FISKEN OG HAVET

nr. 6/2009

Et digitalt temperaturatlas for Norskehavet

A digital temperature archive for the Norwegian Sea

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HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

ISSN 0071 - 5638

PROSJEKTRAPPORT

Distribusjon:
Åpen

Havforskningsprosjektnr.:
10777 (INFERNO)

Oppdragsgiver(e):

Oppdragsgivers referanse:

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

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Dato: 06/11-2009

Program:

Økosystem og bestandsdynamikk

Faggruppe:

Oseanografi

Antall sider totalt:
38

Rapport:	**Nr. - År**
FISKEN OG HAVET	6-2009

Tittel (norsk/engelsk):
Et digitalt temperaturatlas for Norskehavet
A digital temperature archive for the Norwegian Sea

Forfatter(e):

Geir Ottersen

Sammendrag (norsk):

Et digitalt temperaturatlas for Norskehavet laget ut fra 59496 temperaturprofiler presenteres. Det består av interpolerte temperaturfelt for sesongene januar-mars, april-juni, juli-september og oktober-desember for hvert av årene 1990-2007. Atlaset dekker området 20° V - 20° Ø, 60° - 80° N med en romlig horisontal oppløsning på ½ grad i lengderetning * 1/3 grad i bredderetning og med 28 dybdenivå fra 0 til 500 m. To versjoner av atlaset er laget, et basert bare på data fra det aktuelle år og sesong, det andre inkluderer klimatologiske verdier der det mangler aktuelle data.

Summary (English):

A digital temperature archive for the Norwegian Sea compiled from 59496 temperature profiles is presented. It consists of interpolated temperature fields for the quarters January-March, April-June, July-September, and October-December for each of the years 1990-2007. The archive spans the area 20° W - 20° E, 60° - 80° N with a spatial resolution of ½ degree longitude * 1/3 degree latitude and there are 28 depth levels from 0 to 500 m. Two different versions of the archive were produced; one based only on actual data the second including climatological values where data are missing.

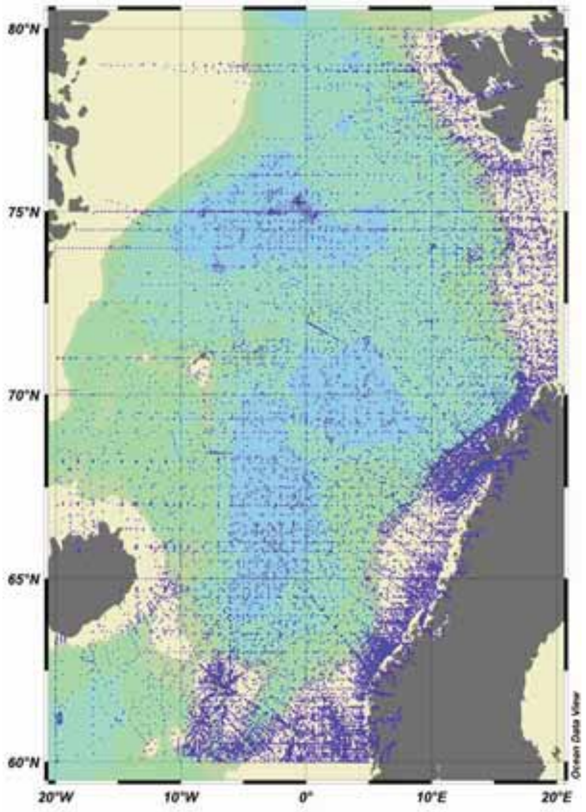
Emneord (norsk):	Subject heading (English):
1. Norskehavet	1. The Norwegian Sea
2. Temperaturatlas	2. Temperature archive
3. Interpolasjon	3. Interpolation

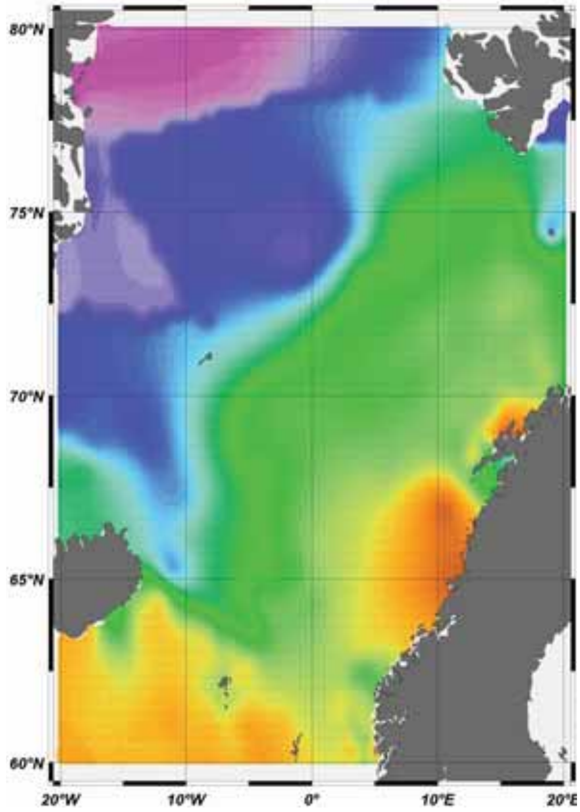
prosjektleder

faggruppeleder

A digital temperature archive for the Norwegian Sea

By Geir Ottersen





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1. Introduction

The main purpose with this temperature archive for the Norwegian Sea is to make historical temperature values available to fisheries biologists, fisheries oceanographers and fisheries managers in a format well suited for their purposes. To my knowledge, no archive of "real" temperature values covering all seasons and many years has been made for the Norwegian Sea before. Actually, an archive of this nature and quality for an area this large is unusual anywhere.

This product is NOT i) a climatology. While one of the main points of this archive is to capture the differences between years, a climatology accumulates across the years all data for a given region and season. A climatology thus represents typical values. ii) output from a model of any kind. It is based only on real measurements and as straight-forward an interpolation scheme as possible. The idea is to make it as objective as possible, independent of specific model parameterizations.

Two versions of the temperature archive were produced, both with a seasonal resolution from 1990-2007. One is based only upon temperature values from the year and season in question with grid points remote from any data point given a "missing" value. In the other version of the atlas "missing" values were replaced with climatological values from World Ocean Atlas 05 (WOA05, Locarnini et al. 2006.

Already Helland-Hansen & Nansen (1909) formulated clearly that there must be some kind of connection between fish stocks and variations in the conditions of the environment surrounding them. For some populations the variability imposed by environmental fluctuations may be minimal compared to other factors. On the other hand, stocks located at the periphery of the geographic range of the species, and especially those which experience extreme conditions, must be expected to exhibit substantial environmentally imposed variability in their population parameters (Ottersen 1996).

Bogstad et al. (1997) put the focus on how stock assessment may be enhanced by employing hydrographic data. To make such information available to stock assessment scientists, observed values should be aggregated and analysed in already established connections between environmental and population parameters. The first important step suggested was to make the data available in a suitable format, a historical database of gridded fields, a temperature archive. Concretely, Bogstad et al. (1997) point to sea temperatures being in use for calculations of fish growth and consumption. They underline the importance of having temperature estimates which reflect, as well as possible, the surroundings in which the fish actually have lived, the ambient temperatures. Bogstad et al. (1997) point to a crucial step towards an operative system for the calculation of ambient temperatures being the establishment of an archive of "true" temperatures. Here "true" means the actual temperature at a given time and location in the ocean.

Although the archive is directed towards fisheries related applications, it will also have its more direct oceanographic uses. Based upon temperature fields for the Barents Sea during the autumn 1970-2000 Ingvaldsen et al. (2003) were able to conclude that three established fixed sections are fairly representative of the Atlantic domain in the Barents Sea, at least during this time of year. Their approach was to construct maps of spatial correlation between the temperature fields and sections. The archive described in this report may be used similarly, e.g. for calculations of various temporal and spatial statistics including temperature mean and variability within regions, spatial variability as a function of distance, decorrelation radii and variability within different frequency ranges.

Further, the archive makes temperature values easily available for modelling purposes. Numerical hydrodynamic ocean models are typically initiated by temperature and salinity fields derived from actual measurements. Often climatological means, from e.g., WOA05, Locarnini et al. 2006 (global), Engedahl et al. 1998 (Nordic Seas) or Damm 1989 (North Sea) are applied, but in many cases values more directly representative for a particular year and season or month are better suited. The temperature archive presented here should be useful also for validation of model output.

2. Material and methods

2.1 Actual temperature data

2.1.1 Data acquisition

The atlas is based upon 59496 CTD (mostly) and Nansen bottle stations for the period 1990-2007 compiled from different sources (Figure 1). The starting point was data from the NISE (Norwegian Iceland Seas Experiment, Nilsen et al. 2006) project. The data made available to this project through NISE originated from the International Council for the Exploration of the Sea's (ICES') Oceanographic Database (www.ices.dk), the Institute of Marine Research, Norway (IMR, www.imr.no), The Faroese Fisheries Laboratory (FFL, www.frs.fo), and the World Ocean Database 2005 (WOD05, http://www.nodc.noaa.gov/OC5/WOD05/pr_wod05.html; Boyer et al. 2006). A significant number of additional stations were also included from IMR, FFL, WOD05 and The Marine Research Institute, Iceland (MRI, www.hafro.is). Most of the stations were sampled by CTD and values available for approximately every decibar (m) or every 5 decibar (m). Data from stations sampled by Nansen bottle were available at standard oceanographic depths.

2.1.2 Data handling

Data handling was done by means of the Ocean Data View (ODV) software (Schlitzer 2006), several FORTRAN programs developed by the author and to a lesser degree SAS (SAS Publishing 2004; www.sas.com). ODV was also used for visualization and some calculations.

ODV is a computer program for the interactive exploration and graphical display of oceanographic and other geo-referenced profile, sequence or gridded data. The software is available for Windows (9x/NT/2000/XP/Vista), Linux, Unix, and Mac OS X systems. ODV data collection and configuration files are platform independent and can be easily exchanged between all supported systems. ODV lets you maintain and analyse large sets of station data on inexpensive and portable hardware. The software can be downloaded from http://odv.awi.de.

2.1.3 Quality control

All data were gathered from trustworthy data bases, and have already been subject to the quality checking routines employed by the respective institutions (e.g., see http://www.ices.dk/Ocean/odmsoft/index.htm for an overview of ICES procedures). Also, since only the period from 1990 is covered, some technical and methodological problems that could apply to older data are not an issue. No thorough quality control routines were thus employed a priori. Unfortunately, during the process a significant number of stations were identified with erroneous format. The most common forms of error were i) stations with depths repeated with different temperature values, ii) stations that started again at low depths (either with the same or different values) and iii) data lines with non-numerical temperature values. In each of these cases there was no way to determine the correct values so either the full station or part of it was deleted from the data set.

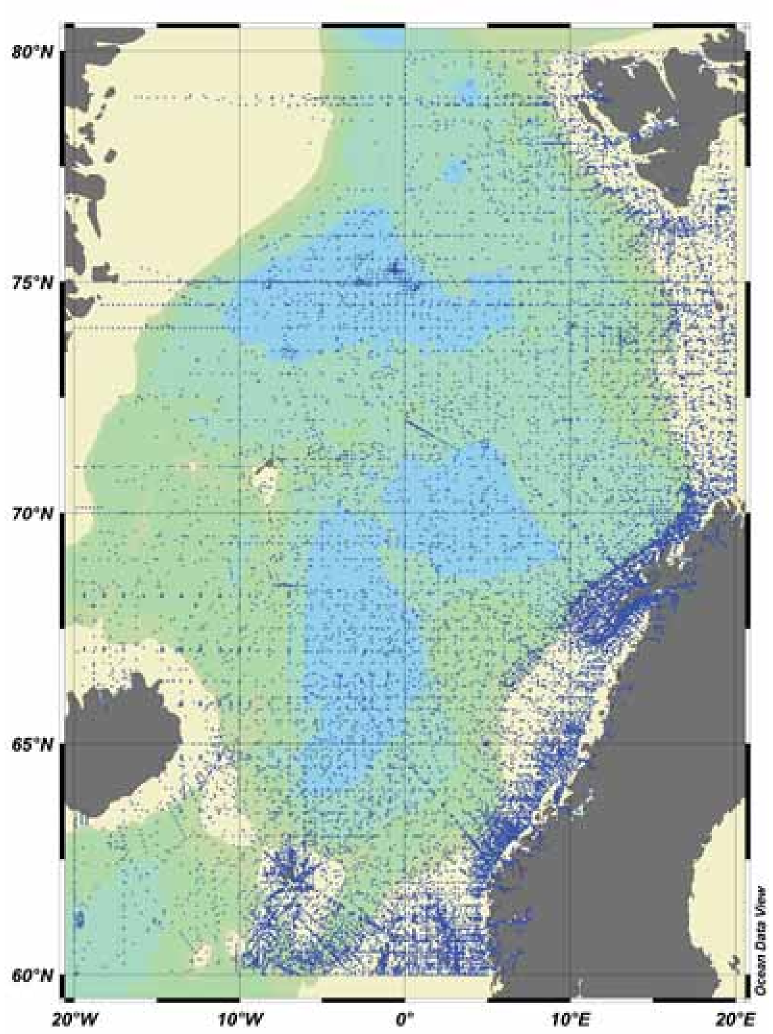

Figure 1. The 59496 hydrographic stations from 1990-2007 that the temperature atlas is based upon.

2.1.4 Duplicates

When accumulating data from several sources, overlap between the different data sets must be expected. Since the different databases typically use different protocols for identifying sources of data origin, countries, cruises and stations, identifying duplicate stations may be complicated. In this case substantial overlap especially between the ICES, IMR and WOD05 had to be taken care of. It was not possible to identify and remove duplicates fully automatically so a semi-manual approach was used.

It could not a priori be assumed that all the relevant IMR data were in the ICES data base, nor could all Norwegian data in the ICES base be expected to be present in IMR's database. After inspection, it was assumed that no Norwegian data is present in WOD05 that isn't also present in the ICES or IMR bases. The following procedure was then applied in ODV. Firstly, all data from WOD05 marked as Norwegian (land code 58) was removed. Secondly, all data from ICES originating from IMR's main vessels GO Sars, Johan Hjort and Michael Sars were removed. Thirdly a semi-manual inspection was performed in all cases where more than one station was identified by ODV to be within the same day and 0.01 degrees latitude by 0.01 degrees longitude area (> 5000 stations). For most cases I concluded that the stations were not identical. For instance, neighbouring stations (in, e.g., fjords) may be closer than 0.01° or for some experiments consecutive stations may be taken at one single location. In all these cases I decided to keep both/all occurrences. In the remaining cases, where actual duplicates were determined, all stations but one were eliminated from each set of replicate stations, mostly on a cruise by cruise basis.

2.2 Climatological temperature values

One of the two versions of the temperature archive also includes climatological values from World Ocean Atlas 05 (WOA05, Locarnini et al. 2006; Figure 2). This is a thoroughly updated version of what is arguably the most well known of all hydrographic archives, which originated as (Levitus 1982). These climatological fields of temperature, salinity and other parameters cover the world oceans on a 1° * 1° spherical grid at standard levels down to 5500m. The fields of WOA05 are monthly for the upper 1500m, seasonal below. The archive was made by means of an objective analysis scheme (Cressman 1951) applied to data from World Ocean Database 2005 (Boyer et al. 2006).

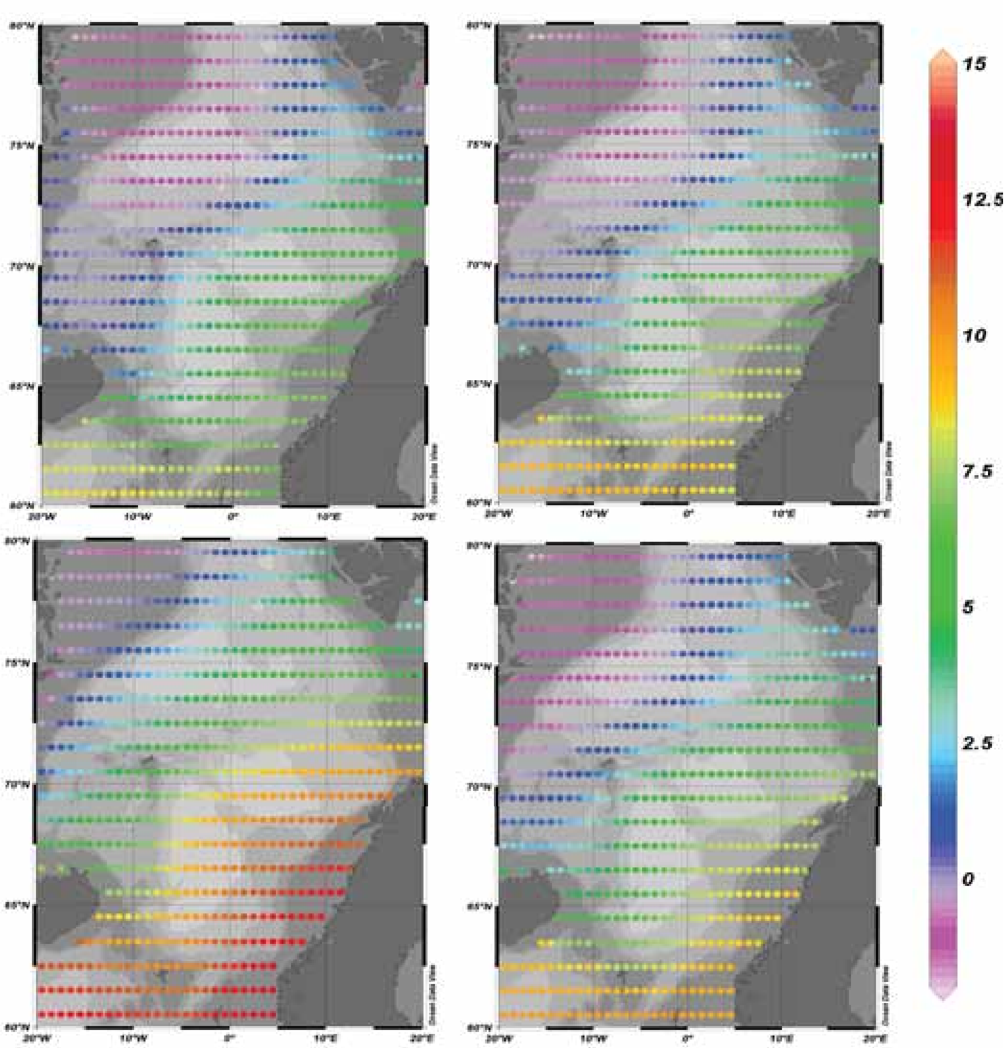

Figure 2. Seasonal climatological values at 0 m from World Ocean Atlas 05 (WOA05; Locarnini et al. 2006). a) January-March, b) April-June, c) July-September, d) October-December.

2.3 Algorithm for producing the archive

2.3.1 General approach

Data from the various databases were imported into ODV source by source and compiled into one single ODV data collection. The data from NISE (Nilsen et al. 2006) were available as an ODV collection while WOD05 data could be imported directly. Other data sets were first transformed to a suitable column-based ascii format by means of self-developed Fortran programs before being imported. Data were extracted from ODV by year and season in the ODV spreadsheet format. They were then transformed to polarstereographic grid coordinates, followed by vertical, then horizontal interpolation. Finally the fields were converted to a latitude/longitude grid and combined to single files in respectively text, SAS, and ODV formats (Figure 3).

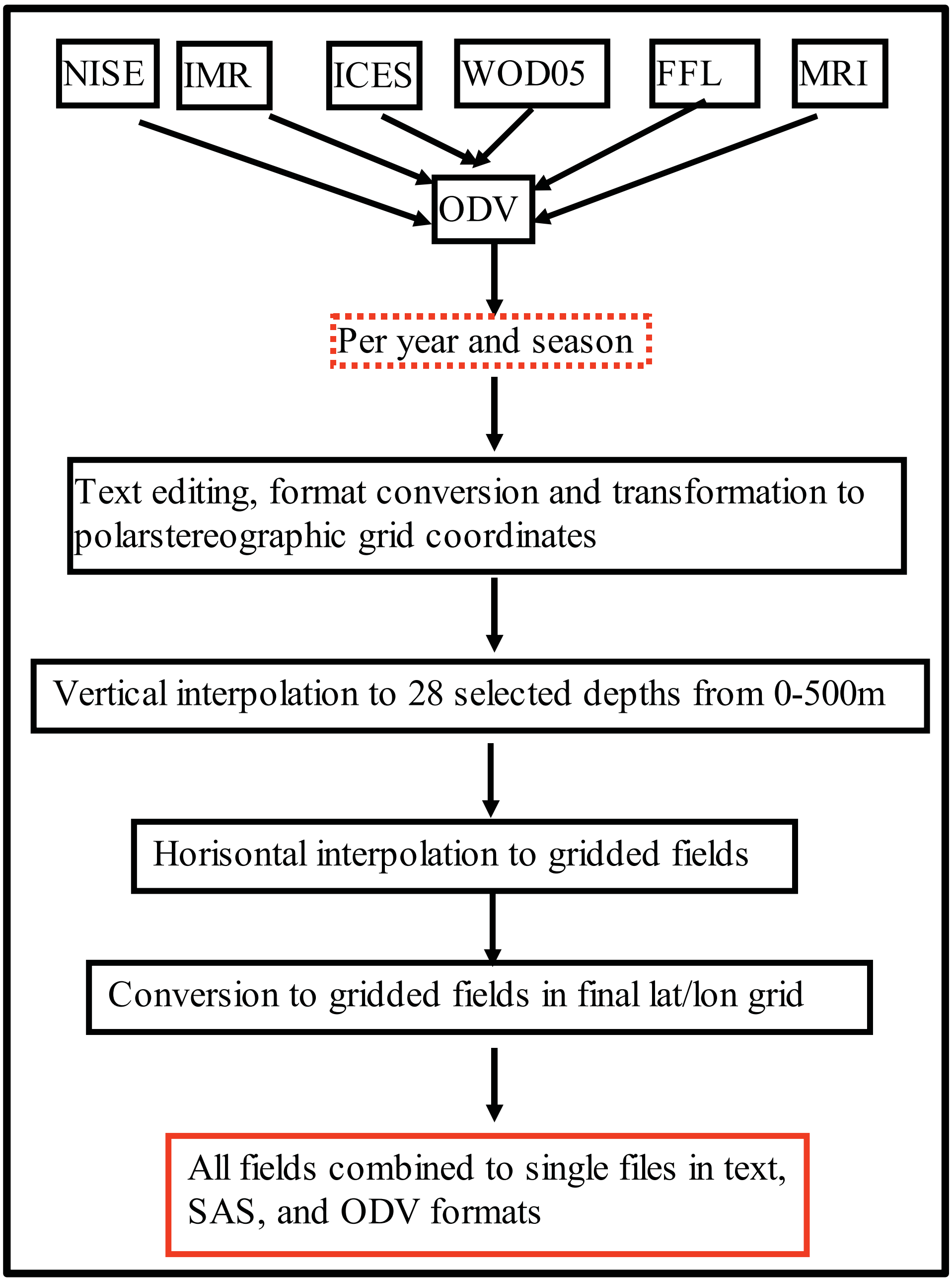

Figure 3. Flowchart of production of temperature archive with fields based solely on data values for the actual year and season.

2.3.2 The Interpolation scheme

An important part of the archive production is how the information in spatially scattered stations is transformed to systematic grids with one value in each square. The MODgrid, Model Oriented Data gridder, software developed by (Ottersen 1991) and updated in connection with this work, was used.

The first step was a simple linear vertical interpolation separately for each station resulting in values at every selected depth level down to the deepest measurement or 500m. The chosen depth levels are 0, 5, 10, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, 150, 200, 250, 300, 400, and 500 metres.

For each separate level a 2d algorithm (Taylor, 1976), combining Laplace and cubic spline interpolation, was then applied. While Laplace interpolation is a 2-dimensional analogy to linear interpolation, cubic spline interpolation involves the fitting of polynomials of degree at most three between data points. Using the method of successive over-relaxation (SOR) the Laplace-spline equation, $\partial^2/\partial x^2\,(z) + \partial^2/\partial y^2(z) - K(\partial^4/\partial x^4(z) + \partial^4/\partial y^4(z))=0$, is solved over the entire grid-net iteratively, improving the solution for non-data grid points. The constant K determines the weight of the spline part of the equation and has a range from 0 (pure laplacian) to infinity (pure spline). K=5 was used here.

The aim of the interpolation was to construct fields with as correct values as possible in the parts of the sea where there were stations. In other areas, the grid was set to “undefined”, not filled with extrapolated values. The inference radius, maximum number of grid cells a grid point may be from a data point without being set to undefined, is restricted to 15. This value was used homogenously and isotropic throughout the grid despite non-uniform data coverage and applied for all years, seasons and depths, independent of the varied number of stations. The interpolation scheme is purely 2d. The values in the original data points are permitted to be adjusted through the interpolation procedure. No smoothing is performed at this stage except for the implicit effect of the interpolation. Points on land (or on “land” at the depth level applied) are set to 99.999, missing sea data points are set to -99.999.

2.3.3 Incorporating climatological values

There is a balance to be found between a high inference radius, which fills in a larger number of grid cells, but may extrapolate to unreasonable values, and a lower inference radius, which may leave many grid cells without a real data value (“missing” values) because their distance to the nearest data point was larger than the inference radius. Here an inference radius of 15 has been chosen, a value that is relatively low given the sparseness of data for some seasons and areas, and thus leaves a number of grid cells with “missing” values.

In some cases fields without any “missing” values are needed or at least highly preferable, e.g., for initiation of hydrodynamic models. Thus, a second version of the temperature atlas was made in which “missing” values were replaced with climatological values. For this version of the temperature atlas climatological seasonal values for the grid area are first extracted from the larger WOA data sets and stored in separate ODV collections. Values are then exported from ODV, edited and interpolated vertically to the same depth levels as the actual data, still in the coarser resolution of the WOA data sets. Further (by means of a self made FORTRAN program), successive iterations are made through the fields gridded from actual data, and “missing” values replaced with the climatological value from the corresponding location and depth (Figure 4).

Close to land there may be grid cells with discrepancies between the depth matrix used when gridding actual values and that of the climatology. This is partly due to the coarser resolution of the climatology. In cases when the cell value is “missing” in the fields from actual data and

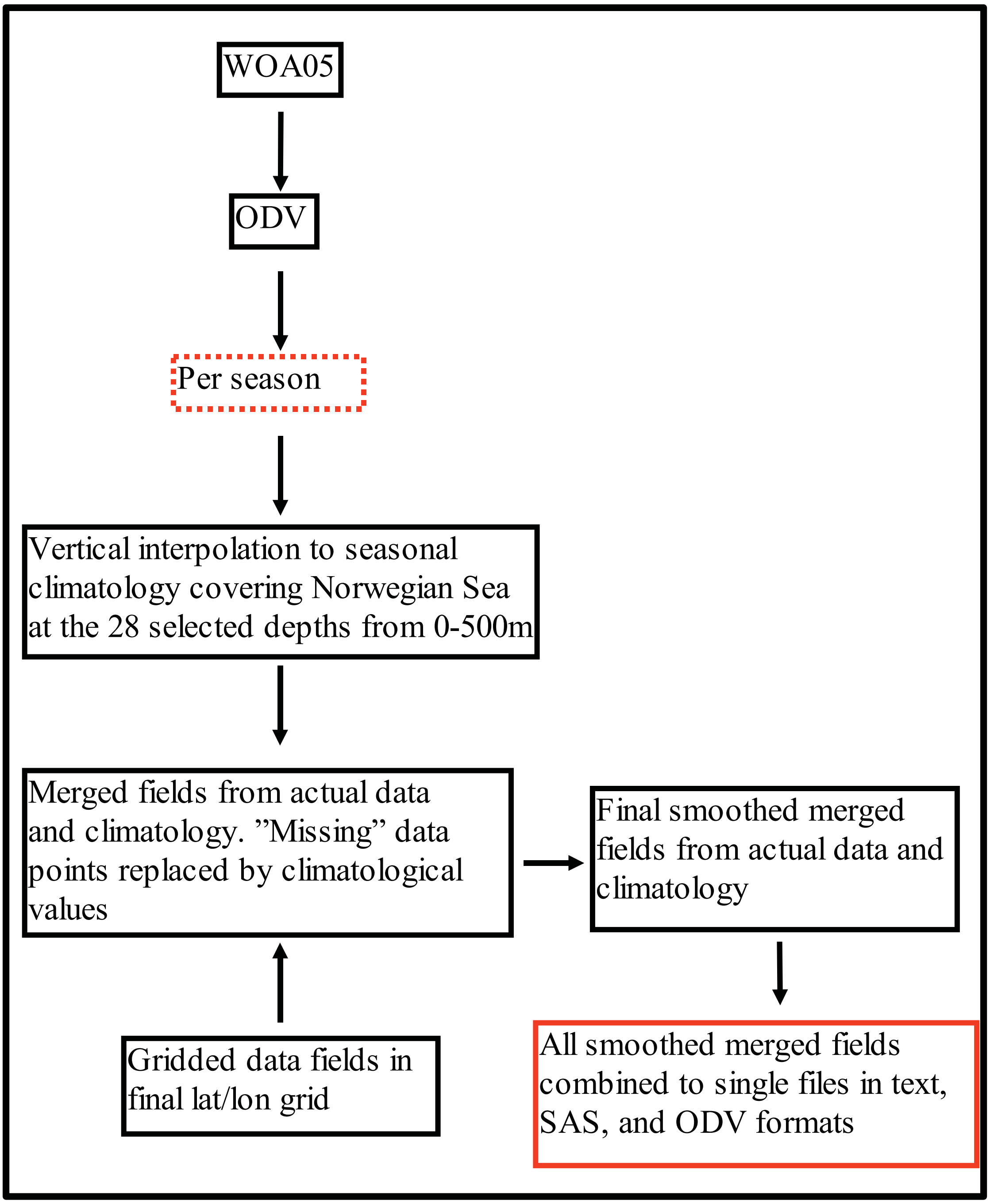

Figure 4. Flowchart of production of temperature archive with fields based on data values for the actual year and season and climatological values.

“land” in the climatology the resulting value is “land”. The final fields therefore consist of three types of values; actual temperature values as before, climatological values, and “land” values.

To avoid unrealistically large gradients in the fields, due to discrepancies between actual and climatological values, Laplacian smoothing was used. Generally, applying a Laplacian smoother to a grid point Zg, implies that

$$Zg = Zg + .25 * [\text{Average}(ZN, ZS, ZE, ZW) - Zg],$$

where ZN, ZS, ZE, and ZW are the values of the surrounding cells. Here, the smoother was applied 5 times.

2.4 Brief discussion of methods

The methods here are by no means state-of-the-art interpolation techniques (see, e.g., http://modb.oce.ulg.ac.be/projects/1/diva for information on the DIVA interpolation tool). However, an earlier version of the interpolation system works in practice and has been applied to, and proven well suited for, interpolation of hydrographic data for a variety of purposes (Martinsen et al. 1992, Ottersen & Ådlandsvik 1993, Ottersen et al. 1994, Engedahl et al. 1998, Ottersen et al. 1998; Ingvaldsen et al. 2003).

The choice of some of the properties of the horizontal interpolation scheme must be argued for. I chose to use an interpolation procedure with a homogeneous inference radius throughout the whole area, even if the data coverage of certain parts of the sea was a lot better than others. Although one locally might be able to get values that are more representative by adjusting the inference radius, this would complicate the overall picture and possibly introduce additional artificial features. A better idea might be a homogeneous, but non-isotropic interpolation procedure. The same inference ellipsis would then be used over the whole region, but directionally differentiated according to the current system. Such a procedure would, however, be complex, especially if the seasonal variations in the current pattern/advection were to be taken into consideration.

Monthly fields, as opposed to the chosen quarterly, would be advantageous for some purposes. However, the statistics (Figure 5) show clearly that the data coverage for most months was too poor to allow for production of monthly fields of a reasonable quality. On the other hand, the spatial resolution is quite high. Technically an even higher resolution could be used, but this would only seemingly give a better archive, the real resolution is determined by the station data. Since fish data often are given with a coarser resolution, acoustic densities typically at 30’ latitude and 1° longitude in Norwegian waters (Ottersen et al. 1998), some main uses of the archive will be at this less refined level.

3. Results

3.1 Brief description of the Temperature Archive

Gridded temperature fields for the Norwegian Sea for the quarters January-March, April-June, July-September, and October-December where prepared for each of the years 1990-2007. The archive spans the area 20° W-20° E, 60°-80° N with a spatial resolution of ½ degree longitude * 1/3 degree latitude and there are 28 depth levels from 0 to 500m. Two different versions of the archive were produced. The first version is based solely on actual data and includes ocean grid cells with “missing” values in addition to real temperature values and cells on land or shallower than the depth level in question. In the second version all “missing” cells have been filled in with climatological values.

3.2 Availability of Temperature Archive

The temperature archive is freely available for scientific non-commercial purposes as long as this report is referred to. Both versions of the archive can be downloaded from the Instittute of Marine Research's web pages in three different formats: ascii/text (1 file 280 Mb), SAS (1 file 400Mb or four files, one for each season at 99 Mb each), and ODV (several files, totalling 107 Mb). Each data line consists of a temperature value for a given year and season, and grid cell given as lat, lon, depth. In the ascii and SAS files each data line is given in the format date (ddmmyyyy), depth, latitude, longitude, temperature.

3.3 Spatio-temporal data coverage

The temperature data the archive is based upon are unevenly distributed both in space and time. The annual number of stations in the region has varied from year to year without any obvious systematic trend, although there was an outstandingly good effort in 1990 (Figure 5). The number is typically highest in the spring and summer giving the best coverage in the 2nd

(April-June) and 3rd (July-September) quarters (Figures 5, 6). There were, for example, 2375 stations in the 2nd quarter of 1990, more than ten times that of the 321 stations in the 4th quarter of 2005 (Figure 7). Spatially there is, as could be expected, a general pattern of more stations in the east and south than in the west and north (Figures 1, 6, 8). The longitudinal peak at around 7° W reflects intense sampling around and south of the Faeroe Islands, the peaks at 5° E and 15° E is mainly due to the pronounced effort along the coast of respectively western Norway and the Lofoten/Vesterålen area in Northern Norway (Figure 8).

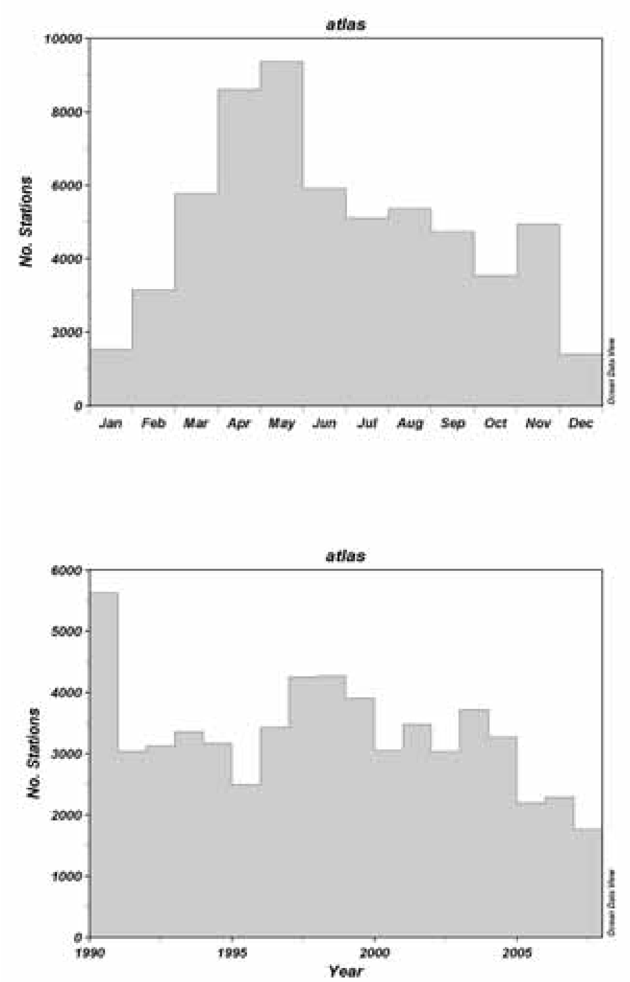

Figure 5. Temporal distribution of stations among months (upper panel) and years (lower panel). Note that while in the upper panel the abbreviation for the month along the x-axis is centred below the corresponding bar, in the lower panel the value for year is positioned to the left of the corresponding bar.

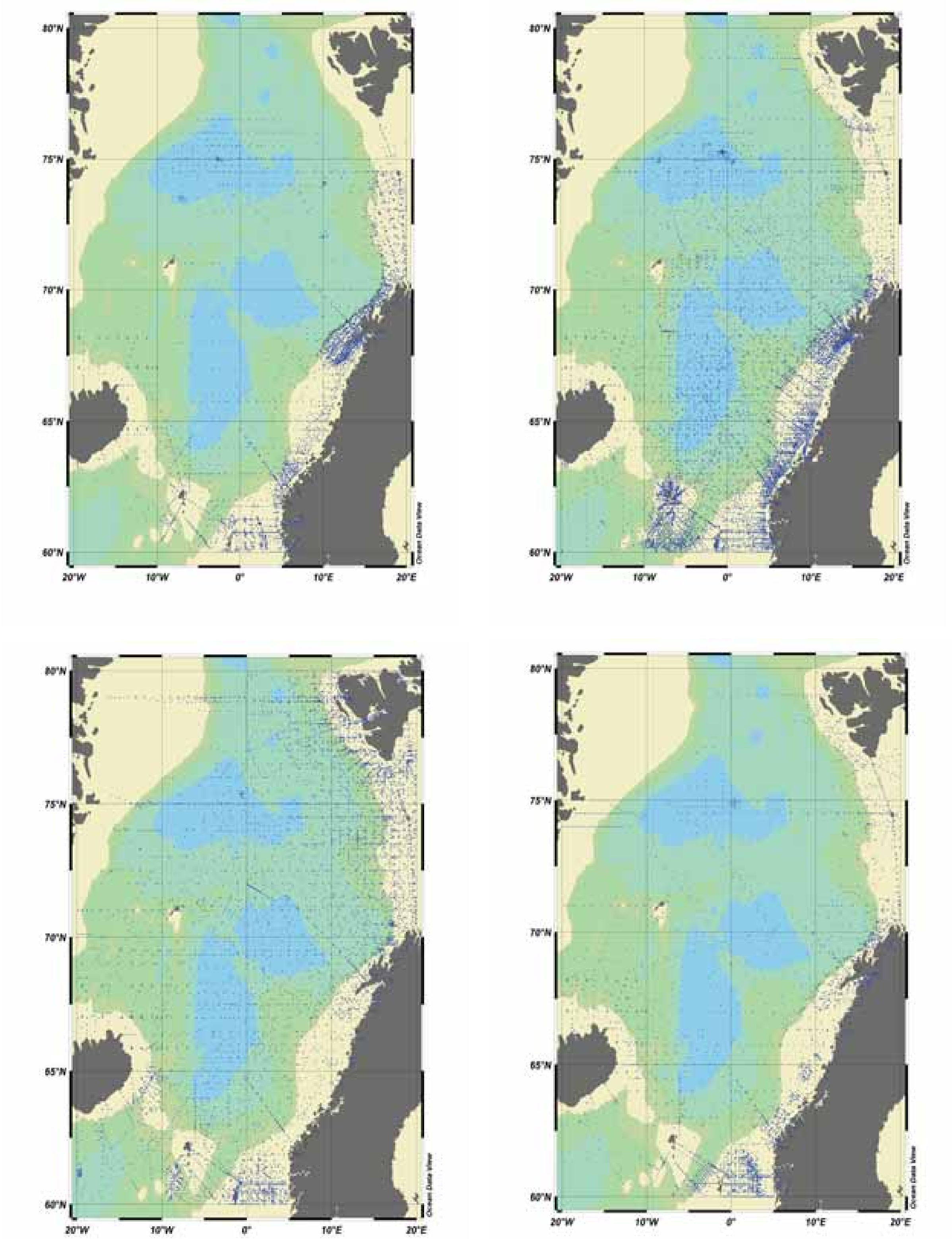

Figure 6. Spatial data coverage per season, all years 1990-2007 for January-March (upper left panel), April-June (upper right), July-September (lower left), and October-December (lower right).

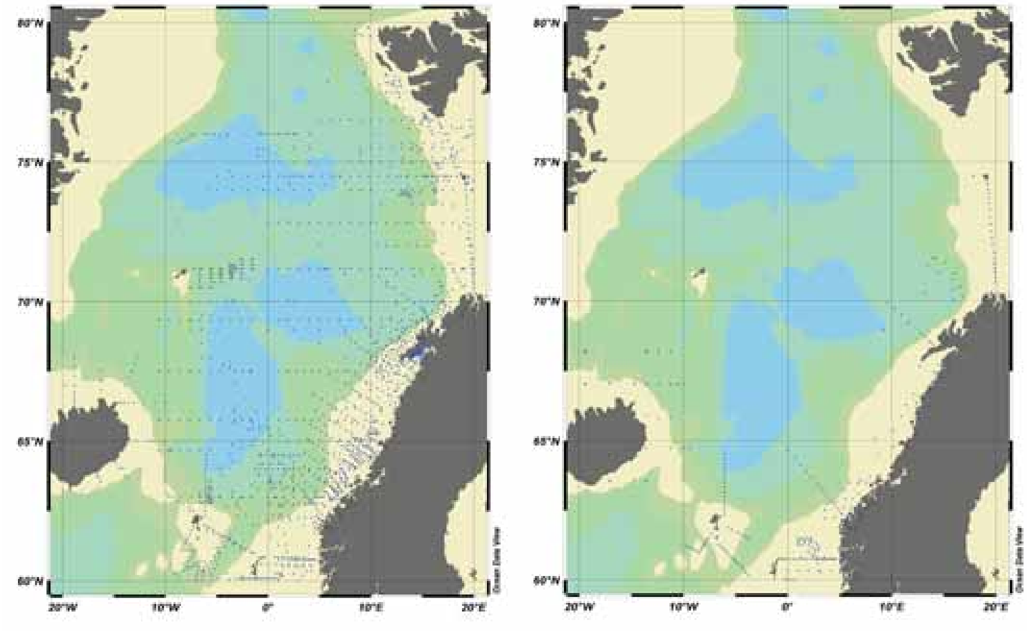

Figure 7. Difference in data coverage between one of the seasons with best coverage (April-June 1990, left panel) and one of the poorest (October-December 2005, right panel).

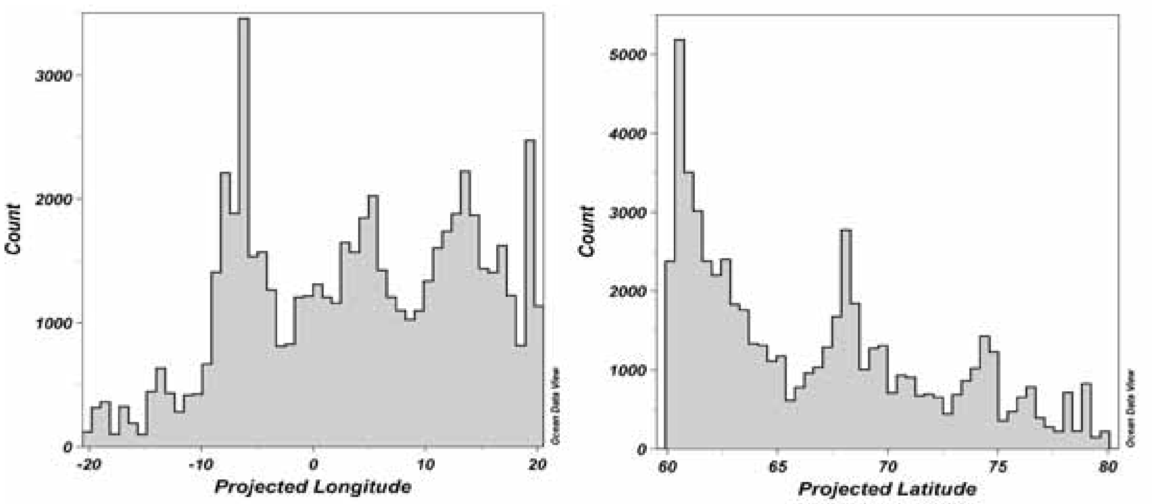

Figure 8. Spatial distribution of data coverage 1990-2007 according to longitude (left panel) and latitude (right panel).

3.4 The temperature fields based upon actual data

Examples of 2D fields from the temperature atlas based only upon actual data are given in Figures 9-12. The underlying data subsets, for any given year, season or subarea, can easily be extracted from the archive by means of, e.g., SAS or ODV, the latter has here been used for visualization.

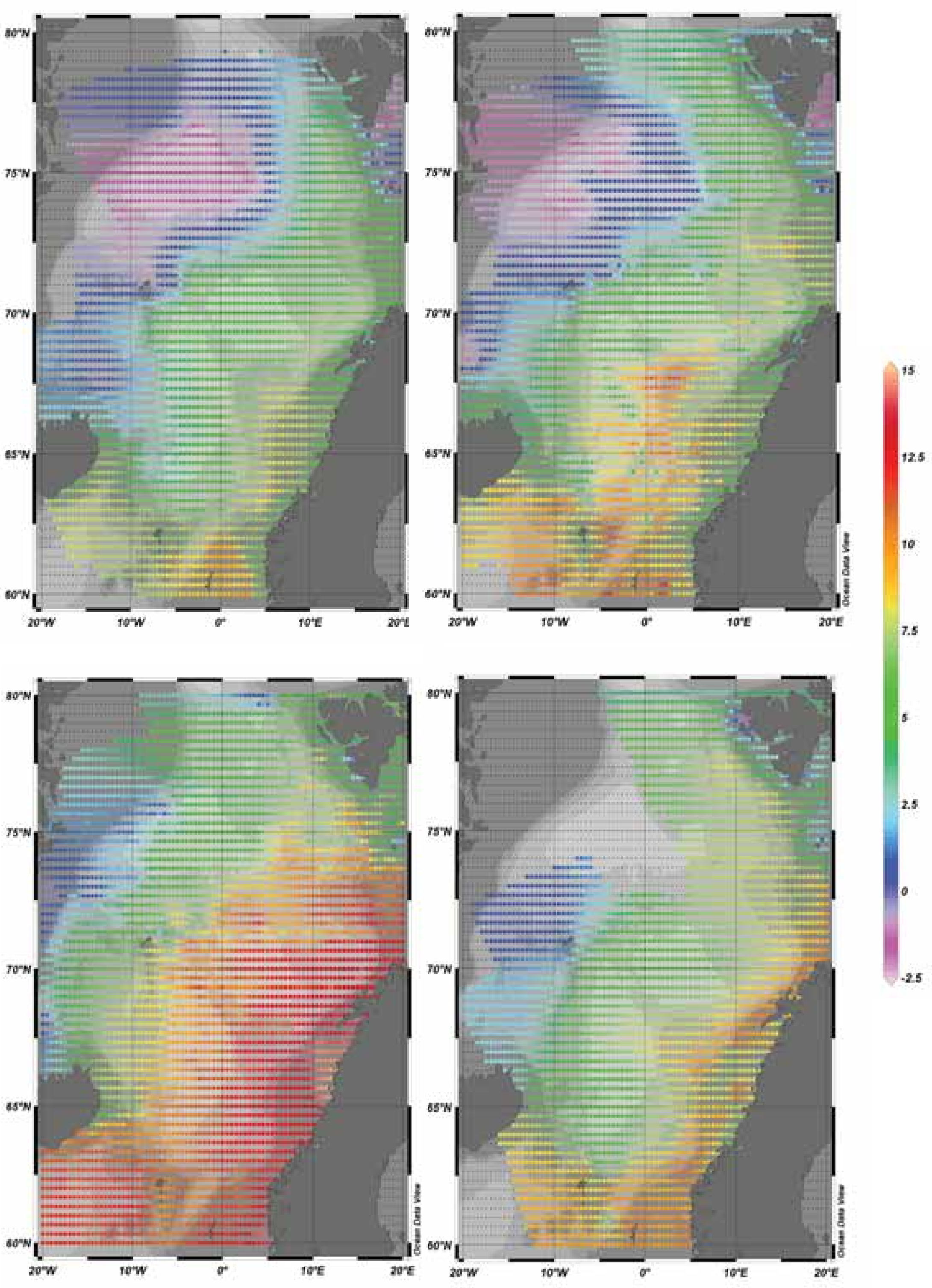

Figure 9. 2D temperature fields at 0 m depth (surface) from the temperature atlas based only upon actual data for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each (non-missing) grid cell shown.

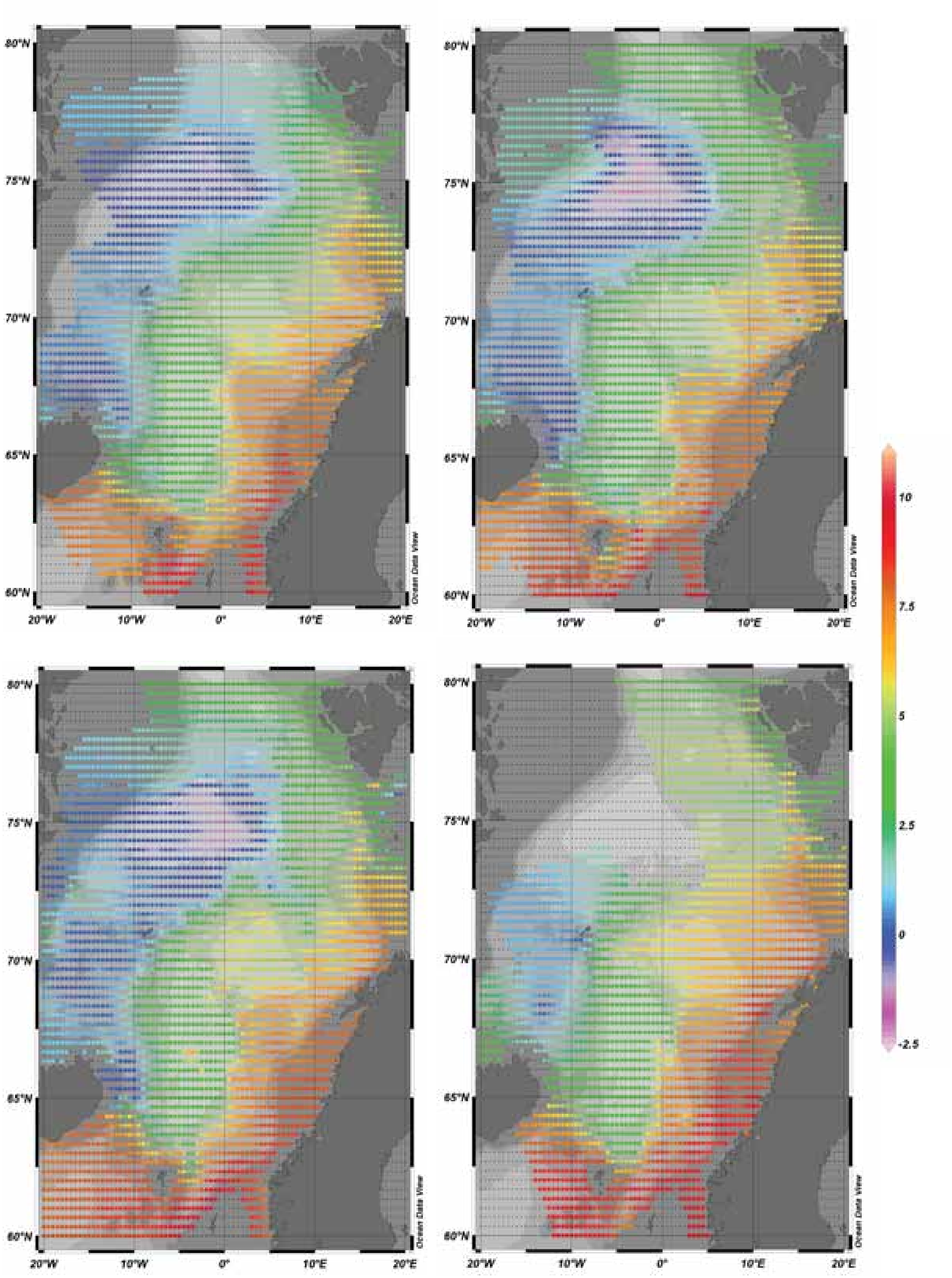

Figure 10. 2D temperature fields at 200 m depth from the temperature atlas based only upon actual data for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each (non-missing) grid cell shown.

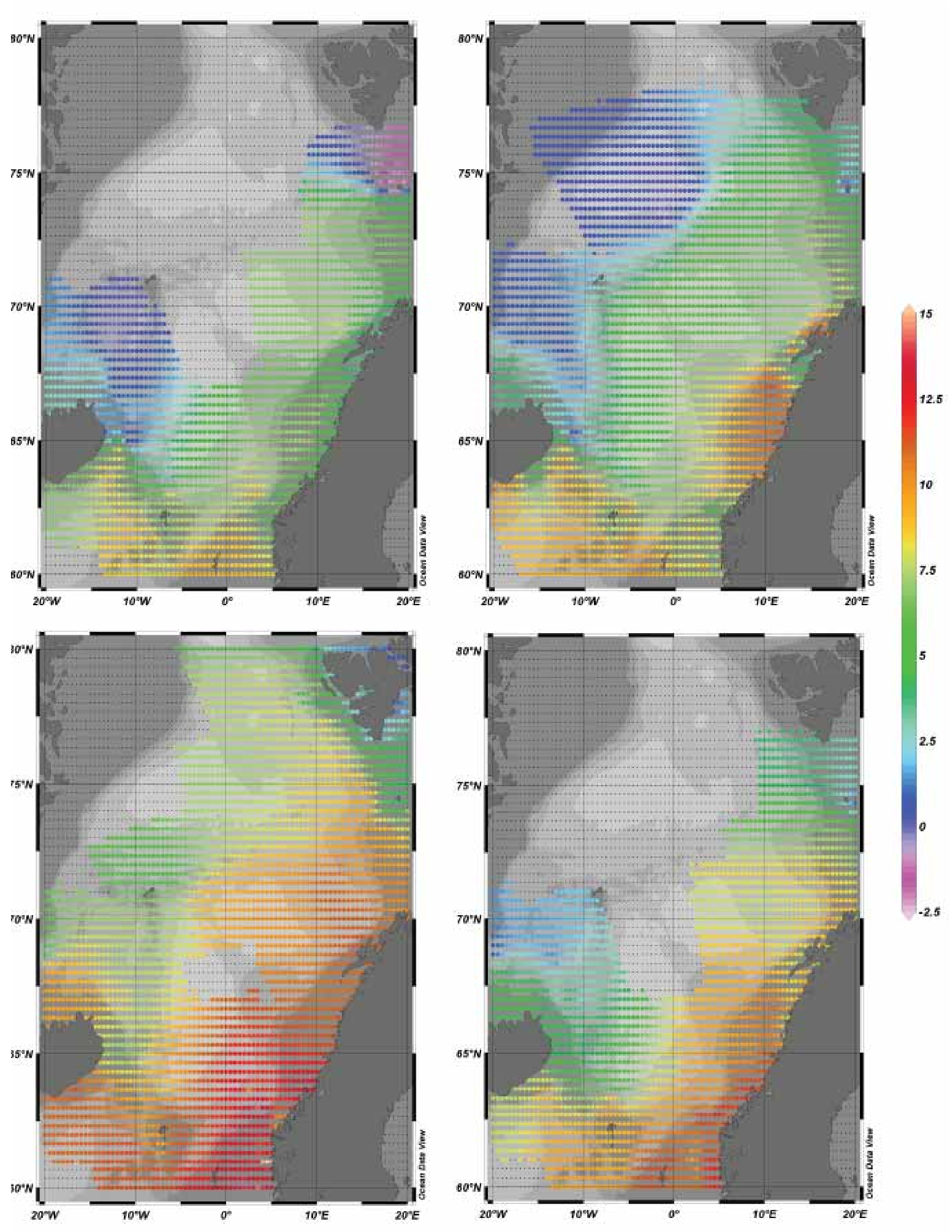

Figure 11. 2D temperature fields at 0 m depth (surface) from the temperature atlas based only upon actual data for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each (non-missing) grid cell shown.

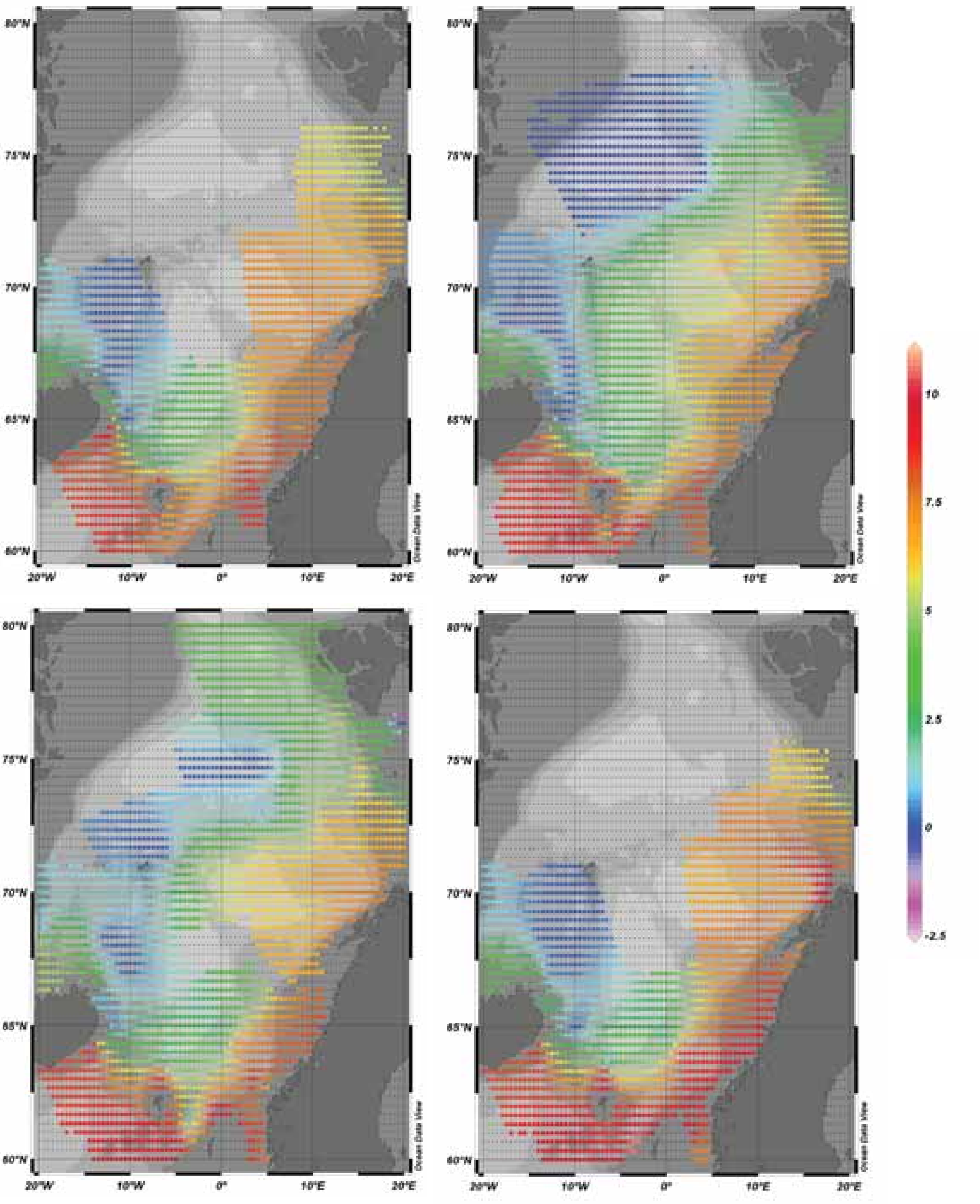

Figure 12. 2D temperature fields at 200 m depth from the temperature atlas based only upon actual data for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each (non-missing) grid cell shown.

3.5 The temperature fields based upon actual data and climatology

Examples of 2D fields from the temperature atlas based upon actual data and WOA05 climatological values are given in Figures 13-20. Non-smoothed values for each (non-missing) grid cell are displayed. The underlying data subsets, for any given year, season or subarea, can easily be extracted from the archive by means of , e.g., SAS or ODV, the latter has here been used for visualization. For each case original values for each grid cell as well as fields smoothed for visualization by DIVA interpolation are shown.

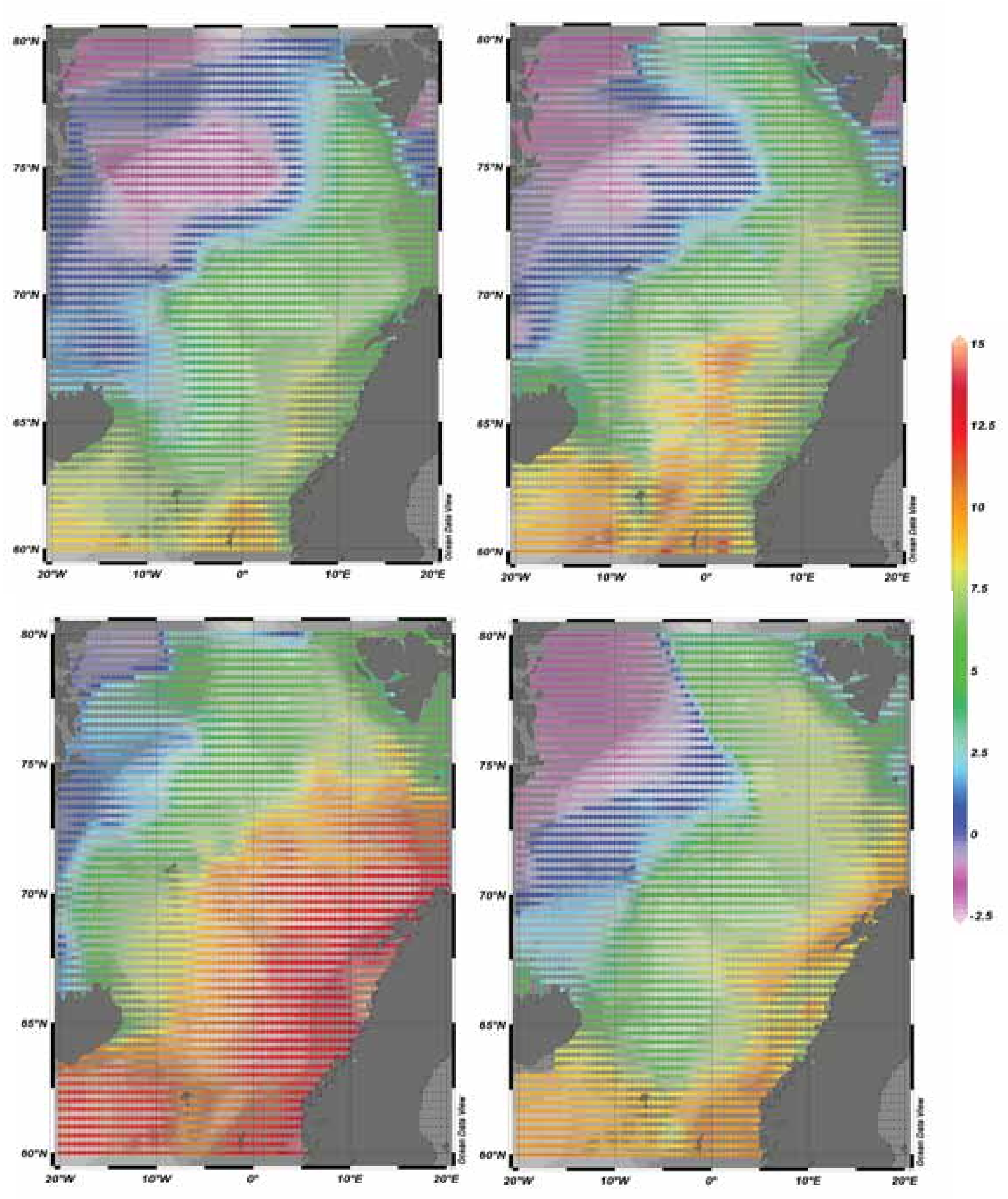

Figure 13. 2D temperature fields at 0 m depth (surface) from the temperature atlas based upon actual data and the WOA 05 climatology for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each grid cell shown.

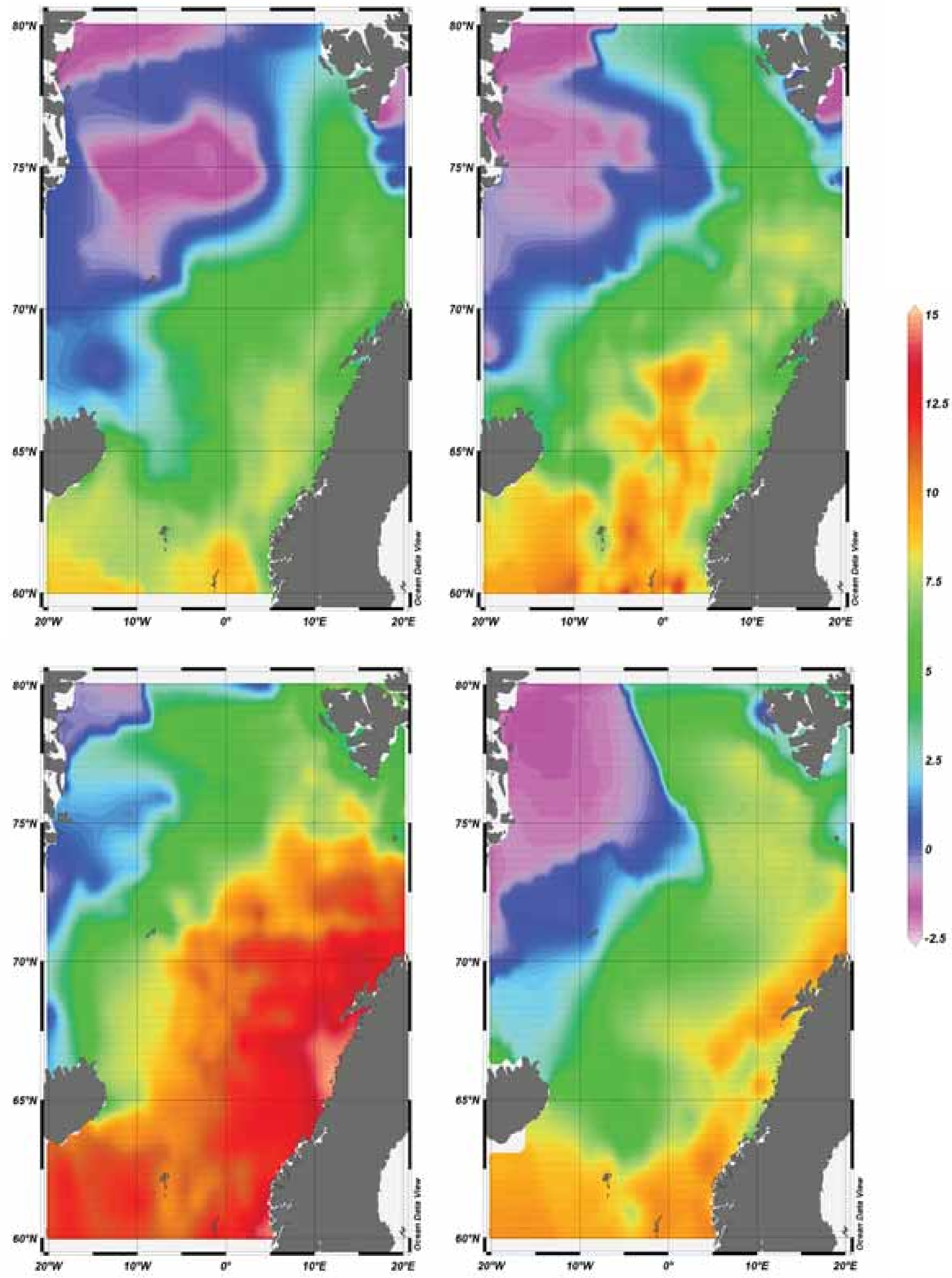

Figure 14. Data as in Figure 13. 2D temperature fields at 0 m depth (surface) from the temperature atlas based upon actual data and the WOA 05 climatology for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Temperature field visualized by DIVA interpolation.

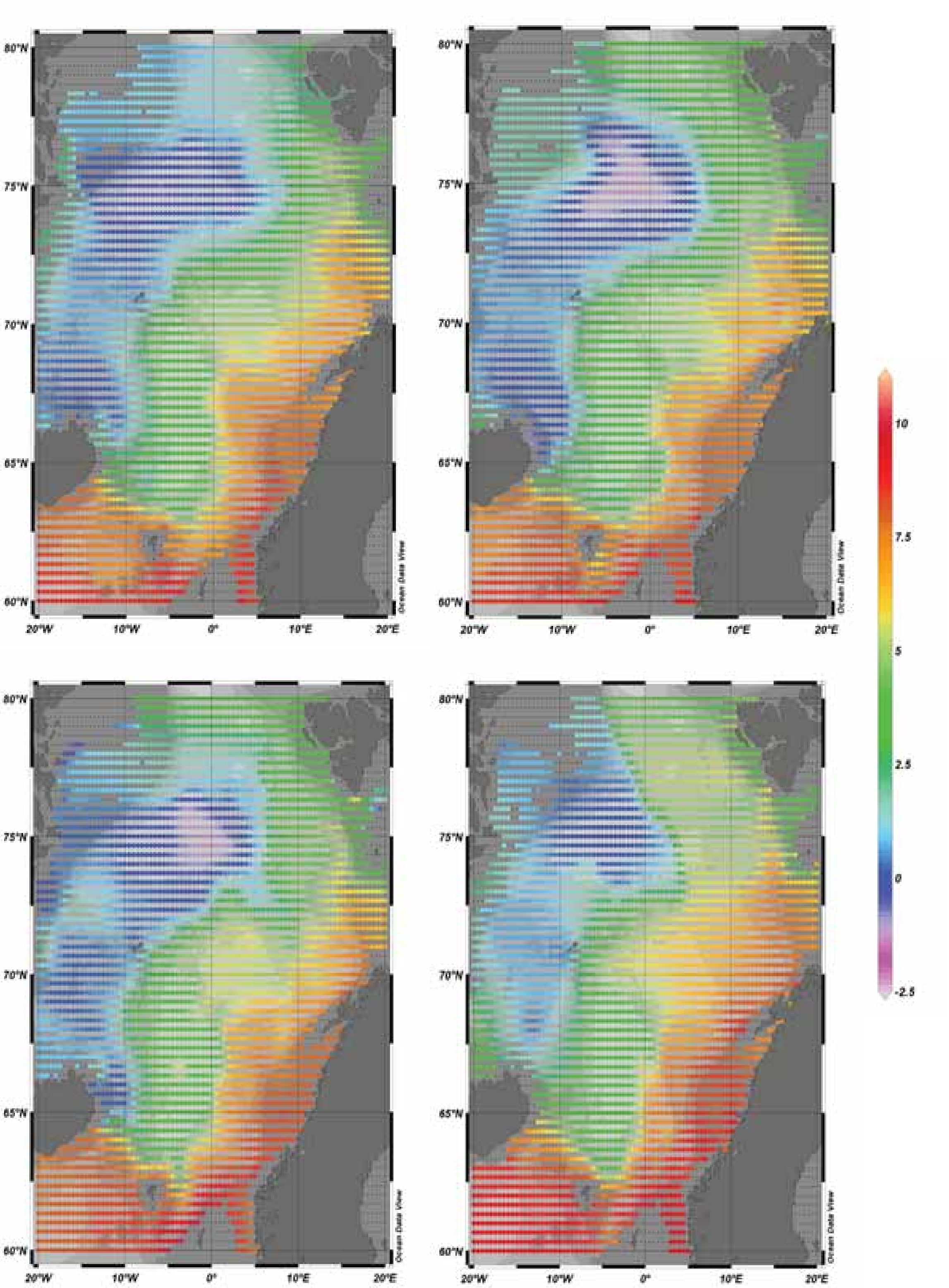

Figure 15. 2D temperature fields at 200 m depth from the temperature atlas based upon actual data and the WOA 05 climatology for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each grid cell shown.

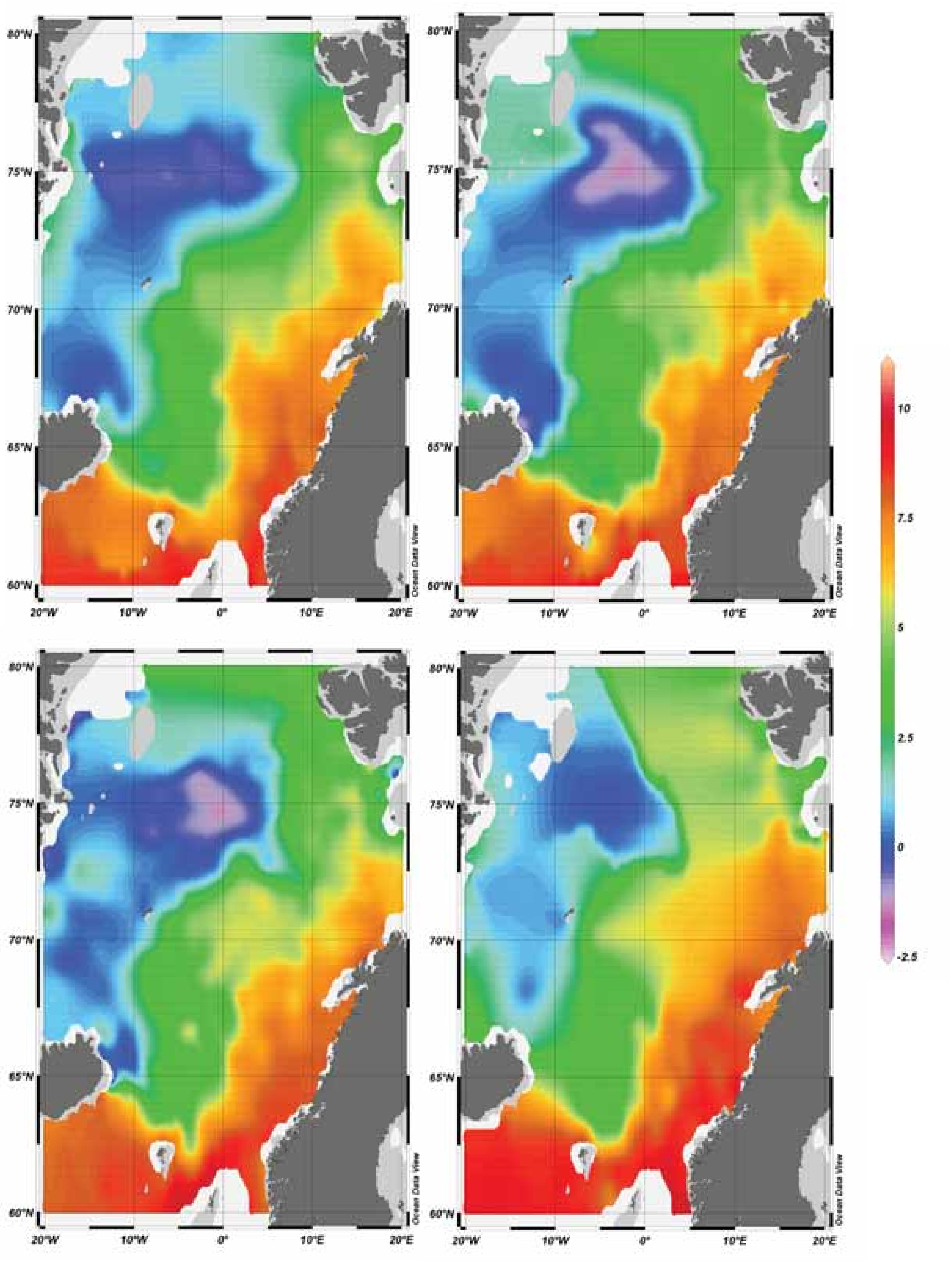

Figure 16. Data as in Figure 15. 2D temperature fields at 200 m depth from the temperature atlas based upon actual data and the WOA 05 climatology for 1990 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Temperature field visualized by DIVA interpolation.

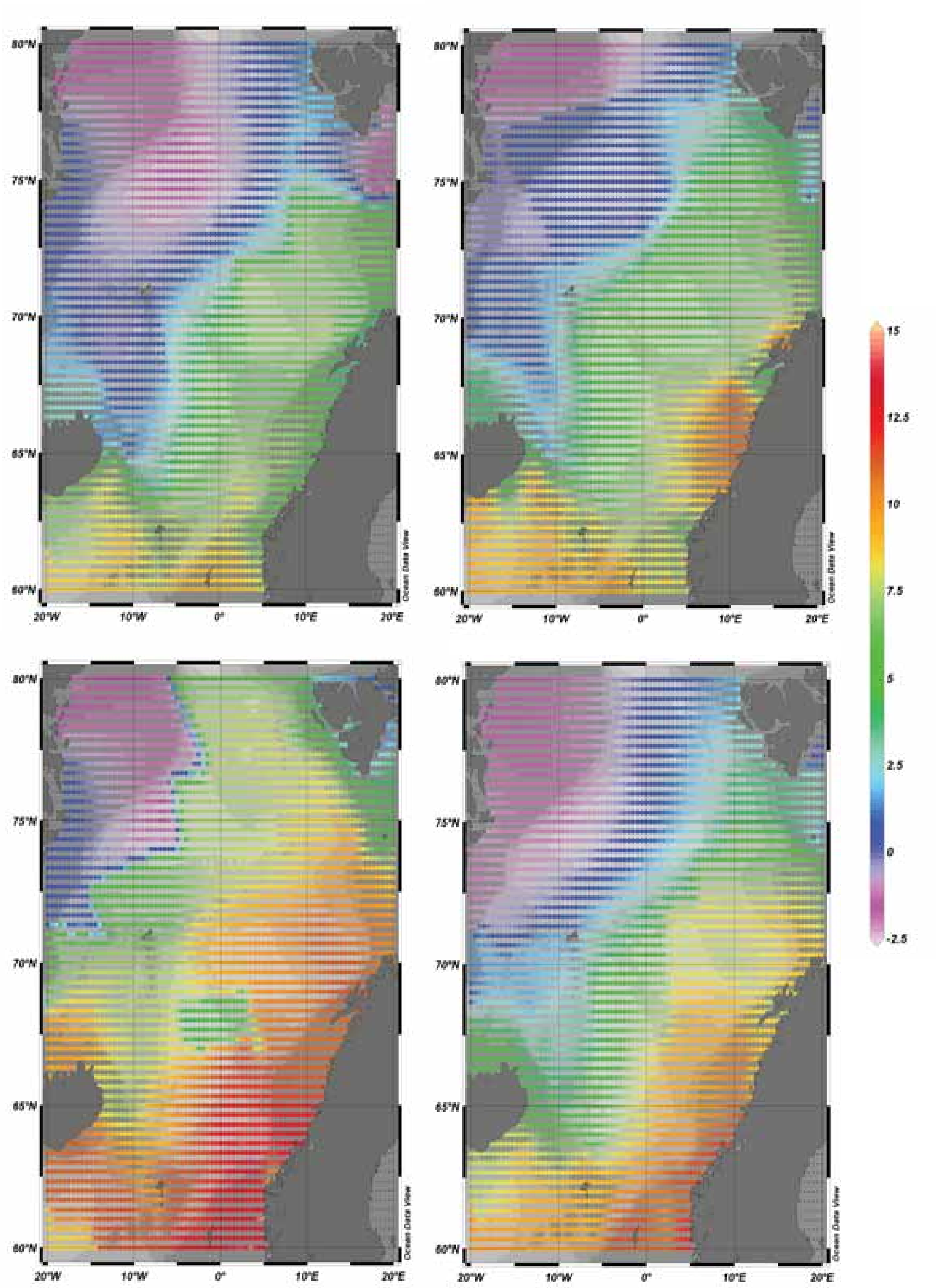

Figure 17. 2D temperature fields at 0 m depth (surface) from the temperature atlas based upon actual data and the WOA 05 climatology for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each grid cell shown.

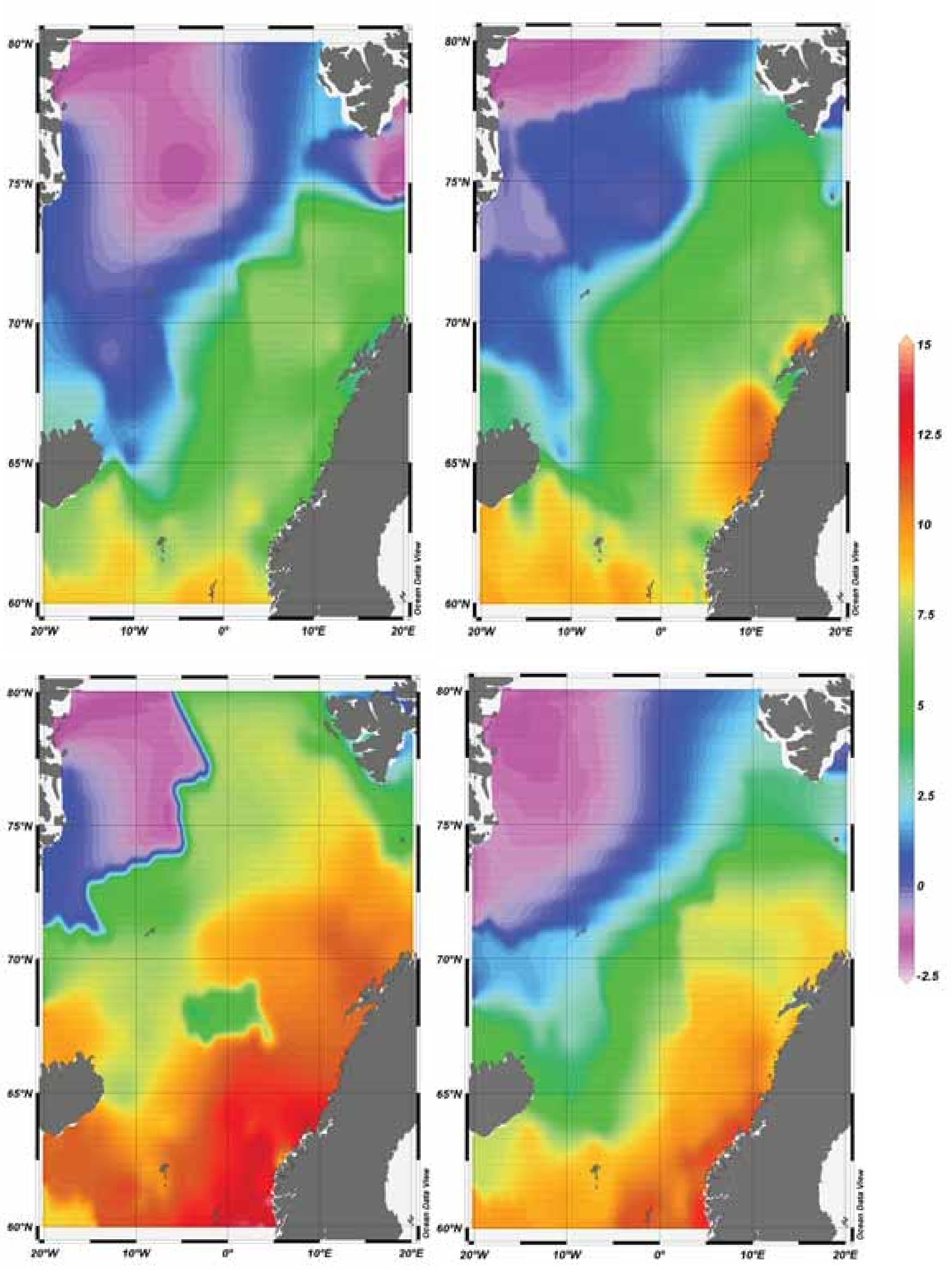

Figure 18. Data as in Figure 17. 2D temperature fields at 0 m depth (surface) from the temperature atlas based upon actual data and the WOA 05 climatology for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Temperature field visualized by DIVA interpolation.

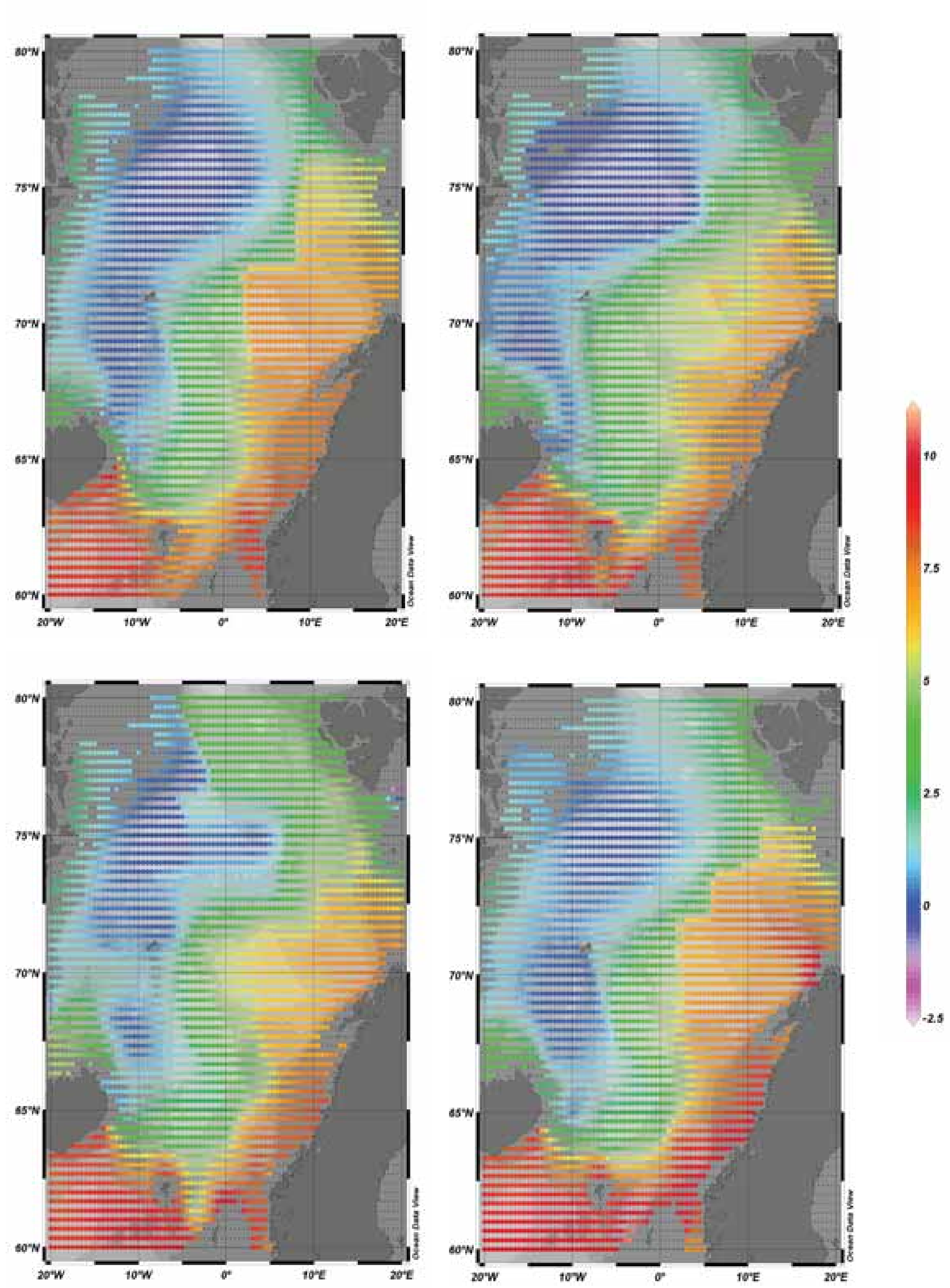

Figure 19. 2D temperature fields at 200 m depth from the temperature atlas based upon actual data and the WOA 05 climatology for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Original values for each grid cell shown.

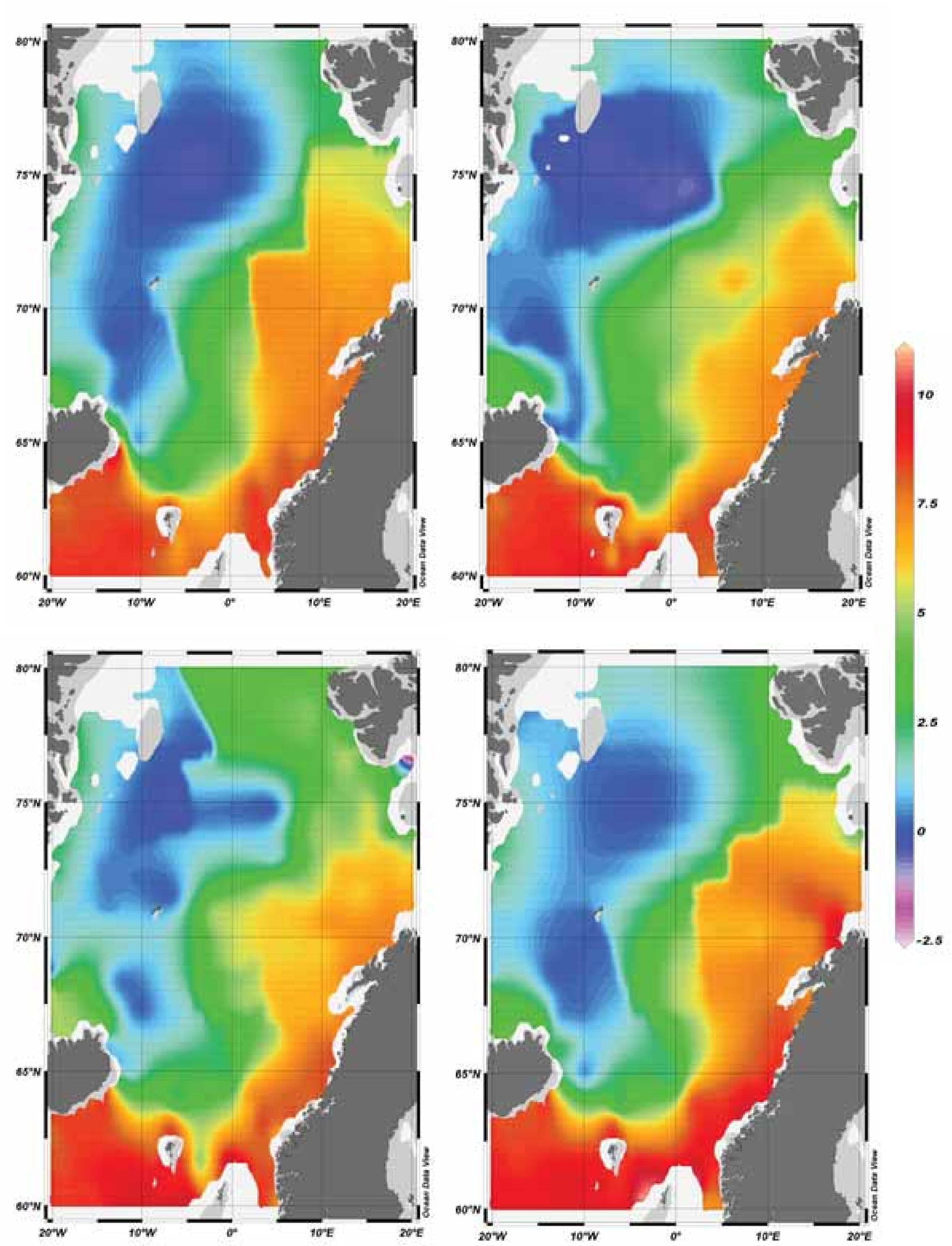

Figure 20. Data as in Figure 19. 2D temperature fields at 200 m depth from the temperature atlas based upon actual data and the WOA 05 climatology for 2005 per season: Upper left: January-March, upper right: April-June, lower left: July-September, lower right: October-December. Temperature field visualized by DIVA interpolation.

3.6 Vertical sections based upon actual data and climatology

Vertical sections can be extracted from the temperature atlas "on-the-go" and displayed by means of, e.g., Ocean Data View. Below examples from IMR's Svinøy transects are shown (Figure 21). However, one of the strengths of the temperature atlas is that sections can be defined from anywhere within the grid area, not only regularly sampled sections like the Svinøy transect. Furthermore, ODV allows one to construct quite complicated sections following, for instance, arbitrary cruise tracks.

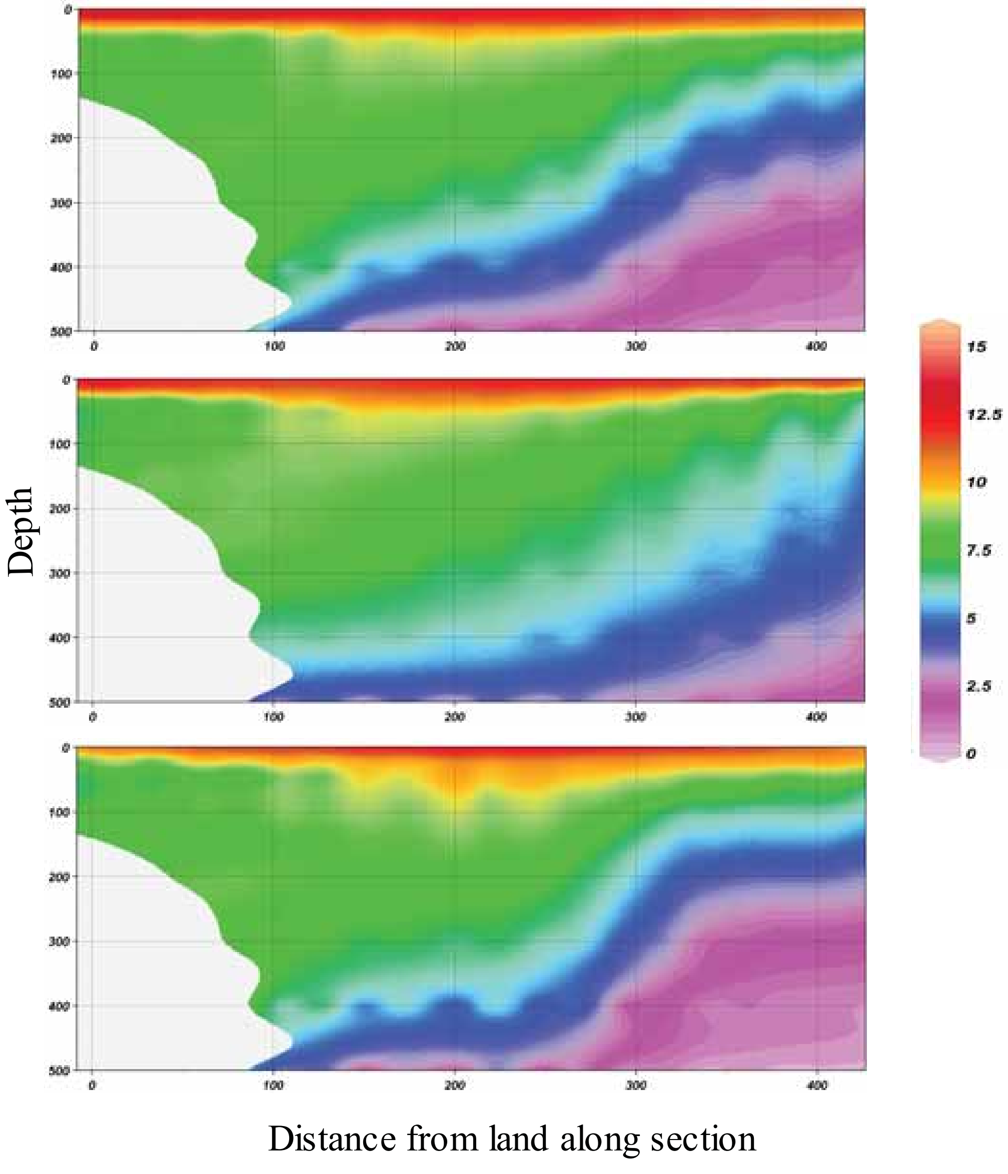

Fig. 21. Example of interannual differences along a vertical profile. The Svinøy section from 62° 22'N, 5° 12'E to 64° 40'N, 0°E at 0-500m depth for the quarter July-September: a) Climatological values for 1990-2007, b) 1990, and c) 2000. Temperature atlas based upon both data and WOA05 climatology used. ODV DIVA interpolation plug-in used for visualization. Moderately non-linear colour scale with higher colour resolution towards lower and higher values applied.

3.7 Examples of applications

The temperature atlas is in general a way to provide temperature values in a systematic, uniform, easily accessible fashion to fisheries ecologists, oceanographers and other researchers. Some examples of possible applications are suggested in the following and results from two concrete, simple sets of calculations are given.

Since fish often may make migration over large areas and inhabit regions of relatively large horizontal temperature gradients they may experience temperature variations that are quite different from those in any geographically fixed point. Thus, to get a realistic estimate of the temperatures a fish population live in, one could calculate a fish density weighted average ambient temperature, in practice by dividing the sum of the products of number of fish and temperature over all rectangles by the sum of number of fish:

$T_{amb}=\sum(N(x, y) \cdot \sum T(x, y))/\sum N(x, y)$

To allow for this, one needs spatially resolved data on fish distribution, typically from an acoustic and/or trawl survey and spatially resolved and preferably uniformly distributed temperature values. The temperature atlas is very well suited for this purpose. To get an estimate of the "temperature history" of a fish population one would integrate (or in practice sum) over time, including as many of the ambient temperature snapshots described above as possible. Using the seasonal temperature archive one can, depending on the availability of fish distribution data, make four such estimates per year. Ambient fish temperatures calculated in this manner have, for instance been applied to North Sea cod (Heessen and Daan, 1994) and Barents Sea cod (Ottersen et al., 1998).

In the preface to Locarnini et al. (2006) Sidney Levitus points to oceanographic climatologies being used as boundary and/or initial conditions in numerical ocean circulation models and atmosphere-ocean models, and for verification of numerical simulations of the ocean towards measured values. The temperature atlas provided here is well suited for such applications to regional, Norwegian Sea models. Indeed, for providing boundary conditions and fields for model verification in the case of model runs where one wants to study interannual differences the present atlas is better suited than any climatology.

3.7.1 3d box averaging

Mean temperature values were calculated within given latitude-longitude-depth boxes based upon the fields combined from data and climatological values. Two examples are chosen representing the water masses theoretically occupied by the full extent of the Norwegian spring-spawning herring summer distribution in respectively April-June and July-September and similar for blue whiting habitat during April-June. The selected box was for herring 62-76 °N, 5 °W-15 °E, 0-100m depth and for blue whiting 60-76 °N, 10 °W – 15 °E, 200-500 m depth. This was done for each year 1990-2007 giving time series of 18 years (Figure 22).

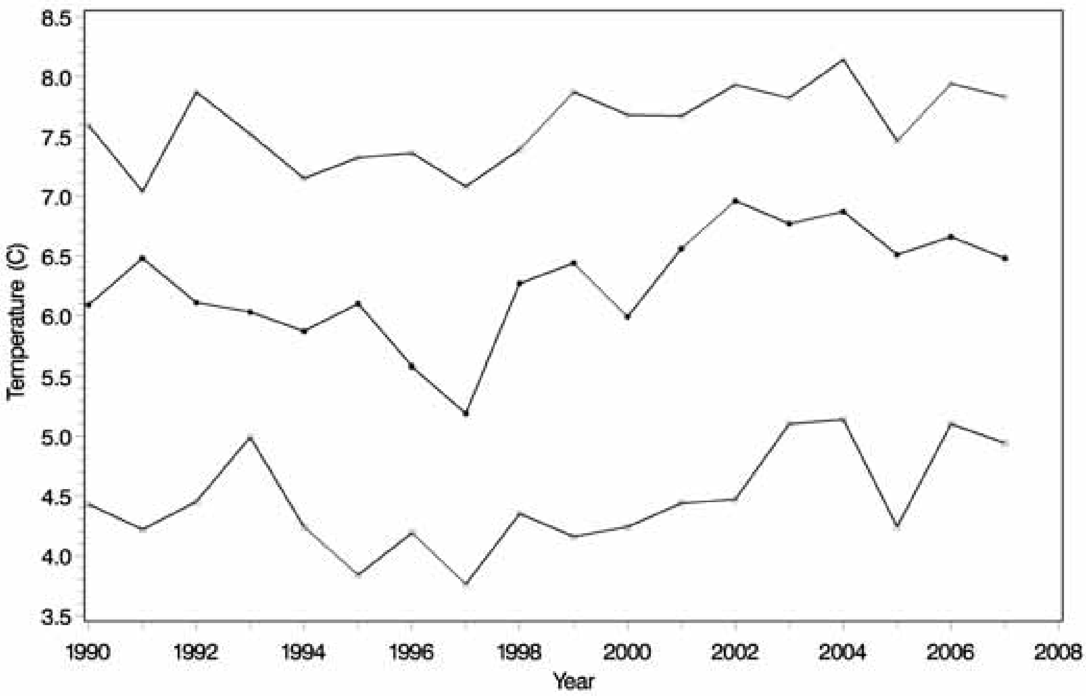

Figure 22. Time series 1990-2007 of averages of temperatures within 3D boxes extracted from the temperature atlas based upon both data and WOA 5 climatology. Upper line, open circles: 62-76°N, 5°W-15°E, 0-100m depth, July-September (representative of the full extent of Norwegian spring-spawning herring feeding distribution). Centre line, filled circles: 62-76°N, 5°W-15°E, 0-100m depth (same box as above), April-June. Lower line, open squares: 60-76°N, 10°W – 15°E, 200-500 m depth, April-June (representative of full extent of the northern component of the blue whiting feeding distribution).

3.7.2 Percentage distribution of area within temperature intervals

The percentage distribution of area within any selected set of temperature intervals may easily be estimated for any chosen year, season and depth level or depth interval by simply counting grid cells. This may be done for the full region covered by the atlas or in principle any selected sub area(s). However, if the number of grid cells included is low the results are less meaningful and for one grid cell only the percentage distribution will deteriorate to one single value. Here an example of percentage distribution of area (number of grid cells) in the region 60-76 °N, 10 °W – 15 °E within two degree temperature intervals is given. The distribution shown is for April-June at 200m depth for four selected years (Figure 23). The selected area is representative for the full horizontal extent of the feeding distribution of the northern blue whiting component, 200m is towards the upper limit of the depth interval normally inhabited by them. As above, the fields combined from data and climatological values are used.

4. Acknowledgements

The author wishes to thank the Norwegian Research Council's HAVKYST programme for economical support through the project INFERNO (Effects of interactions between fish populations on ecosystem dynamics and fish recruitment in the Norwegian Sea). Furthermore, I thank the centre for Ecological and Evolutionary Synthesis, University of Oslo, for infrastructure support. Dr. Reiner Schlitzer, Alfred Wegner Institute, is thanked for making the excellent Ocean Data View programme freely available to the scientific community. The current work was done within the framework of the GLOBEC (Global Ocean Ecosystem Dynamics) programme.

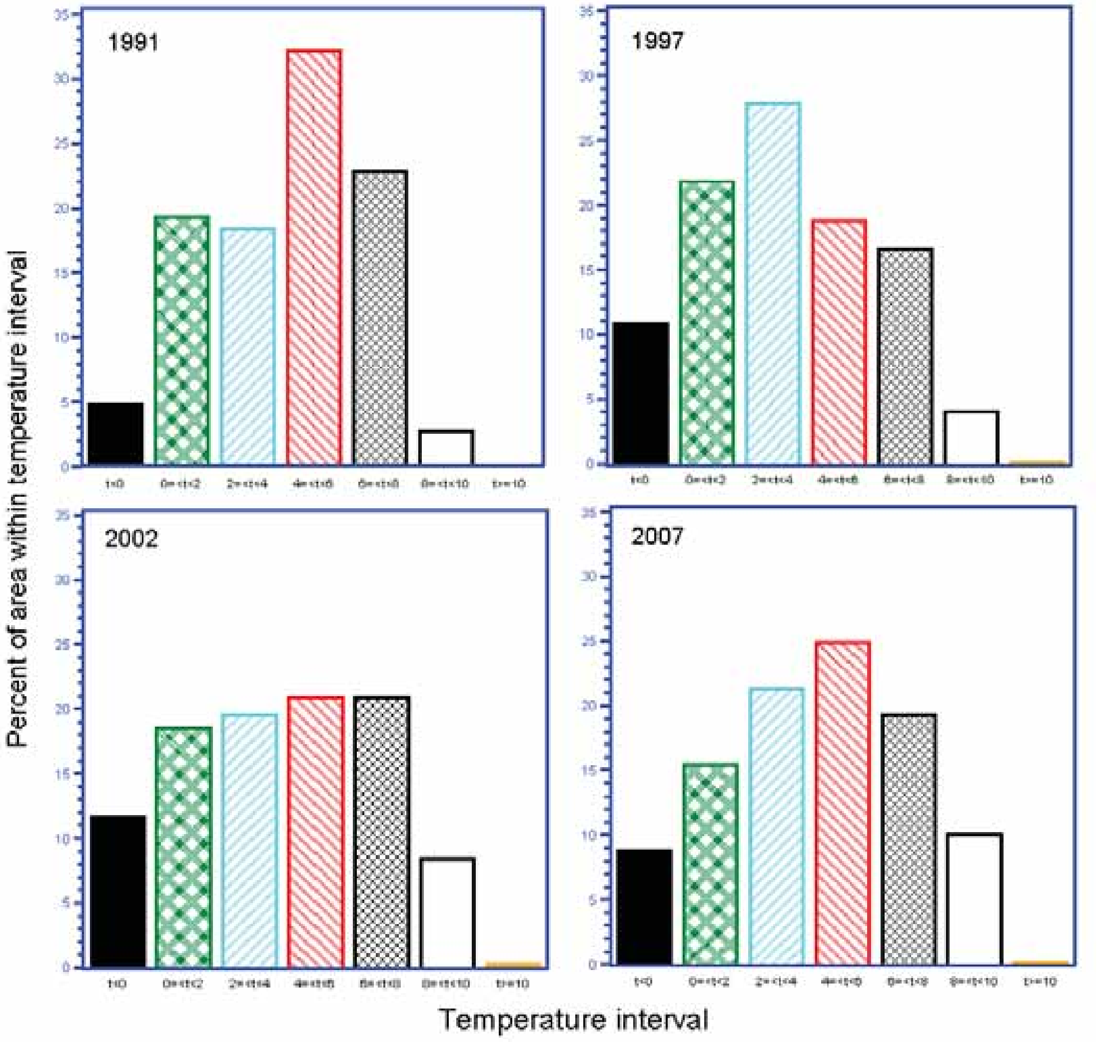

Fig 23. Percentage distribution of number of grid cells in the region 60-76 °N, 10 °W – 15 °E at 200m depth within temperature intervals during April-June for the four selected years 1991 (upper left panel), 1997 (upper right), 2002 (lower left), and 2007 (lower right).

5. References

Bogstad B, Hassel A, Loeng H, Nakken O (1997) Rapport om havmiljø og bestandsvurdering, Institute of Marine Research, Bergen

Boyer TP, Antonov JI, Garcia HE, Johnson DR, Locarnini RA, Mishonov AV, Pitcher MT, Baranova OK, Smolyar IV (2006) World Ocean Database 2005. S. Levitus, Ed., NOAA Atlas NESDIS 60., U.S. Government Printing Office, Washington, D.C. 190 pp., DVDs.

Cressman GP, (1951) An operational objective analysis scheme. Monthly Weather Review 87:329-340

Damm, P, 1989. Klimatologischer Atlas des Salzgehaltes, der Temperatur und Der Dichte in der Nordsee, 1968-1985. Technischer Report 6-89, Institut für Meereskunde der Universität Hamburg (in German).

Engedahl H, Ådlandsvik B, Martinsen EA (1998) Production of monthly mean climatological archives for the Nordic Seas. J mar Sys 14:1-26

Heessen HJL, Daan N (1994) Cod distribution and temperature in the North Sea. ICES mar Sci Symp 198:244-253

Helland-Hansen B, Nansen F (1909) The Norwegian Sea. FiskDir Skr Ser HavUnders 2:1-360

Ingvaldsen R, Loeng H, Ottersen G, Ådlandsvik B (2003) Climate variability in the Barents Sea during the 20th century with focus on the 1990s. ICES Mar Sci Symp 219:160-168

Levitus S, (1982) Climatological atlas of the world ocean. NOAA, p 173

Locarnini RA, Mishonov AV, Antonov JI, Boyer TP, Garcia HE (2006) World Ocean Atlas 2005, Volume 1: Temperature. NOAA Atlas NESDIS 61. , Washington, D.C.

Martinsen EA, Engedahl H, Ottersen G, Ådlandsvik B, Loeng H, Balino B (1992) MetOcean MOdelling Project (MOMOP), Climatological and Hydrographical data for Hindcast of Ocean Currents. The Norwegian Meteorological Institute, Oslo, p 93

Nilsen JEØ, Hatun H, Mork KA, Valdimarsson H (2006) The NISE data collection, Bergen, p 18.

Ottersen G, (1991) MODgrid, a Model Oriented Data grider. Institute of Marine Research, Div. Of Marine Environment, Bergen, p 27

Ottersen G, Ådlandsvik B (1993) Climatological temperature and salinity fields for the Nordic seas. Institute of Marine Research, Div. Mar. Env., Bergen, p 120 pp

Ottersen G, Loeng H, Raknes A (1994) Influence of temperature variability on recruitment of cod in the Barents Sea. ICES mar Sci Symp:471-481

Ottersen G, (1996) Environmental impact on variability in recruitment, larval growth and distribution of Arcto-Norwegian cod. University of Bergen north-east arctic cod. Ices J mar Sci 55:67-85

Ottersen G, Michalsen K, Nakken O (1998) Ambient temperature and distribution of north-east arctic cod. Ices J mar Sci 55:67-85

SAS Publishing (2004) SAS/STAT 9.1 User's Guide, Volumes 1-7, Vol, Cary, N.C., USA

Schlitzer R, (2006) Ocean Data View, http://odv.awi.de Alfred Wegener Institute, Bremerhaven

Taylor J, (1976) CONMAP: A computer program for contouring oceanographic data. Marine Environmental Data Service, Canada

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