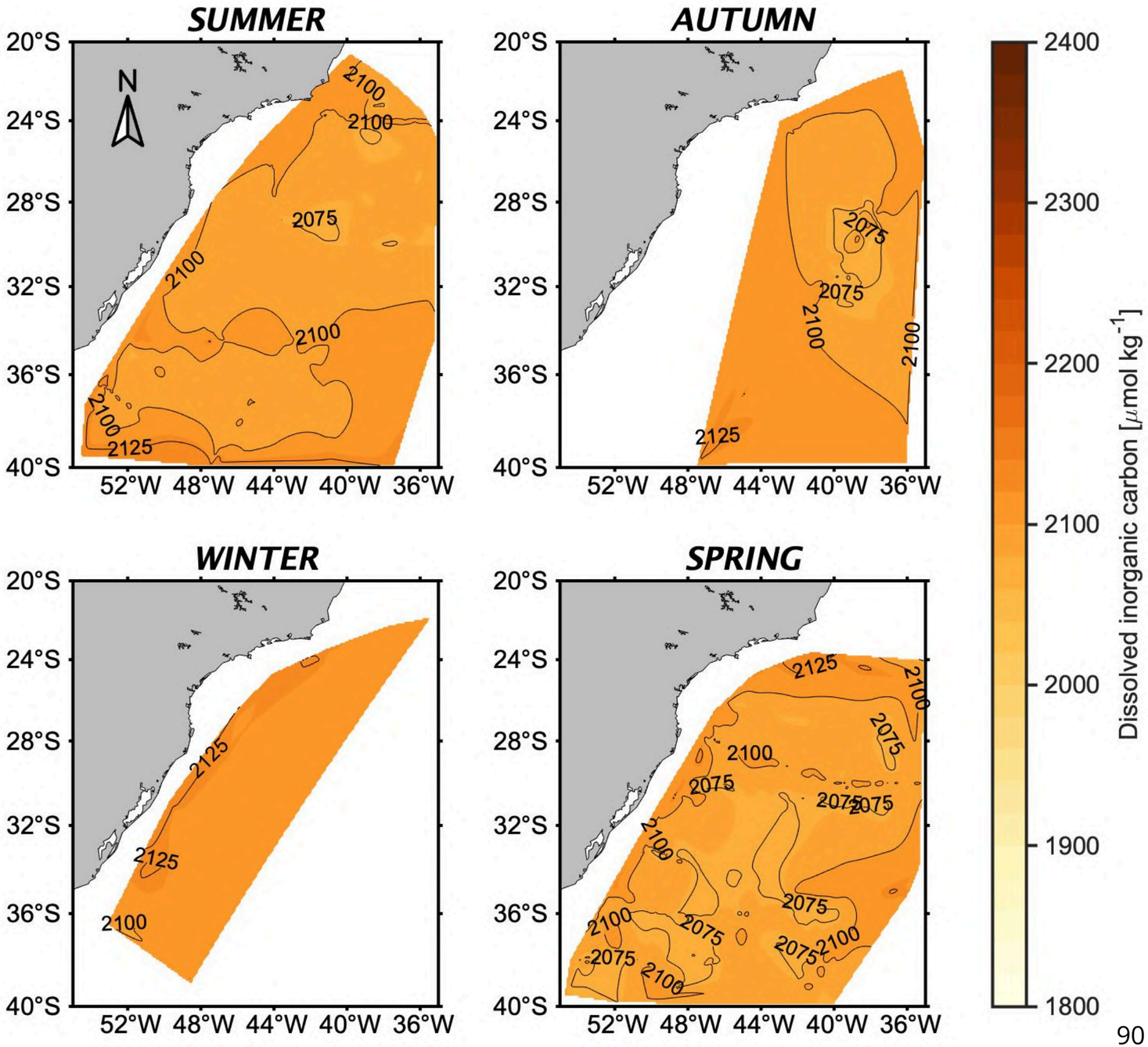
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

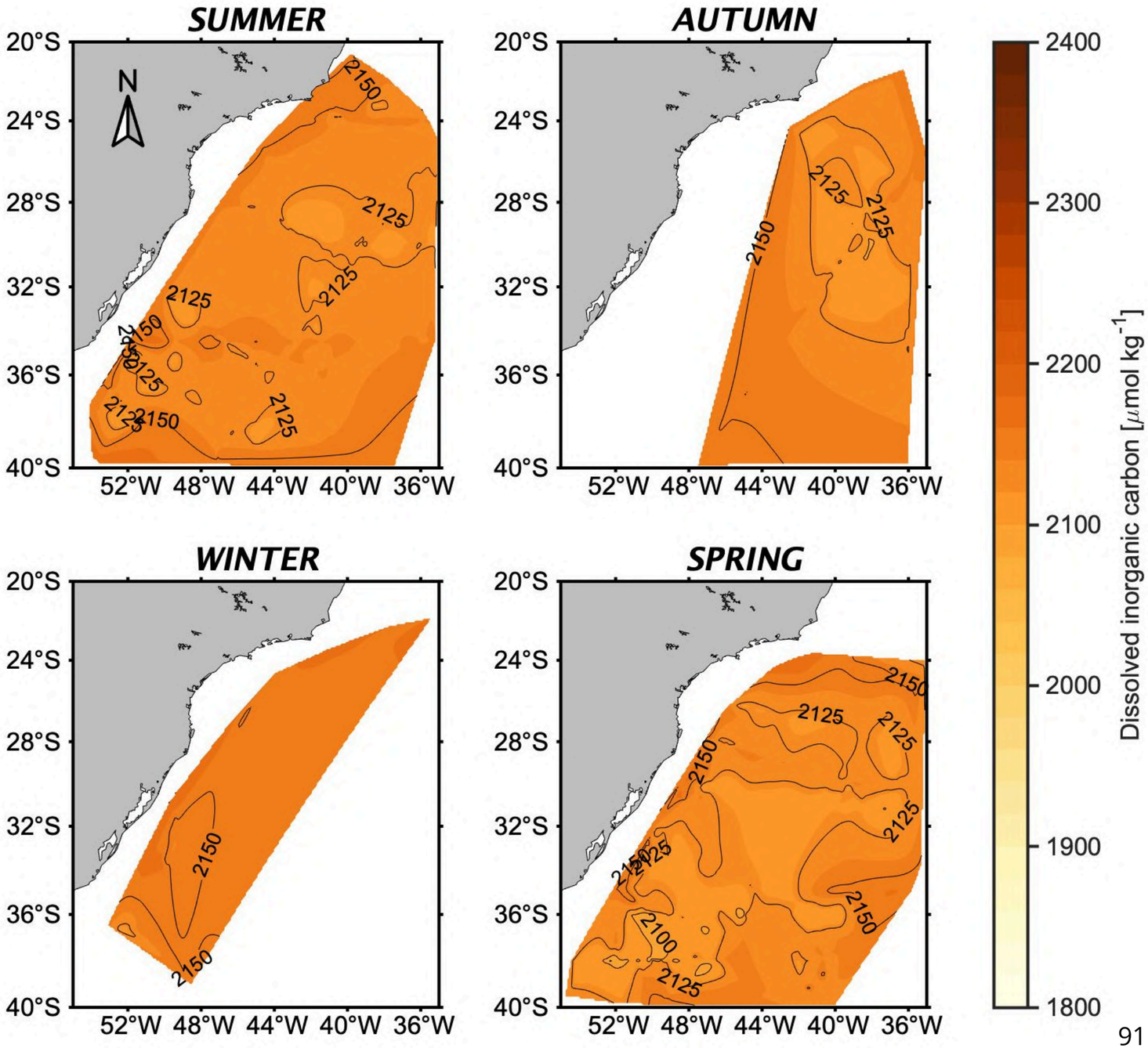
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Dissolved inorganic carbon* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

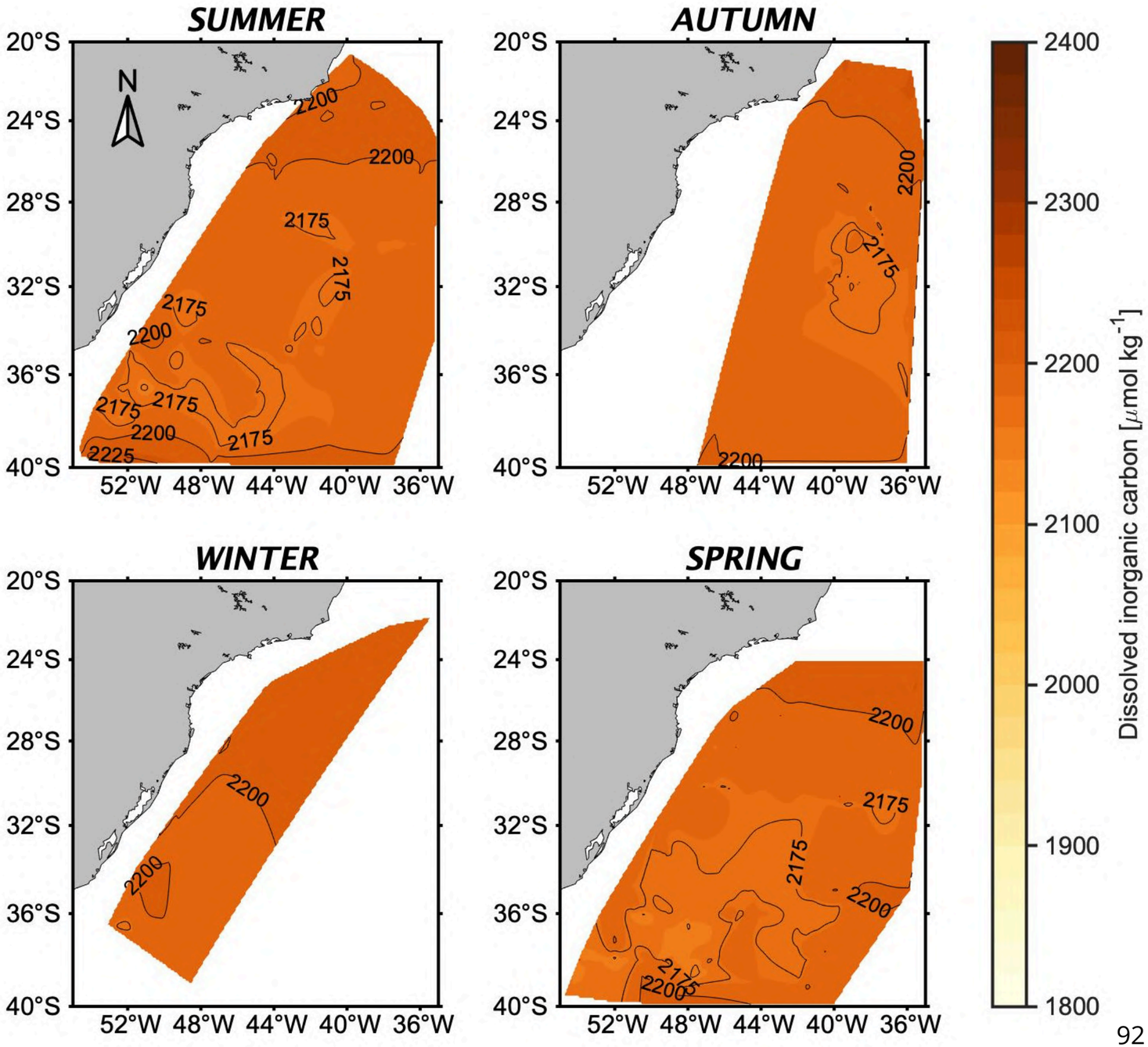
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



04.7 pH

Atlantic yellow-nosed albatross (*Thalassarche chlororhynchos*)

The pH exerts control over so many biogeochemical processes that it is often referred to as the "master" variable in aquatic systems. It expresses the degree of acidity or alkalinity of a solution and is defined as the negative logarithm of the molar concentration of H+ ions. Under natural conditions, the surface pH of ocean waters was around 8.2. Some studies show that the global ocean's pH has already decreased by 0.1 since the pre-industrial period (1750), increasing ocean acidity by 26%, reducing the concentration of carbonate ions, and lowering the saturation state of calcium carbonate minerals. Together, these changes are commonly referred to as the process of ocean acidification. Climate studies suggest that ocean pH could drop by another 0.3-0.4 units by 2100 if drastic changes are not made to our way of life. This represents a significant impact on calcifying organisms, such as certain types of algae, corals, plankton, and mollusks.

pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

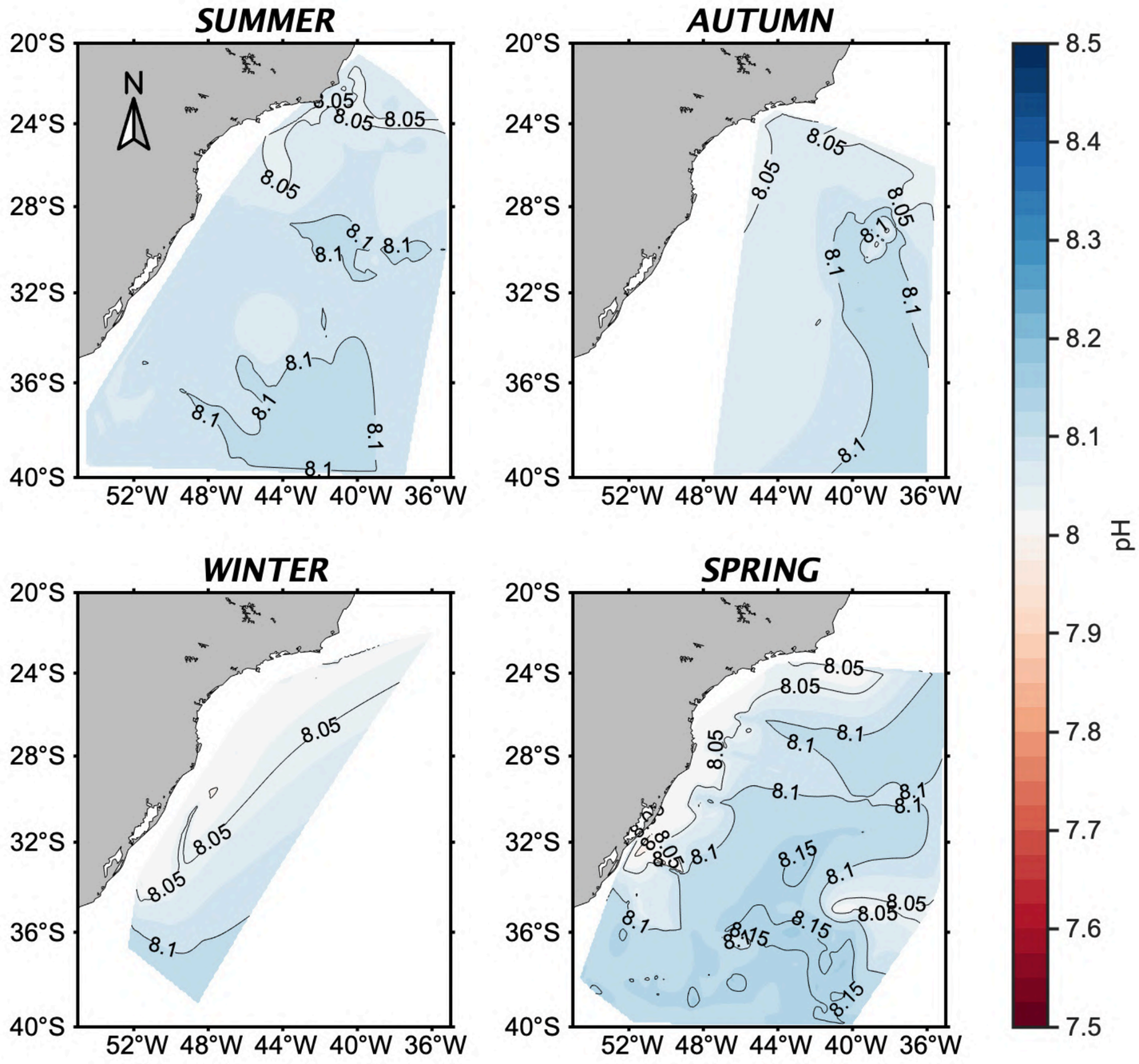
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 320
- Autumn = 123
- Winter = 63
- Spring = 450

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

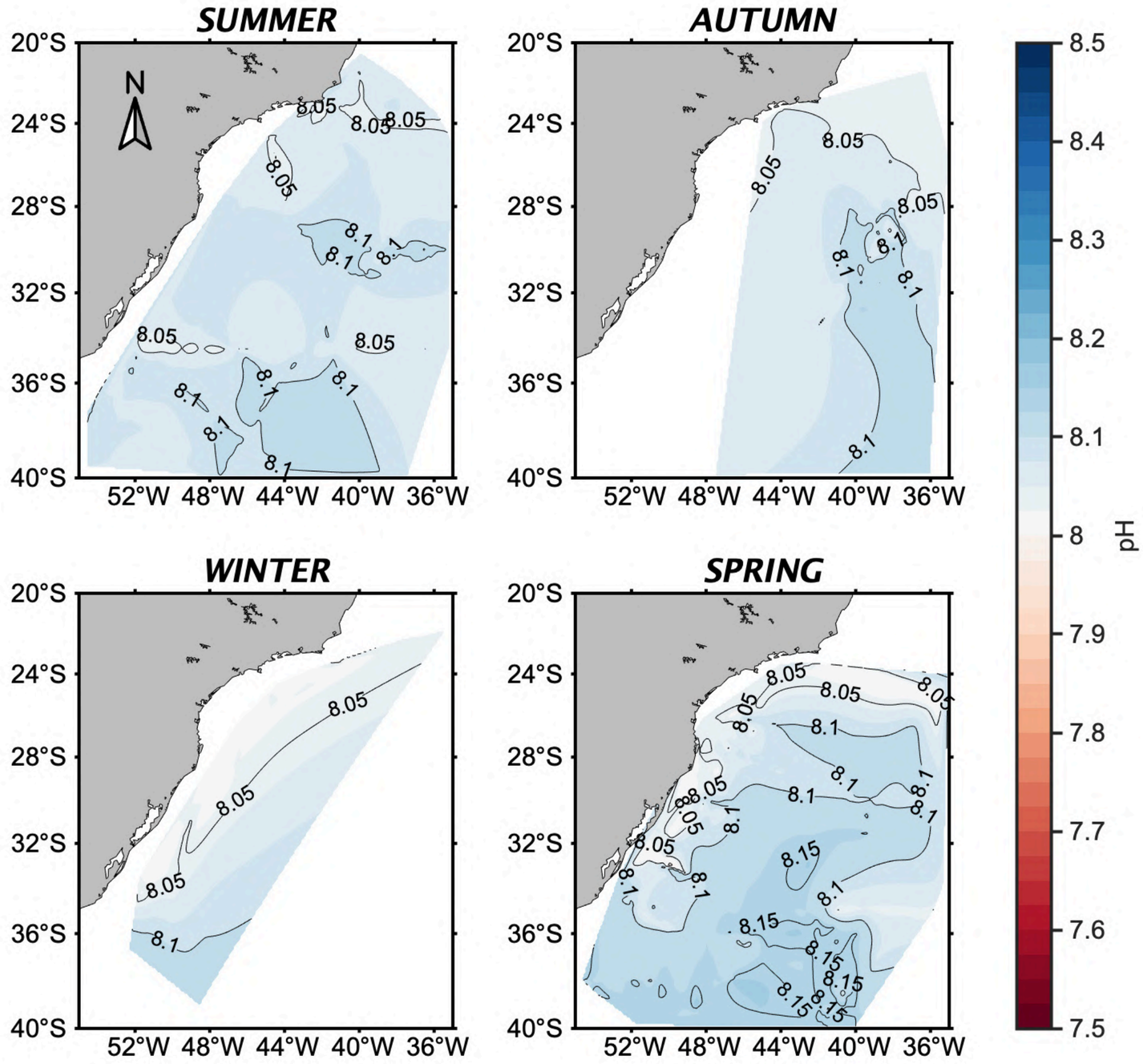
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 485
- Autumn = 176
- Winter = 70
- Spring = 518

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

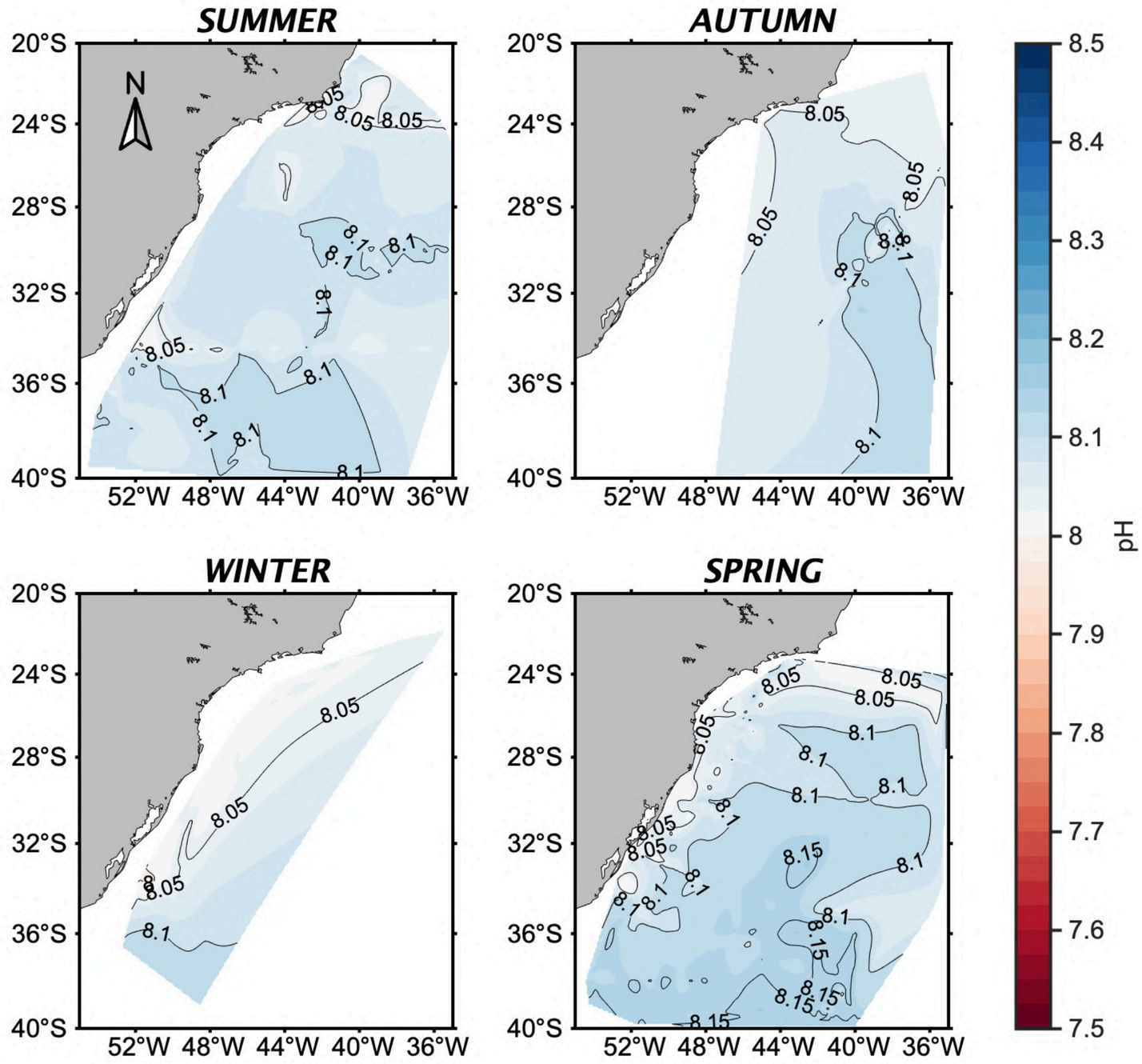
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 509
- Autumn = 182
- Winter = 71
- Spring = 553

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

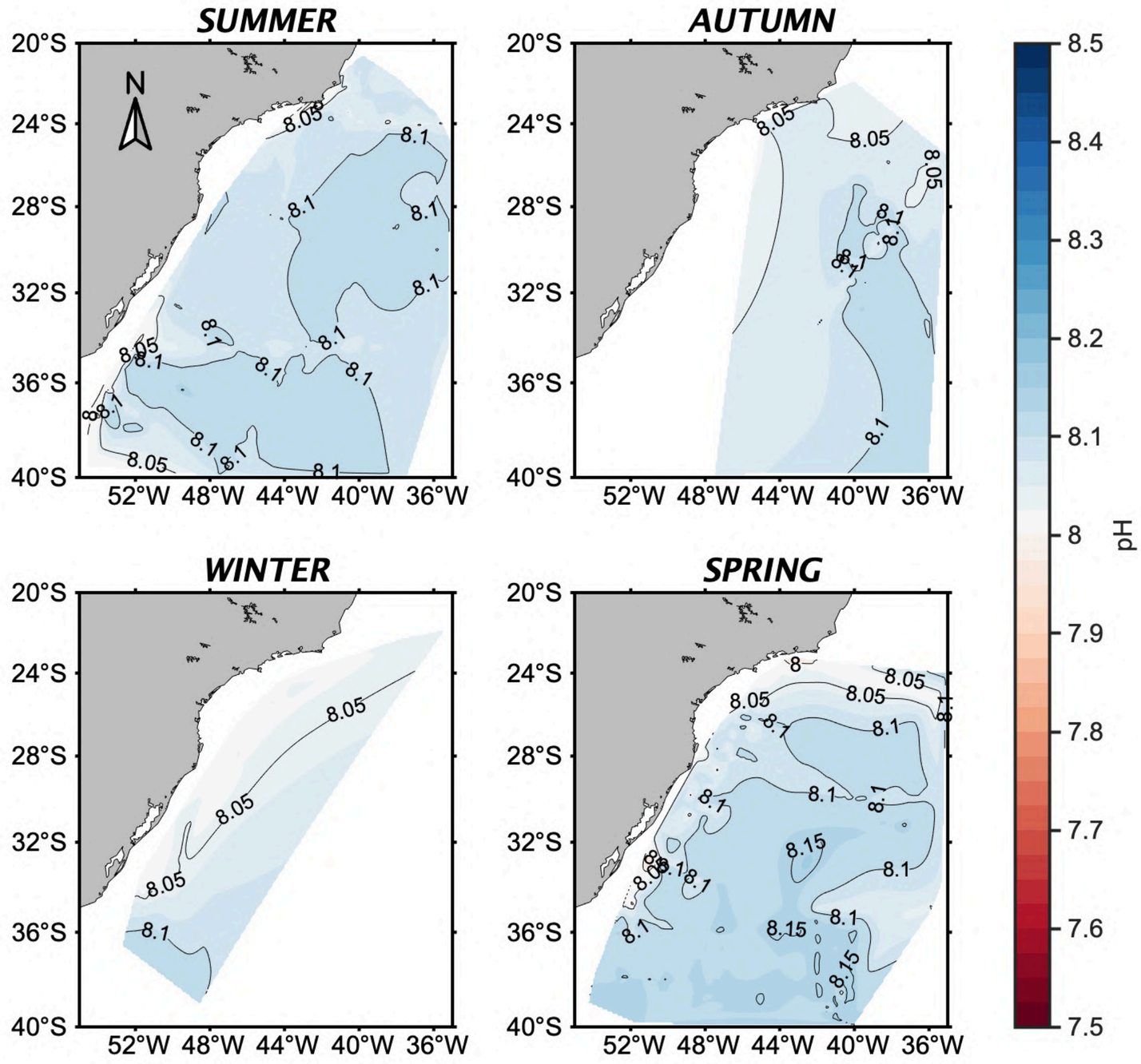
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 505
- Autumn = 180
- Winter = 71
- Spring = 554

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

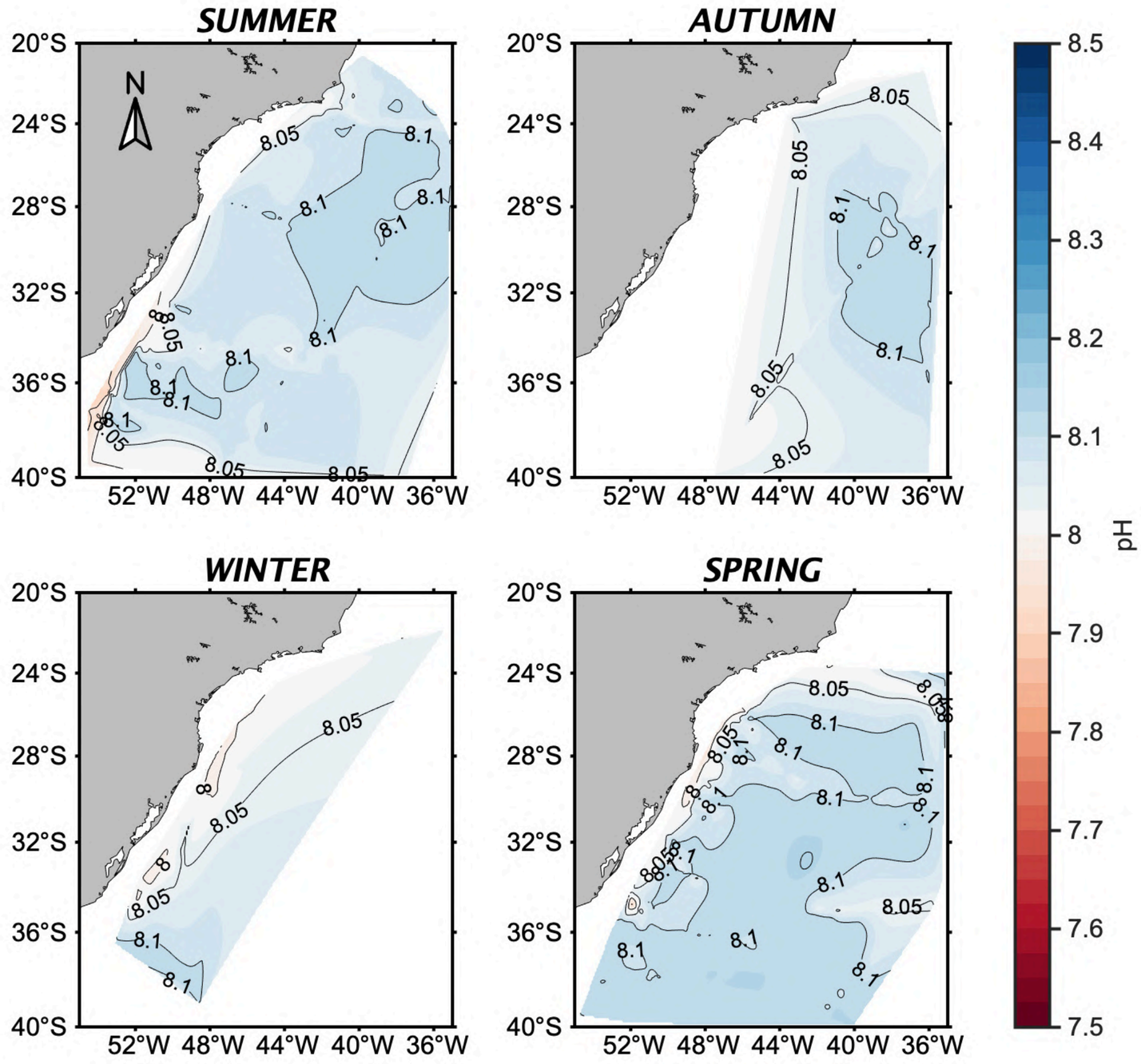
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 498
- Autumn = 182
- Winter = 72
- Spring = 551

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

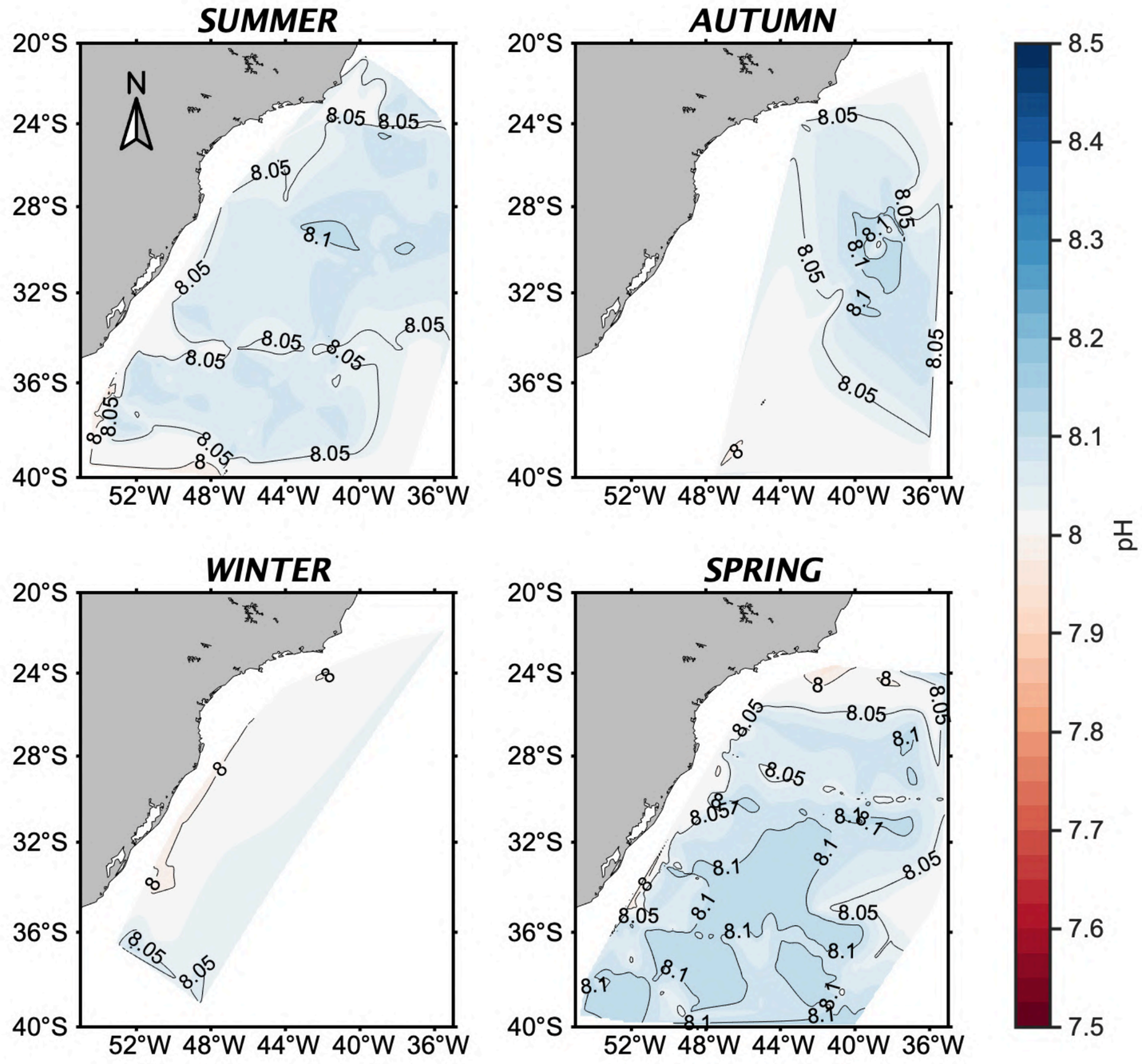
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

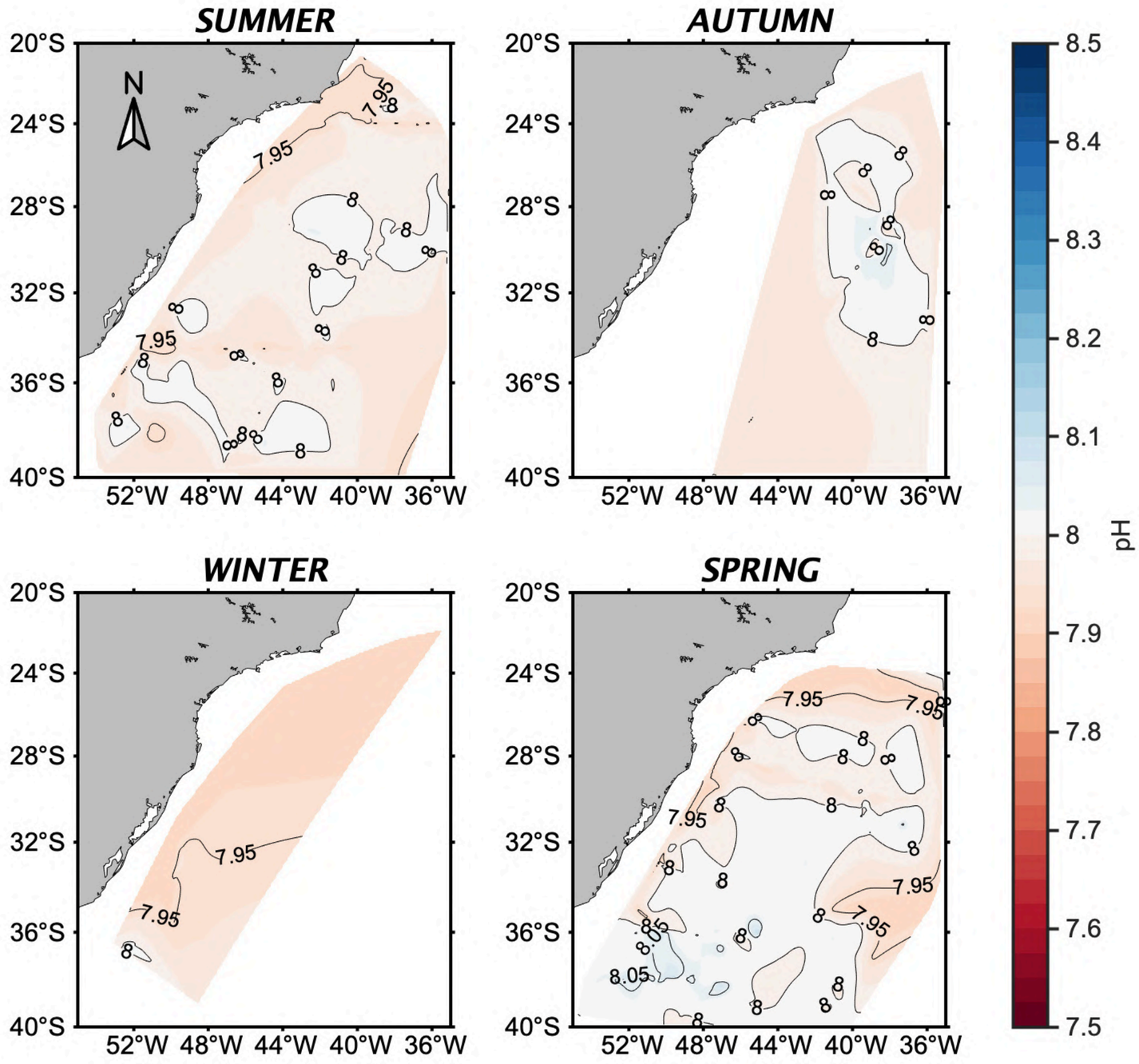
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



pH* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

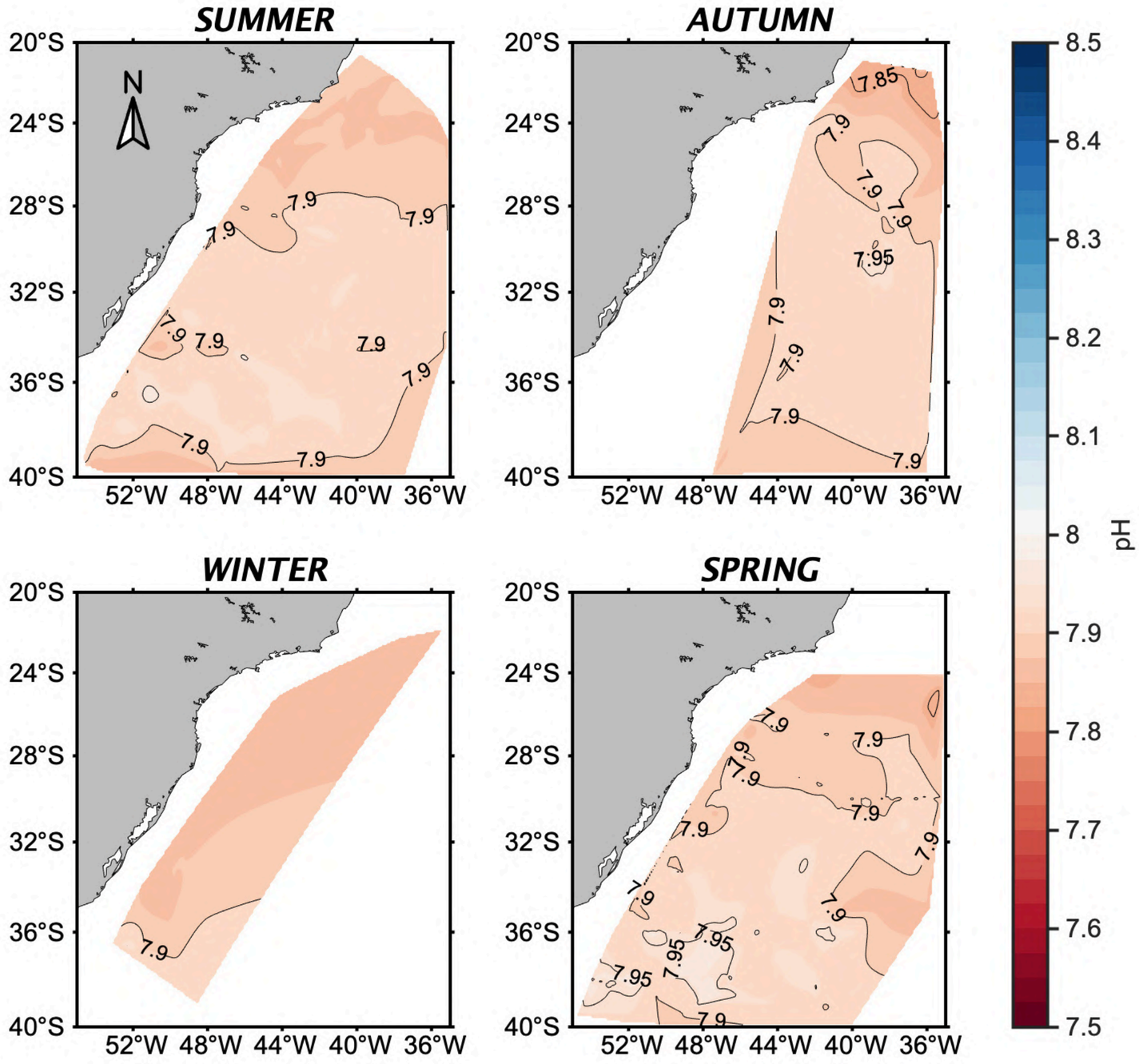
Interpolation method = triangulation-based natural neighbor interpolation

Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

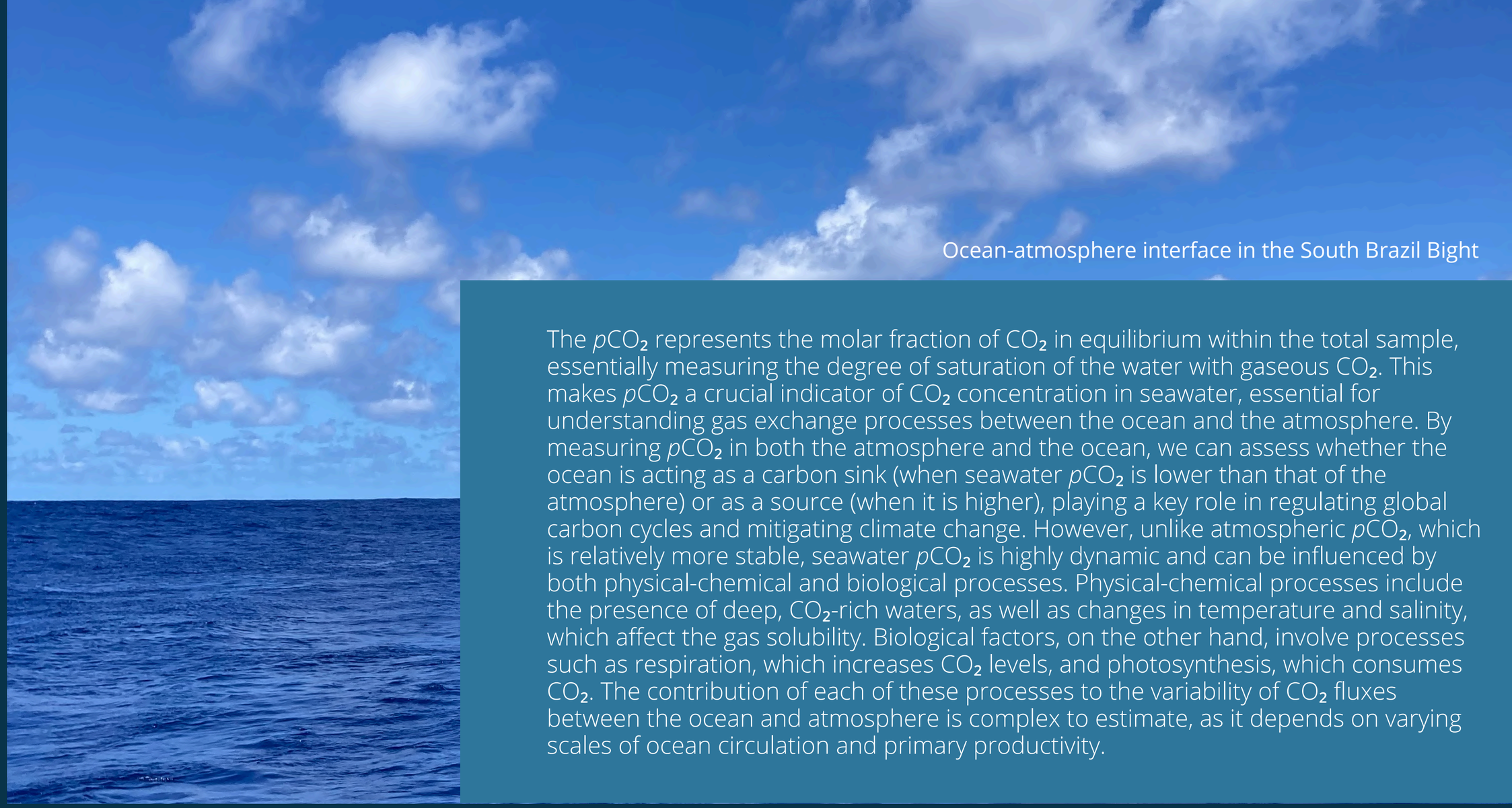
Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar



*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328

04.8 Partial Pressure of CO_2 (pCO_2)



Ocean-atmosphere interface in the South Brazil Bight

The pCO_2 represents the molar fraction of CO_2 in equilibrium within the total sample, essentially measuring the degree of saturation of the water with gaseous CO_2. This makes pCO_2 a crucial indicator of CO_2 concentration in seawater, essential for understanding gas exchange processes between the ocean and the atmosphere. By measuring pCO_2 in both the atmosphere and the ocean, we can assess whether the ocean is acting as a carbon sink (when seawater pCO_2 is lower than that of the atmosphere) or as a source (when it is higher), playing a key role in regulating global carbon cycles and mitigating climate change. However, unlike atmospheric pCO_2, which is relatively more stable, seawater pCO_2 is highly dynamic and can be influenced by both physical-chemical and biological processes. Physical-chemical processes include the presence of deep, CO_2-rich waters, as well as changes in temperature and salinity, which affect the gas solubility. Biological factors, on the other hand, involve processes such as respiration, which increases CO_2 levels, and photosynthesis, which consumes CO_2. The contribution of each of these processes to the variability of CO_2 fluxes between the ocean and atmosphere is complex to estimate, as it depends on varying scales of ocean circulation and primary productivity.

Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

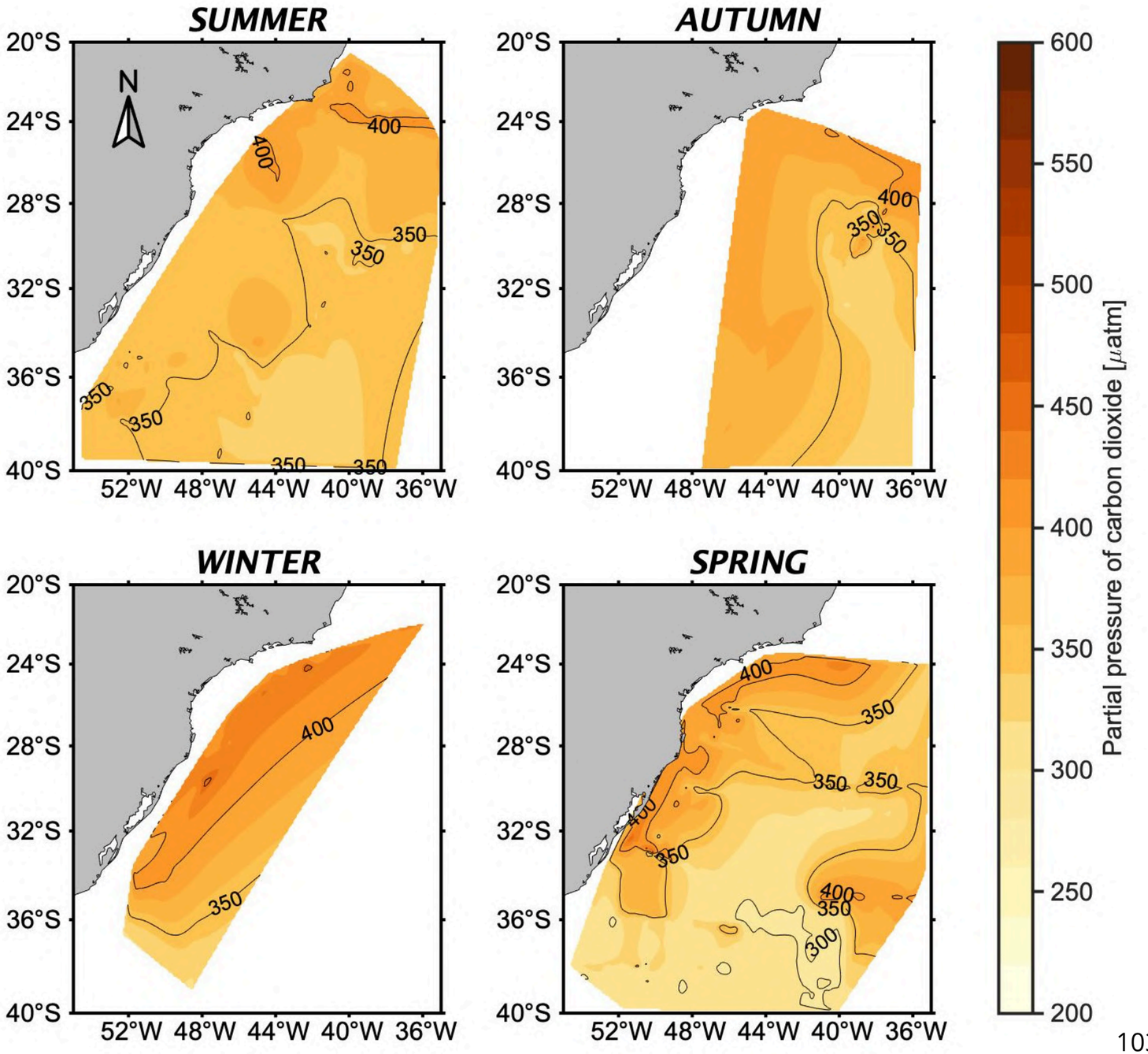
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 320
- Autumn = 123
- Winter = 63
- Spring = 450

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 5 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

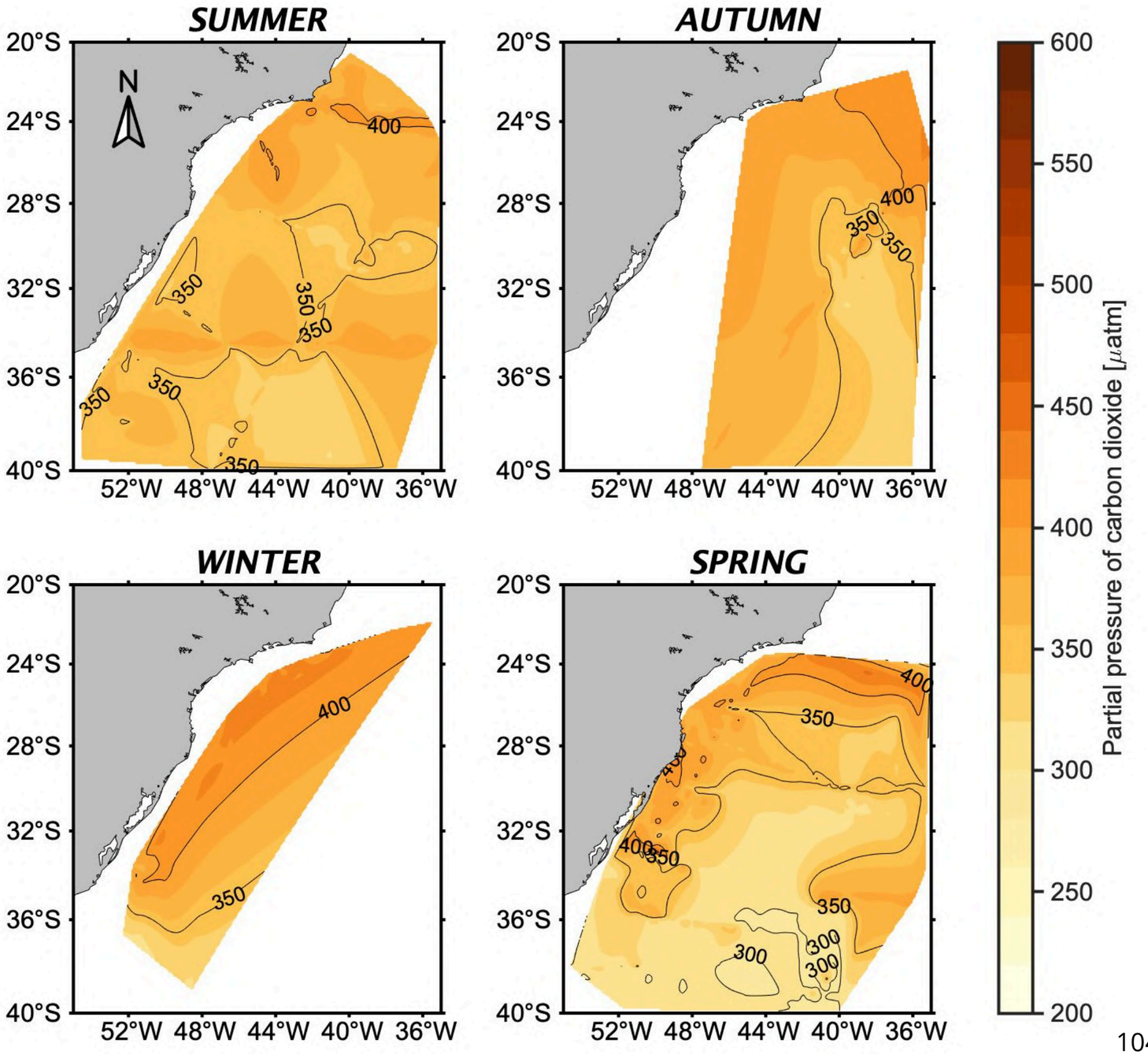
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 485
- Autumn = 176
- Winter = 70
- Spring = 518

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 10 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

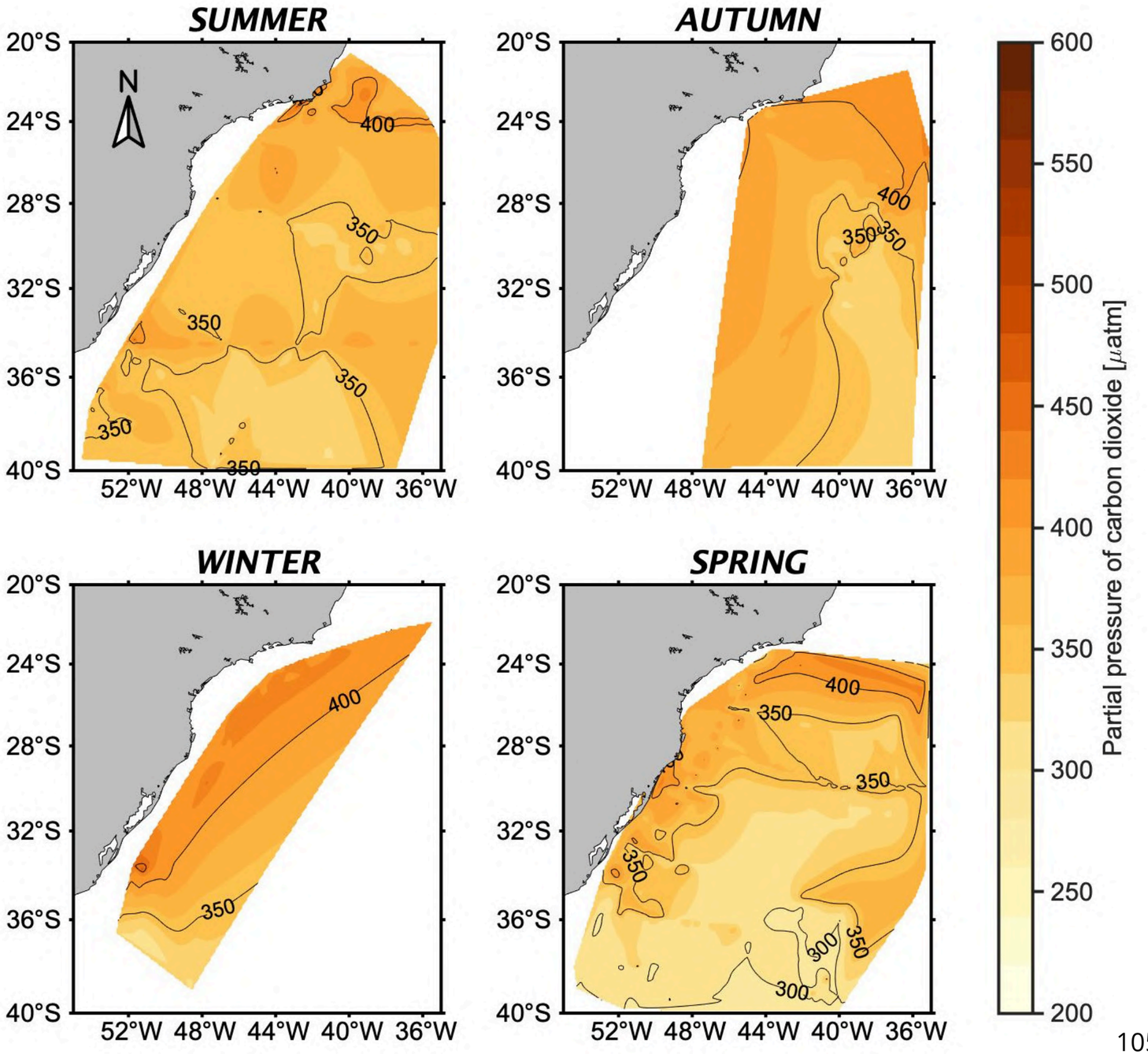
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 509
- Autumn = 182
- Winter = 71
- Spring = 553

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 25 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

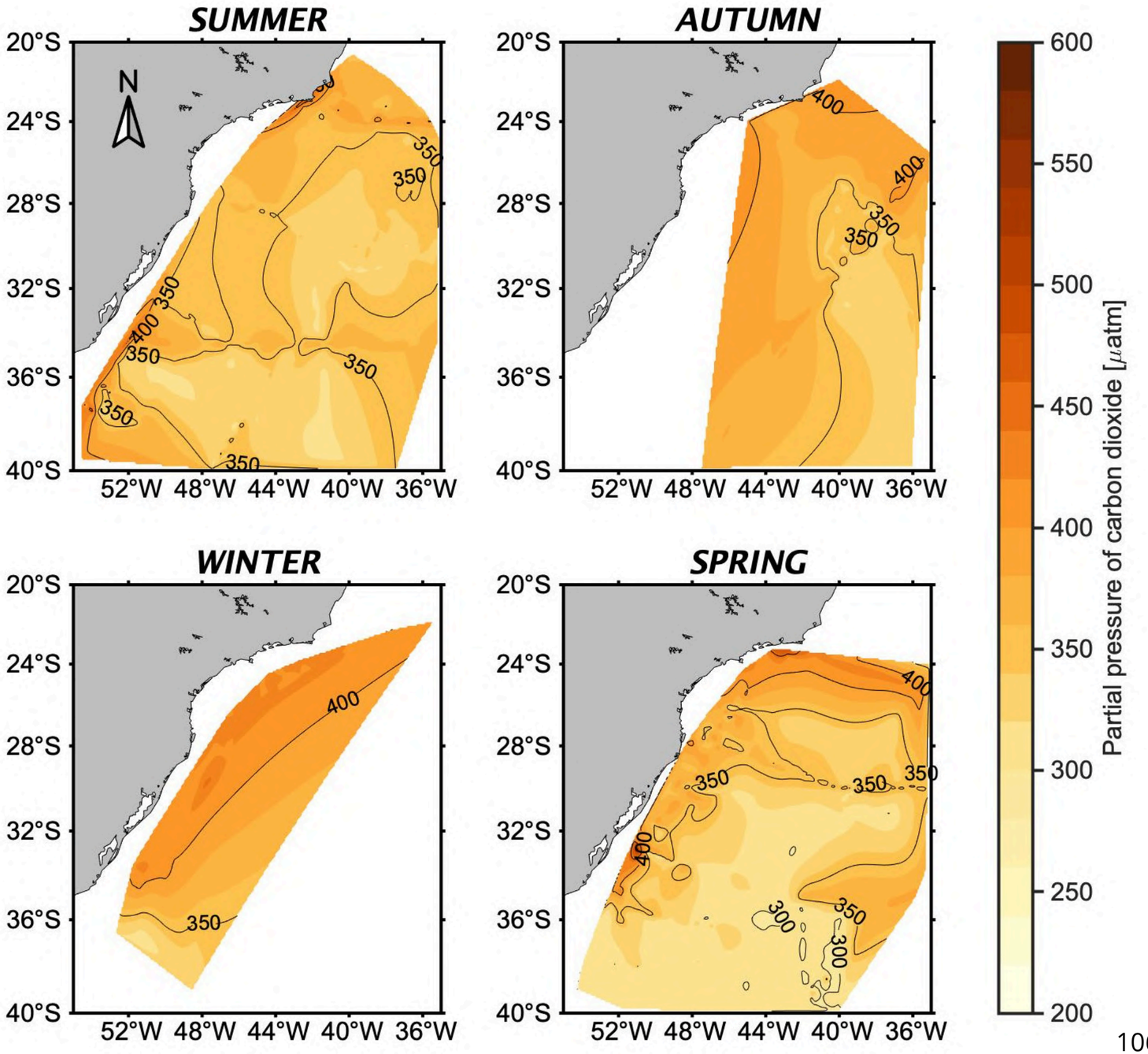
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 505
- Autumn = 180
- Winter = 71
- Spring = 554

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

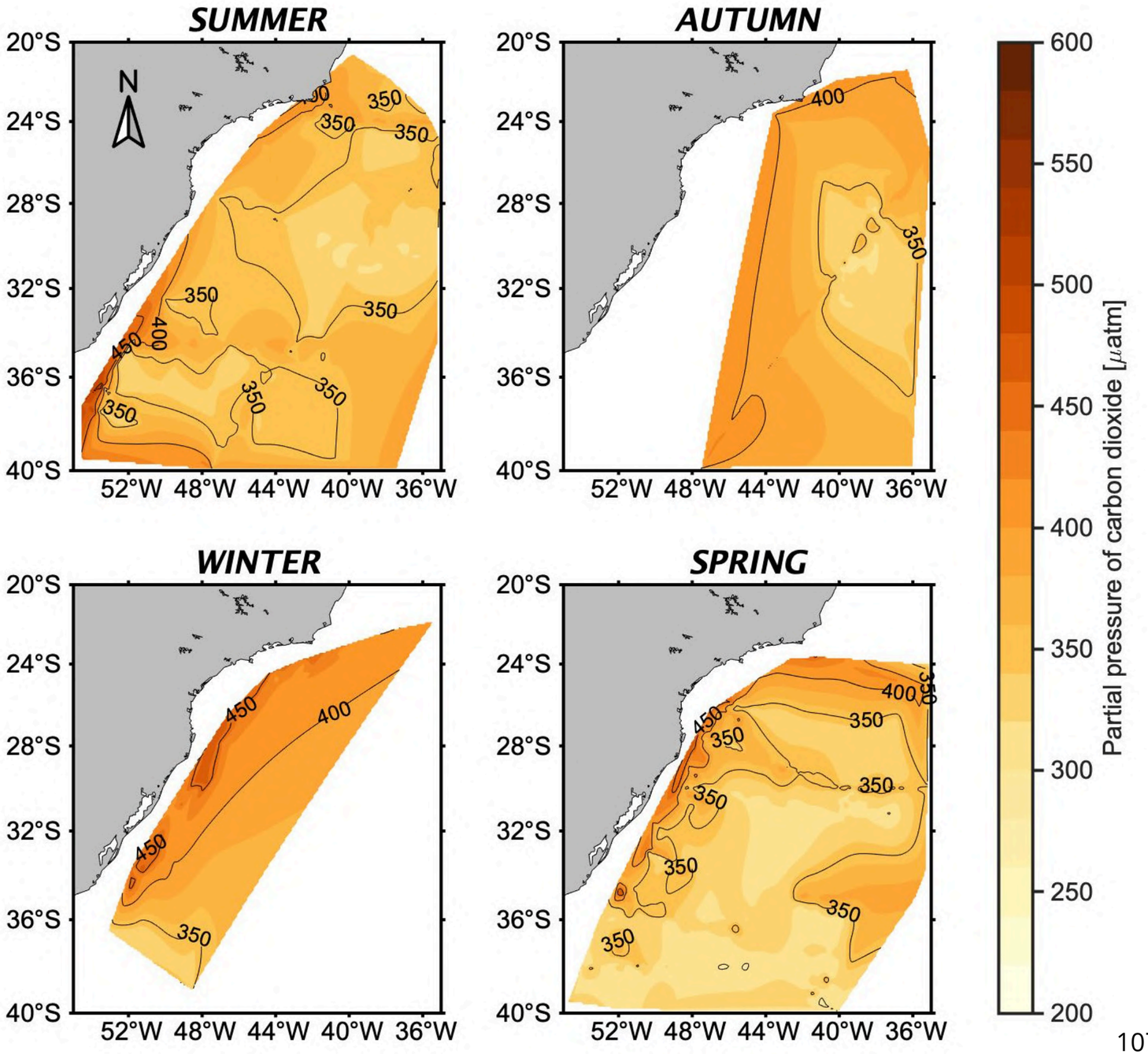
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 498
- Autumn = 182
- Winter = 72
- Spring = 551

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

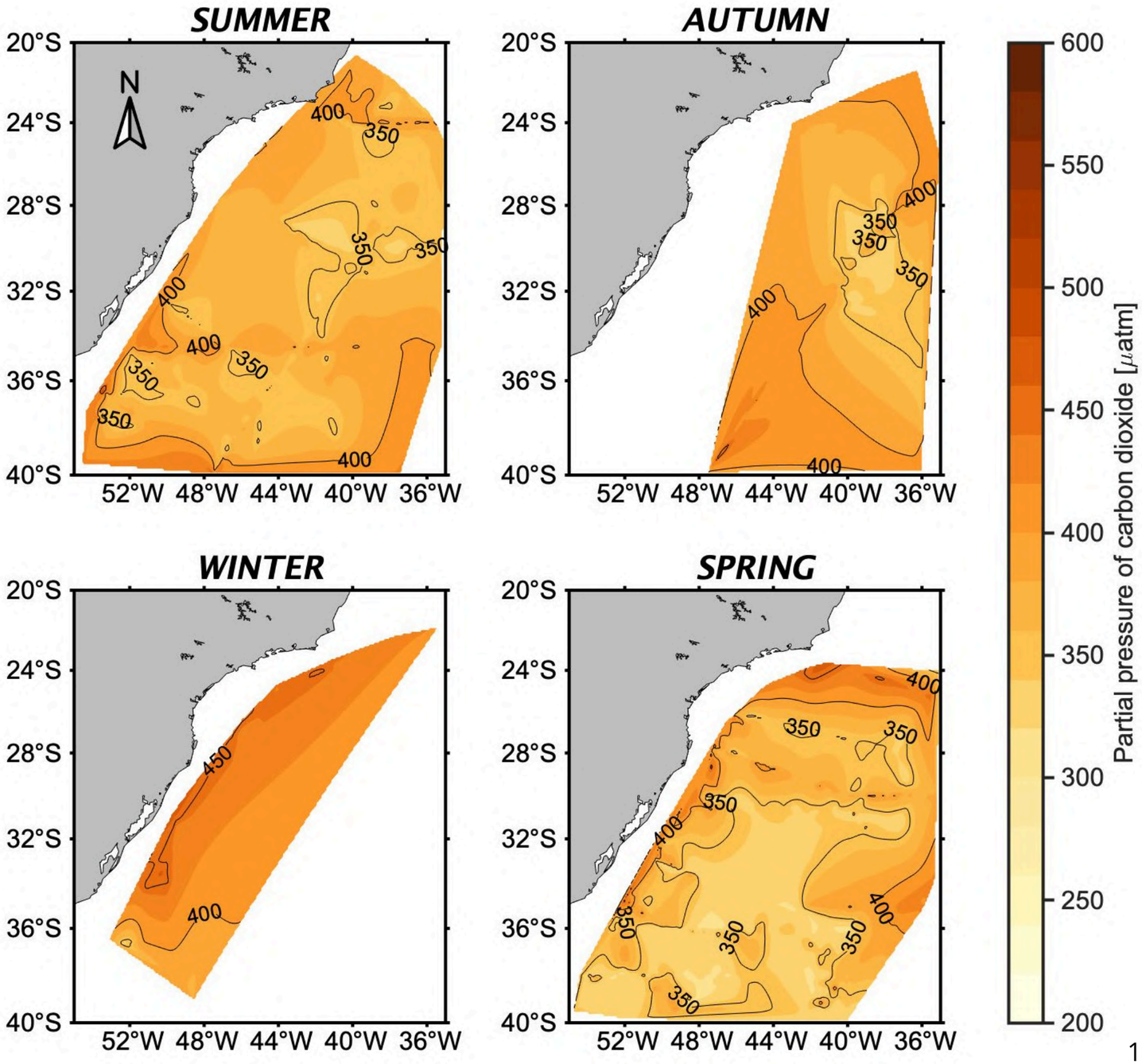
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

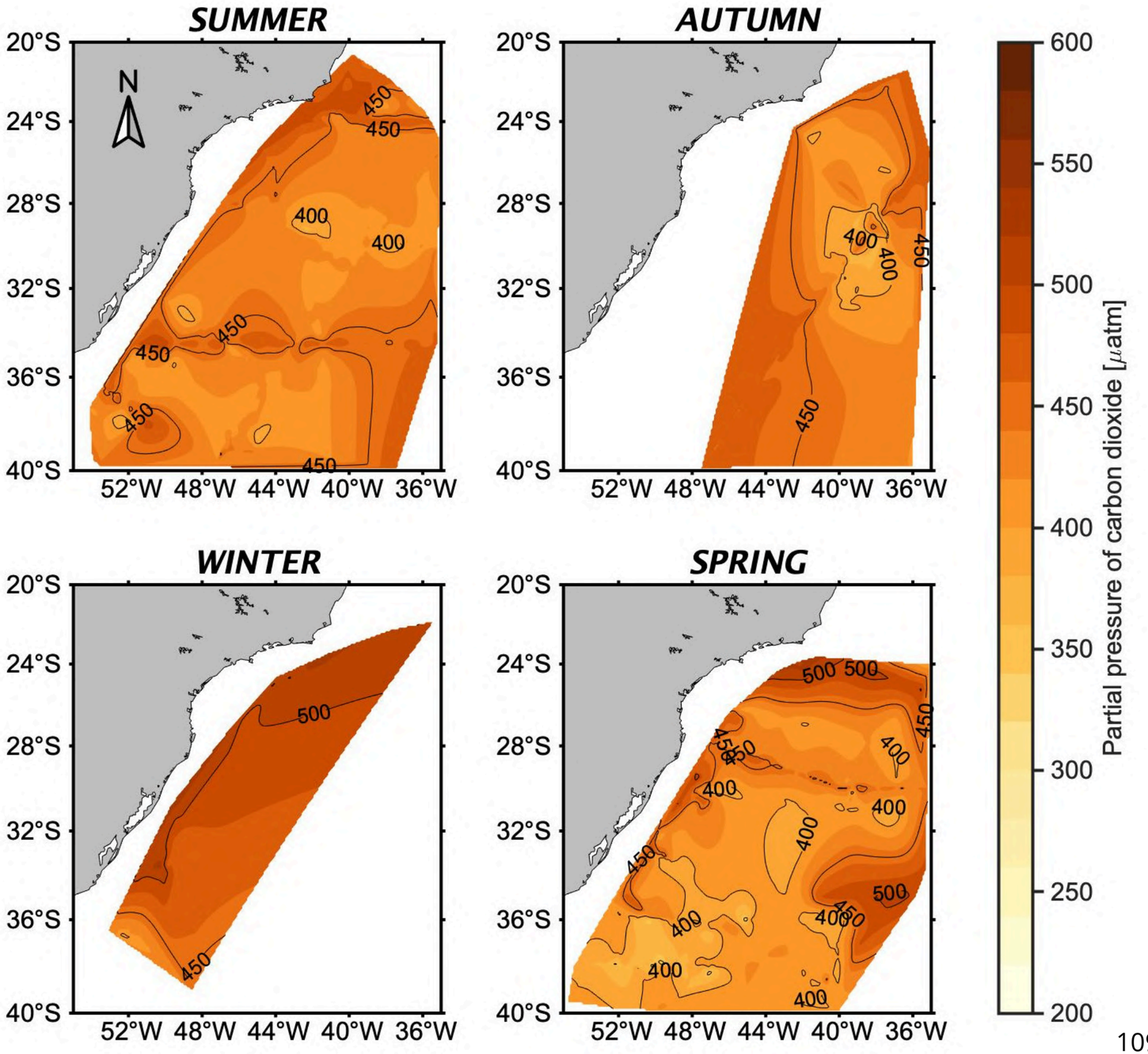
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Partial pressure of carbon dioxide (pCO_2)* climatology

From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

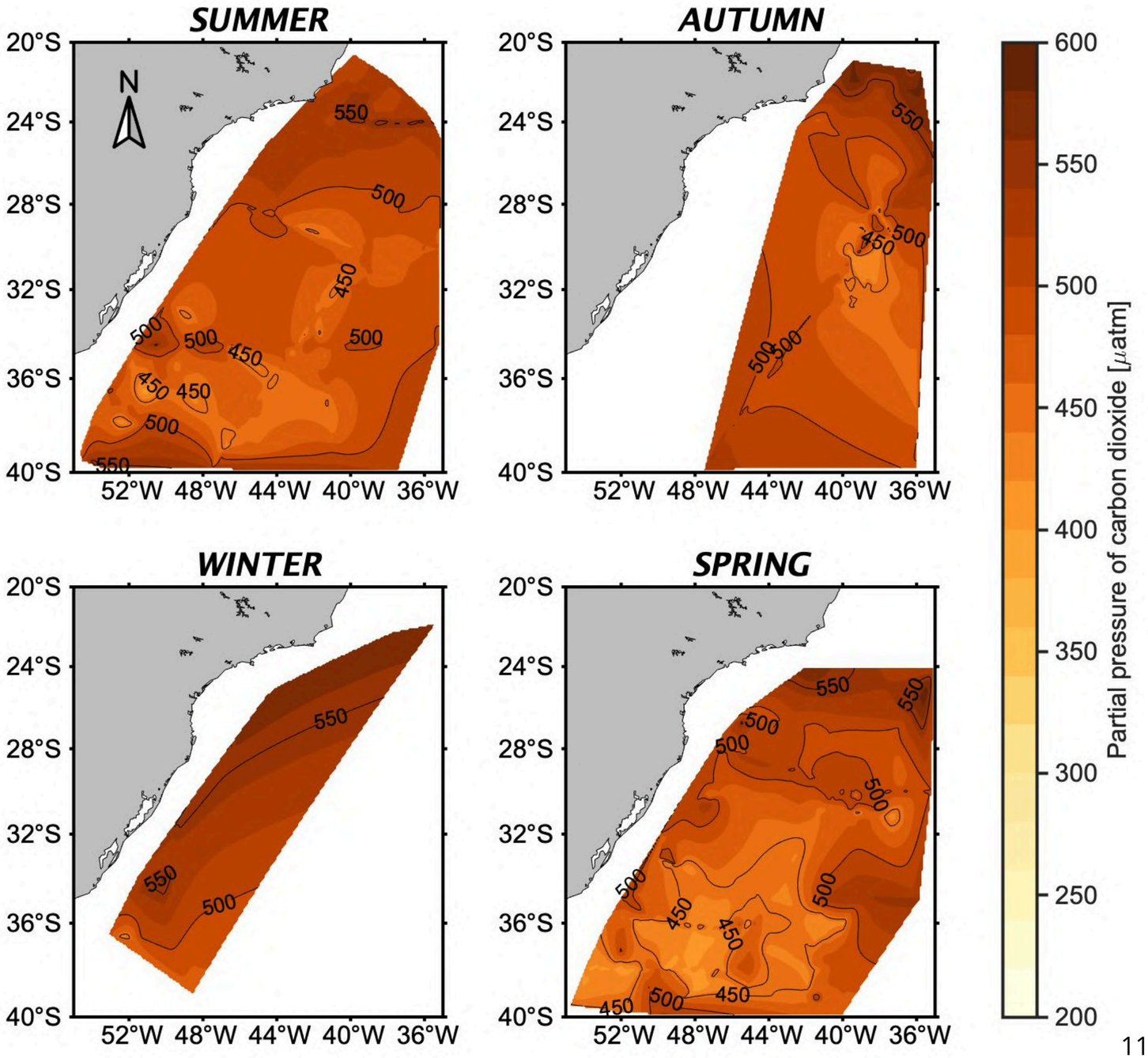
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

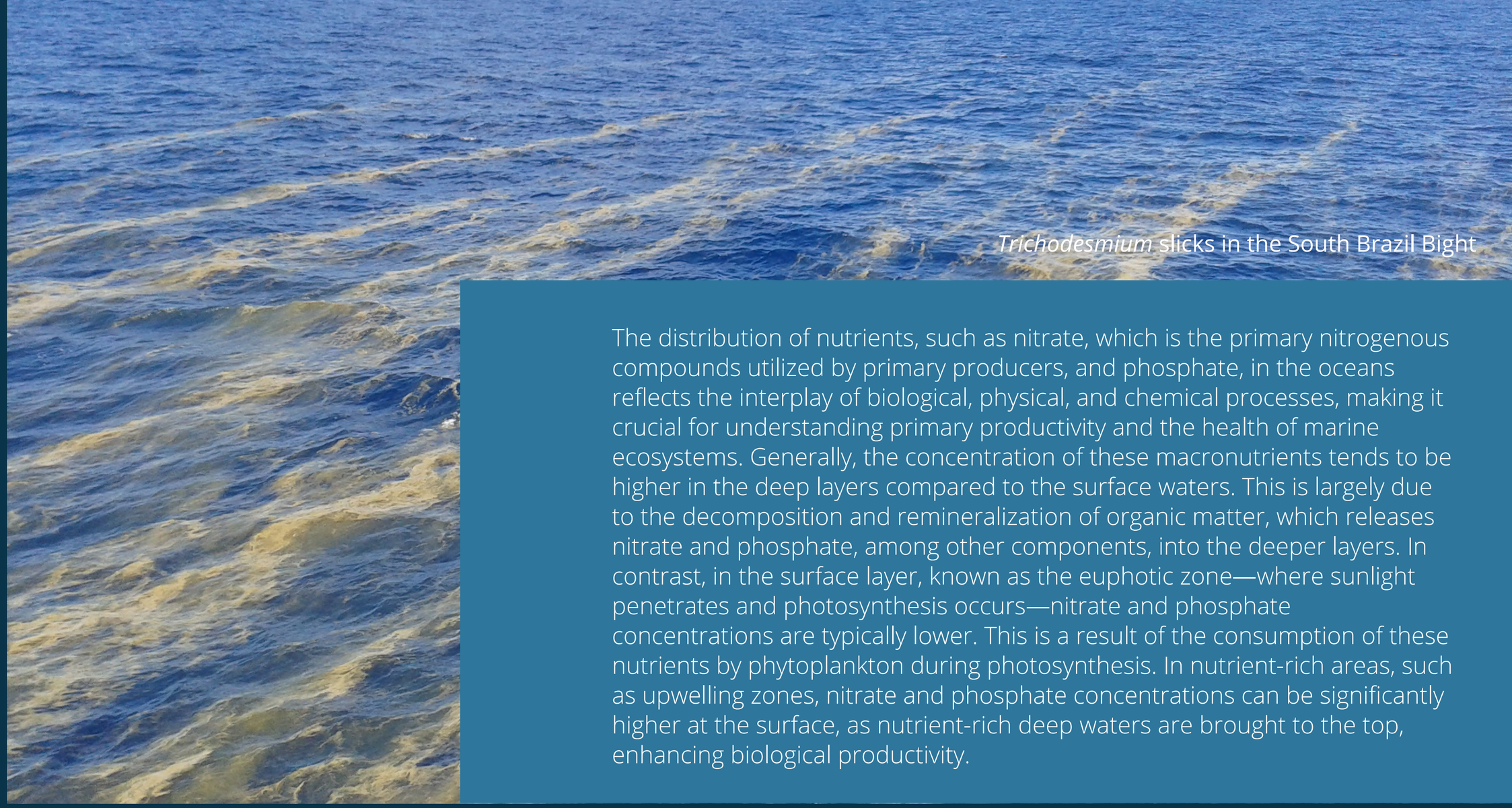
Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



04.9 Dissolved Nutrients



Trichodesmium slicks in the South Brazil Bight

The distribution of nutrients, such as nitrate, which is the primary nitrogenous compounds utilized by primary producers, and phosphate, in the oceans reflects the interplay of biological, physical, and chemical processes, making it crucial for understanding primary productivity and the health of marine ecosystems. Generally, the concentration of these macronutrients tends to be higher in the deep layers compared to the surface waters. This is largely due to the decomposition and remineralization of organic matter, which releases nitrate and phosphate, among other components, into the deeper layers. In contrast, in the surface layer, known as the euphotic zone—where sunlight penetrates and photosynthesis occurs—nitrate and phosphate concentrations are typically lower. This is a result of the consumption of these nutrients by phytoplankton during photosynthesis. In nutrient-rich areas, such as upwelling zones, nitrate and phosphate concentrations can be significantly higher at the surface, as nutrient-rich deep waters are brought to the top, enhancing biological productivity.

Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

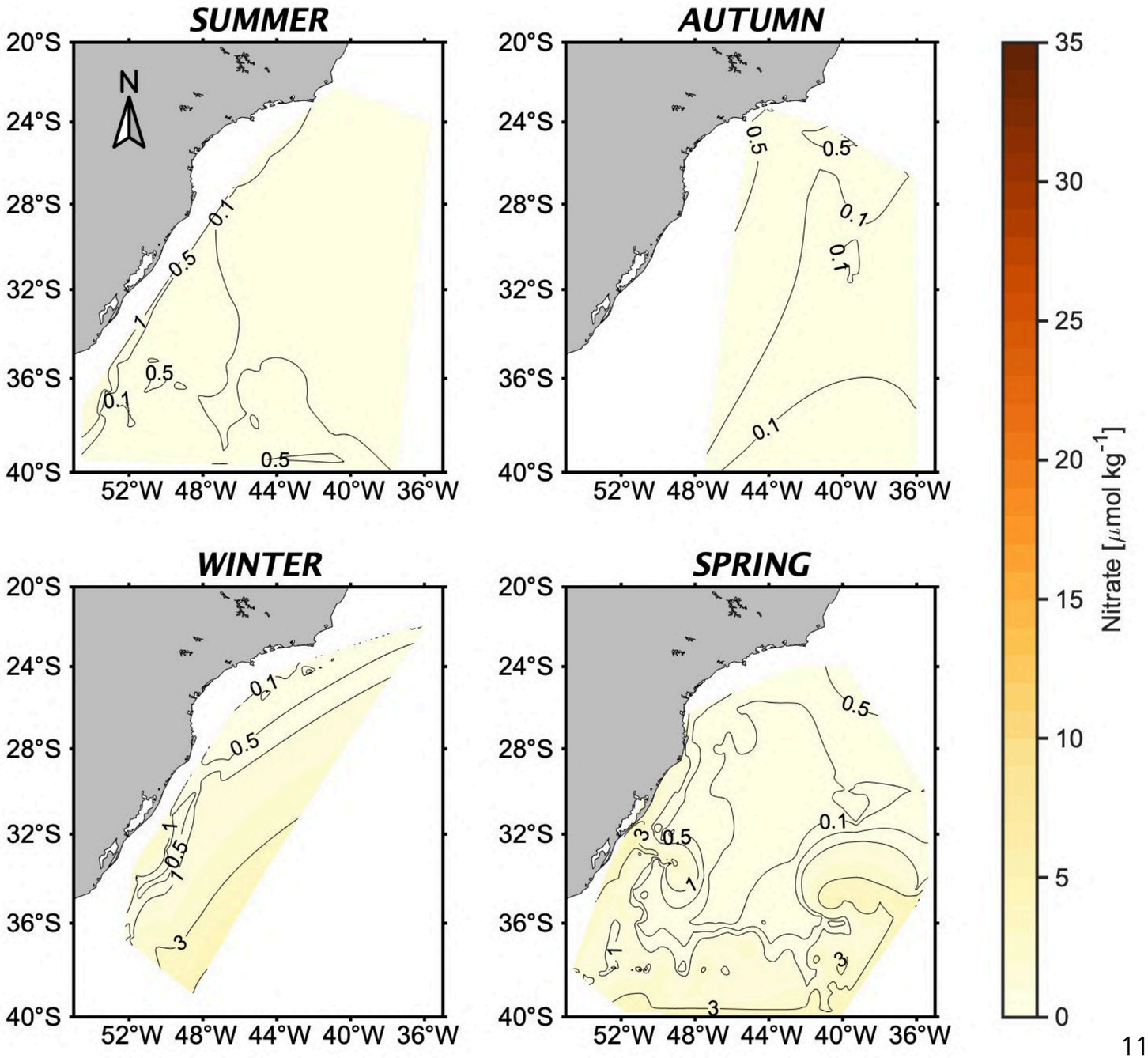
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 85
- Autumn = 54
- Winter = 59
- Spring = 307

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 5 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

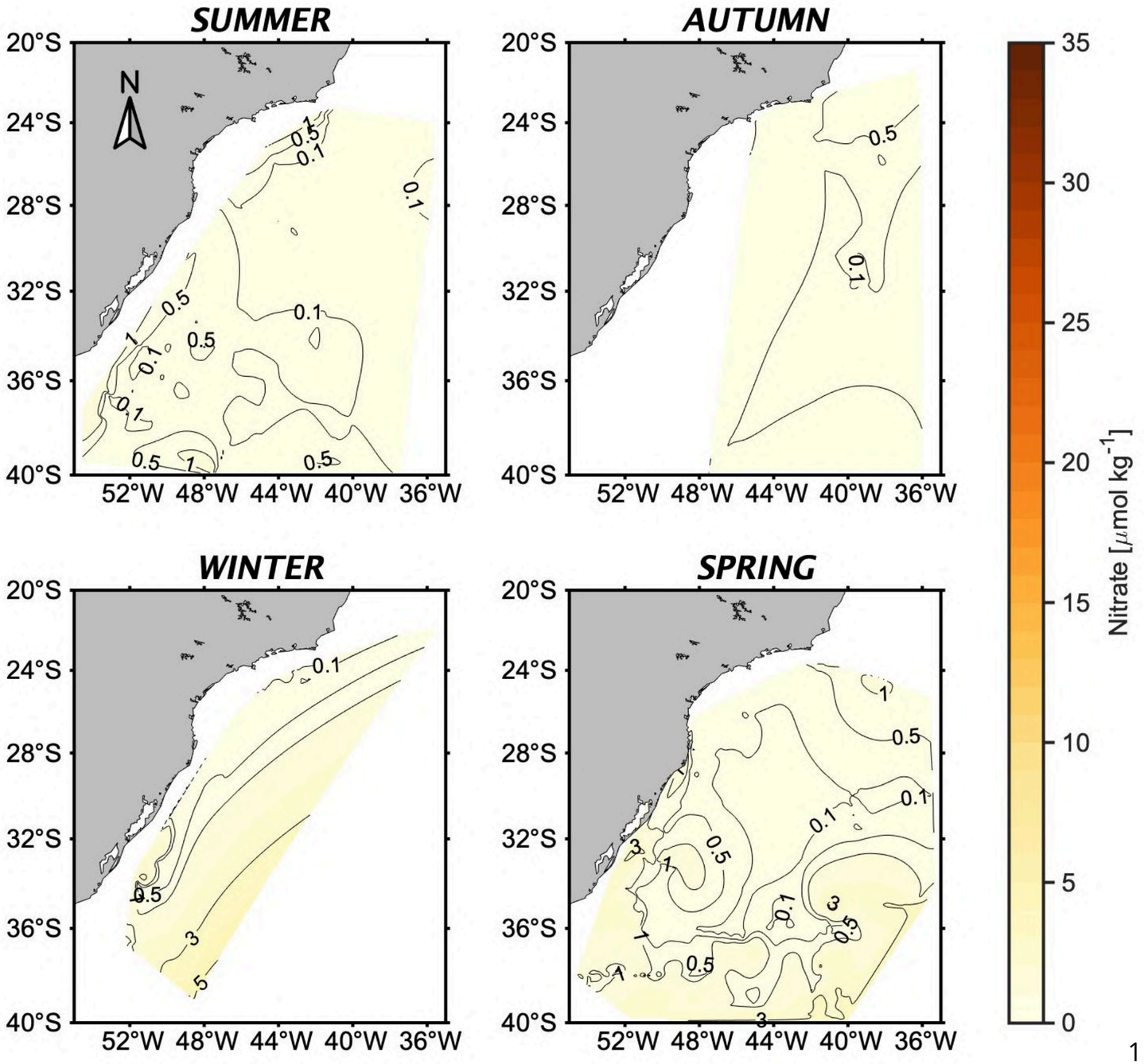
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 131
- Autumn = 67
- Winter = 67
- Spring = 349

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 10 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

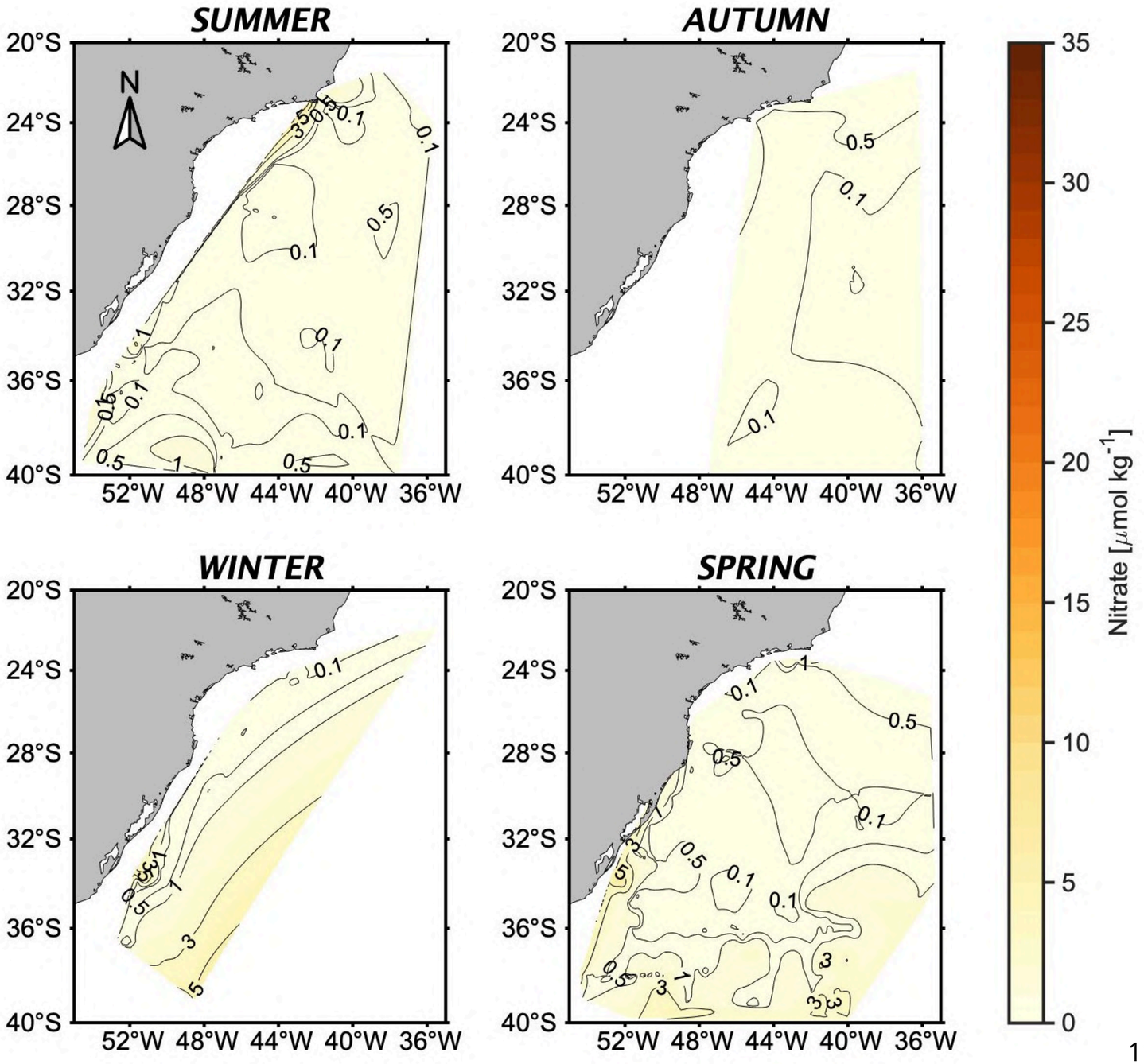
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 122
- Autumn = 68
- Winter = 69
- Spring = 359

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 25 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

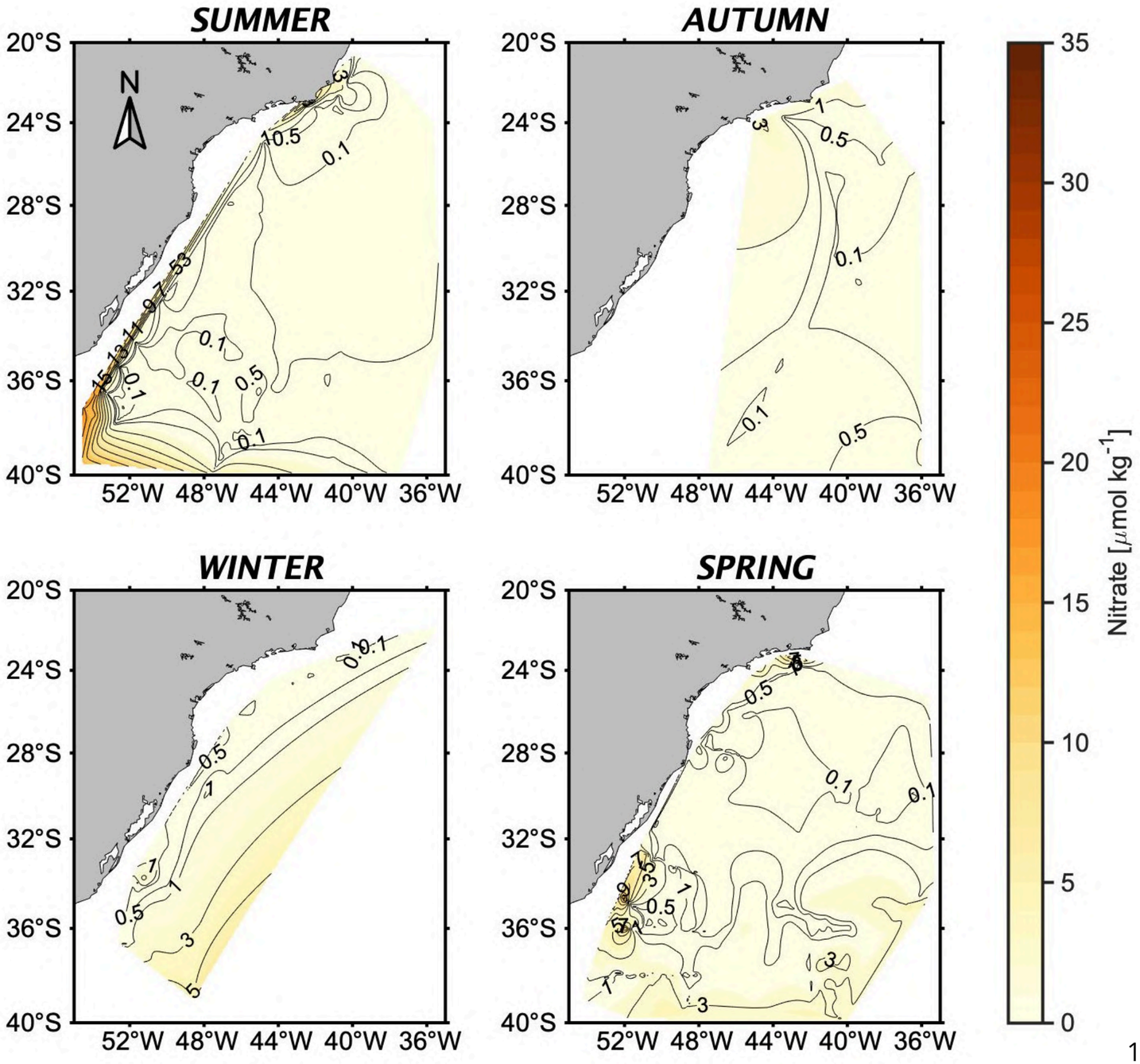
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 147
- Autumn = 73
- Winter = 71
- Spring = 398

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 50 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

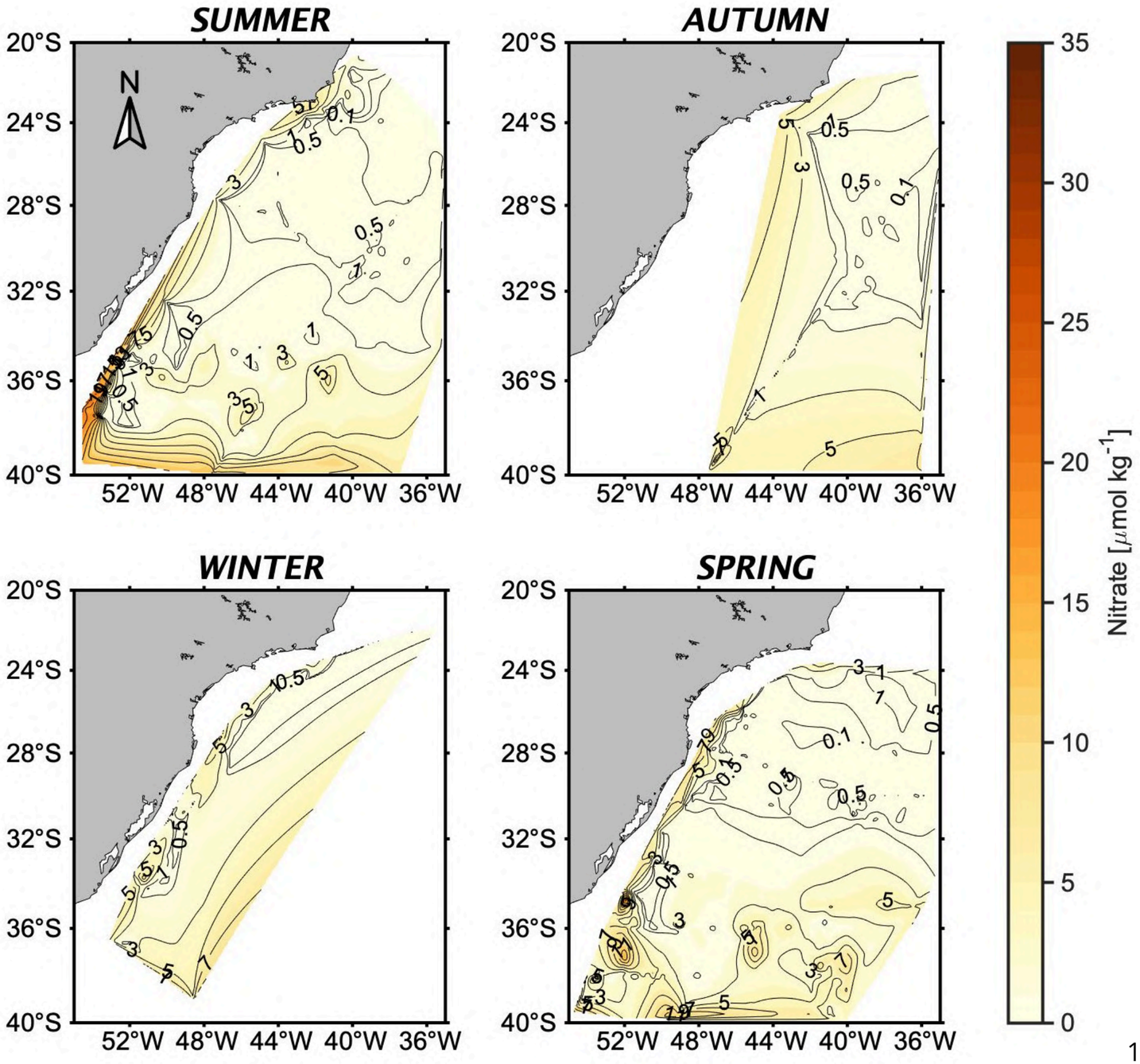
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 433
- Autumn = 162
- Winter = 72
- Spring = 519

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 100 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

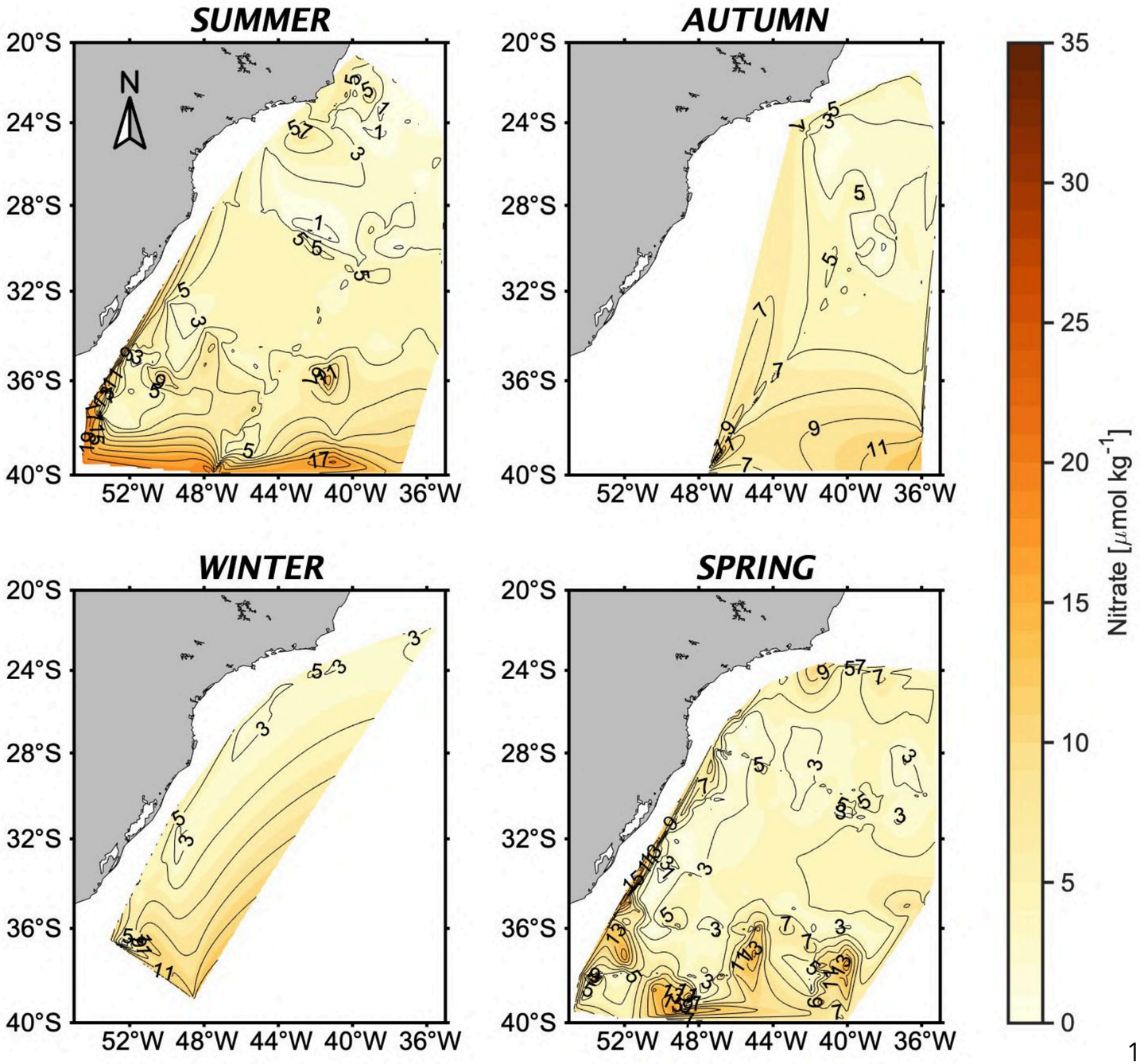
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

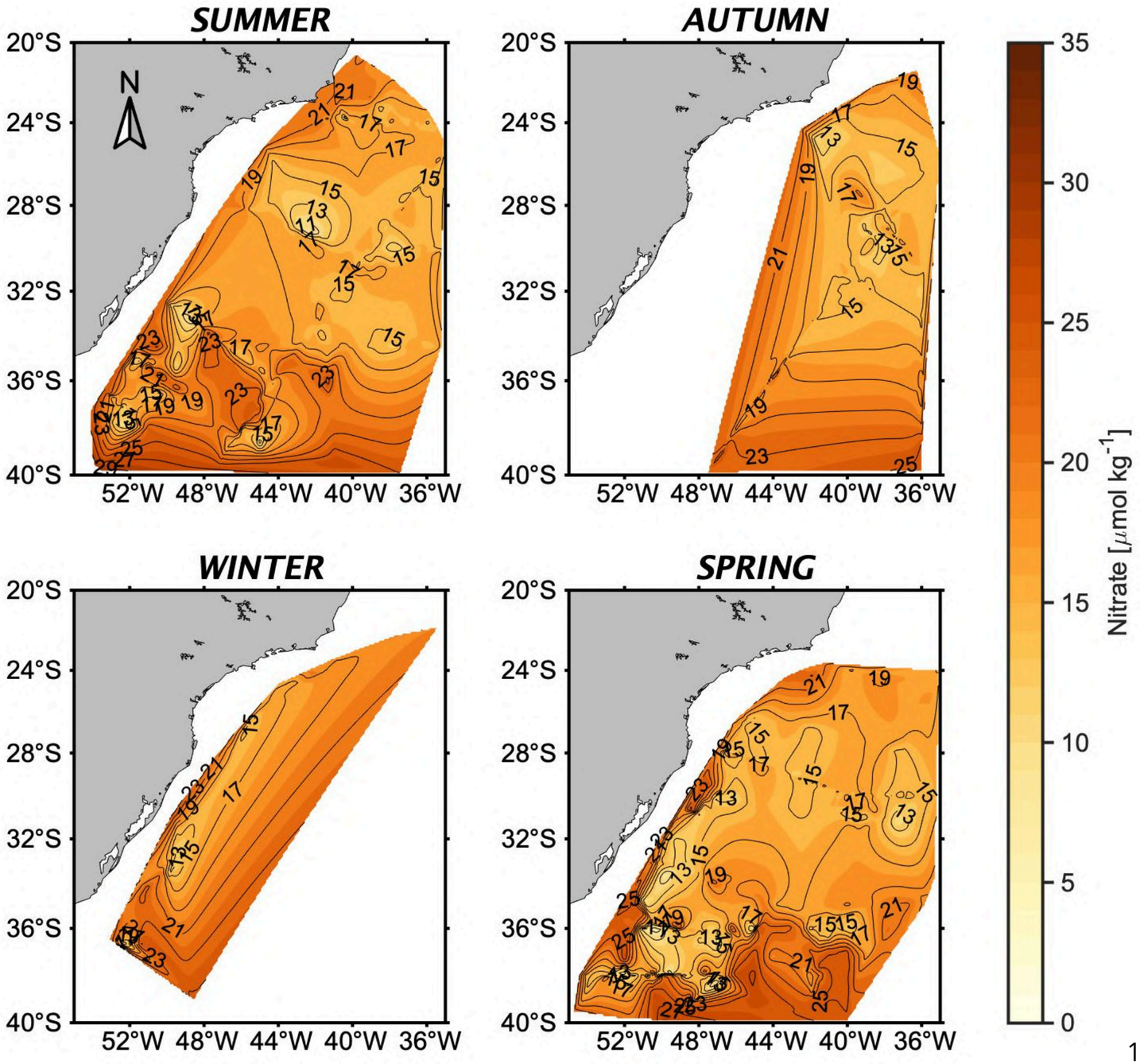
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 500 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Nitrate (NO_3)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

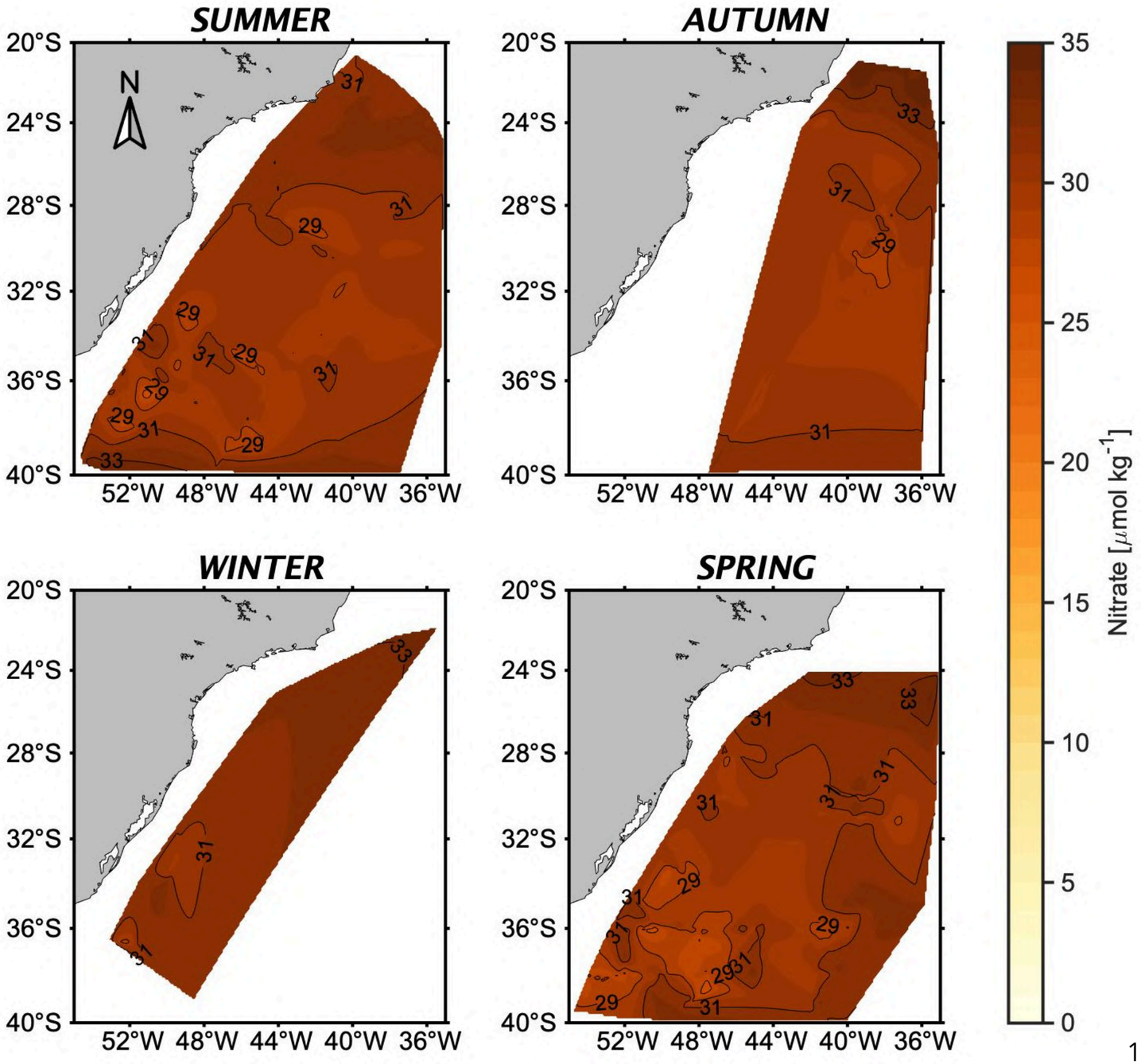
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 1000 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

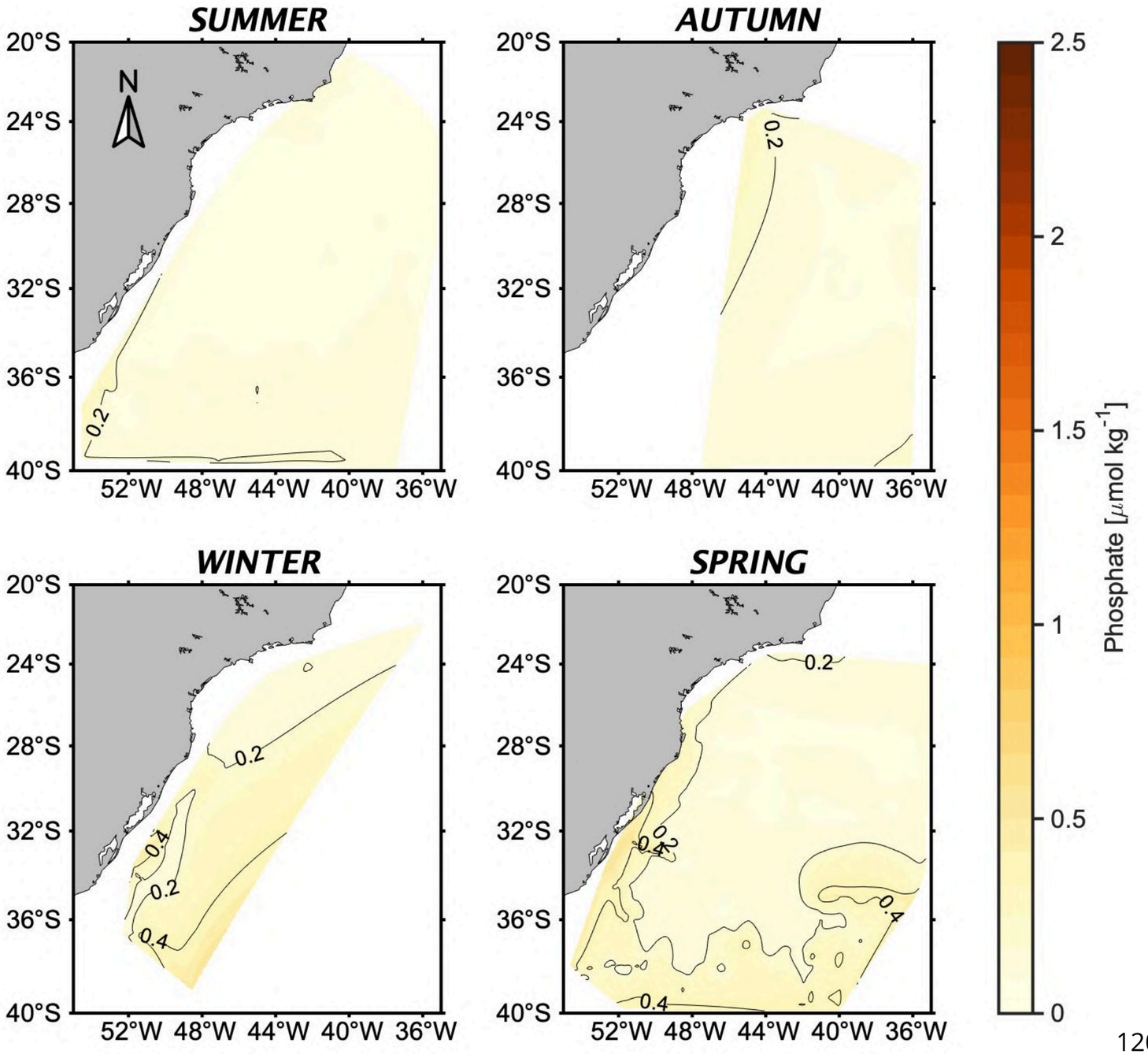
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 320
- Autumn = 123
- Winter = 63
- Spring = 450

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 5 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

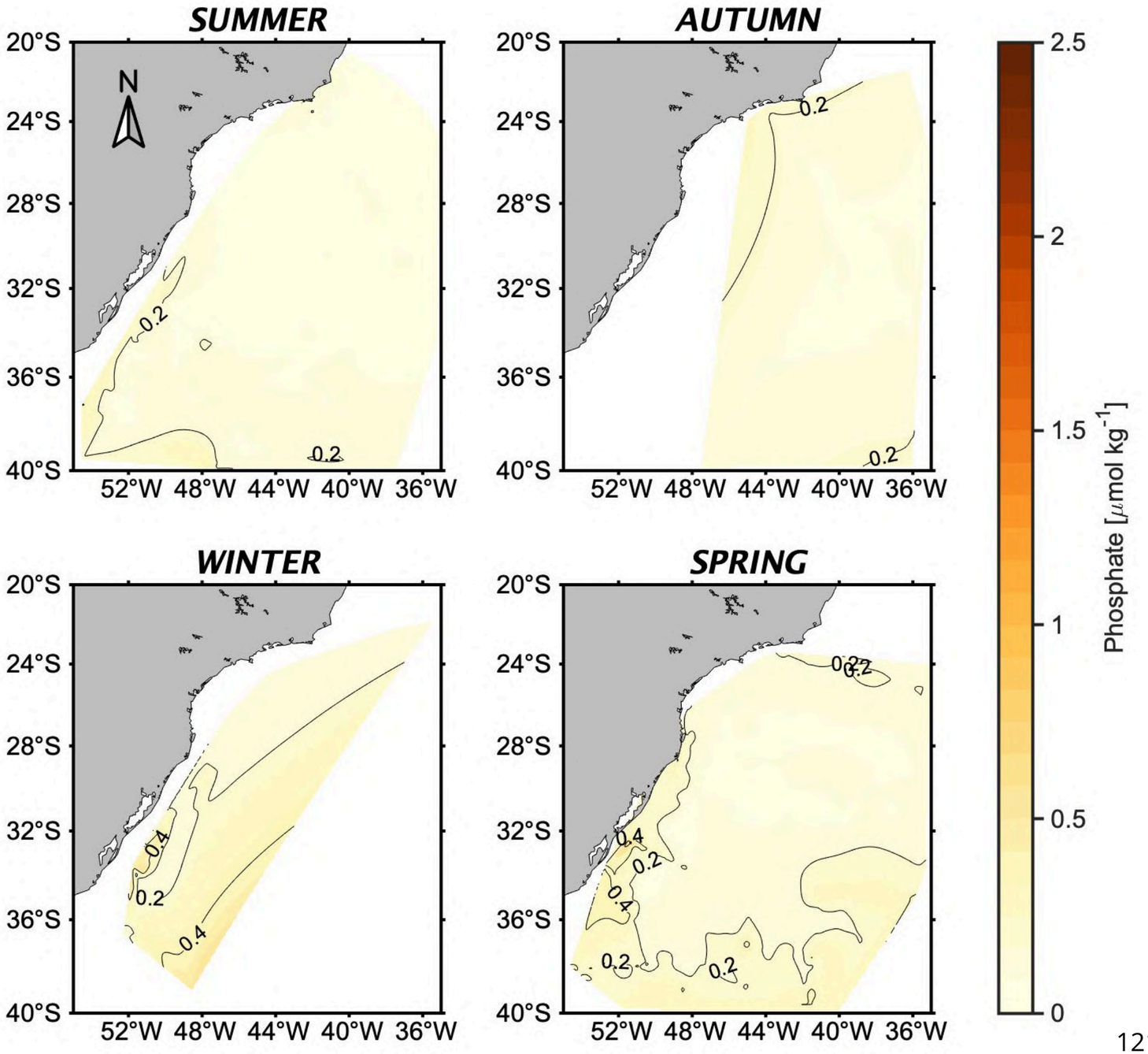
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 485
- Autumn = 176
- Winter = 70
- Spring = 518

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 10 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

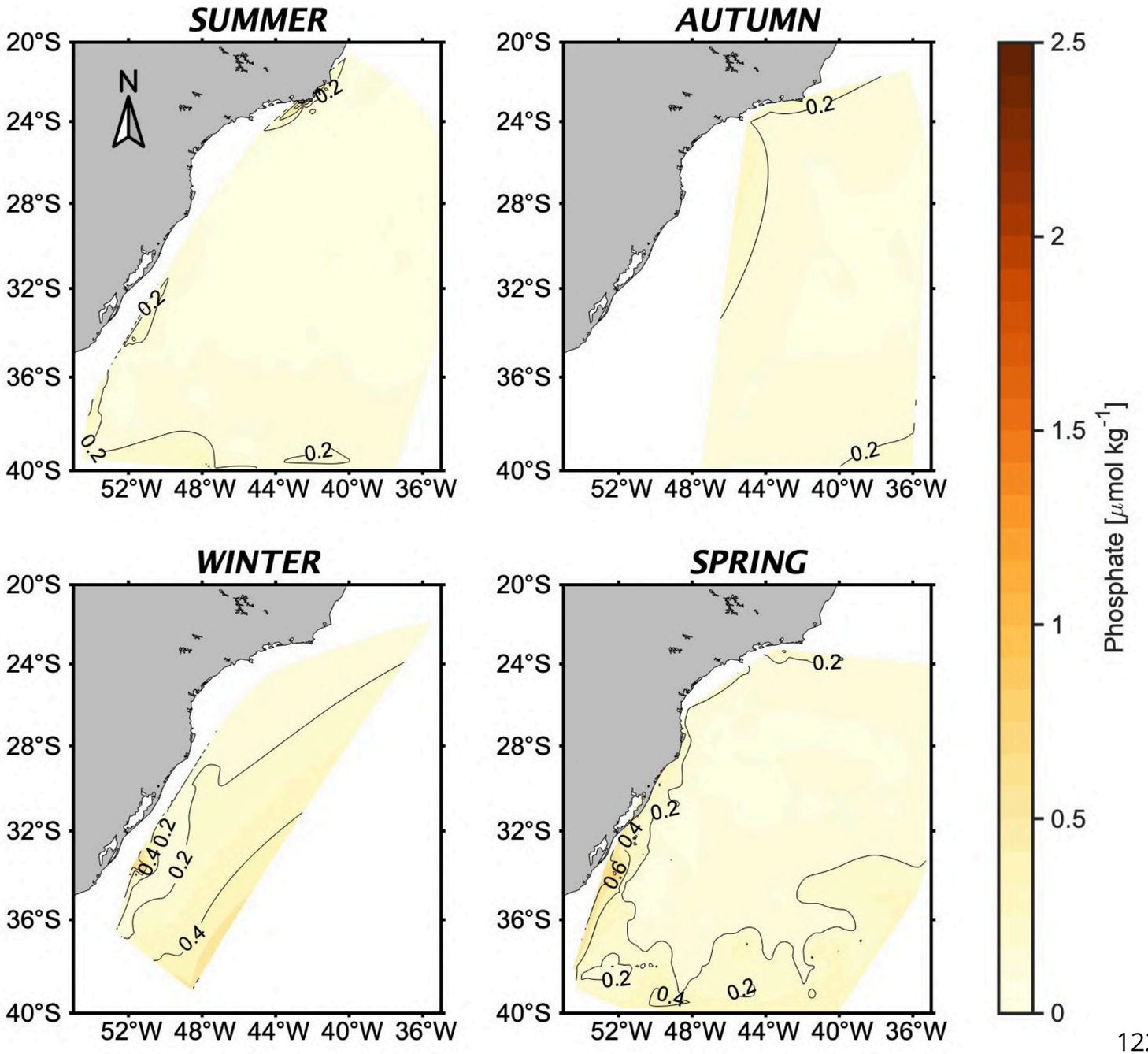
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 509
- Autumn = 182
- Winter = 71
- Spring = 553

Depth levels = 5, 10, 25, 50, 100, 200, 300000, 1000 dBar

Pressure = 25 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

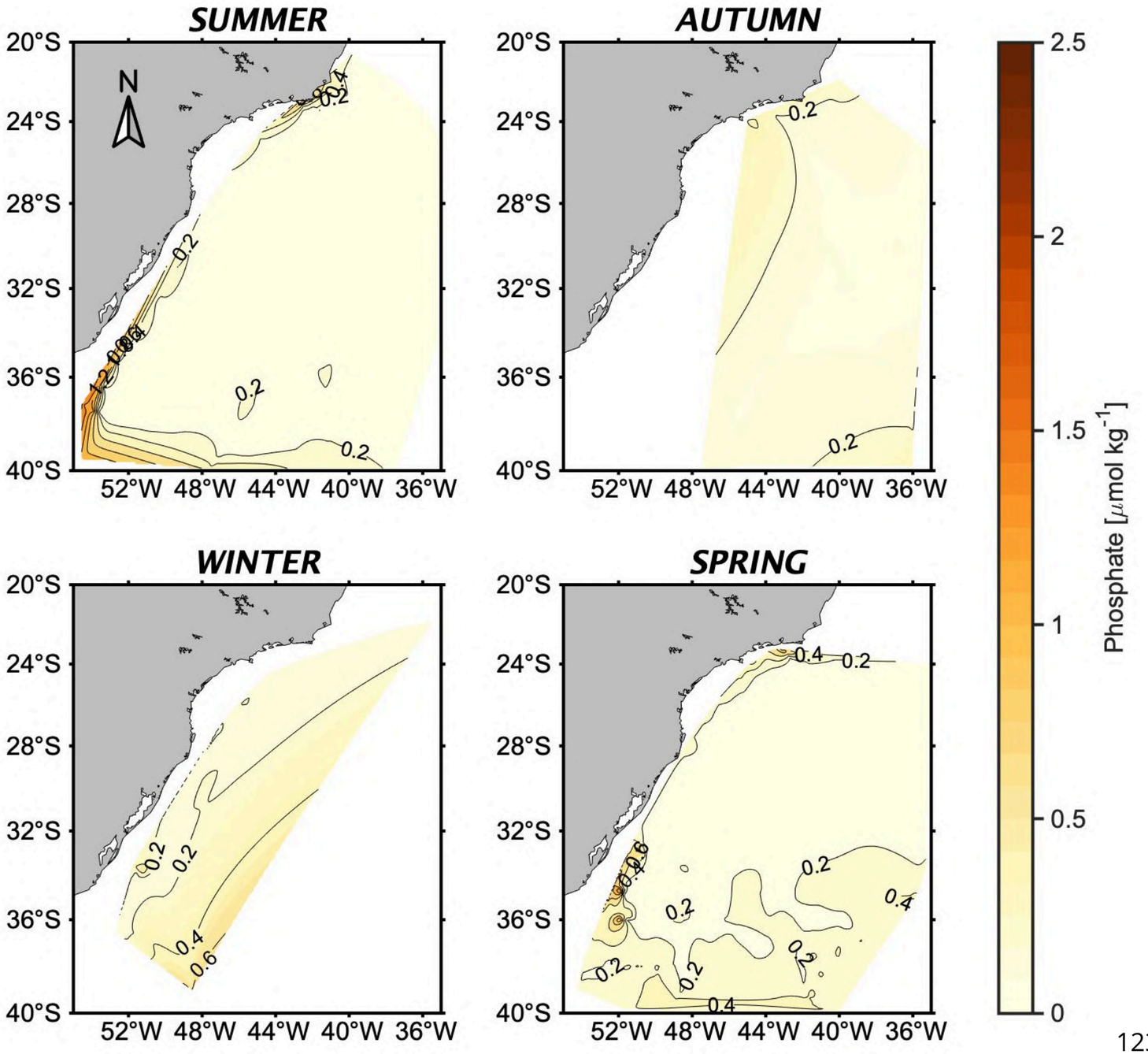
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 505
- Autumn = 180
- Winter = 71
- Spring = 554

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 50 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

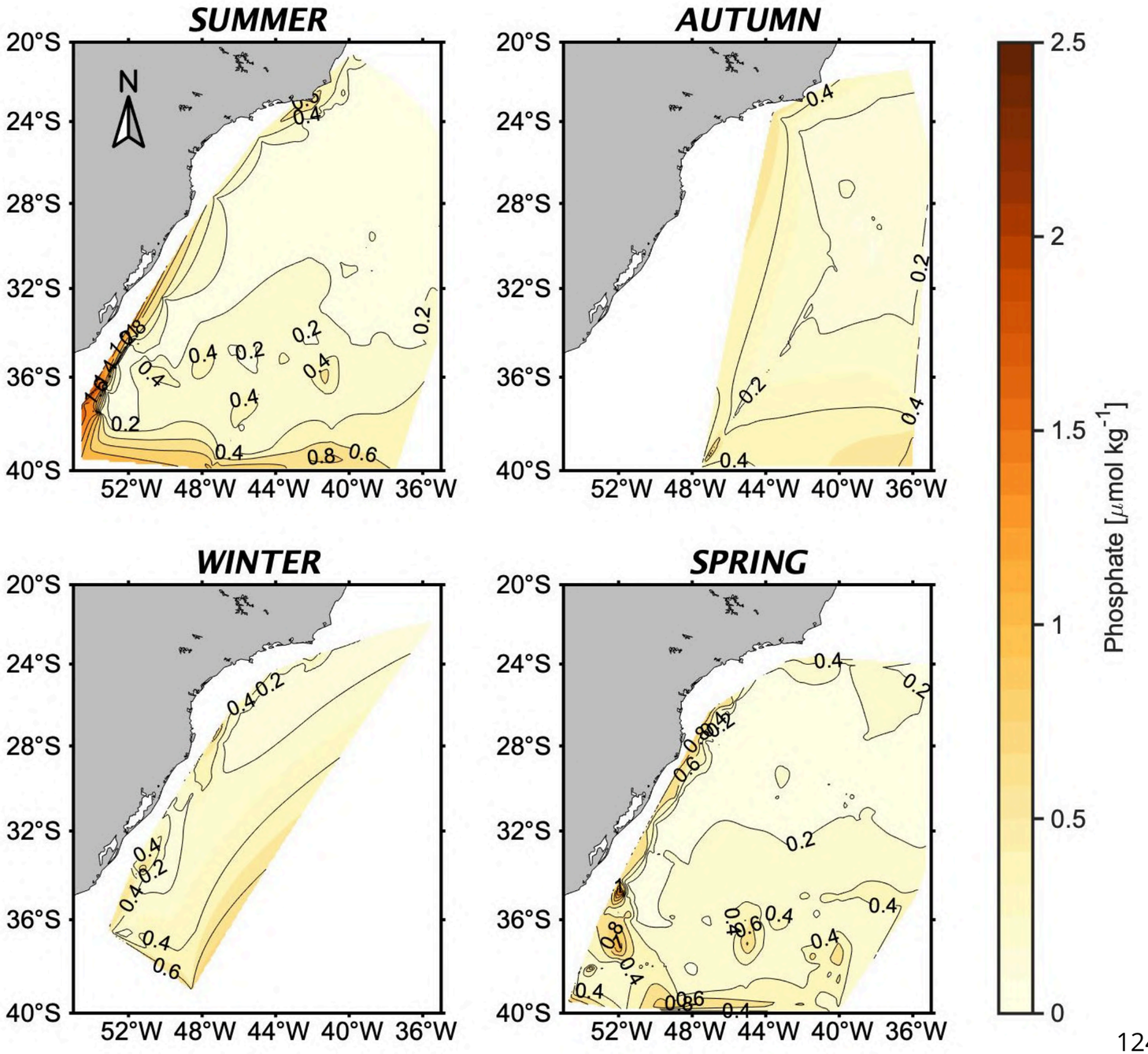
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 498
- Autumn = 182
- Winter = 72
- Spring = 551

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 100 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology
From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

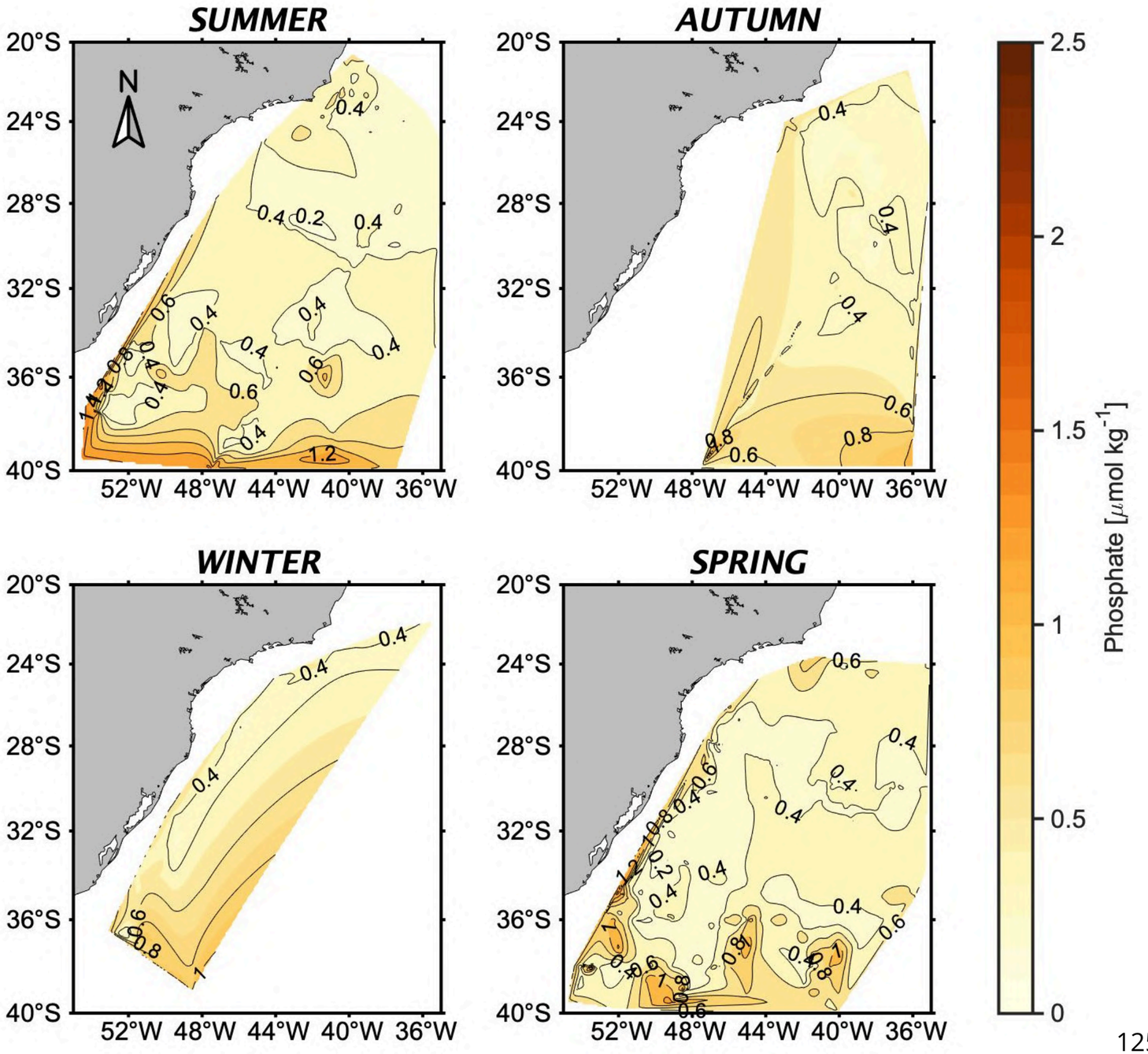
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 474
- Autumn = 179
- Winter = 47
- Spring = 512

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 200 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

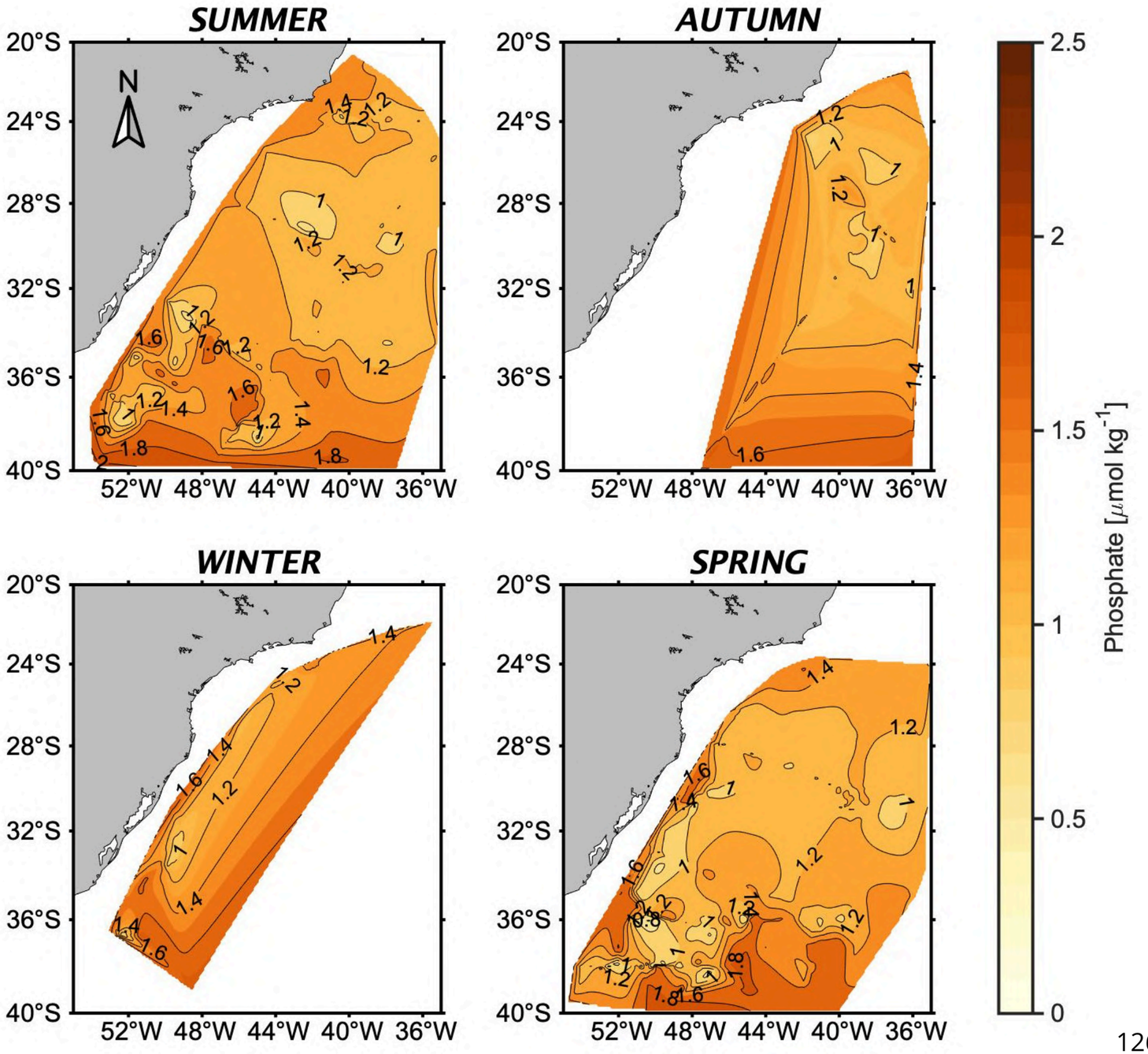
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 445
- Autumn = 179
- Winter = 46
- Spring = 459

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 500 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



Phosphate (PO_4)* climatology From 1972 to 2024

Grid resolution = 10 km, 223 x 223 points

Interpolation function = griddata

Interpolation method = triangulation-based natural neighbor interpolation

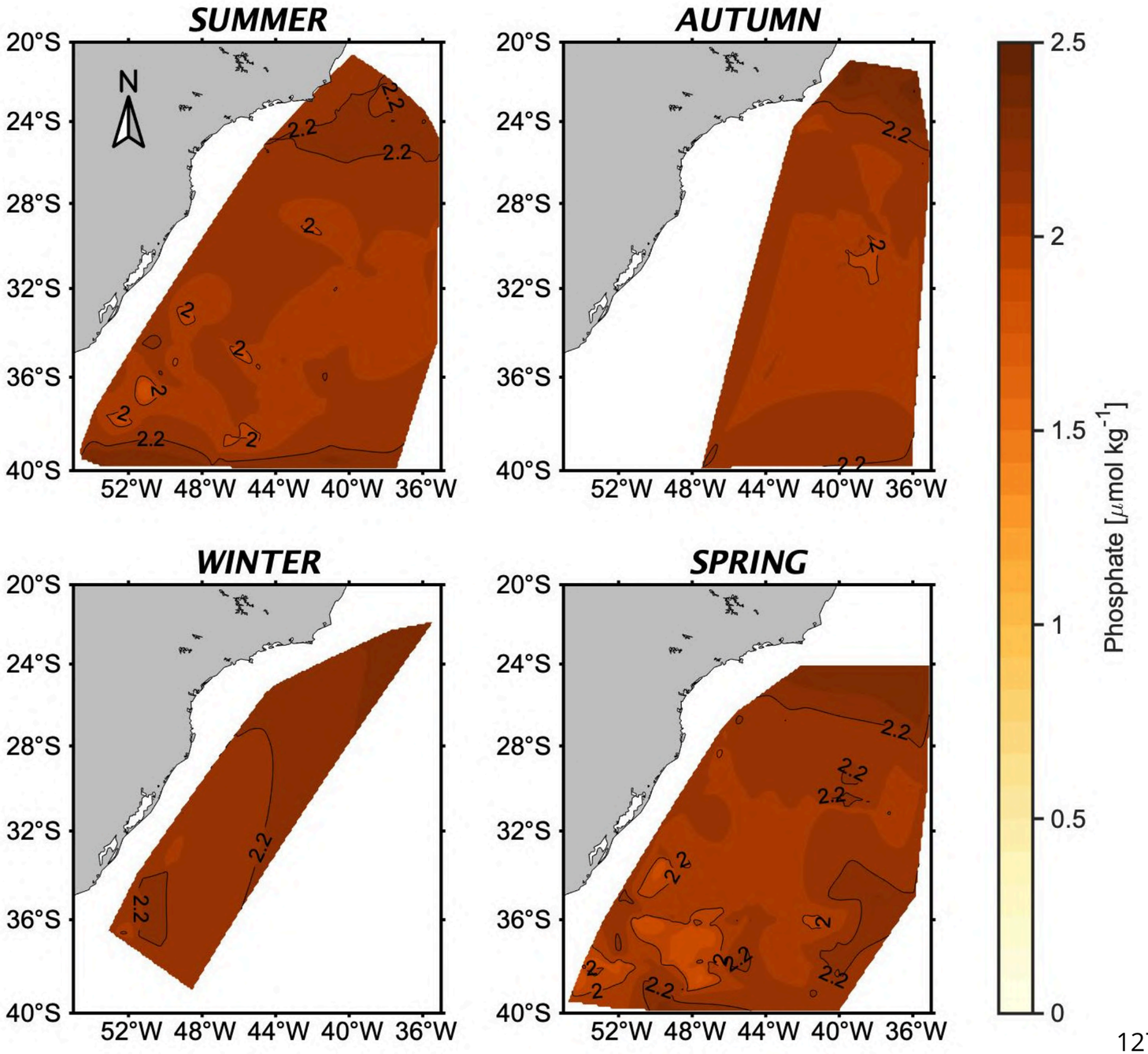
Number of *in situ* observations (S,T,O_2) used for interpolation per season:

- Summer = 438
- Autumn = 189
- Winter = 36
- Spring = 432

Depth levels = 5, 10, 25, 50, 100, 200, 500, 1000 dBar

Pressure = 1000 dBar

*Property determined by CANYON-B method: Bittig et al. (2018). An alternative to static climatologies: Robust estimation of open ocean CO2 variables and nutrient concentrations from T, S and O_2 data using Bayesian neural networks. Front. Mar. Sci. 5:328. doi:10.3389/fmars.2018.00328



05 Hydrographic sections

Three cross-shelf hydrographic sections were selected to verify the physical properties such as temperature, salinity, and density along the transition from the continental shelf to the open ocean domains. One section is located in the SBB, near Cabo Frio, another in the boundary between the SBB and the SBS, centered around Cabo de Santa Marta Grande, and the third in the SBS, near the mouth of the Patos Lagoon. Only data from the Talude cruises were used to map the properties in these vertical sections.

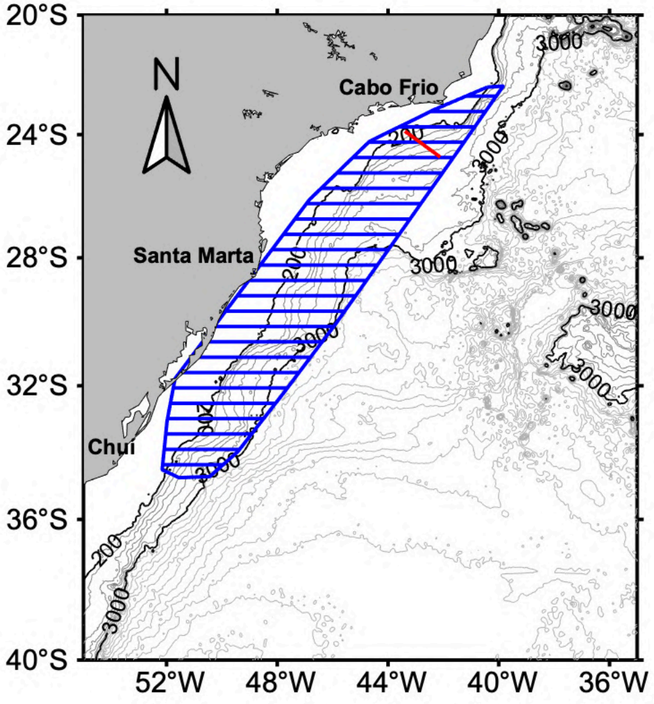
Whale swimming by the Research Vessel "Atlântico Sul"

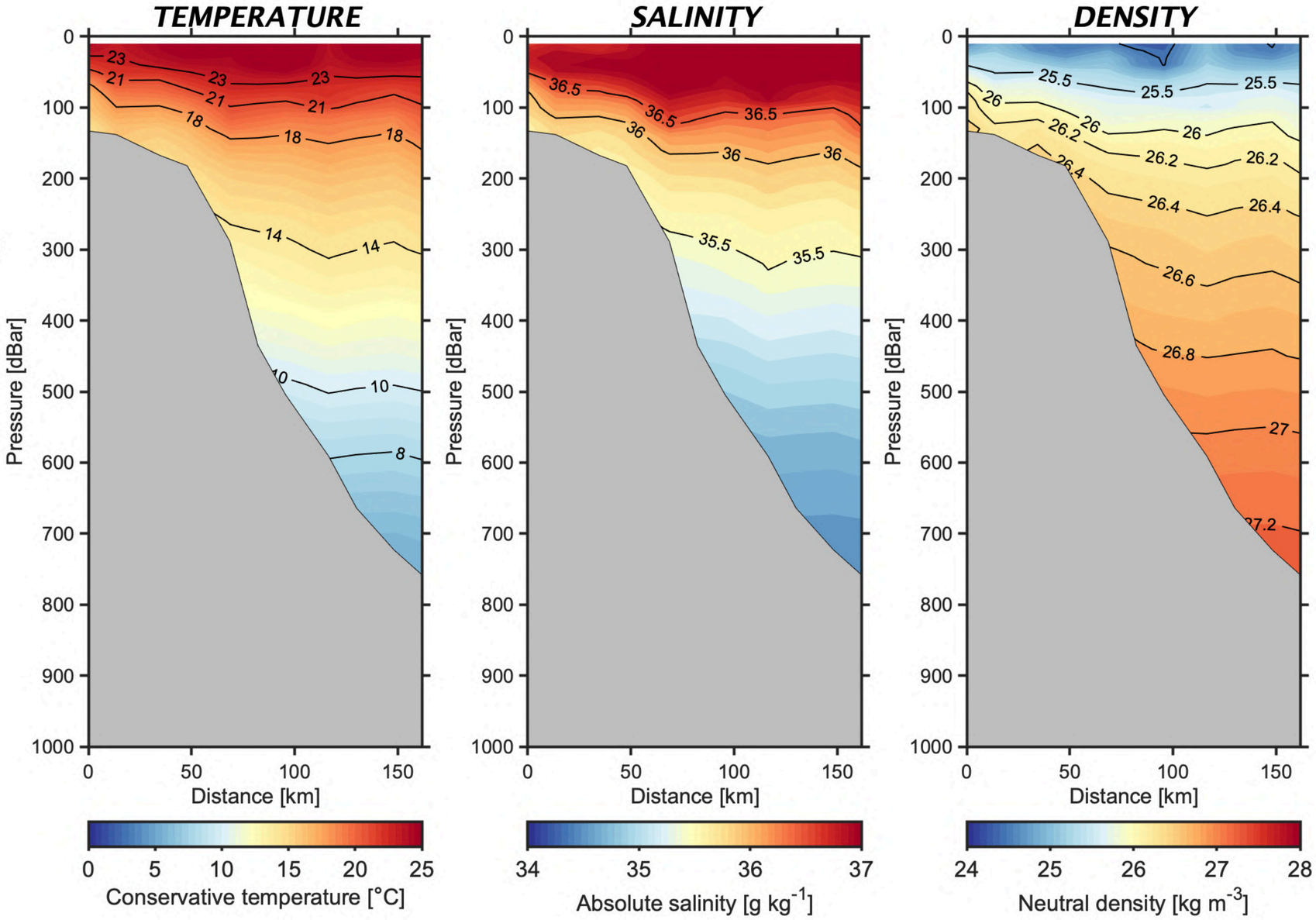
TALUDE data vertical section climatology

Temporal coverage: from 2009 to 2024

Spatial coverage: shelf break and continental rise from Chuí to Cabo Frio

Vertical resolution:
- Observed data (CTD): 1m
- Interpolated data: 10 m from surface to 500 m and 100 m from 500 to 1000 m



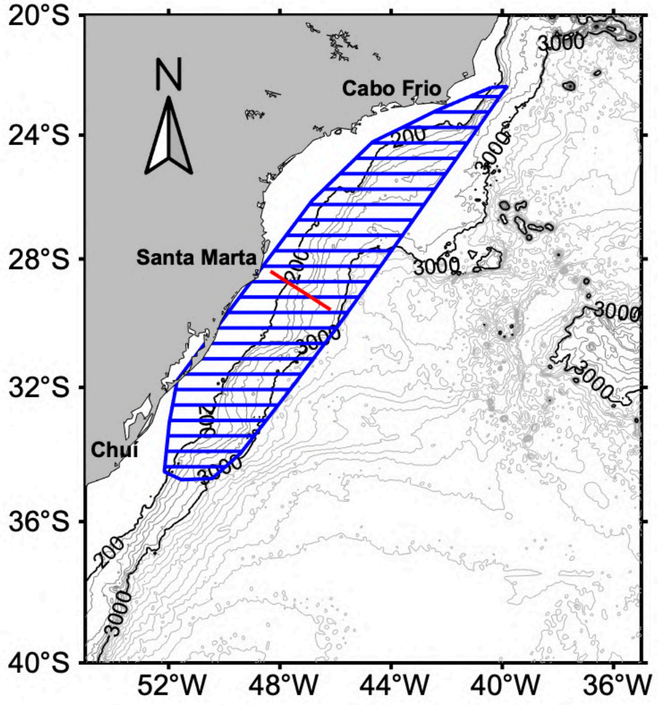


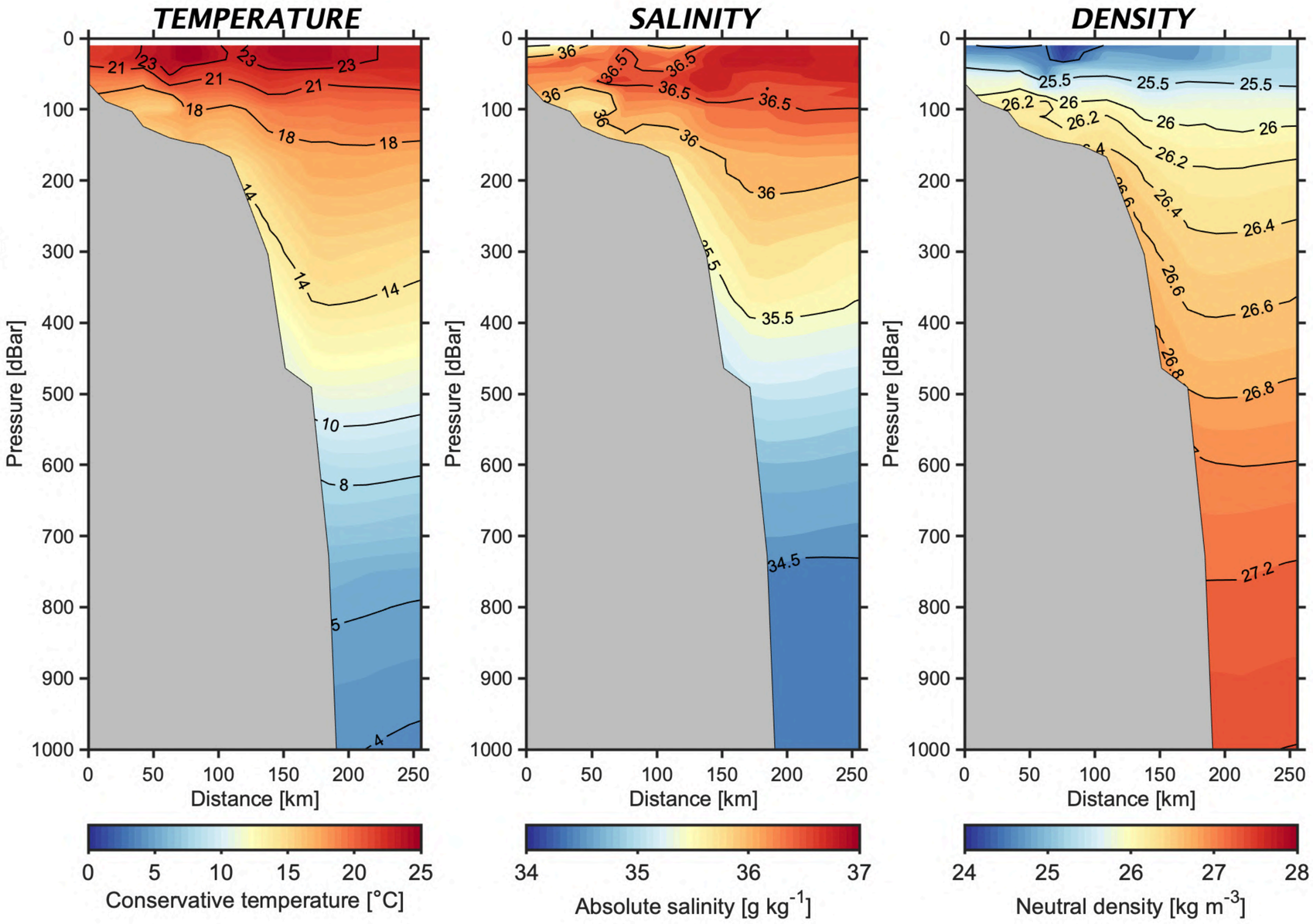
TALUDE data vertical section climatology

Temporal coverage: from 2009 to 2024

Spatial coverage: shelf break and continental rise from Chuí to Cabo Frio

Vertical resolution:
- Observed data (CTD): 1m
- Interpolated data: 10 m from surface to 500 m and 100 m from 500 to 1000 m



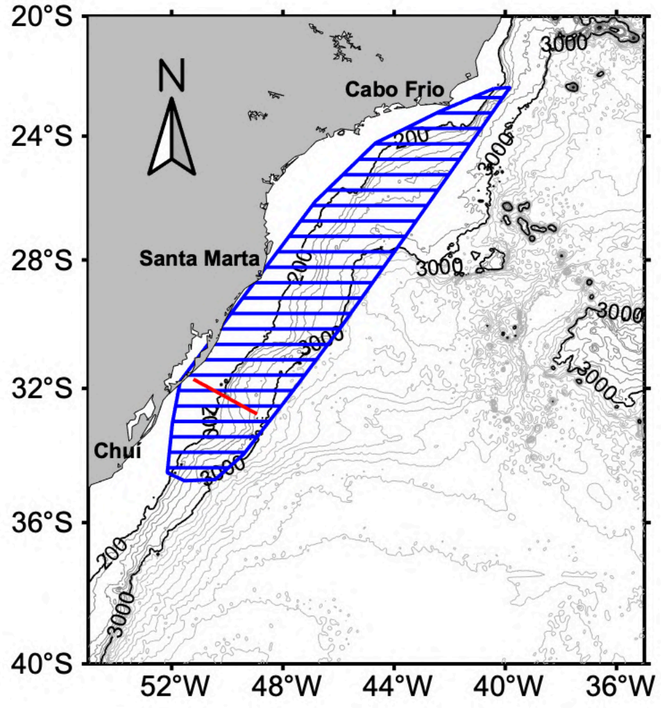


TALUDE data vertical section climatology

Temporal coverage: from 2009 to 2024

Spatial coverage: shelf break and continental rise from Chuí to Cabo Frio

Vertical resolution:
- Observed data (CTD): 1m
- Interpolated data: 10 m from surface to 500 m and 100 m from 500 to 1000 m



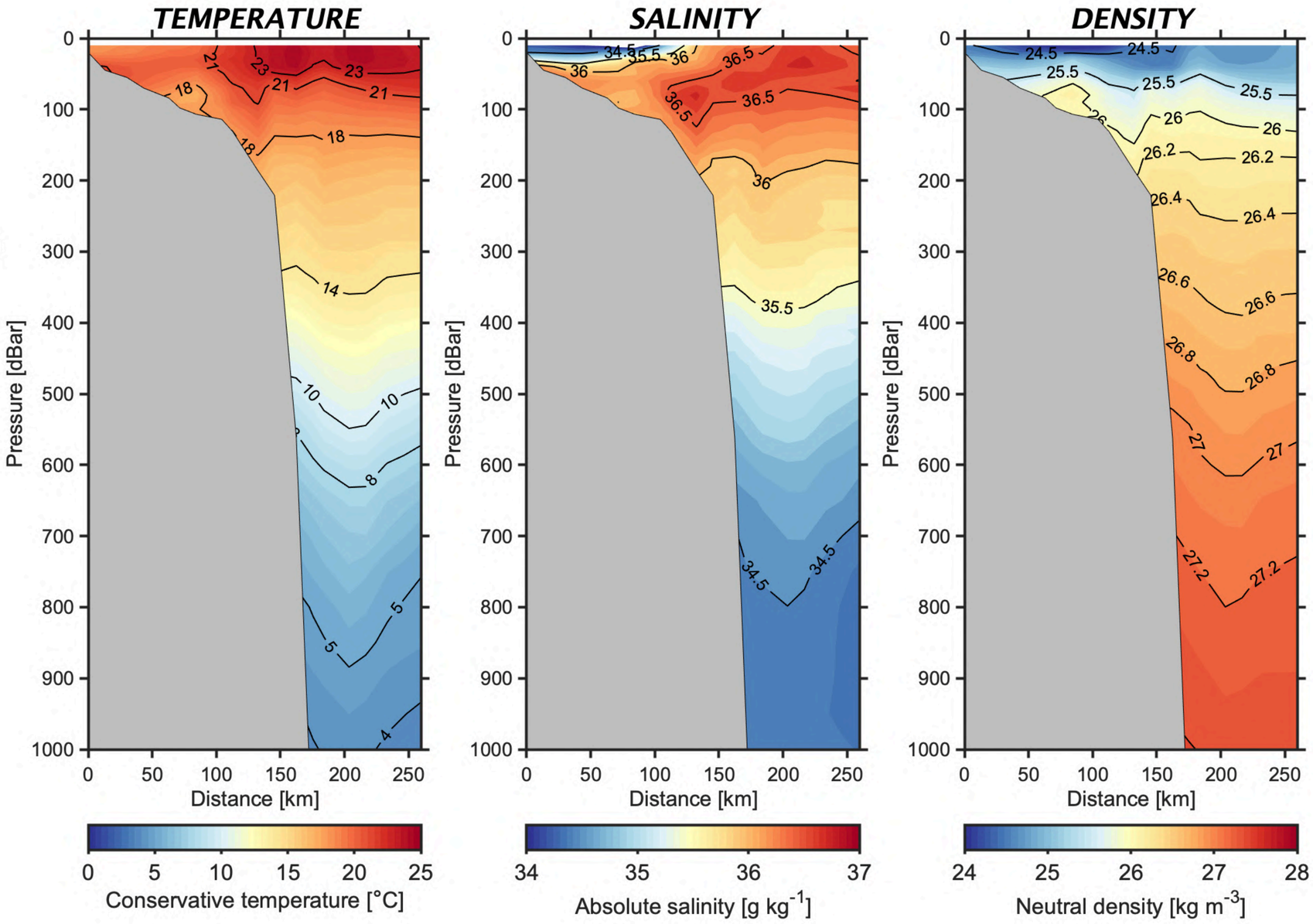


Photo credits: Talude and MARES projects, and INCT-BAA

Cover - Rodrigo Genoves
Page 13 - Thiago Monteiro da Silva
Page 14 - Rodrigo Genoves
Page 15 - Nicholas W. Daudt
Page 16 - Luiz Cláudio P. de S. Alves
Page 17 - Juliana C. di Tullio
Page 18 - Luiz Cláudio P. de S. Alves
Page 19 - Rodrigo Genoves
Page 20 - Rodrigo Genoves
Page 21 - Rodrigo Genoves
Page 22 - Rodrigo Kerr
Page 23 - Rodrigo Genoves
Page 24 - Elisa Seyboth
Page 25 - Liane Dias
Page 36 - Luísa de Moraes Garcia
Page 39 - Luciano Dalla Rosa
Page 48 - Nicholas W. Daudt
Page 57 - Thiago Monteiro da Silva
Page 66 - Luísa de Moraes Garcia
Page 75 - Rodrigo Kerr
Page 84 - José Luiz L. de Azevedo
Page 93 - Nicholas W. Daudt
Page 102 - Luísa de Moraes Garcia
Page 111 - Lorena Collares
Page 128 - Rodrigo Genoves

The research projects that allowed the construction of this Atlas was sponsored or received financial and/or logistic support from

EDITORA E GRÁFICA DA FURG
CAMPUS CARREIROS
CEP 96203 900
editora@furg.br

ISBN 978-65-5754-245-3