Analysis of cold weather patterns over the period 1991-2012

A report for Anglian Water plc

NSRI Report: WU33703V

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Report cover: Snow in Olney, Buckinghamshire. T. Farewell

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A report for Anglian Water

Farewell, T.S., Hallett, S.H., and Truckell, I.G.

Abstract:

Within the context of an observed increase in the numbers of burst pipes associated with colder winters in the Anglian water region, we have analysed temperature data for England and Wales from the period 1991-2012 to identify cold winter periods. To do so, we have calculated the annual accumulated temperature below 1 °C for each MORECS square over the winter period. The resulting data has been mapped for both the whole of England and Wales as well as just for the Anglian Water region.

The data shows that the four winters between 2008-2012 were considerably colder than the preceding eleven winters. Additionally, for the winter of 2011-2012, the average temperature for all England of Wales was warmer than the 1991-2011 period average. However locally, in the Anglian Water region, the average temperatures were colder than the 1991-2011 average. The available MORECS data shows that while there are some periods of time with warmer winters (e.g. 1997-2008) and periods with colder winters (1990-1994, 1995-1997 and 2008- 2012), the lengths of these periods are considerably variable. From the MORECS data for the period 1991-2012, there does not appear to be a cyclical or predictable pattern in determining the harshness of the winter period.

Contents

Figures

Data Preparation

Temperature data and grid

MORECS weekly temperature data was collected from the MET office and from Anglian Water and integrated into one dataset for processing and analysis. The lower left of each MORECS square was used to create a 40 km by 40 km grid to plot the MORECS data (Figure 1). Data for the 2012-2013 is not complete (we are only halfway through the winter). This data may be included in a future evaluation. The Anglian Water Region refers to the 28 MORECS squares which intersect the Anglian Water operating area (Figure 3). The full MORECS dataset for England and Wales covers 120 squares (Figure 2).

Methodology

Winter temperature analysis

A Perl script 'CreATe' was written to calculate the winter Accumulated Temperature equal to or below 1 °C for each year (running June to May so as to include the whole winter, not broken on the calendar year) (Appendix One). For each week having a mean temperature below or equal to a 1 °C threshold, the temperature below this threshold is accumulated for the winter period. For example, in a given winter, if there were three weeks with mean temperatures below 1 °C (-1 °C, -10 °C, and 0 °C), the accumulated temperature (AT) for that winter would be: 2+12+1 = 14°C. The larger the value of Accumulated Temperature, the colder the winter.

We have used the temperature provided at land surface level above Ordnance Datum (AOD).

We also ran the model with thresholds at 0 and 2 °C. In the previous Anglian Water bursts project, we settled on a threshold of 1 °C and we continue to believe this represents an appropriate level, as a week with an average temperature of 1 °C is likely to have periods of frost. We think that this is the most appropriate threshold and so have only presented the findings from the 1 °C threshold. Other threshold data is available if required.

The Perl script 'CreATe' is presented in Appendix One.

Mapping

A series of UK maps displaying the Accumulated Temperature below or equal to 1°C between the period 1991 and 2012 were prepared (Figure 2). Additionally, a series of Anglian Water Region maps were prepared, displaying the accumulated temperature for the same period (Figure 3).

Full versions of the individual maps are presented in the Appendix 2, including a series of maps with the approximate boundaries of the water companies in the UK overlain on the data.

Graphical analysis

We have produced a series of graphs (Figure 4 to Figure 11) showing the trend of the accumulated temperature as a measure of the harshness of the winters between 1991 and 2012.

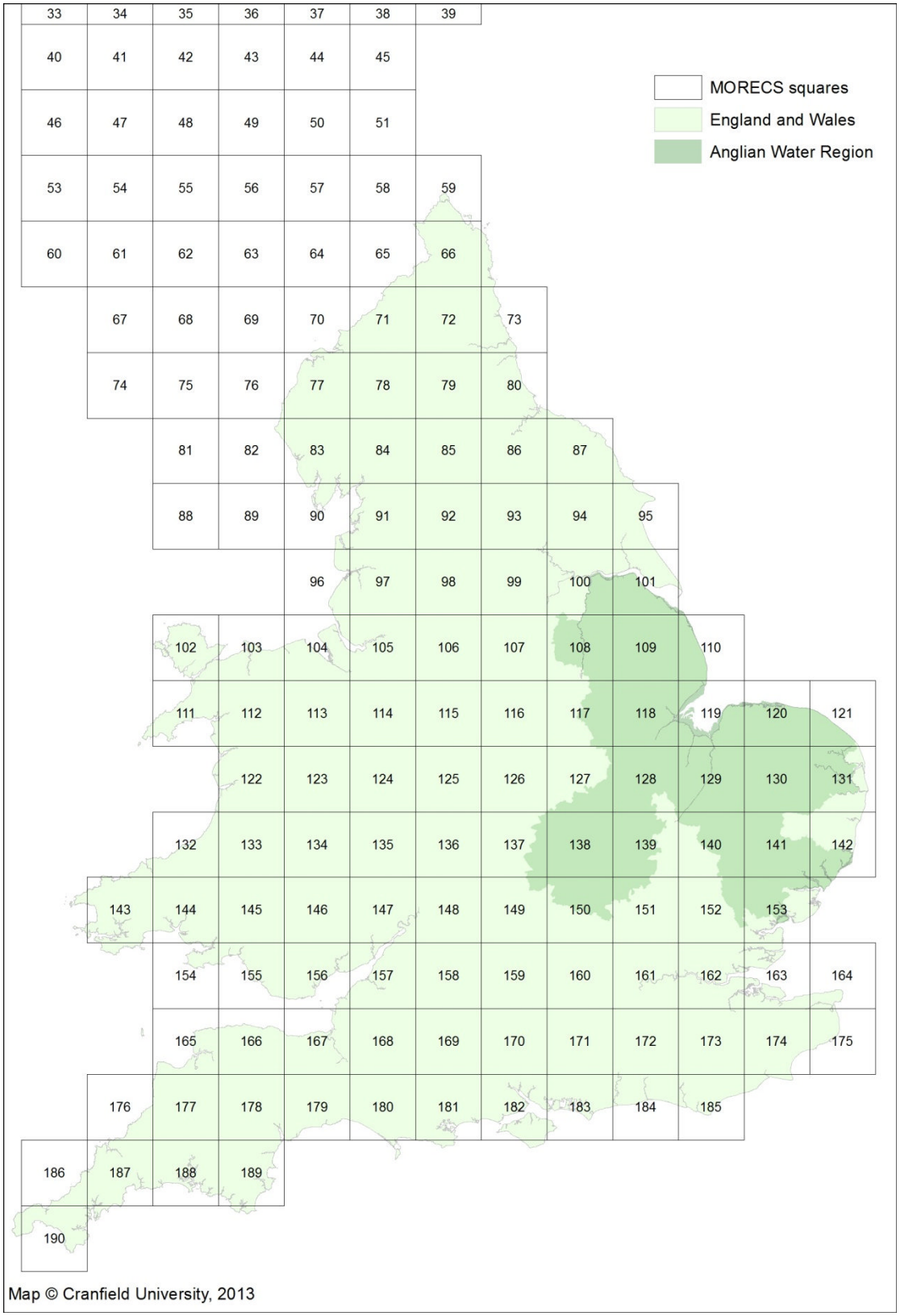


Figure 1 - Location of MORECS squares across England and Wales

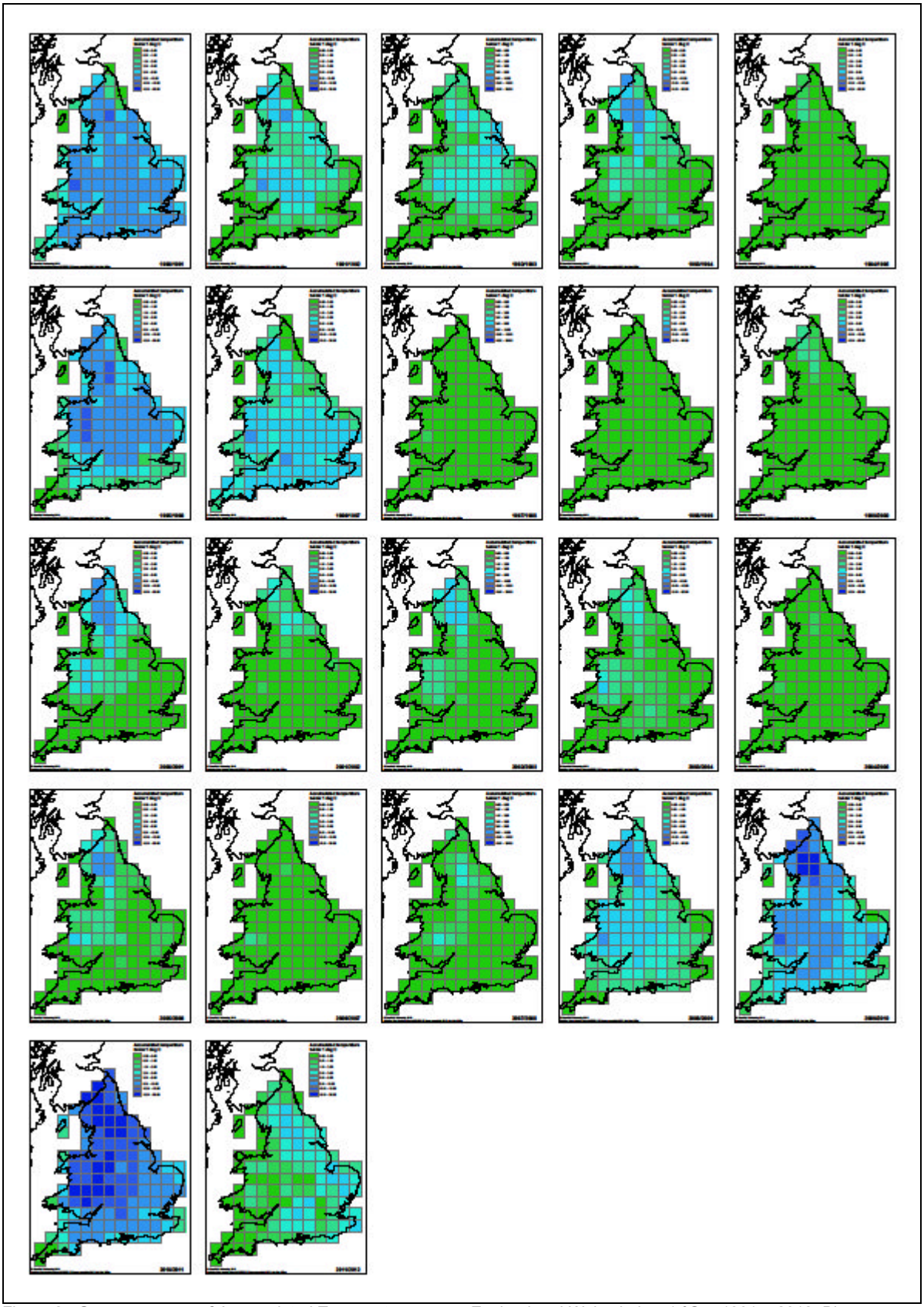


Figure 2 - Summary maps of Accumulated Temperature across England and Wales below 1 °C - 1991 – 2012. Blue areas represent areas colder conditions.

Detailed versions of the maps are provided in Appendix 2.

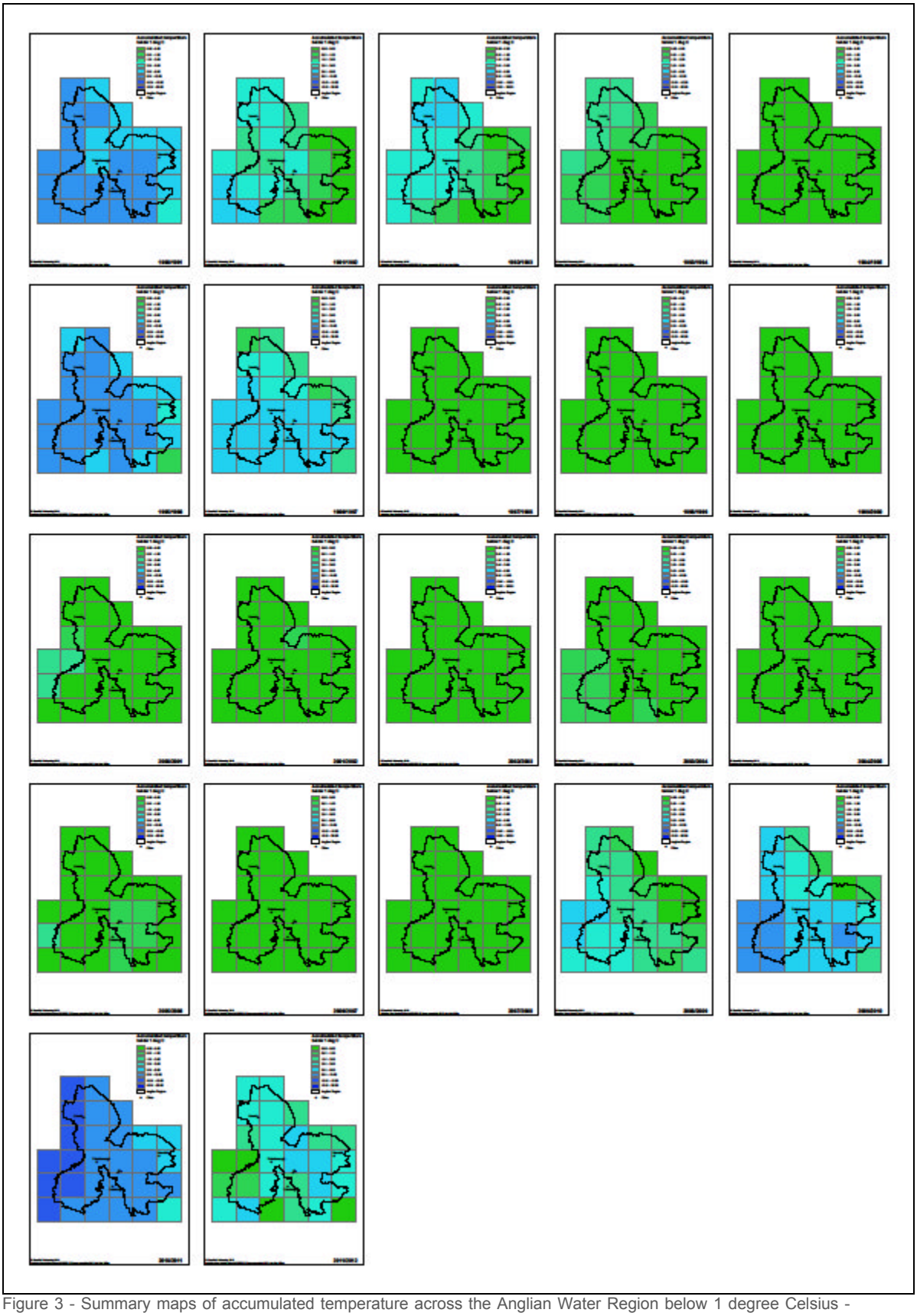


Figure 3 - Summary maps of accumulated temperature across the Anglian Water Region below 1 degree Celsius - 1991 – 2012. Blue areas represent areas colder conditions.

Detailed versions of the maps are provided in the Appendix 2.

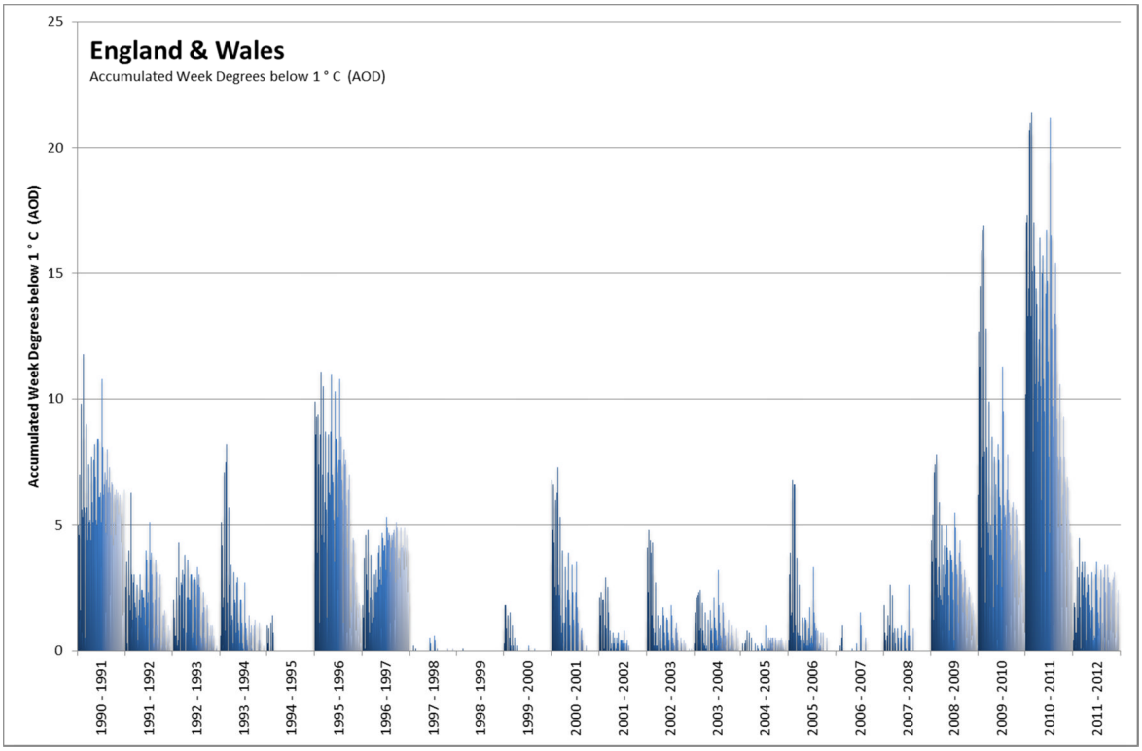


Figure 4 – Accumulated Temperature below 1 degree for MORECS squares in England and Wales.

Note: Temperature provided at land surface level above ordnance datum (AOD). MORECS squares are presented in sequential order. The darkest line represents MORECS square 59. The lightest line represents square 190.

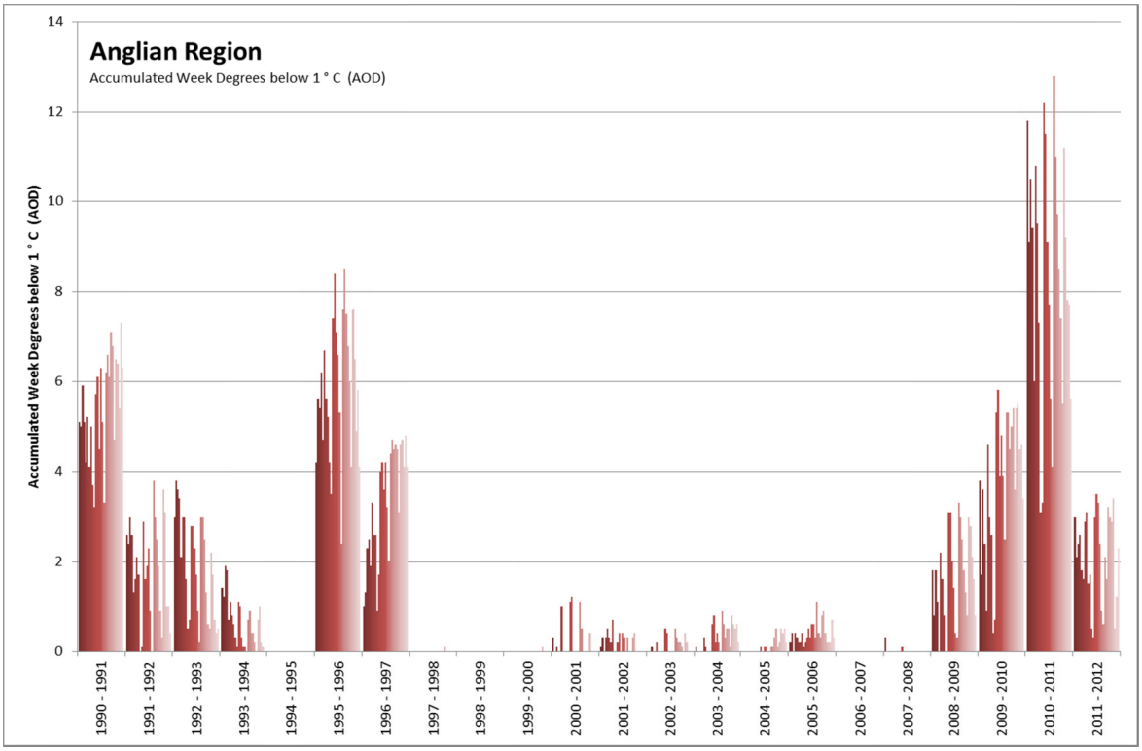


Figure 5 - Accumulated Temperature below 1 degree for MORECS squares in the Anglian Water Region.

Note: Temperature provided at land surface level above ordnance datum (AOD). MORECS squares are presented in sequential order. The darkest line represents MORECS square 100. The lightest line represents square 149.

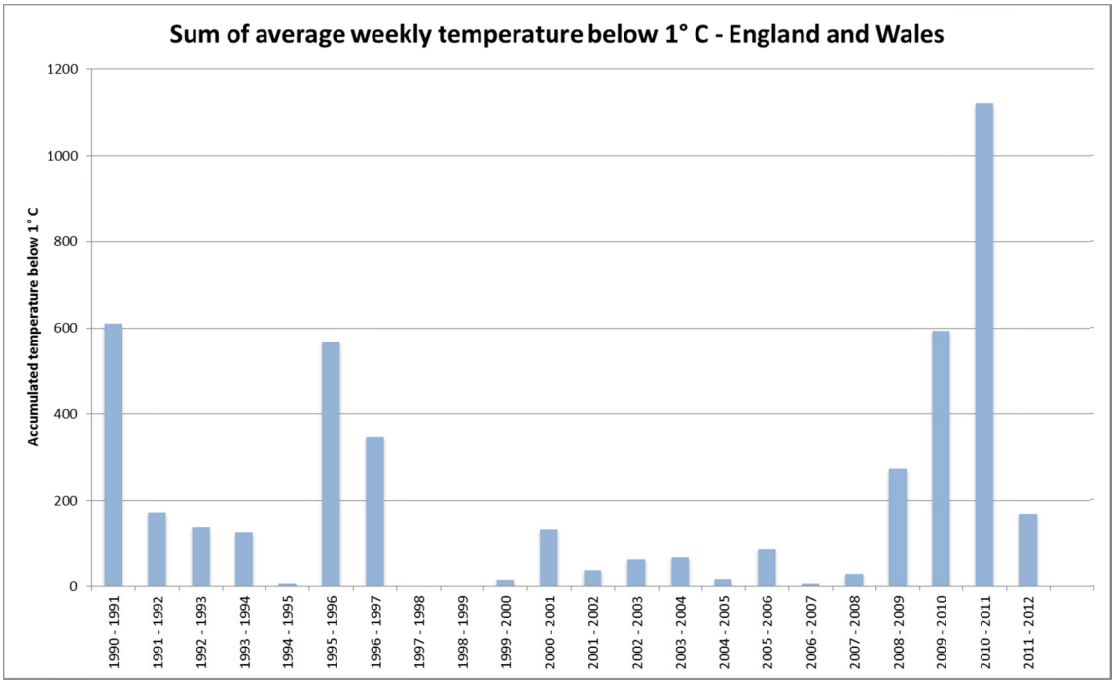


Figure 6 - Accumulated Temperature below 1 degree - England and Wales

Note: higher bars indicate colder temperatures

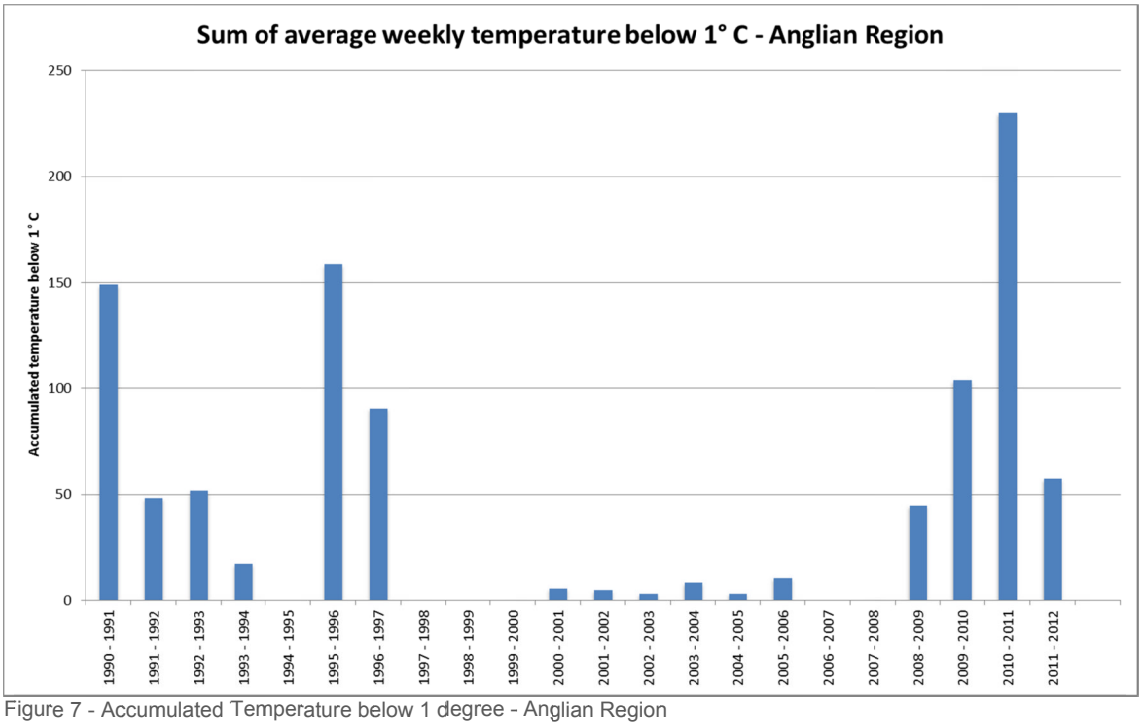


Figure 7 - Accumulated Temperature below 1 degree - Anglian Region

Note: higher bars indicate colder temperatures

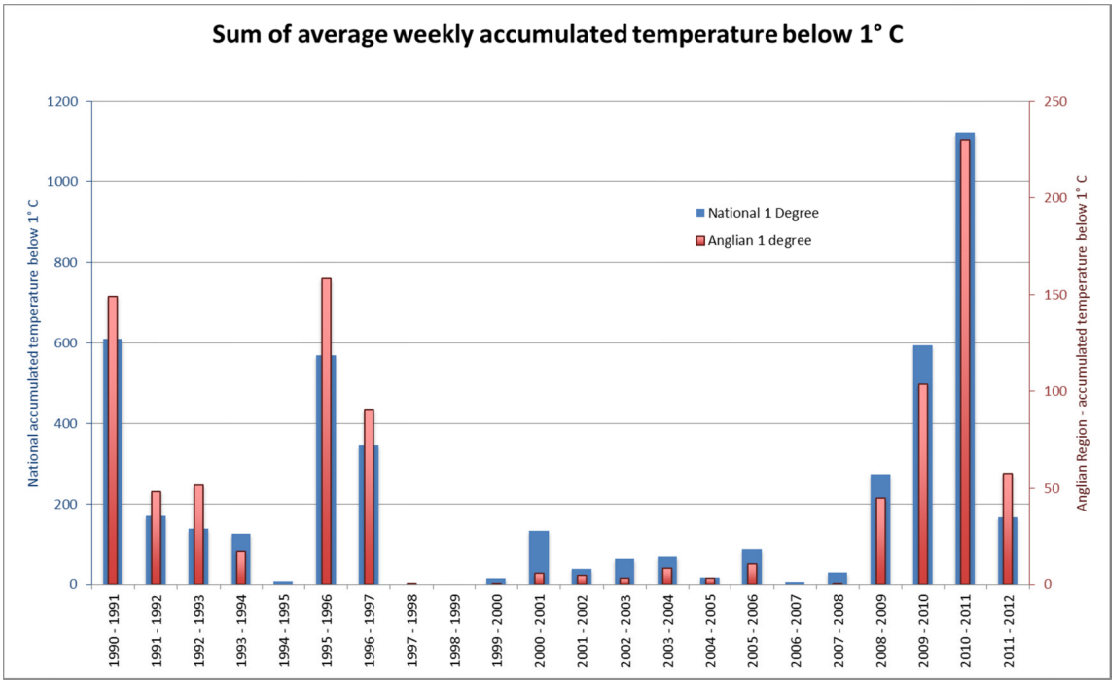


Figure 8 - Comparison between average winter Accumulated Temperatures - England and Wales vs. Anglian Region

Note: Higher bars indicate colder temperatures. Blue bars represent England and Wales and are plotted on the primary axis. Red bars represent the Anglian region and are plotted on the secondary axis. Diffferent scales are combined to show the relative pattern.

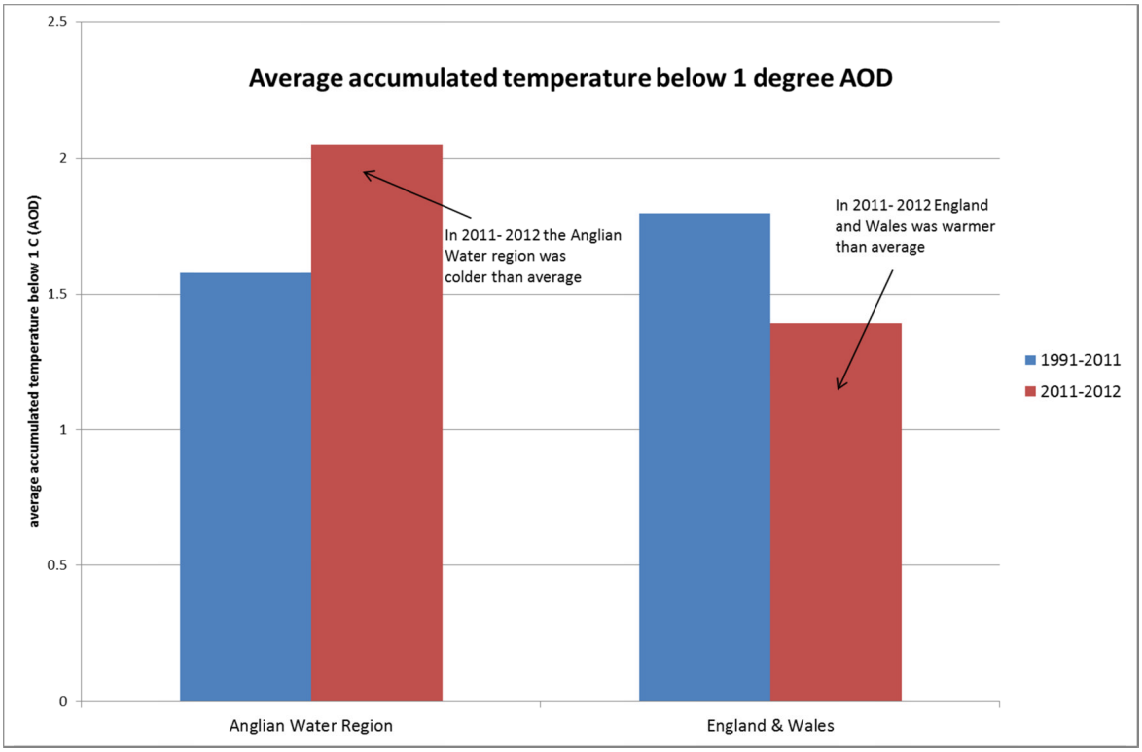


Figure 9 - Average Accumulated Temperature below 1 degree for England and Wales and Anglian Water region.

Note: Higher bars indicate colder temperatures. The blue bars represent the 1991-2011 average accumulated temperature. The red bars represent the 2011-2012 winter.

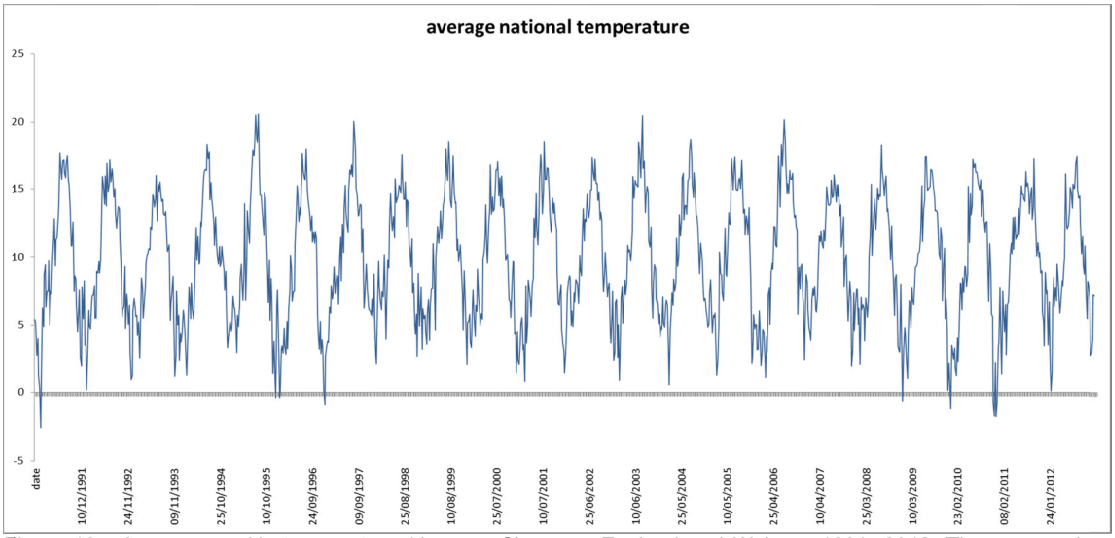


Figure 10 - Average weekly temperature (degrees C) across England and Wales – 1991- 2012. The average has been calculated from all 120 MORECS squares covering England and Wales.

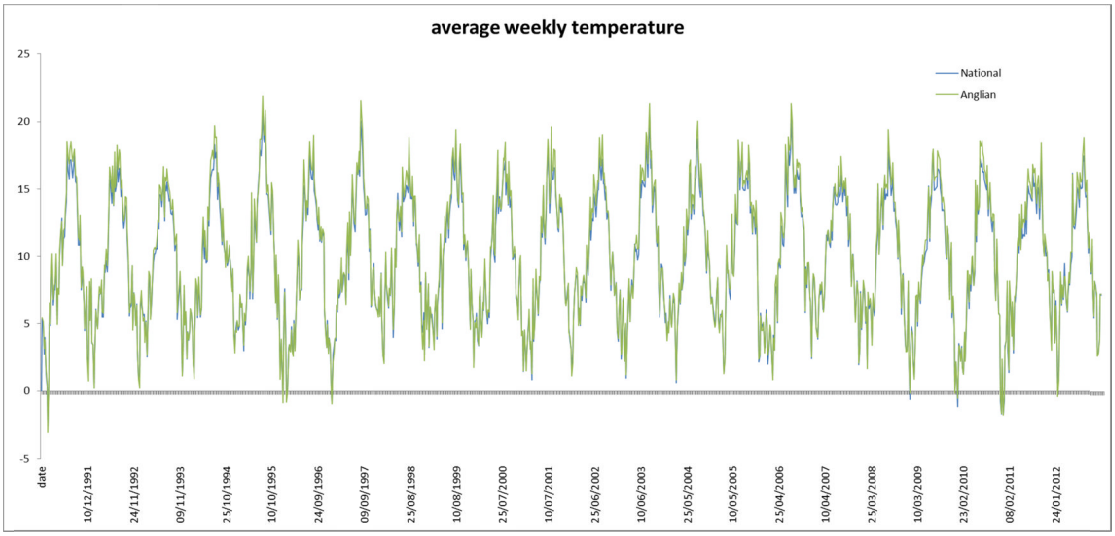


Figure 11 - Average weekly temperature (degrees C) across the Anglian Water Region and England and Wales – 1991- 2012. The average has been calculated from the 28 MORECS squares across the Anglian Region.

Results and Discussion

4 recent colder winters (2008-2012)

The four winters 2008-2009 to 2011-2012 were markedly colder, both nationally, and specifically in the Anglian Region, than the preceding 11 winters. This can been seen from the mapped Accumulated Temperature data (Figure 2 and Figure 3) as well as the data plotted for each MORECS square in the Anglian Region (Figure 5) as well as the whole of England and Wales (Figure 4). The Accumulated Temperatures for these regions are presented in Figure 6 and Figure 7. 1996-1997 and 1995-1996 were the colder winters before this 11 year period or relatively warm winters between 1997 and 2008.

The 2011-2012 winter in the Anglian Water Region

Considered across all England of Wales, the winter of 2011 was 0.5 °C warmer than the 1991-2011 period average Accumulated Temperature below 1 °C, however locally, in the Anglian Water region, the average temperatures were 0.4 °C colder than the 1991-2011 period average. This comparison can been seen in Figure 9 and the relative differences in Figure 8. This difference in the regional patterns may explain why some consider the winter of 2011-2012 to have been more mild than average, while others perceived it as being a harsh winter.

Consideration of a cyclical pattern to the occurrence of cold winters.

We understand that OFWAT may have suggested looking to see if there may be a cyclical pattern to the occurrence of colder winters in the UK. While the annual temperature pattern is expected to be cyclical (Figure 10 and Figure 11), the severity of the winter period does not seem to follow a predictable pattern (e.g. Figure 8). The available MORECS data shows that there are some warmer periods (e.g. 1997-2008) and colder winter periods (1990-1994, 1995-1997 and 2008- 2012), however, the lengths of these period are variable. From the data 1991-2012, there does not appear to be a predictable pattern in determining the harshness of the winter period.

To consider the longer term picture, we accessed summary historic data on the MET office website at http://www.metoffice.gov.uk/climate/uk/actualmonthly/. Figure 12 shows the mean daily minimum temperature for the whole winter period for the last 100 years. Figure 13 to Figure 17 show the individual monthly average temperatures for England for the last 100 years. Again, there does not appear to be a predictable cyclical pattern of minimum winter temperatures.

For interest, the annual mean temperature for England is plotted in Figure 18. This graph indicates that the mean temperature has been warmer than average for the last few years.

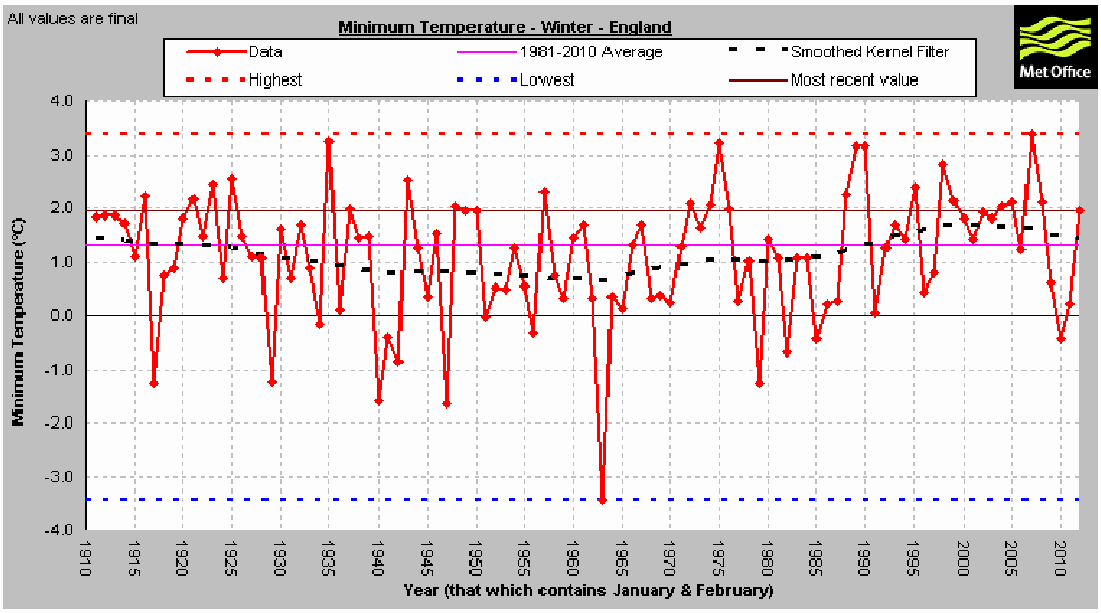


Figure 12 - Winter - Mean daily minimum temperature

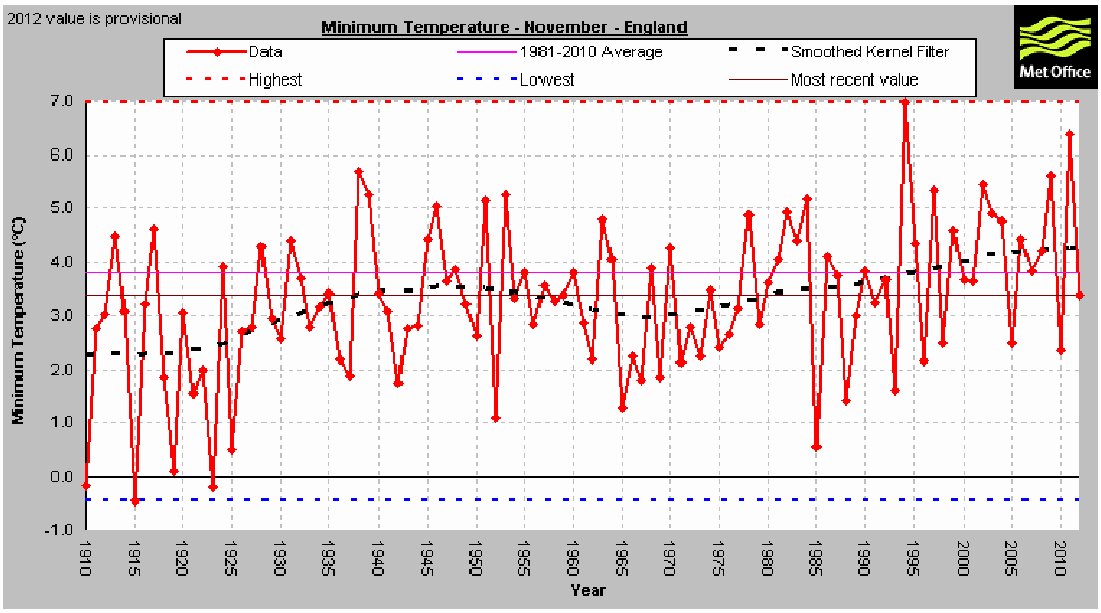


Figure 13 – November – Mean daily minimum temperature

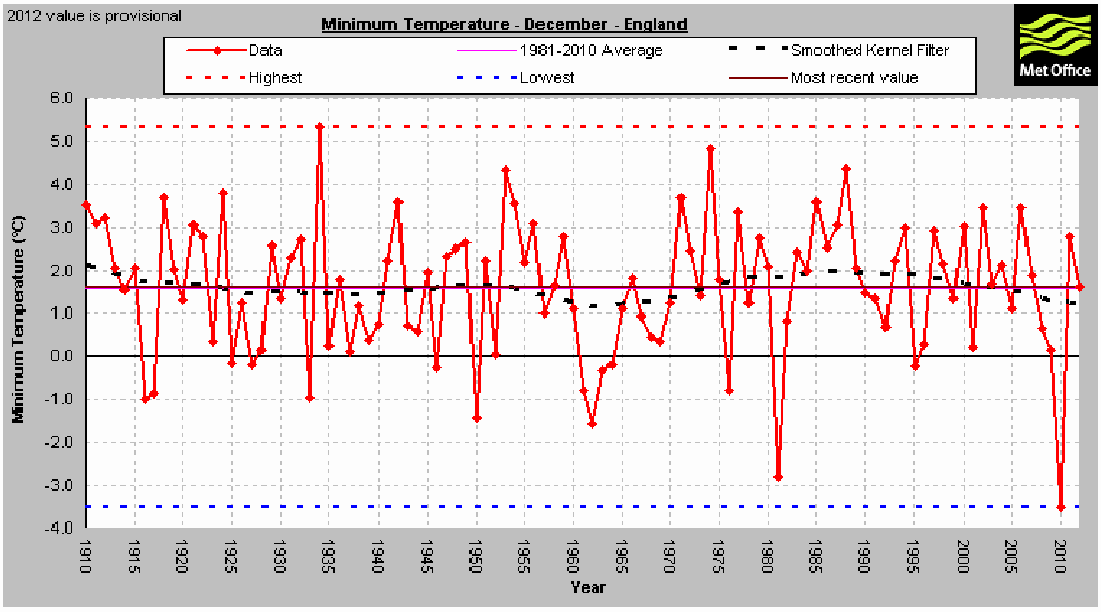


Figure 14 – December – Mean daily minimum temperature

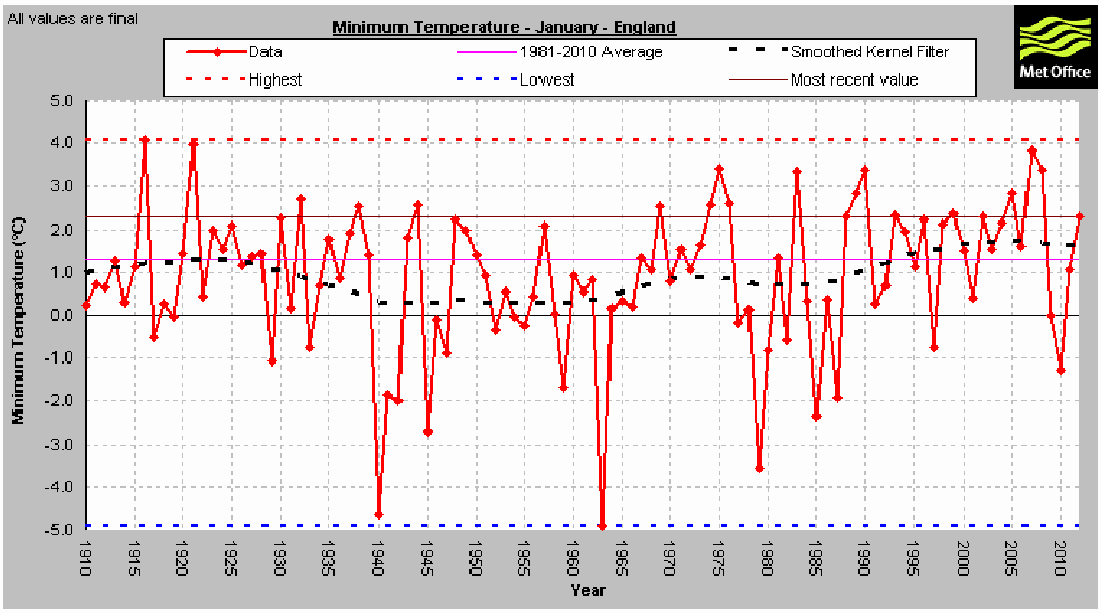


Figure 15 – January – Mean daily minimum temperature

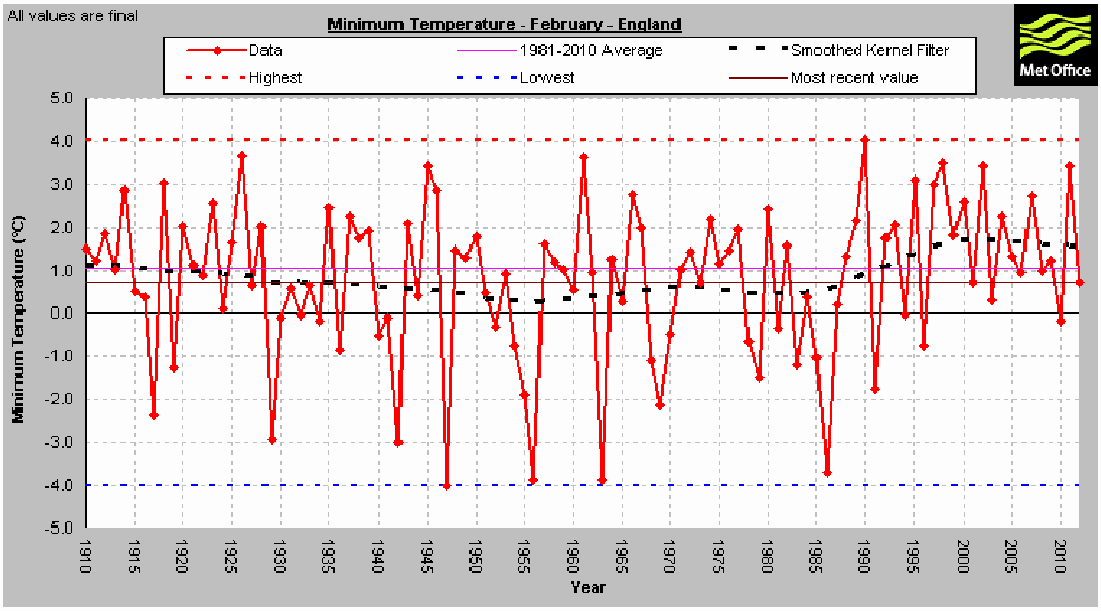


Figure 16 – February – Mean daily minimum temperature

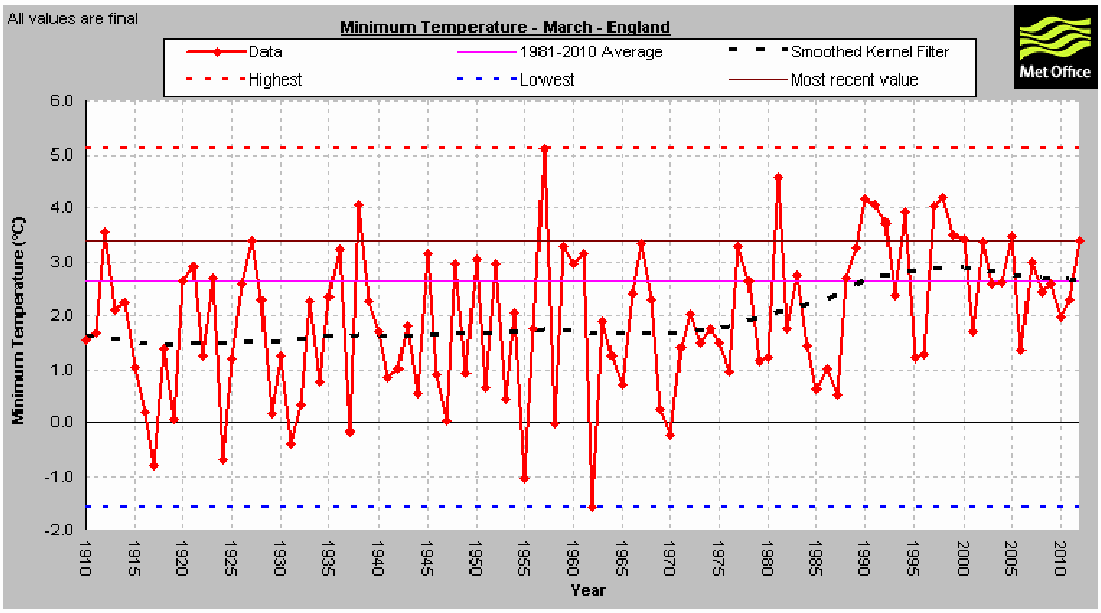


Figure 17 – March – Mean daily minimum temperature

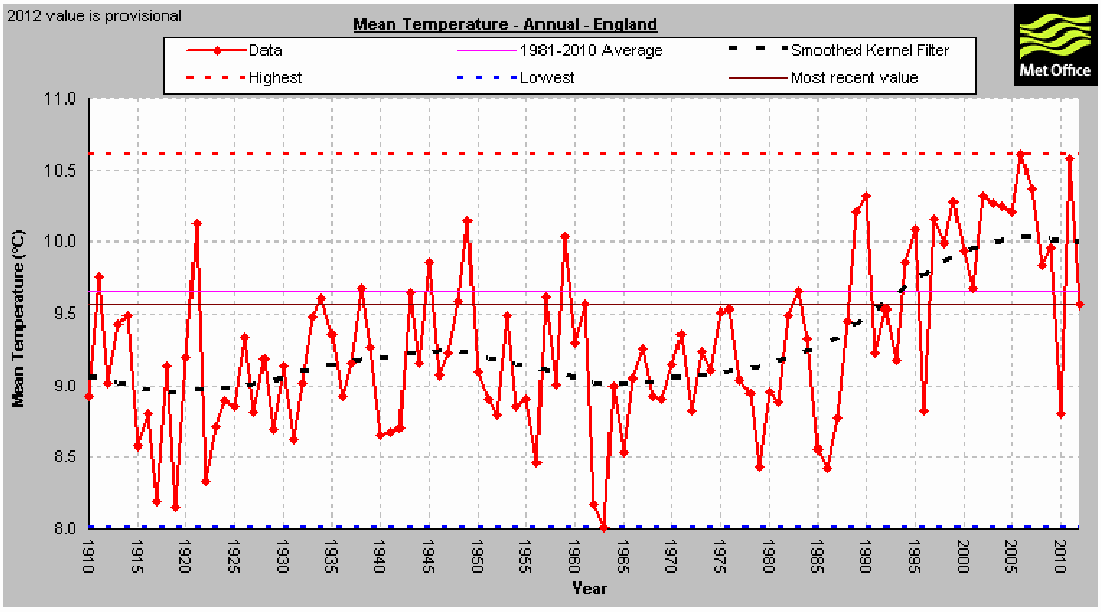


Figure 18 - Annual - Mean temperature - (not minimum)

Appendix 1 - Calculation of Accumulated temperature

The following Appendix presents a script, written in the programming language 'PERL', designed to calculate the Accumulated Temperature of the processed MORECS datafiles. The Basal Threshold, mode and totals column are presented as user-defined options.

```
# CreATe.pl [PERL] v3
# Purpose: Create Accumulated Degree Days below basal threshold for MORECS grid data
# for the Anglian Water Winter Temperature Analysis Project
# AT is the integrated excess or deficiency of temperature around a threshold (below threshold in this case)
# S Hallett, NSRI 21/1/13
# Run on cmd line as: perl CreATe_v3.pl, or double click file icon (with perl installed)
# Processes file '../MORECS 1990_2013_withGridData.csv'
#!/usr/bin/perl

################################
# USER EDITABLE VALUES BELOW  #
my $basalThreshold  = 2;      # threshold in degrees centigrade
my $mode = "ATOD";            # calculation mode, namely: "both", "MSL", or "ATOD"
my $total_cols = "no";        # include totals columns, namely: "yes", or "no"
################################

## DONT EDIT BELOW HERE ##########################################

#initialise
if ($mode ne "both" && $mode ne "MSL" && $mode ne "ATOD") {die "\n\nOops - Mode settings were wrong, please check\n\n"};
if ($total_cols ne "yes" && $total_cols ne "no") {die "\n\nOops - Total Columns settings were wrong, please check\n\n"};
my $lapseRate = 0.0064; # fixed adiabatic lapse rate
my $counter = 1;        # value counter
my $periodIndex=-1;     # commencing value
open(INFILE,"../MORECS 1990_2013_withGridData.csv") || die "Could not open '../MORECS 1990_2013_withGridData.csv' file";
open(OUTFILE,">MORECS_1990_2013_ATOutput_" . $basalThreshold ."_" . $mode . ".csv") || die "Could not create 'MORECS_1990_2013_ATOutput_" .
$basalThreshold ."_" . $mode . ".csv' file";
print "Starting ...\n";

# Process file
while (<INFILE>) {
  chop;
  @_ = split /,/;
  if ($counter == 1) { @Header = @_;}
  if ($counter == 2) { @East = @_;} #don't need
  if ($counter == 3) { @North = @_;} #don't need
  if ($counter == 4) { @Altitude = @_;} #don't need
  if ($counter >= 5) { # morecs data
    $currentPeriod = @_[1];
    for ($index=2; $index<=@_-1; $index++) { # process Morecs squares, skipping date and processing period col
      if (@_[$index] <= $basalThreshold) { # accumulate deficit
        if  (!grep(  /^$currentPeriod$/,  @period_labels))  {push(@period_index,  ++$periodIndex);  push(@period_labels,  $currentPeriod);}  # store  each
processing period
          if ($mode eq "both") {
            $tmpOD = abs($basalThreshold - (@_[$index]+0));
                    $tmpMSL = abs($basalThreshold - (@_[$index]+($lapseRate*@Altitude[$index])));
            $Years_OD[$periodIndex][$index] += $tmpOD;
                    $Years_MSL[$periodIndex][$index] += $tmpMSL;
                                    if ($total_cols eq "yes") {
                  @Total_OD[$index] += $tmpOD;
                    @Total_MSL[$index] += $tmpMSL;
                                    }
          } elsif($mode eq "MSL") {
                    $tmpMSL = abs($basalThreshold - (@_[$index]+($lapseRate*@Altitude[$index])));
                    $Years_MSL[$periodIndex][$index] += $tmpMSL;
                                    if ($total_cols eq "yes") {
                      @Total_MSL[$index] += $tmpMSL;
                                    }
          } elsif($mode eq "ATOD") {
            $tmpOD = abs($basalThreshold - (@_[$index]+0));
            $Years_OD[$periodIndex][$index] += $tmpOD;
                                    if ($total_cols eq "yes") {
                  @Total_OD[$index] += $tmpOD;
                                    }
      }
              }
    }
  }
  $counter++;
}

# Debug mode
#use Data::Dumper;
#print OUTFILE Dumper \@period_index;
#print OUTFILE Dumper \@period_labels;
#print OUTFILE Dumper \@Years_OD[0];
#print OUTFILE Dumper \$Years_OD[0][0];
#print OUTFILE Dumper \@Total_OD;

# Output results
#header
if ($mode eq "both") {
  if ($total_cols eq "yes") {
    print OUTFILE "Morecs_Id,Total_ATOD_$basalThreshold,Total_ATMSL_$basalThreshold";
  } elsif ($total_cols eq "no") {
    print OUTFILE "Morecs_Id";
  }
  for( $period = 0; $period<= @period_labels-1; $period++) { # each separate period
    printf(OUTFILE ",ATOD_%s_$basalThreshold,ATMSL_%s_$basalThreshold", @period_labels[$period], @period_labels[$period]);
  }
```

```
  print(OUTFILE "\n");
} elsif($mode eq "MSL") {
  if ($total_cols eq "yes") {
    print OUTFILE "Morecs_Id,Total_ATMSL_$basalThreshold";
  } elsif ($total_cols eq "no") {
    print OUTFILE "Morecs_Id";
  }
  for( $period = 0; $period<= @period_labels-1; $period++) { # each separate period
    printf(OUTFILE ",ATMSL_%s_$basalThreshold", @period_labels[$period]);
  }
  print(OUTFILE "\n");
} elsif($mode eq "ATOD") {
  if ($total_cols eq "yes") {
    print OUTFILE "Morecs_Id,Total_ATOD_$basalThreshold";
  } elsif ($total_cols eq "no") {
    print OUTFILE "Morecs_Id";
  }
  for( $period = 0; $period<= @period_labels-1; $period++) { # each separate period
    printf(OUTFILE ",ATOD_%s_$basalThreshold", @period_labels[$period]);
  }
  print(OUTFILE "\n");
}

#data
if ($mode eq "both") {
  for($i=2; $i<=@Header-1; $i++) { # skipping first element
    if ($total_cols eq "yes") {
      printf(OUTFILE "%s,%.02f,%.02f", @Header[$i], @Total_OD[$i], @Total_MSL[$i]);
    } elsif ($total_cols eq "no") {
      printf(OUTFILE "%s", @Header[$i]);
    }
    for($period=0; $period<=@period_index-1; $period++) { # each separate period
      printf(OUTFILE ",%.02f,%.02f", $Years_OD[@period_index[$period]][$i], $Years_MSL[@period_index[$period]][$i]);
    }
    print(OUTFILE "\n");
  }
} elsif($mode eq "MSL") {
  for($i=2; $i<=@Header-1; $i++) { # skipping first element
    if ($total_cols eq "yes") {
      printf(OUTFILE "%s,%.02f", @Header[$i], @Total_MSL[$i]);
    } elsif ($total_cols eq "no") {
      printf(OUTFILE "%s", @Header[$i]);
    }
    for($period=0; $period<=@period_index-1; $period++) { # each separate period
      printf(OUTFILE ",%.02f", $Years_MSL[@period_index[$period]][$i]);
    }
    print(OUTFILE "\n");
  }
} elsif($mode eq "ATOD") {
  for($i=2; $i<=@Header-1; $i++) { # skipping first element
    if ($total_cols eq "yes") {
      printf(OUTFILE "%s,%.02f", @Header[$i], @Total_OD[$i]);
    } elsif ($total_cols eq "no") {
      printf(OUTFILE "%s", @Header[$i]);
    }
    for($period=0; $period<=@period_index-1; $period++) { # each separate period
      printf(OUTFILE ",%.02f", $Years_OD[@period_index[$period]][$i]);
    }
    print(OUTFILE "\n");
  }
}

# Close files
close(INFILE);
close(OUTFILE);
print "... Finished\n";
####################

# eof: CreATe.pl
```

Appendix 2 – Mapped data

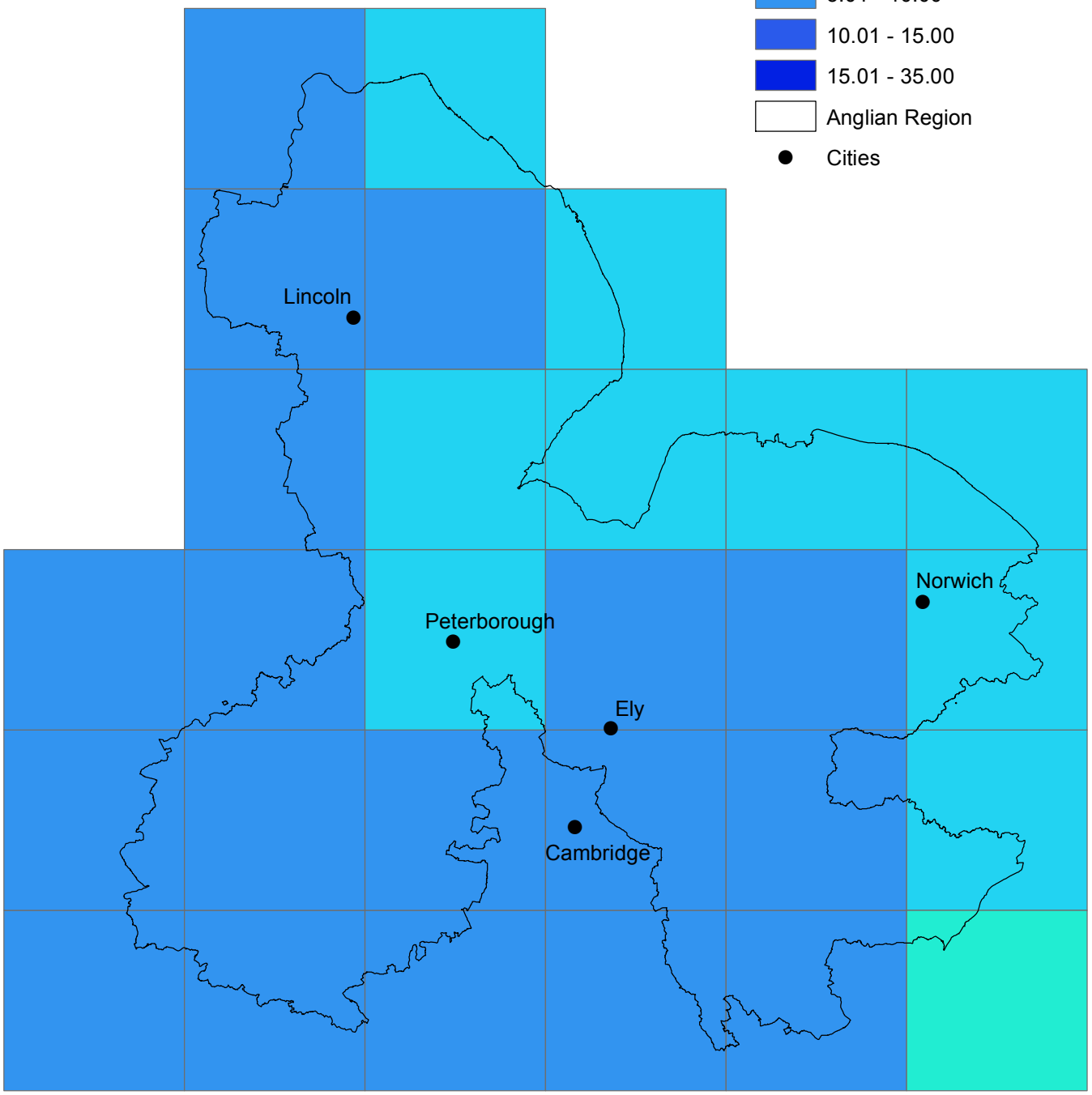
This appendix includes three sets of maps:

1) Accumulated temperature below 1 degree for the Anglian Water Region

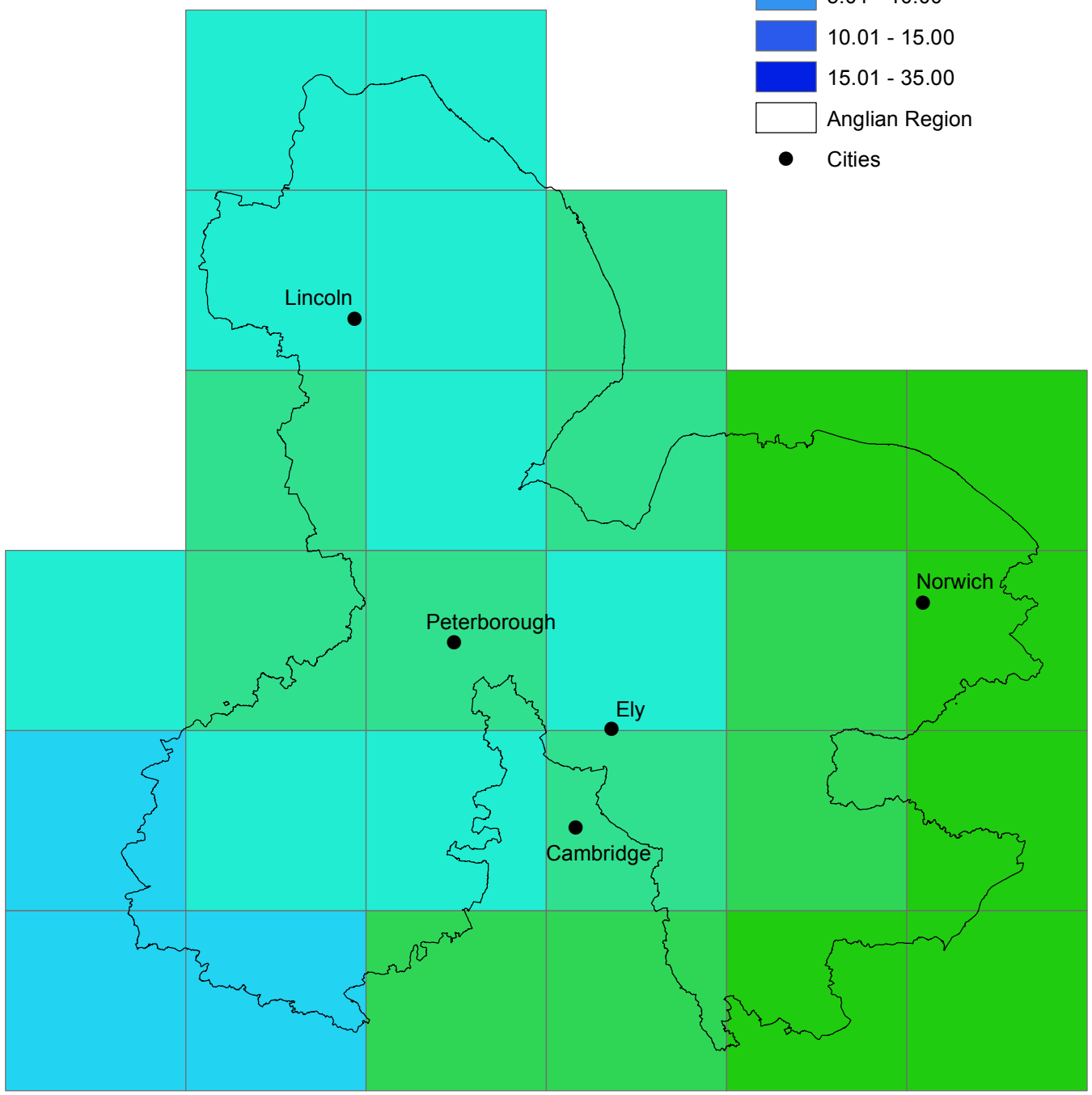
2) Accumulated temperature below 1 degree for England and Wales

3) Accumulated temperature below 1 degree for England and Wales with the approximate boundaries of all the UK water companies.

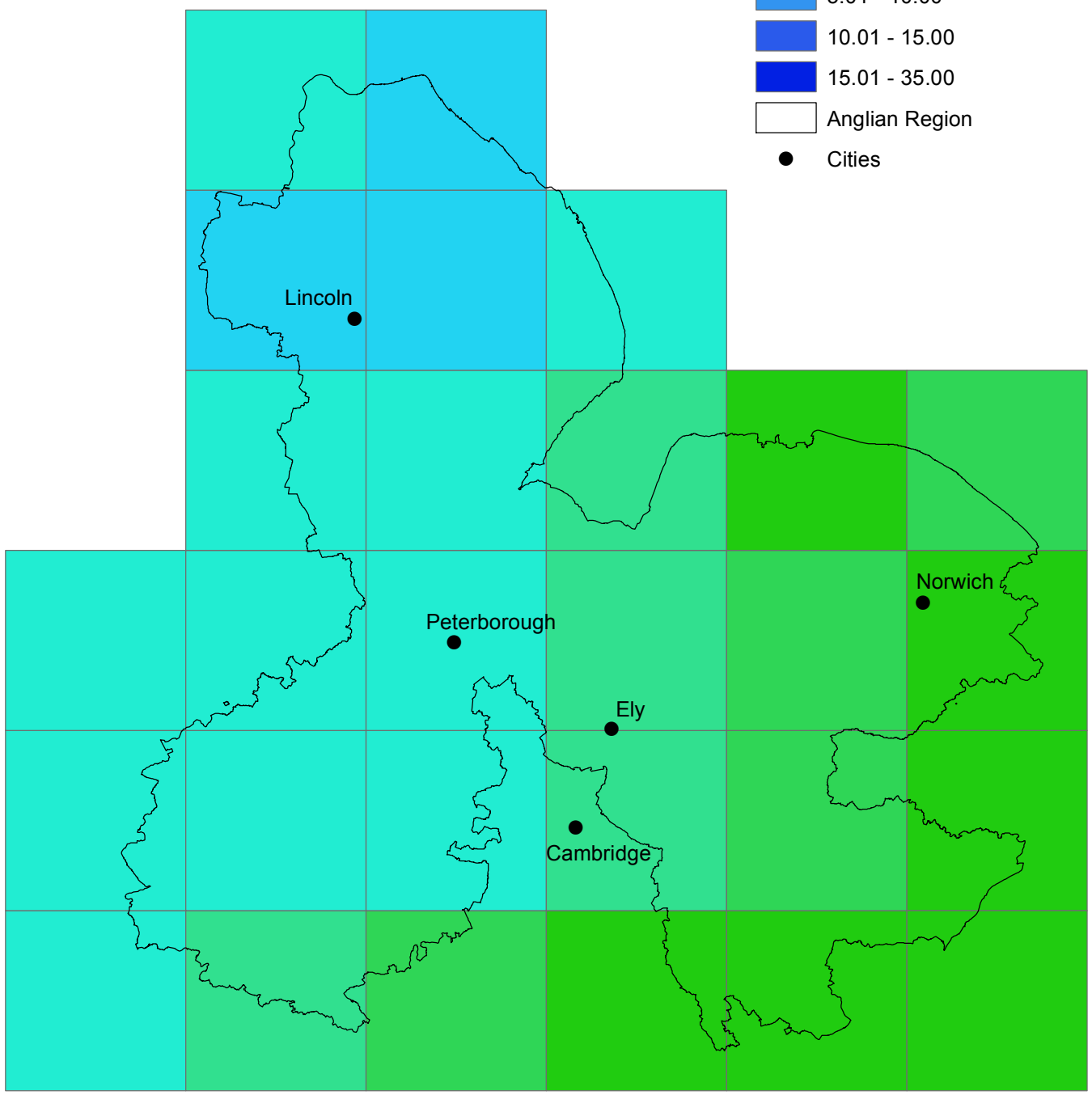
The first two sets of maps are summarised on single pages in Figure 2 and Figure 3.



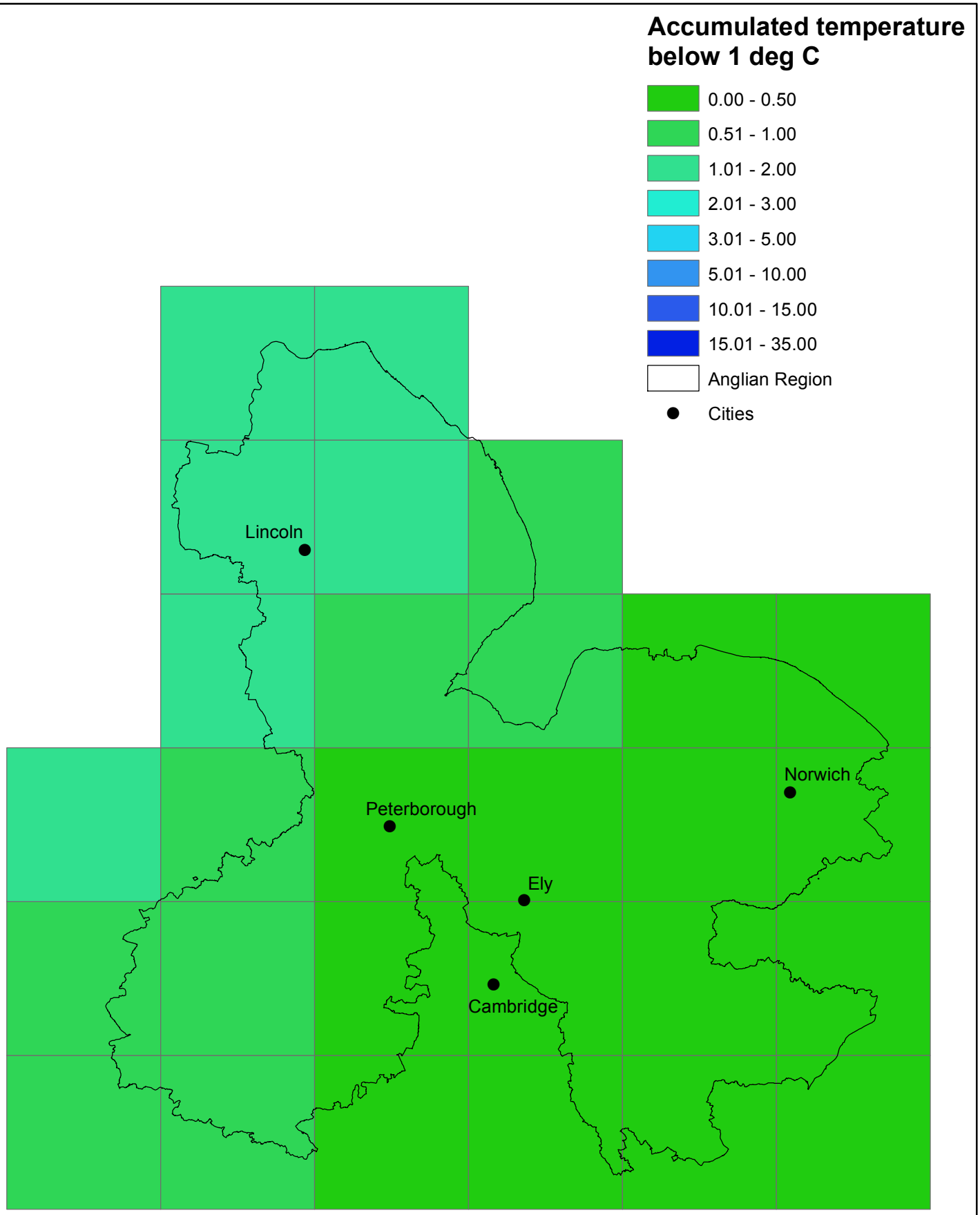
1990/1991



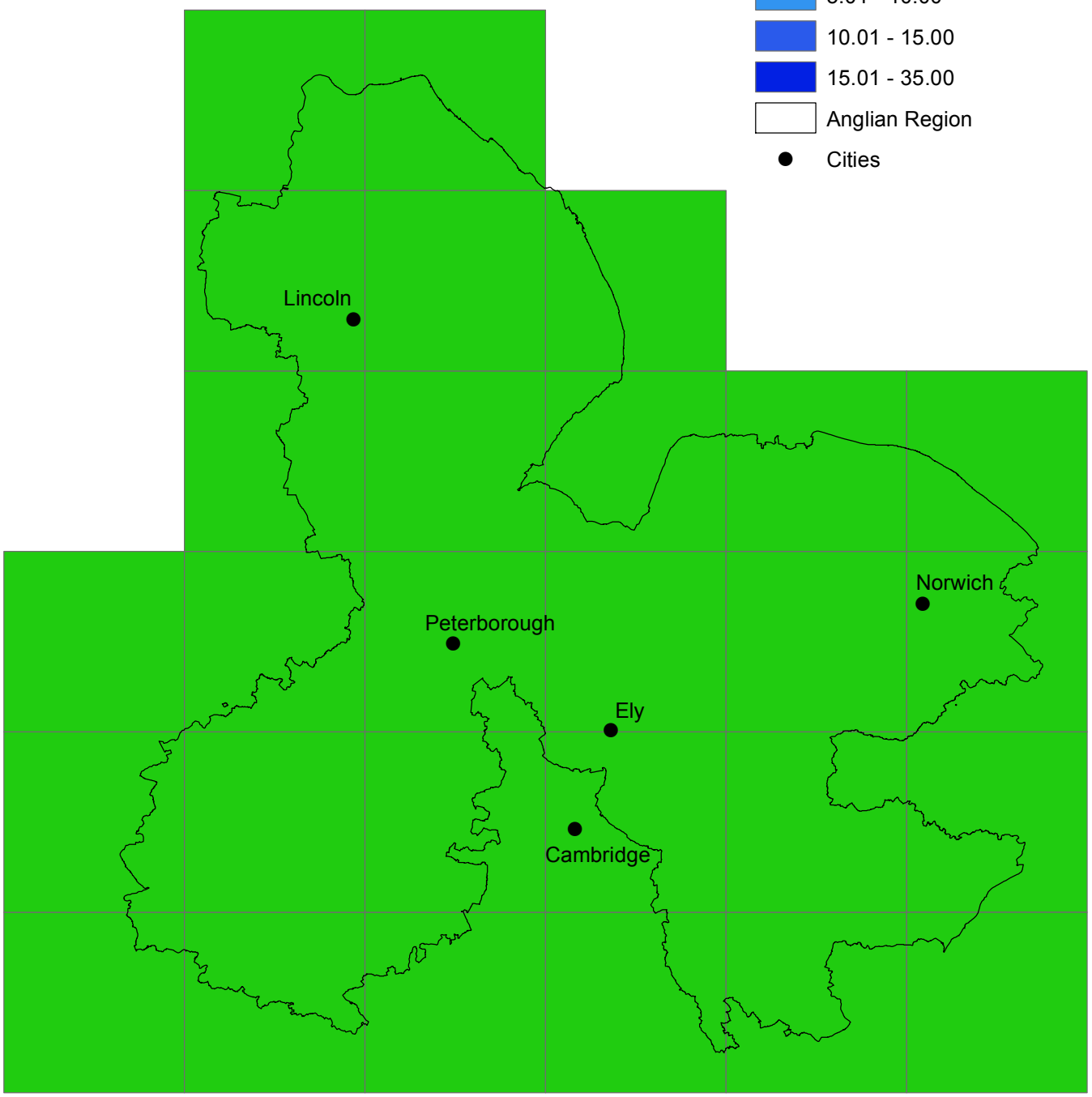
1991/1992



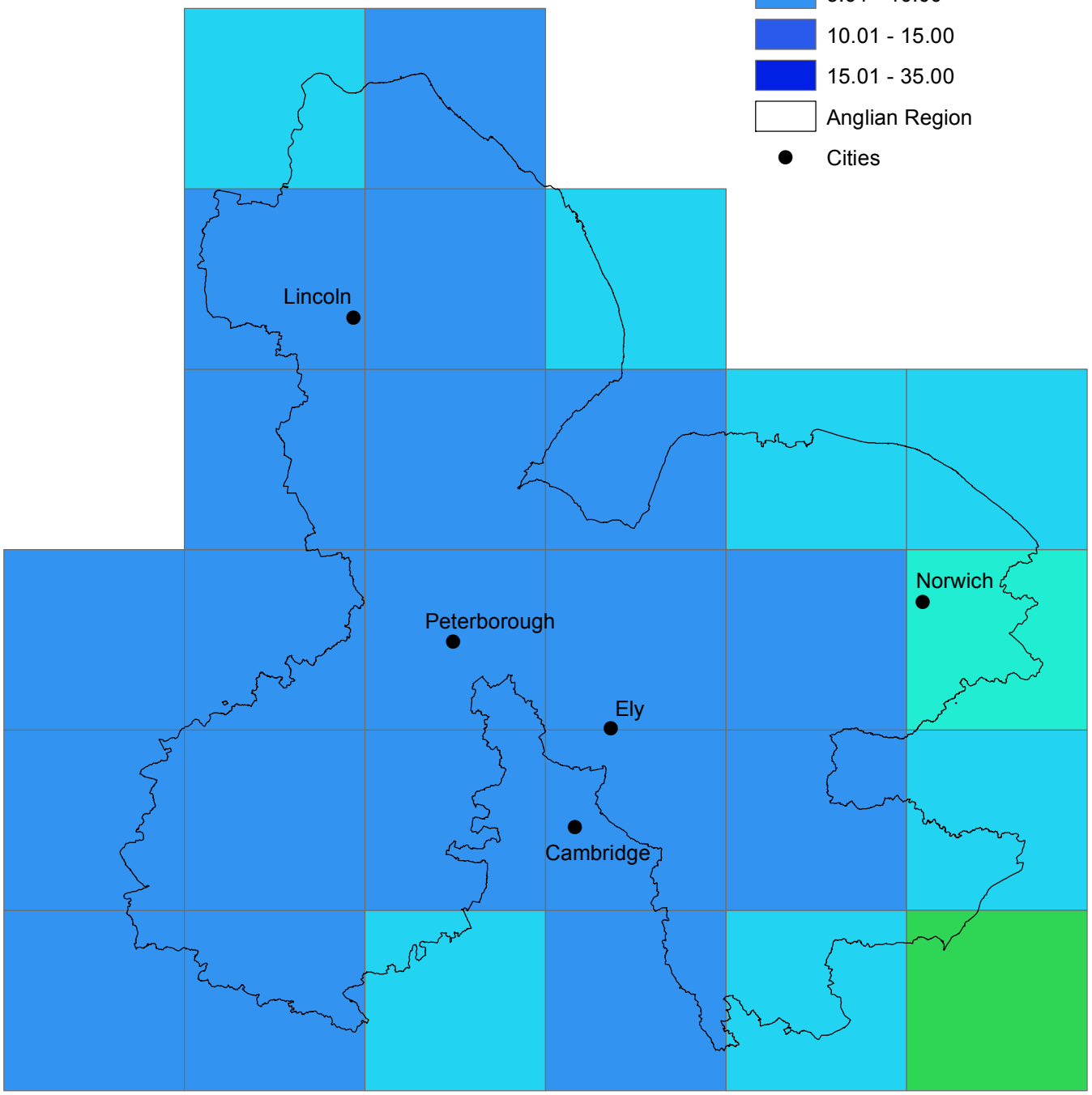
1992/1993



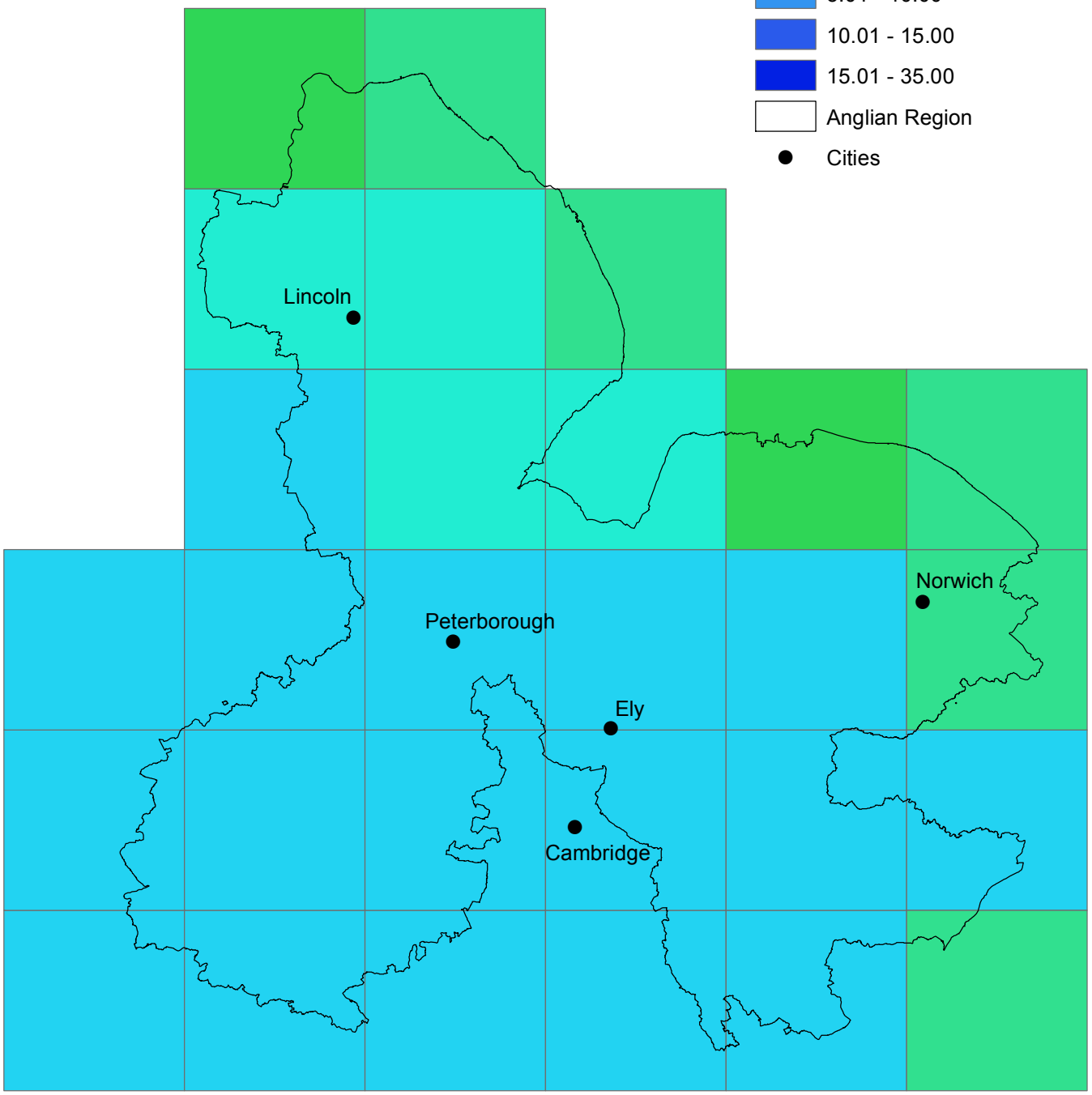
1993/1994



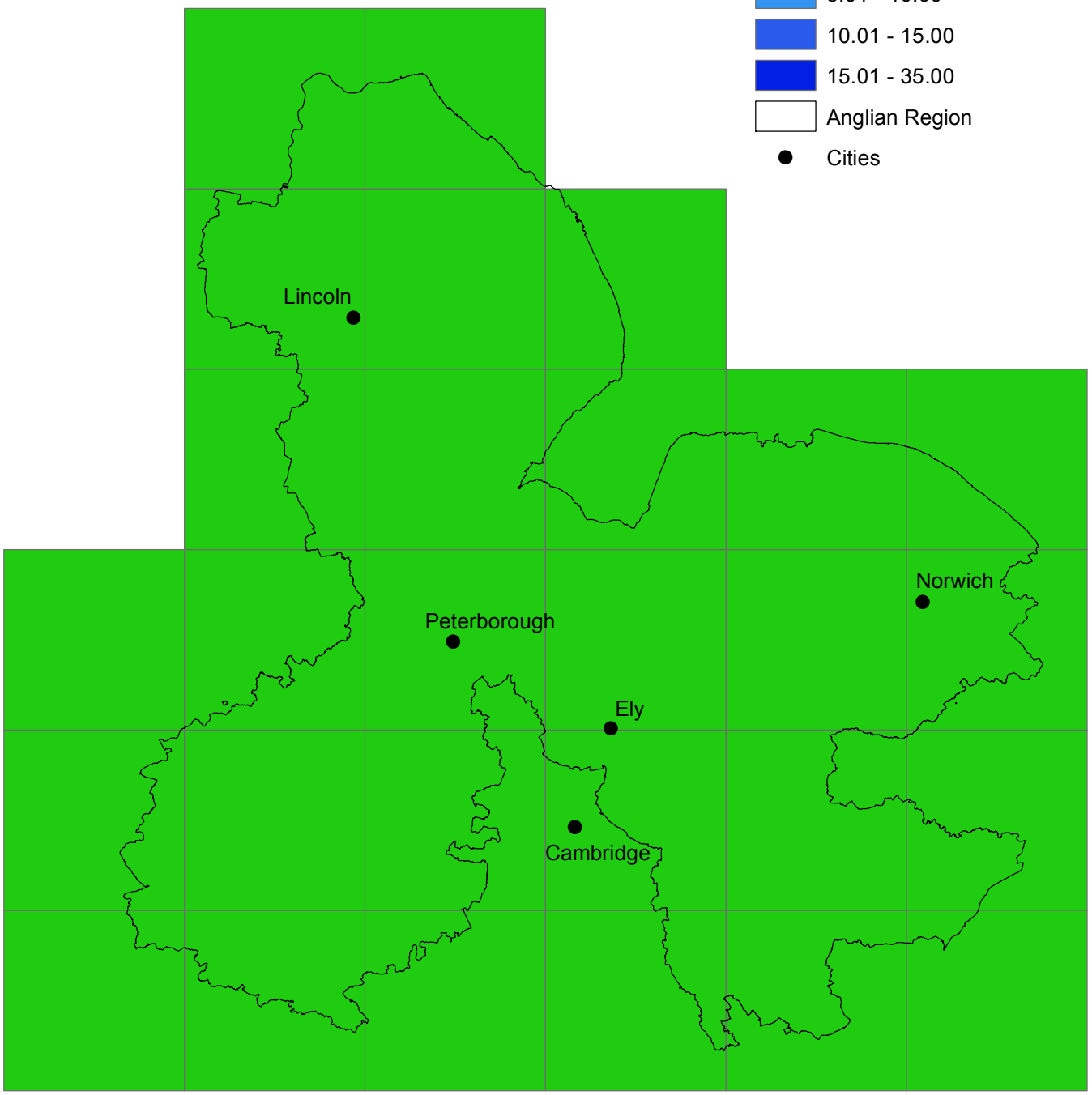
1994/1995



1995/1996



1996/1997



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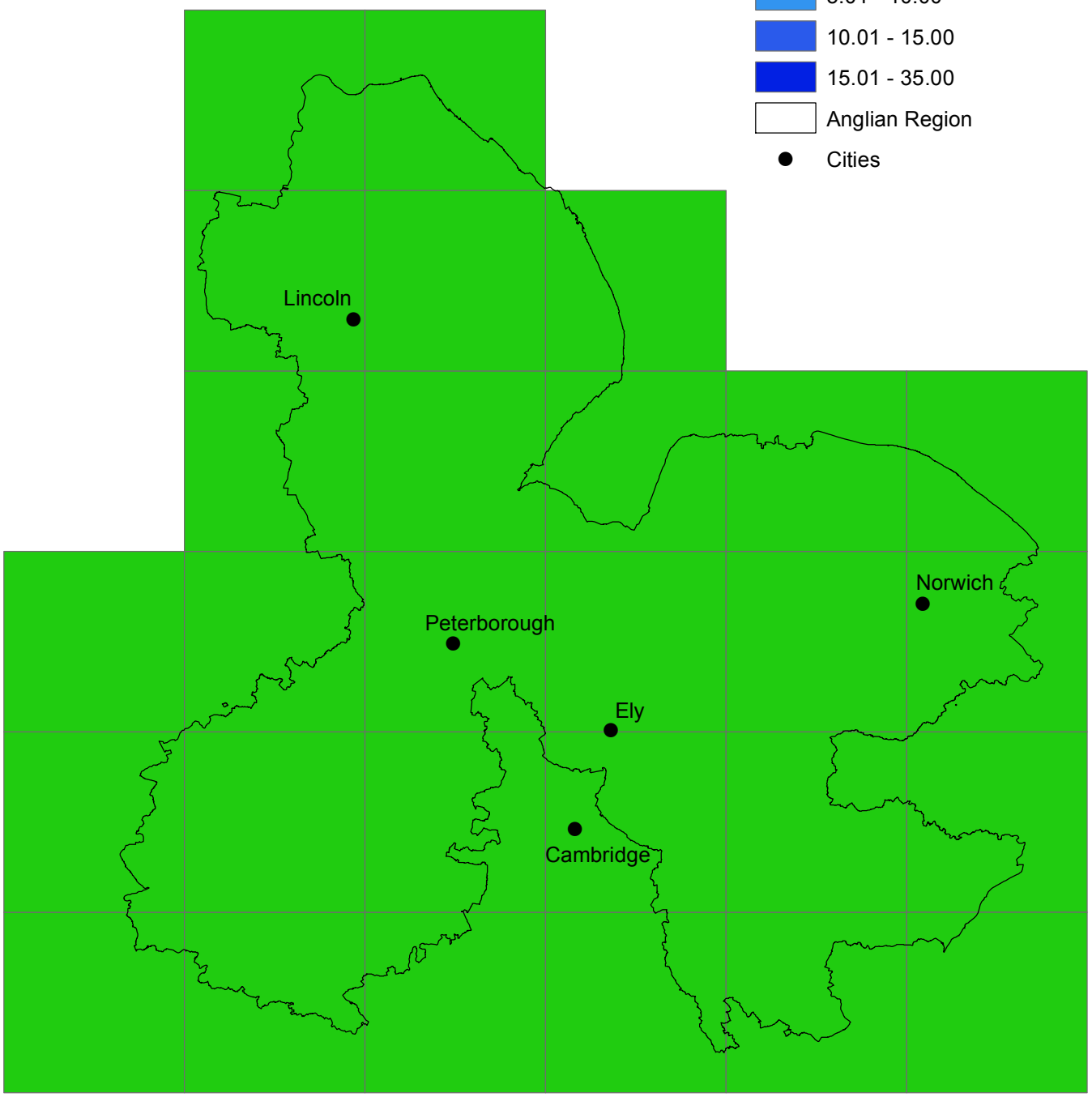

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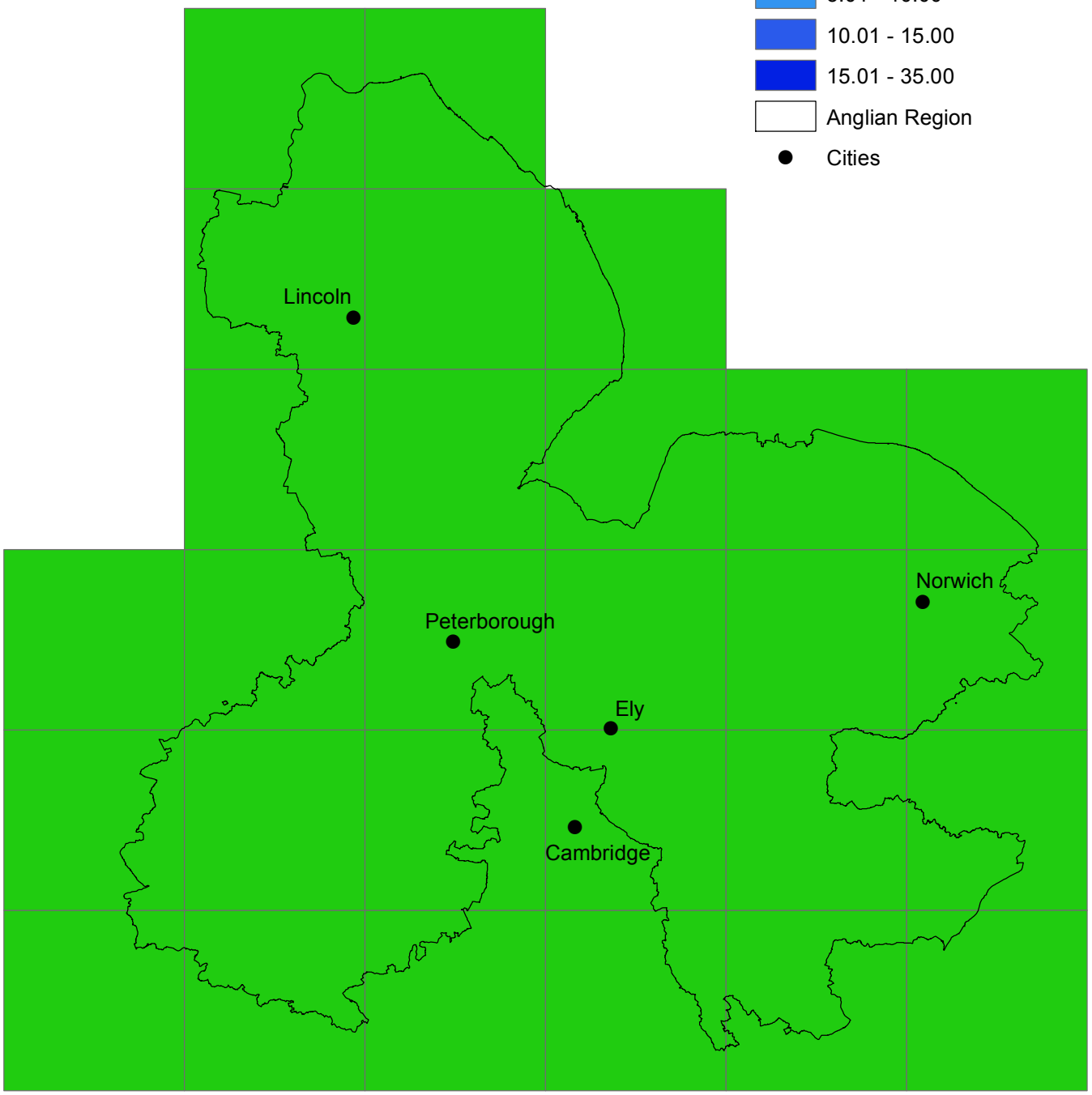

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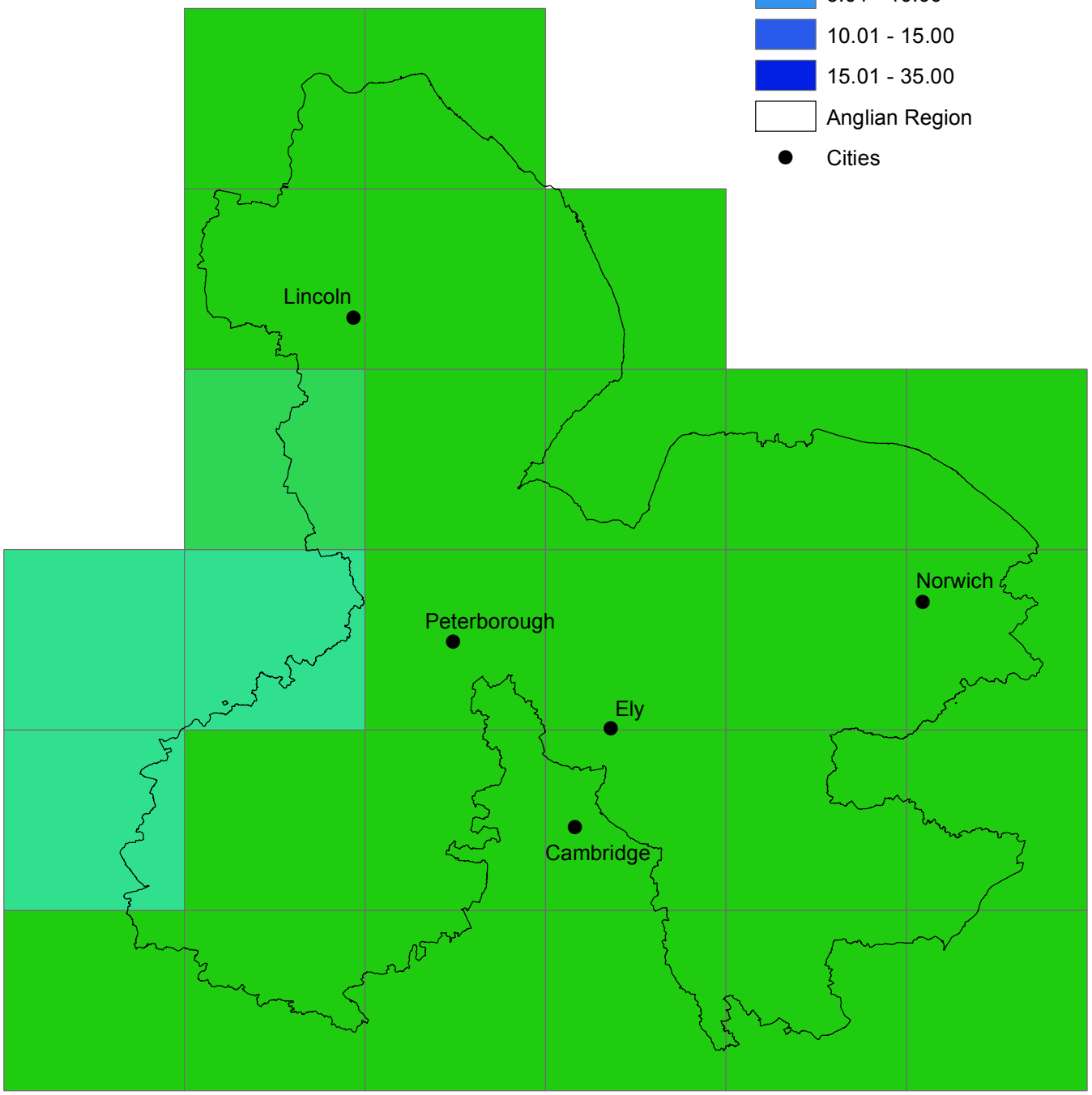

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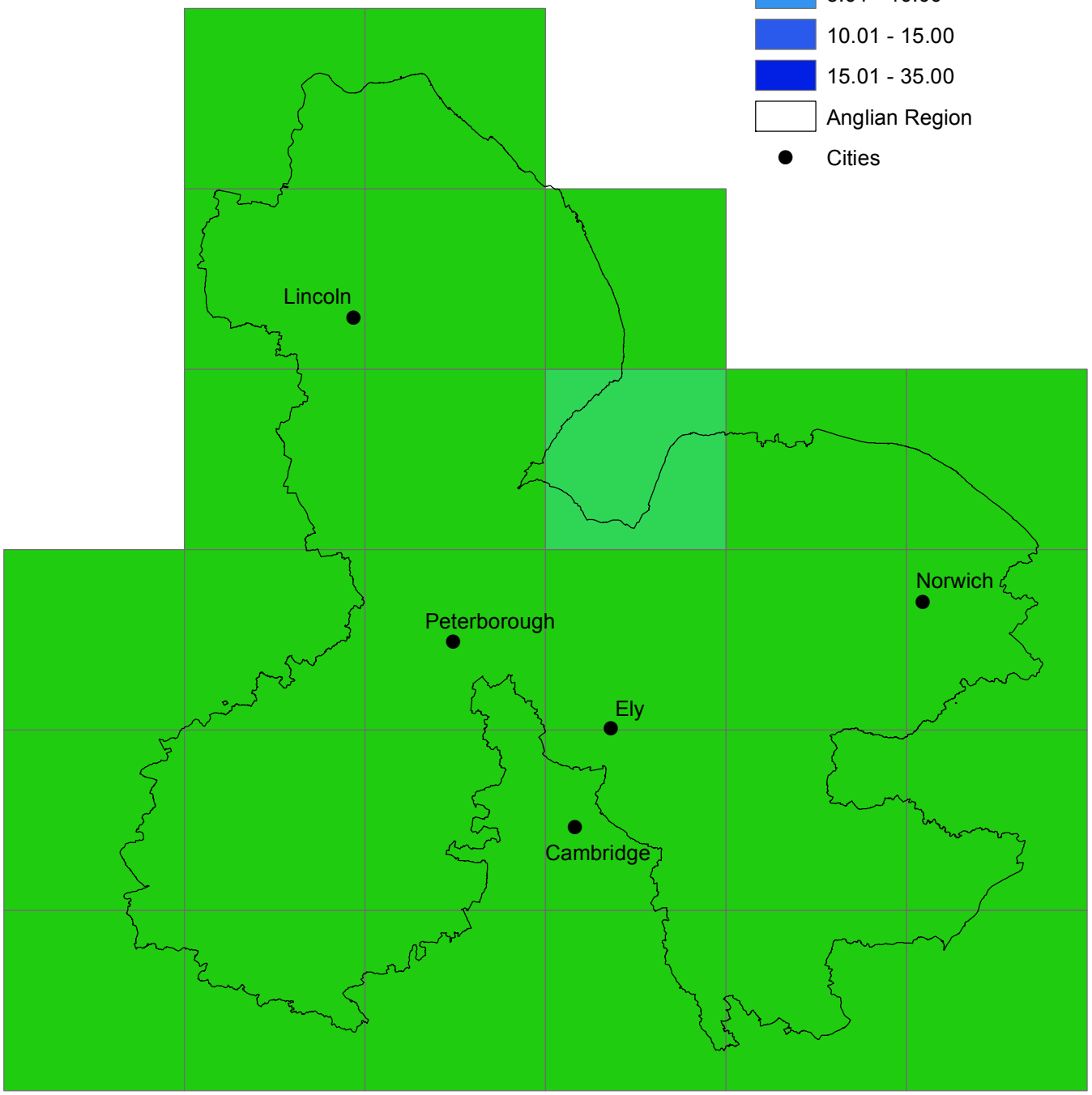

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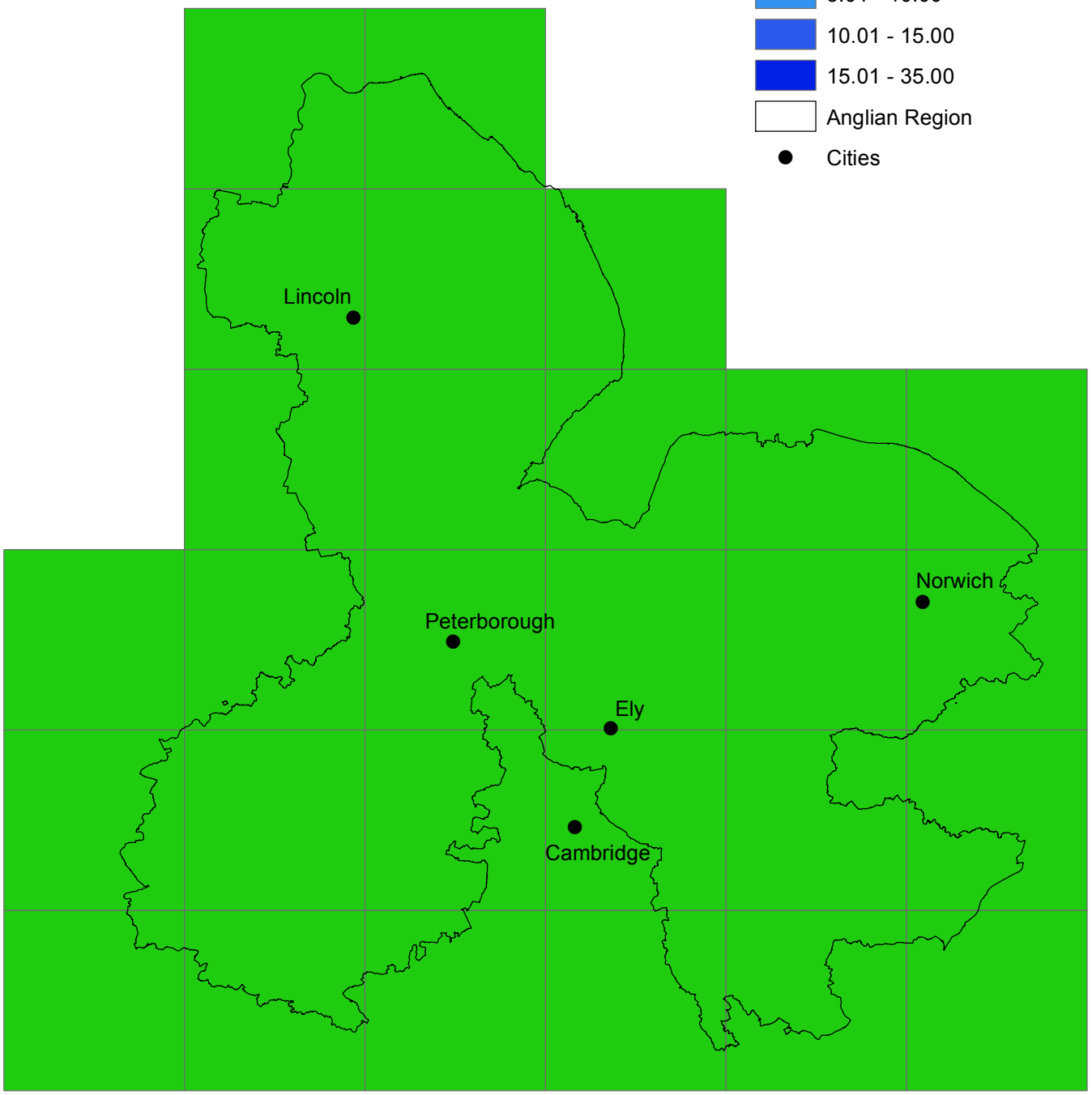

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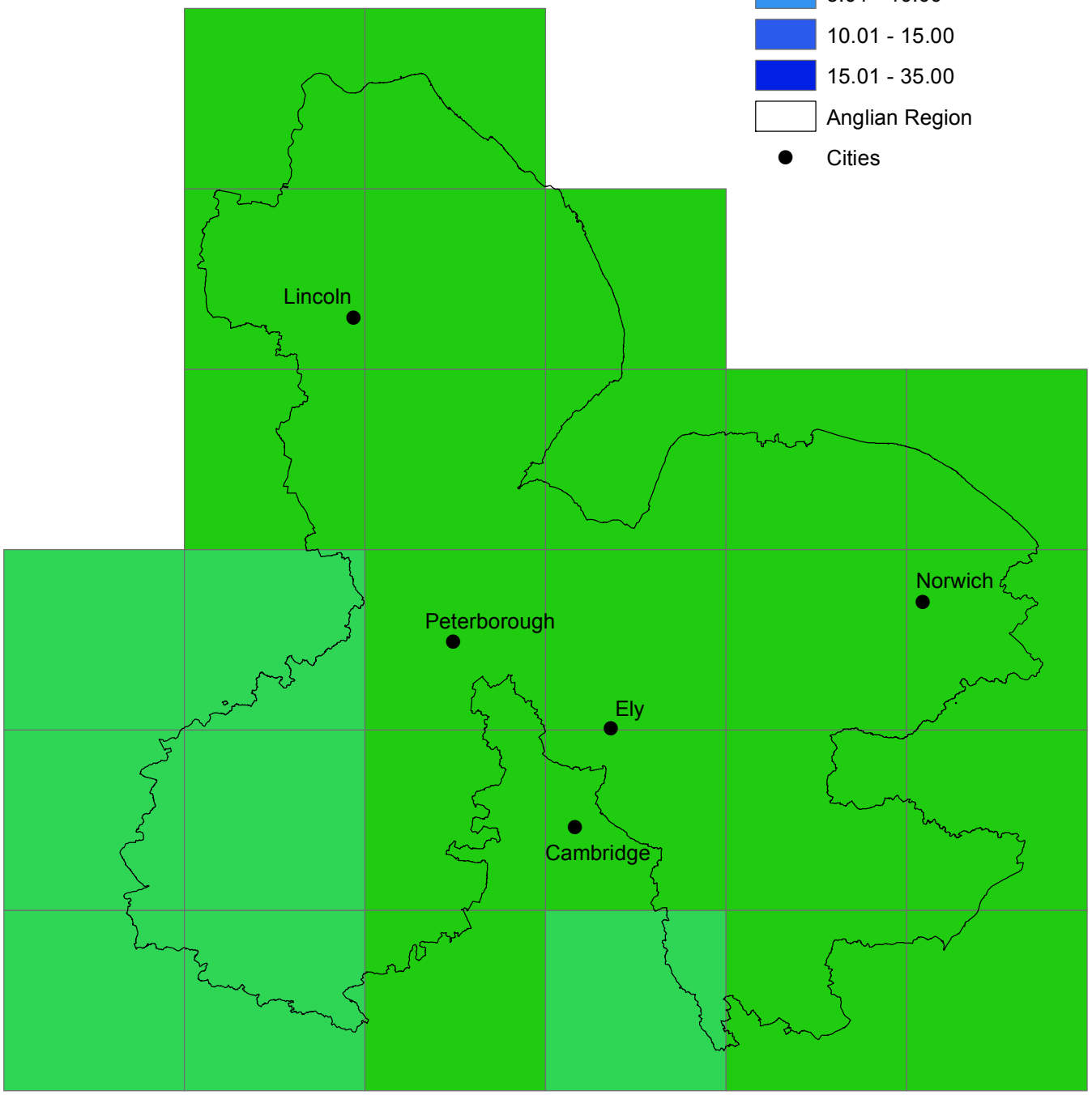

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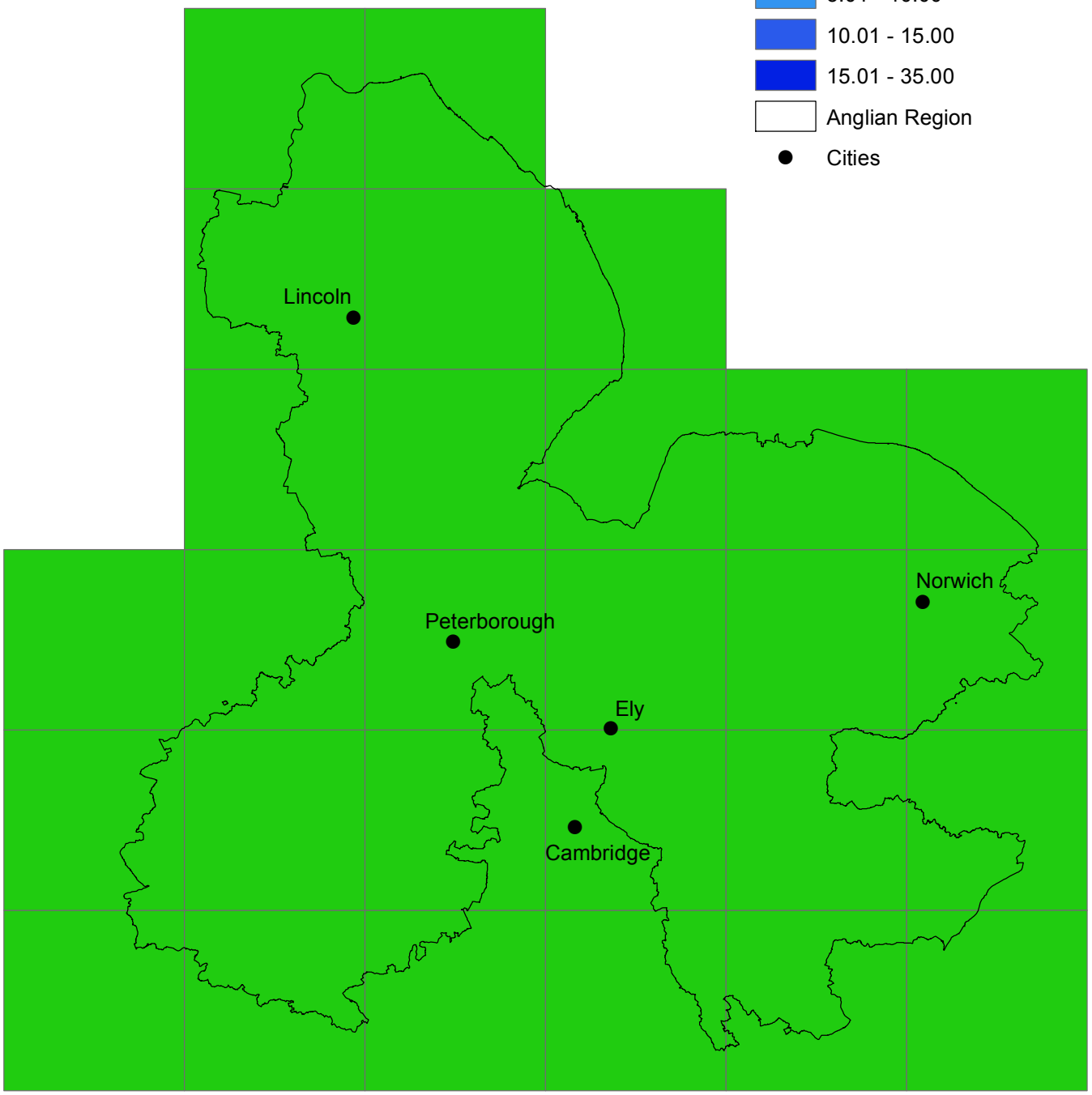

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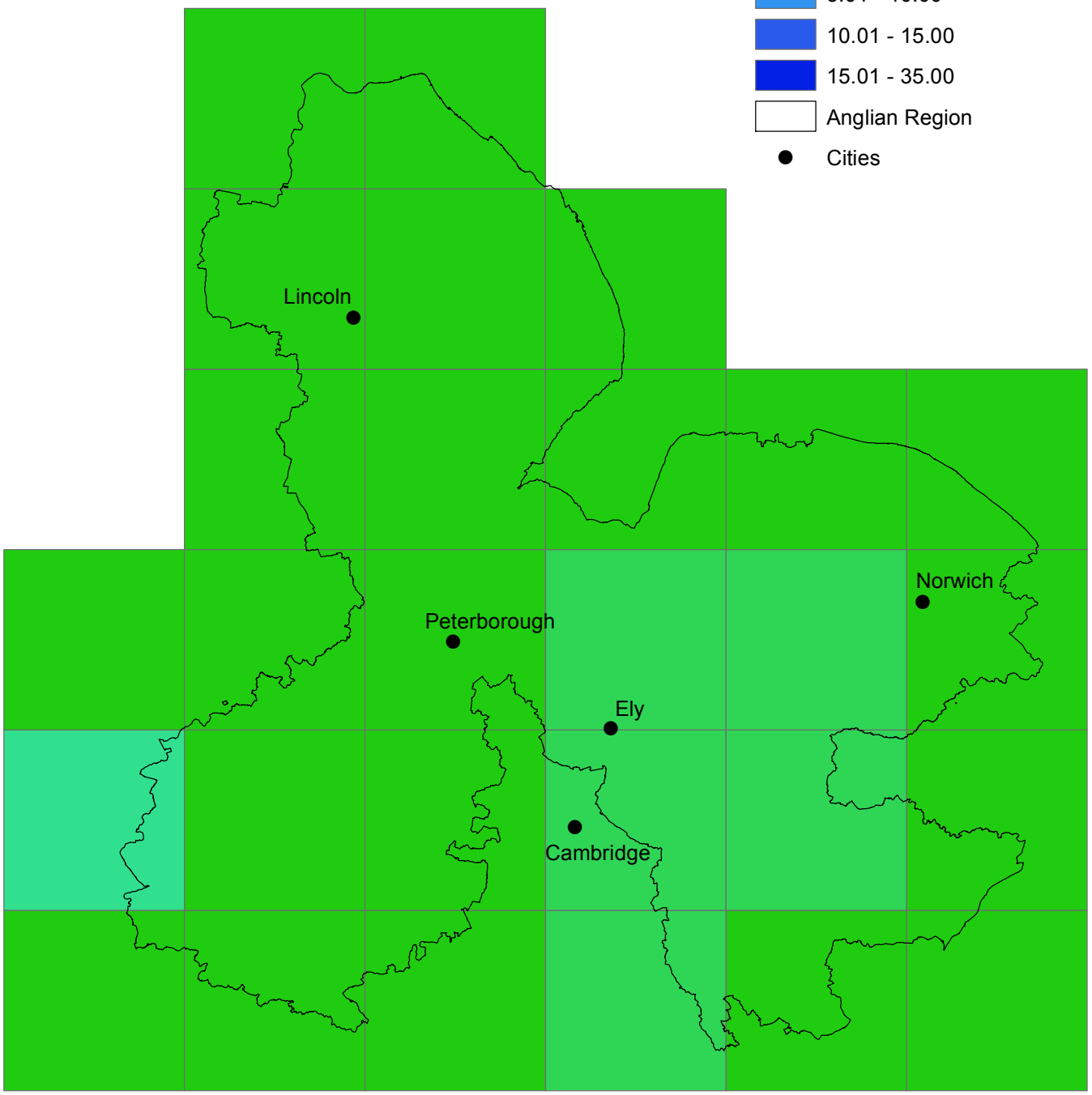

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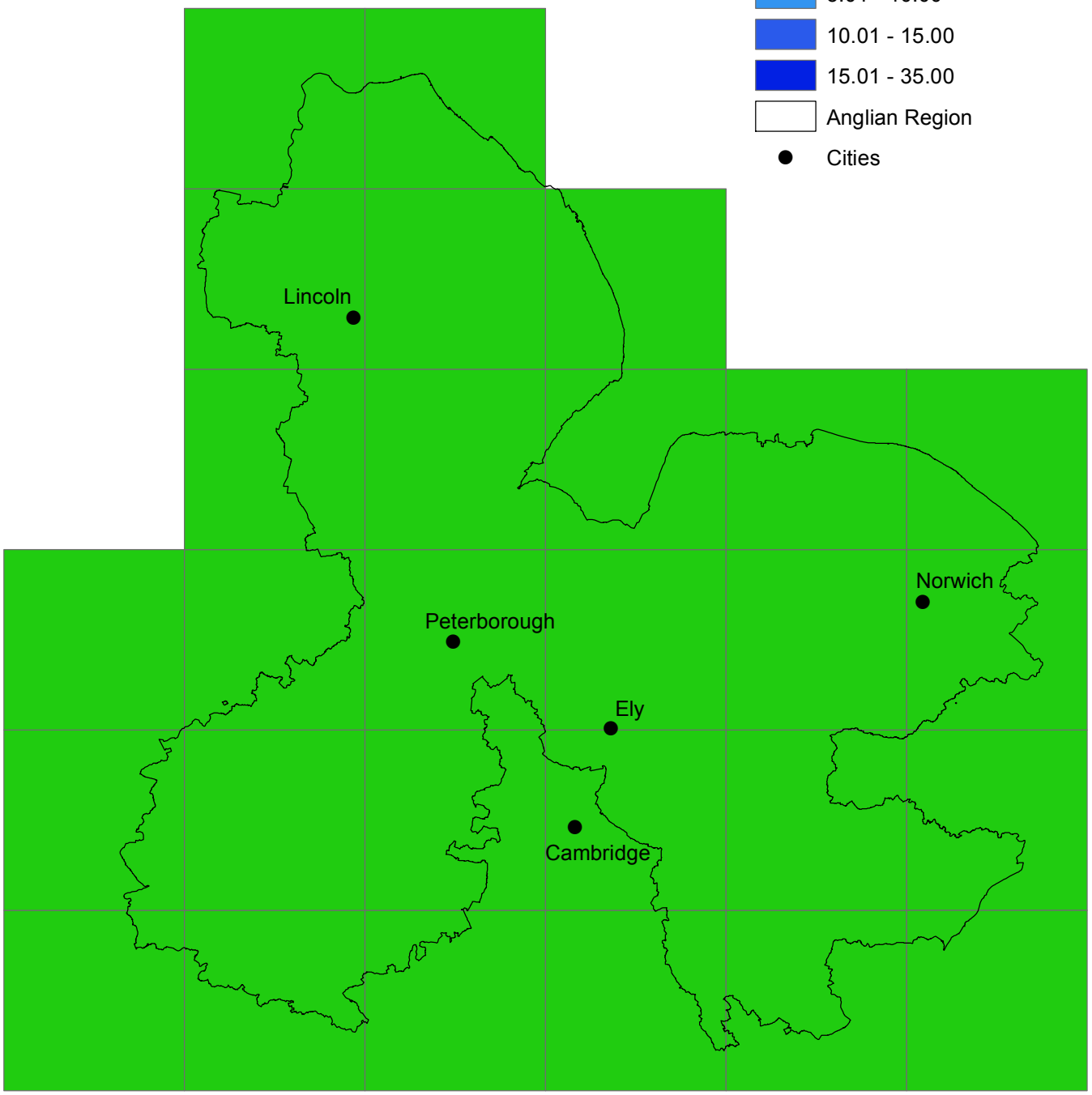

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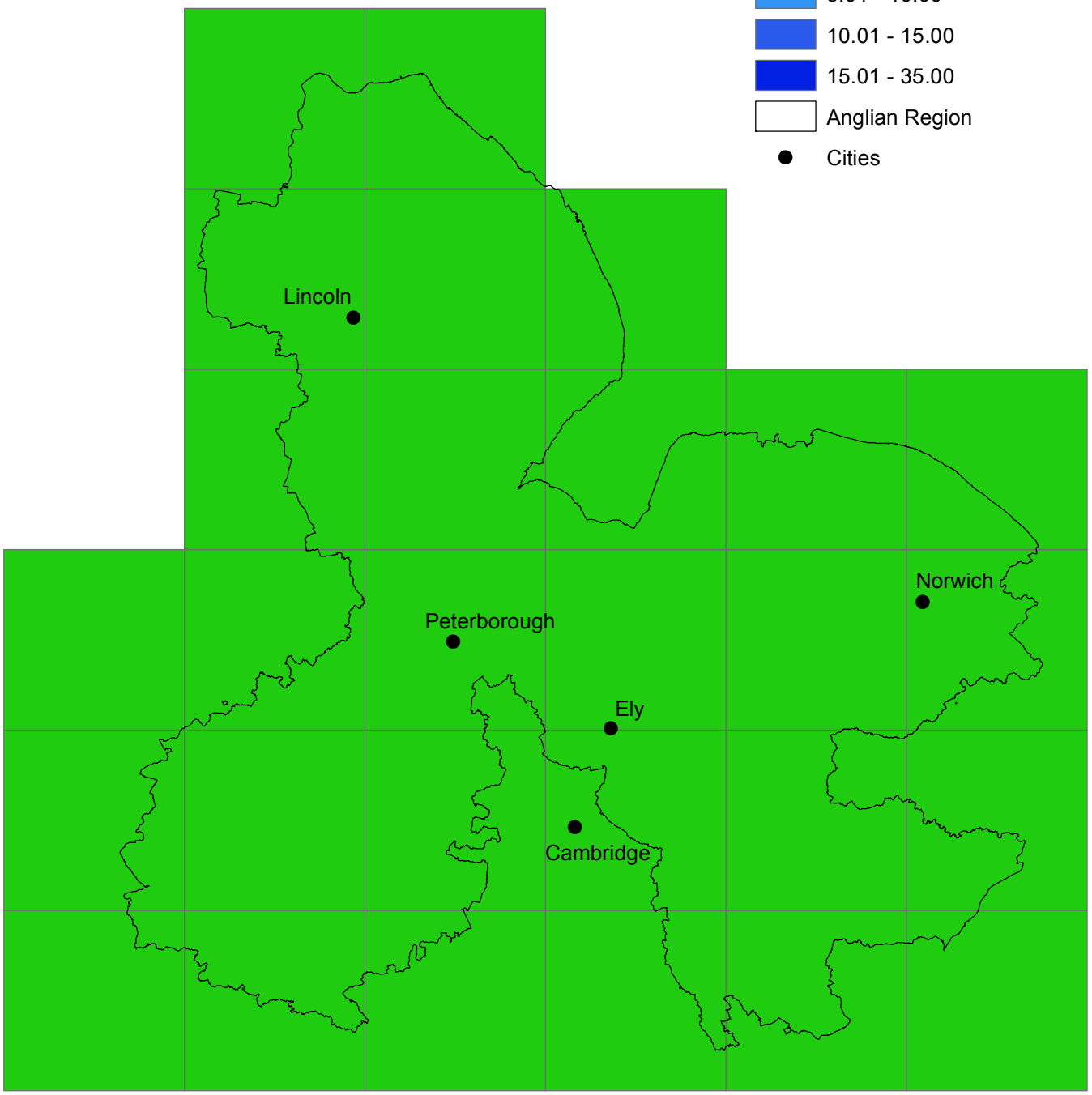

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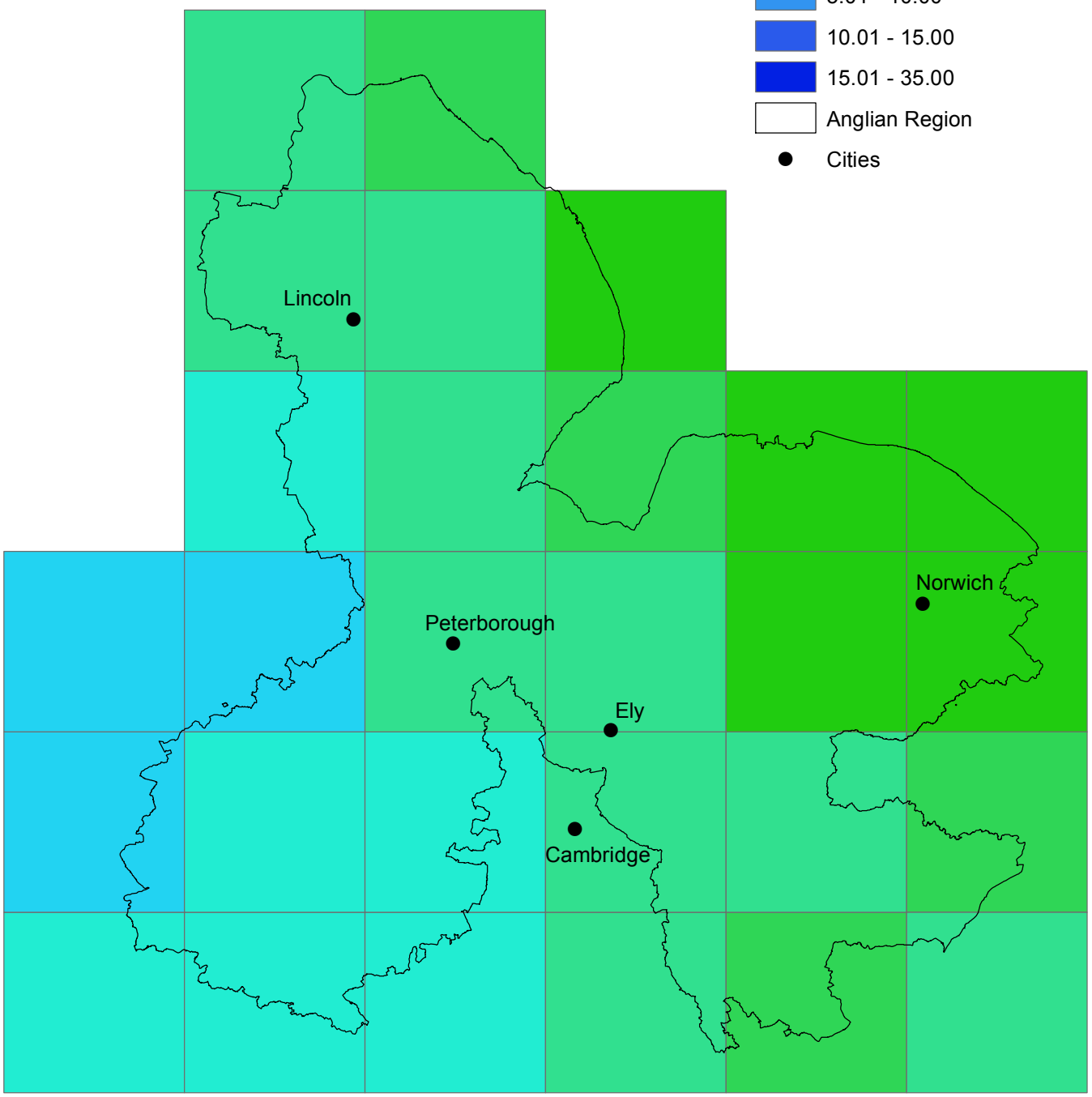

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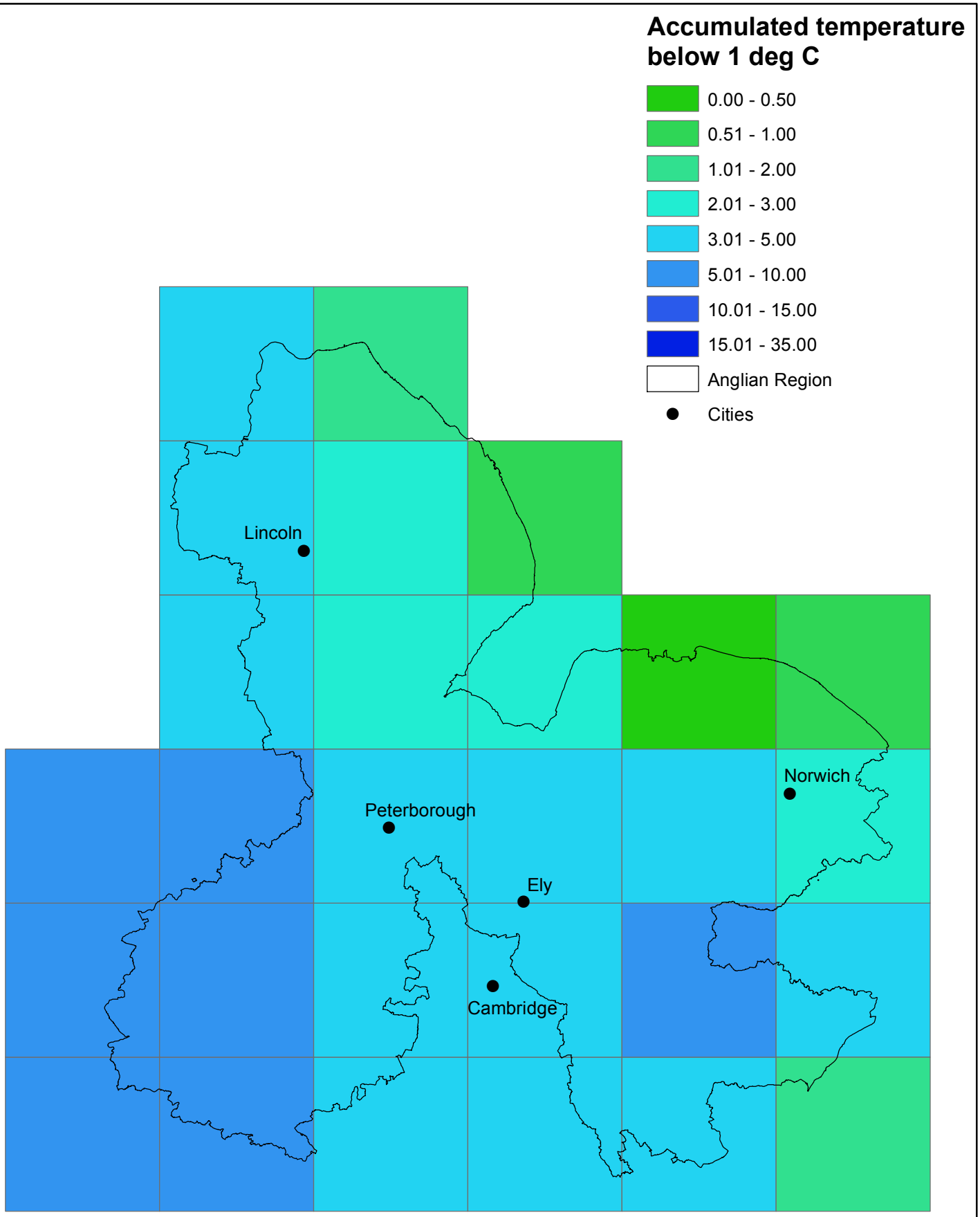

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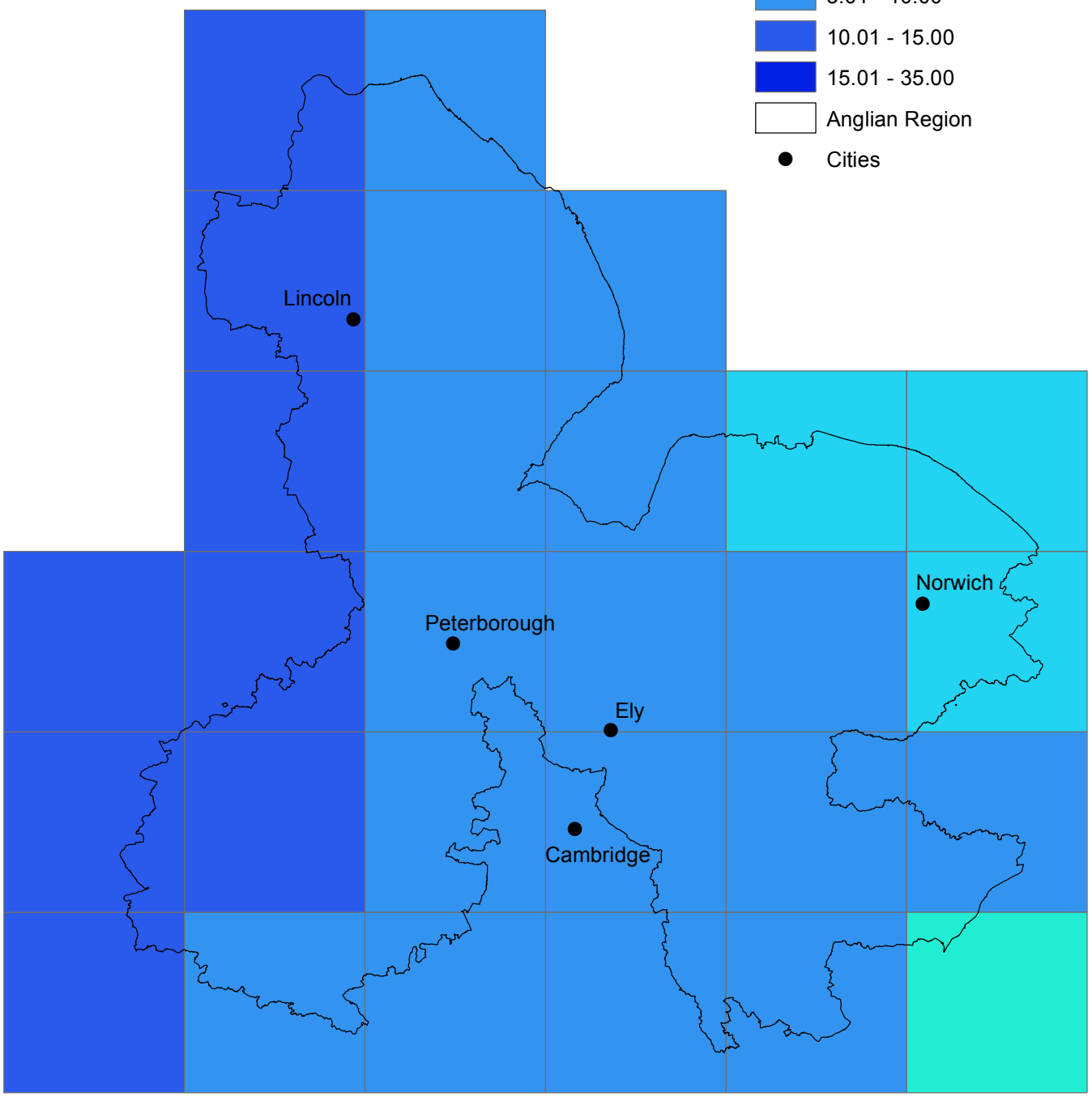

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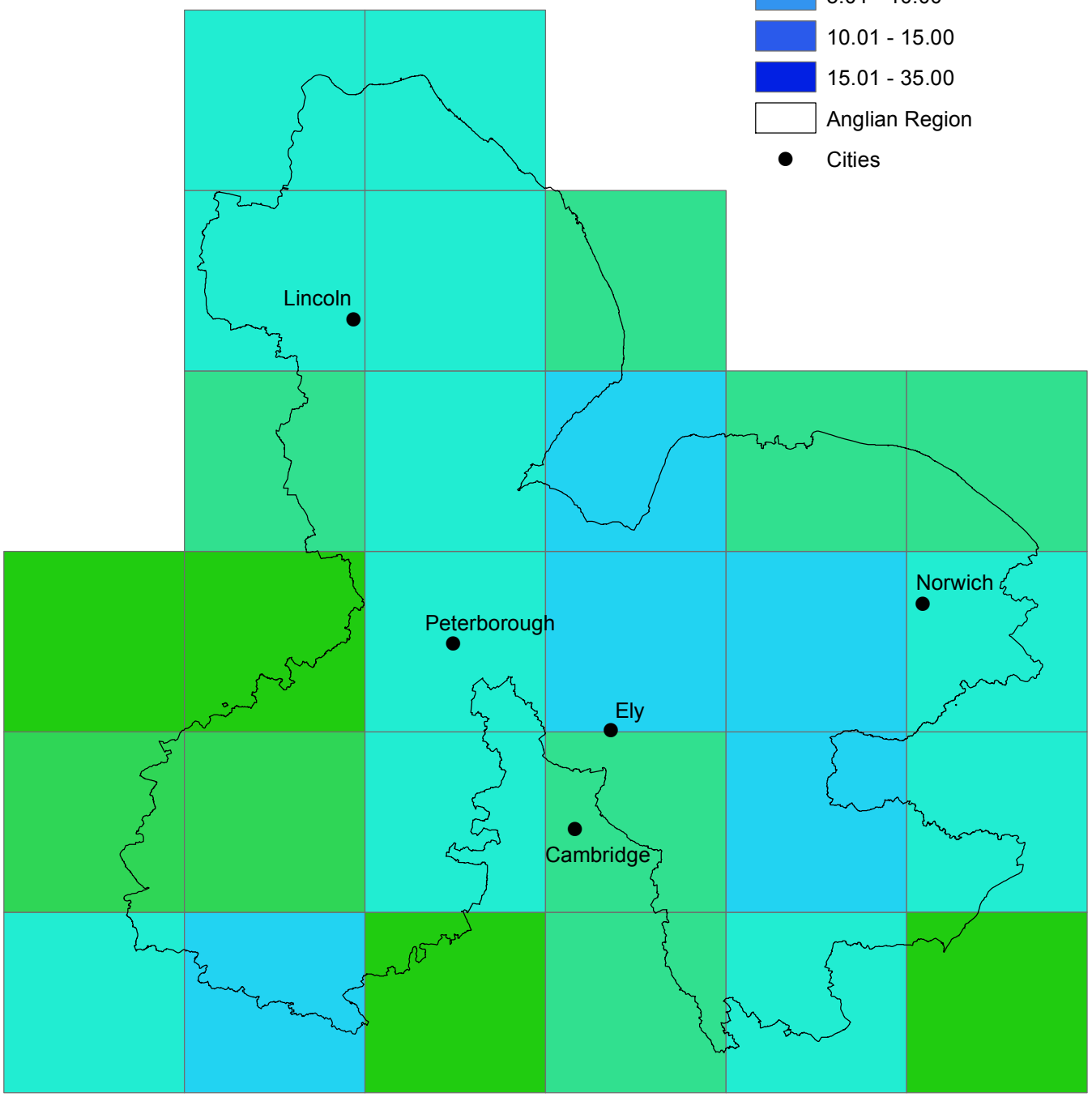

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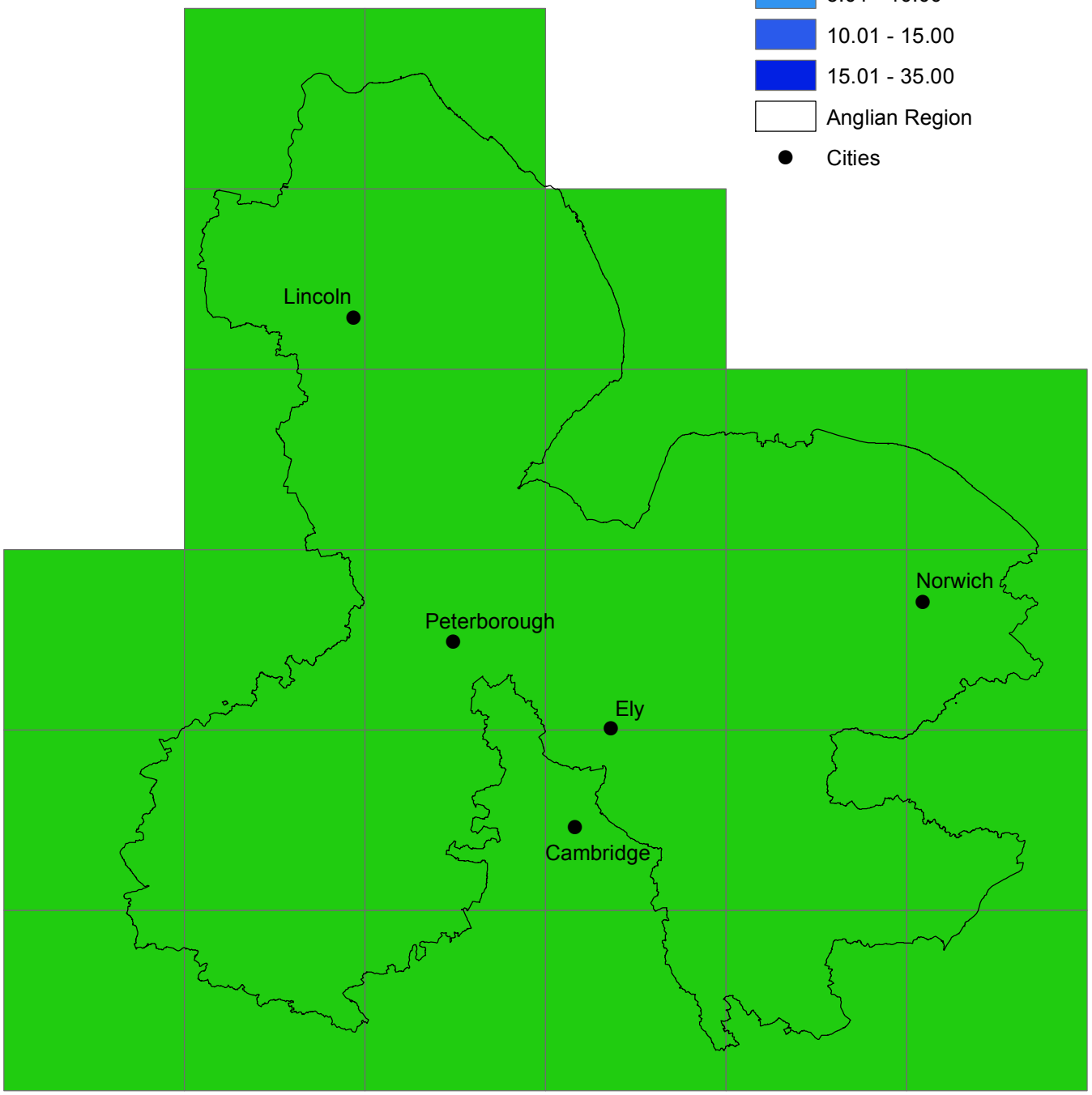

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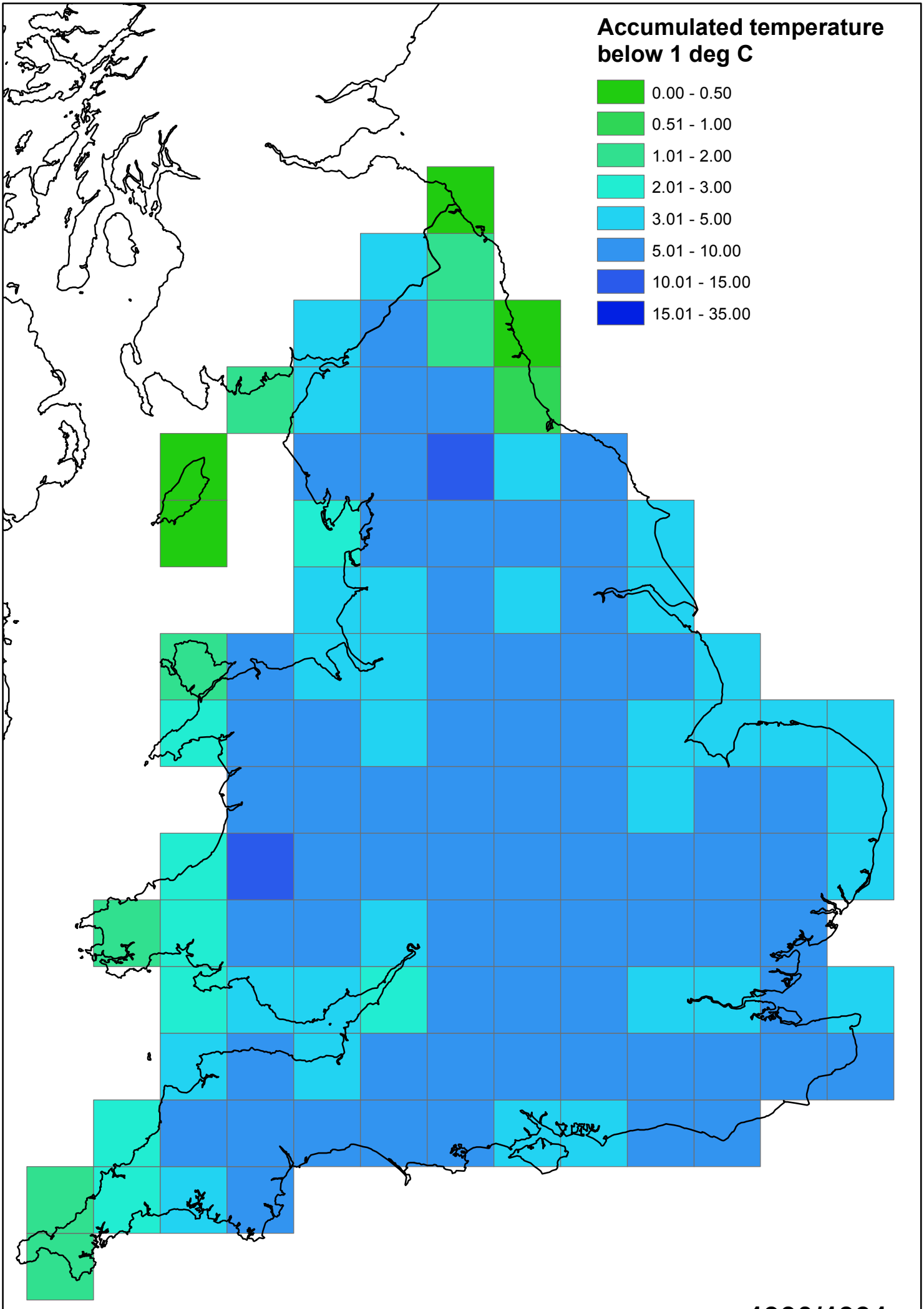

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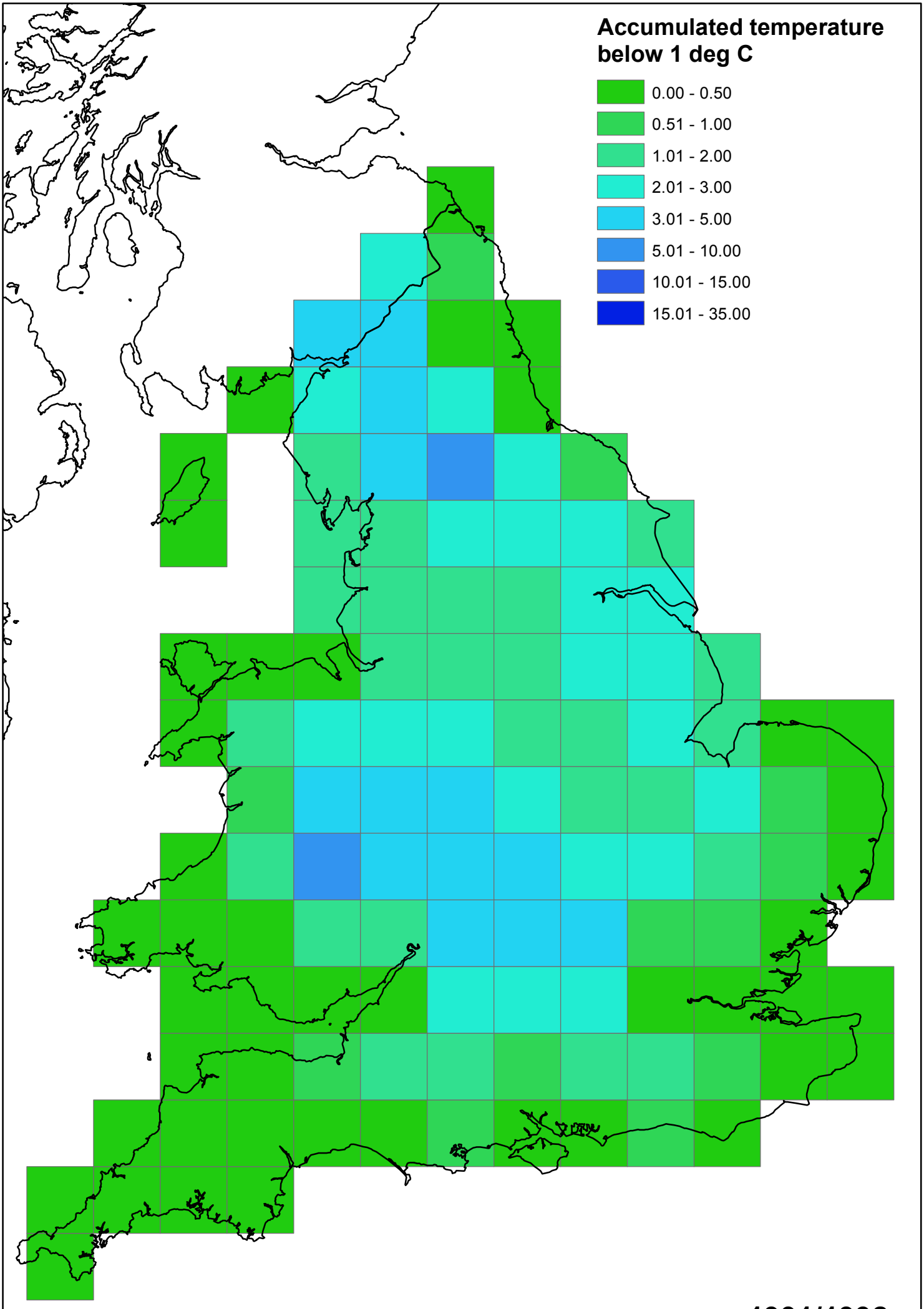

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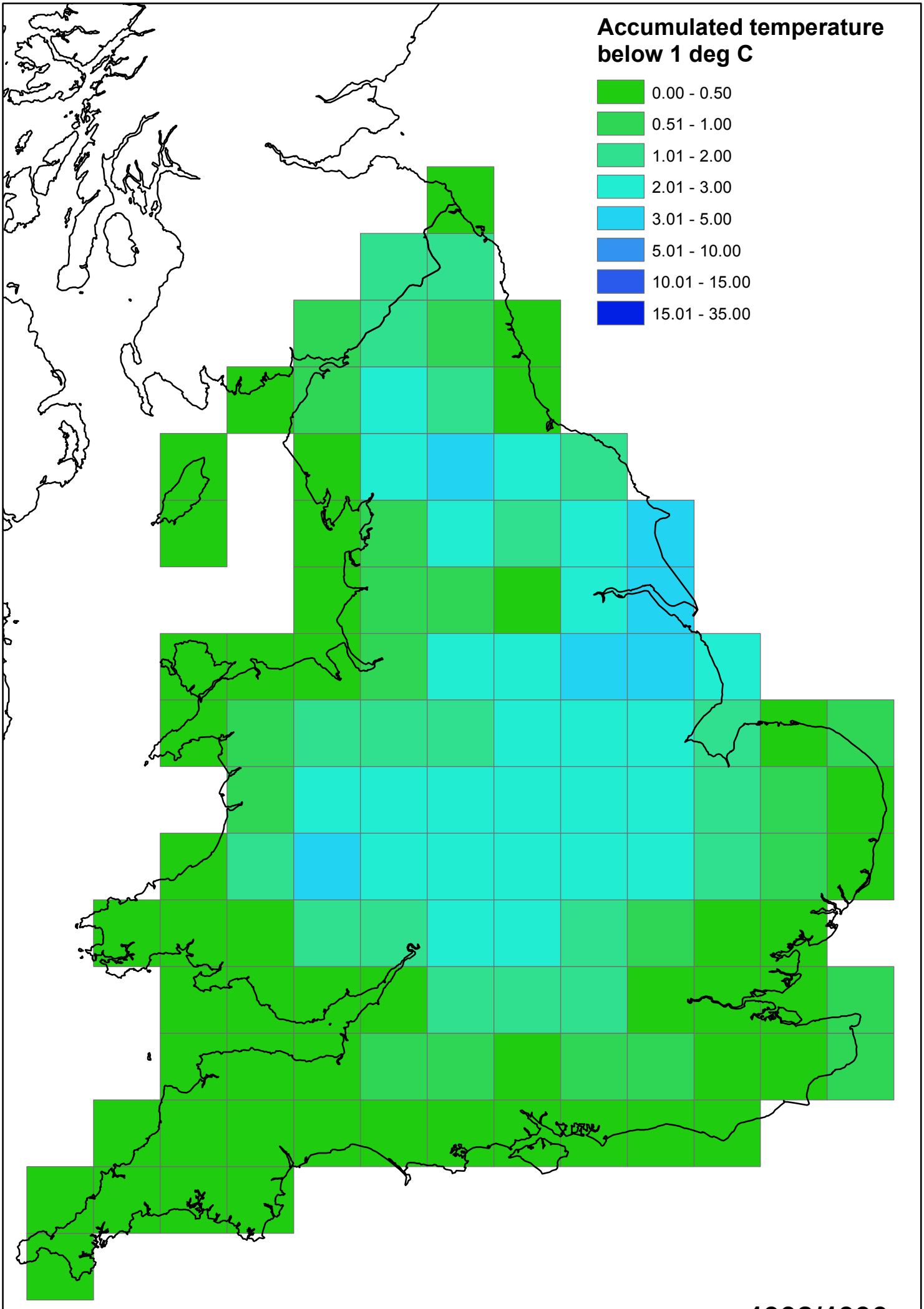

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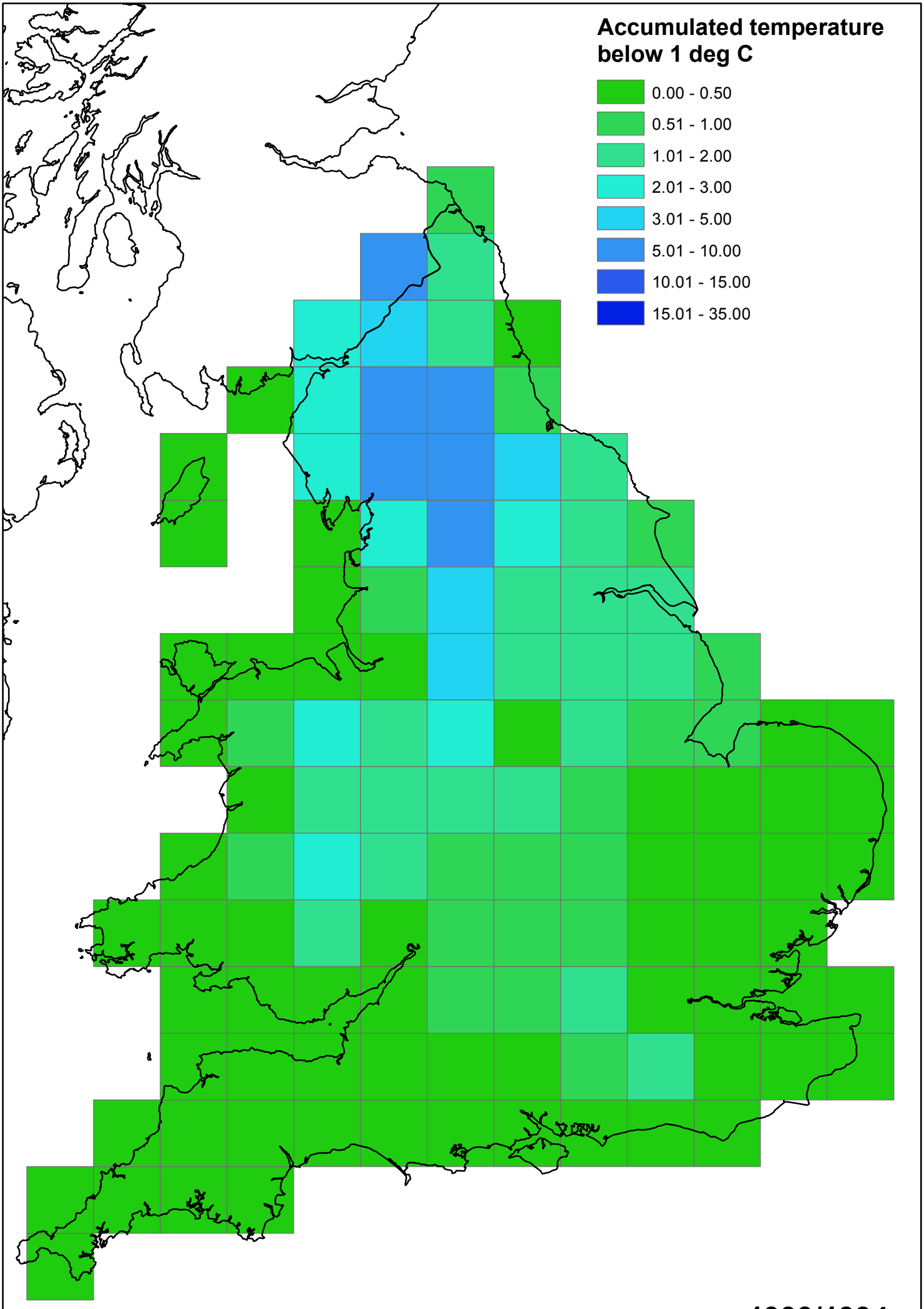

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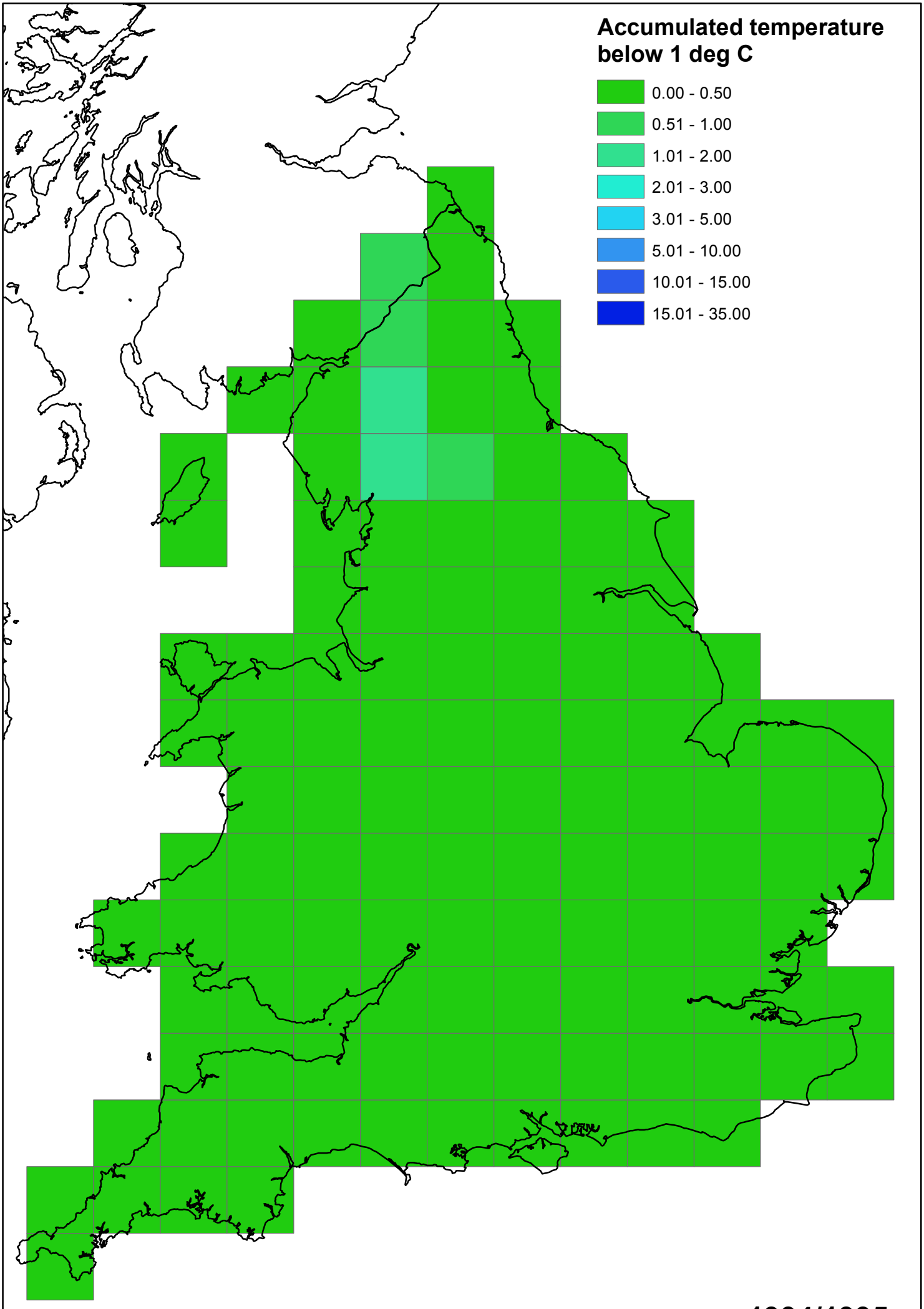

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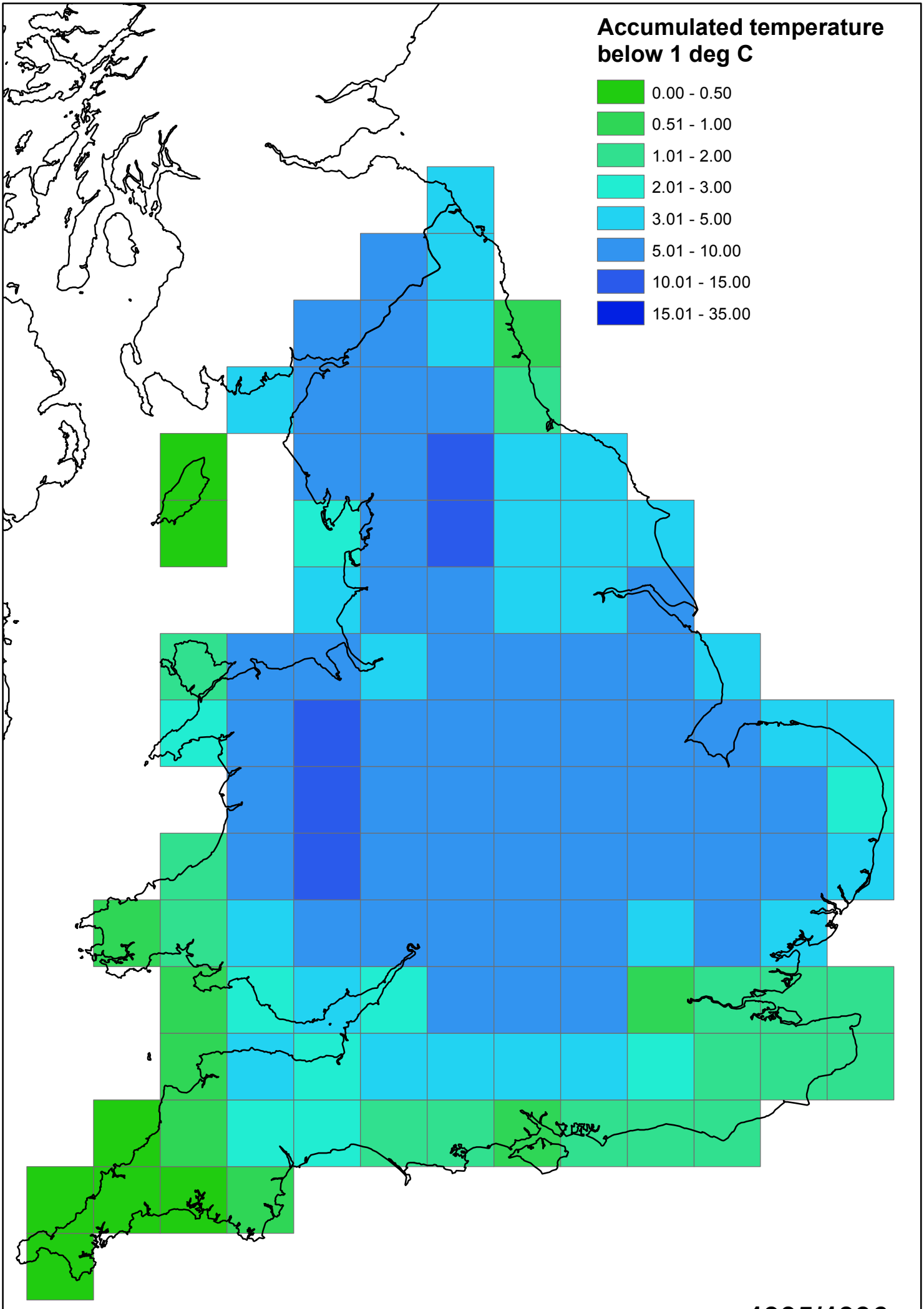

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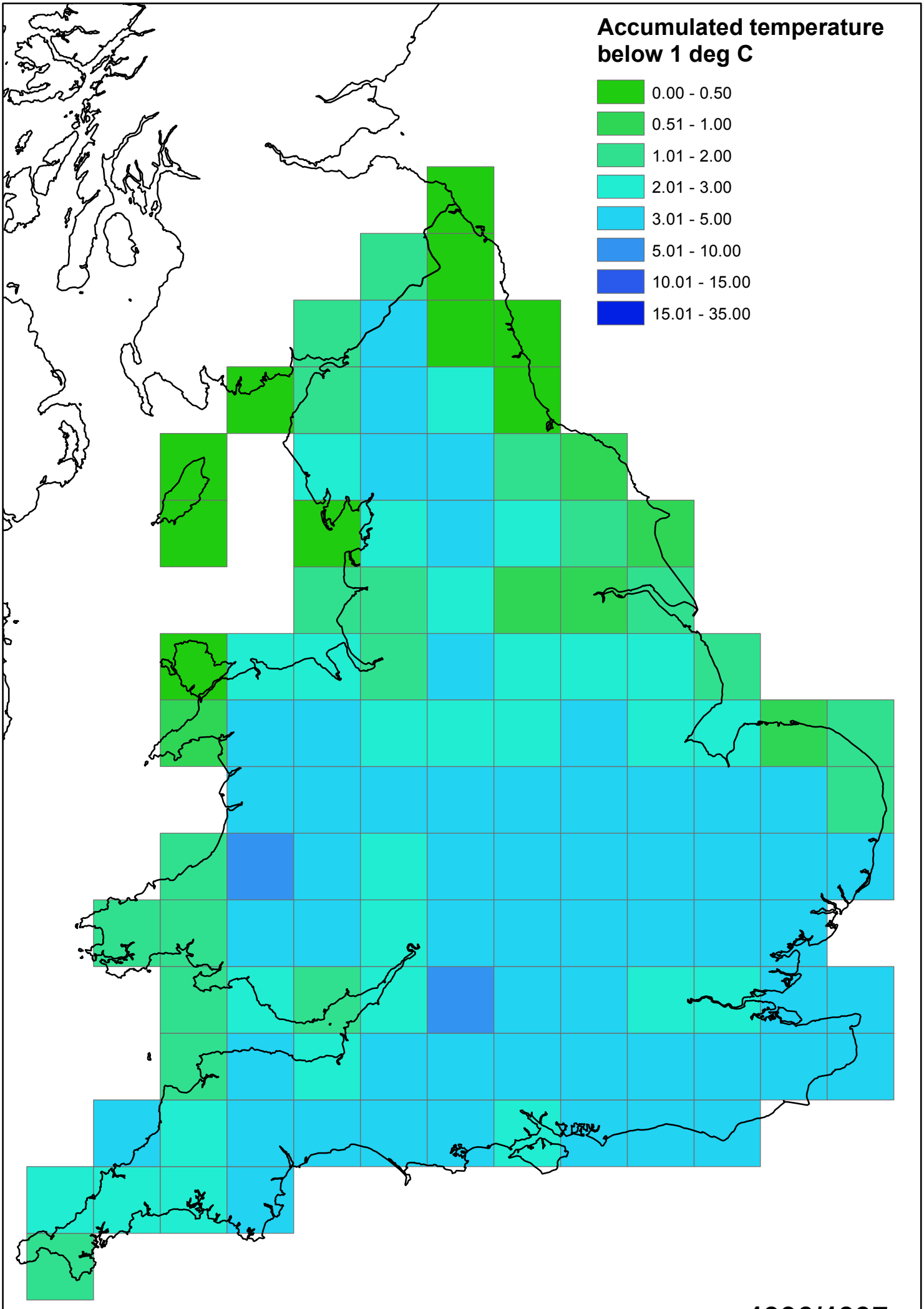

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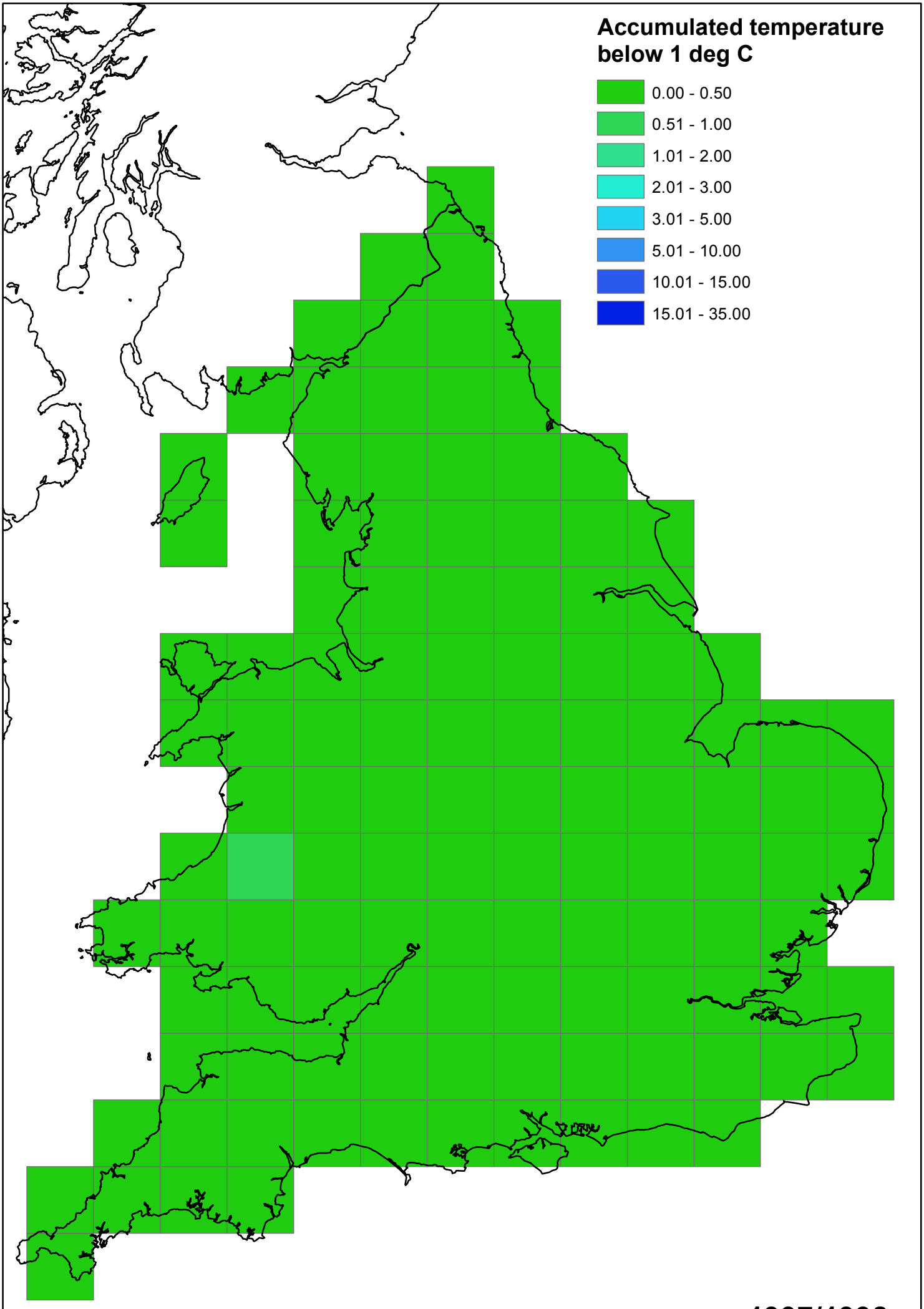

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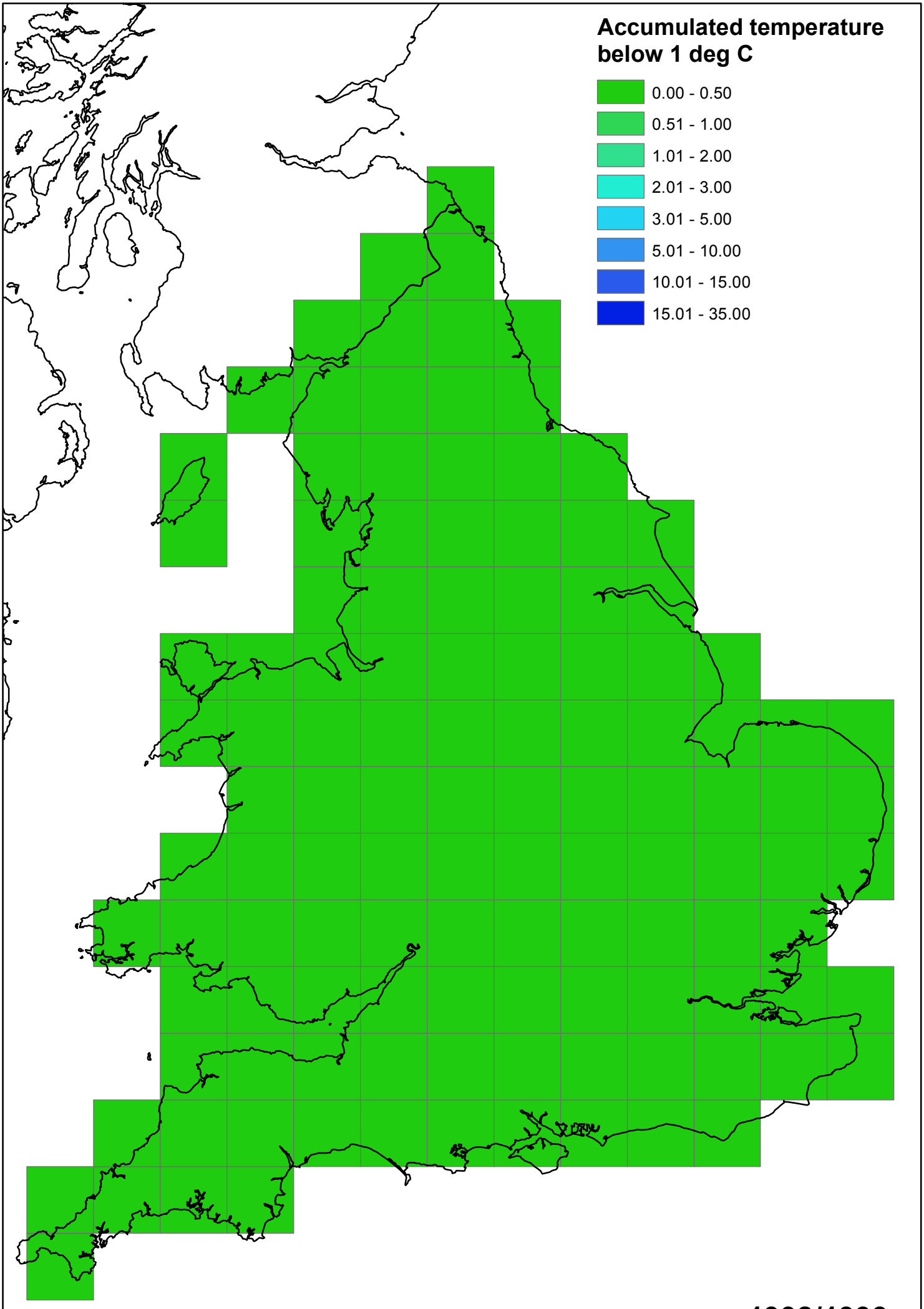

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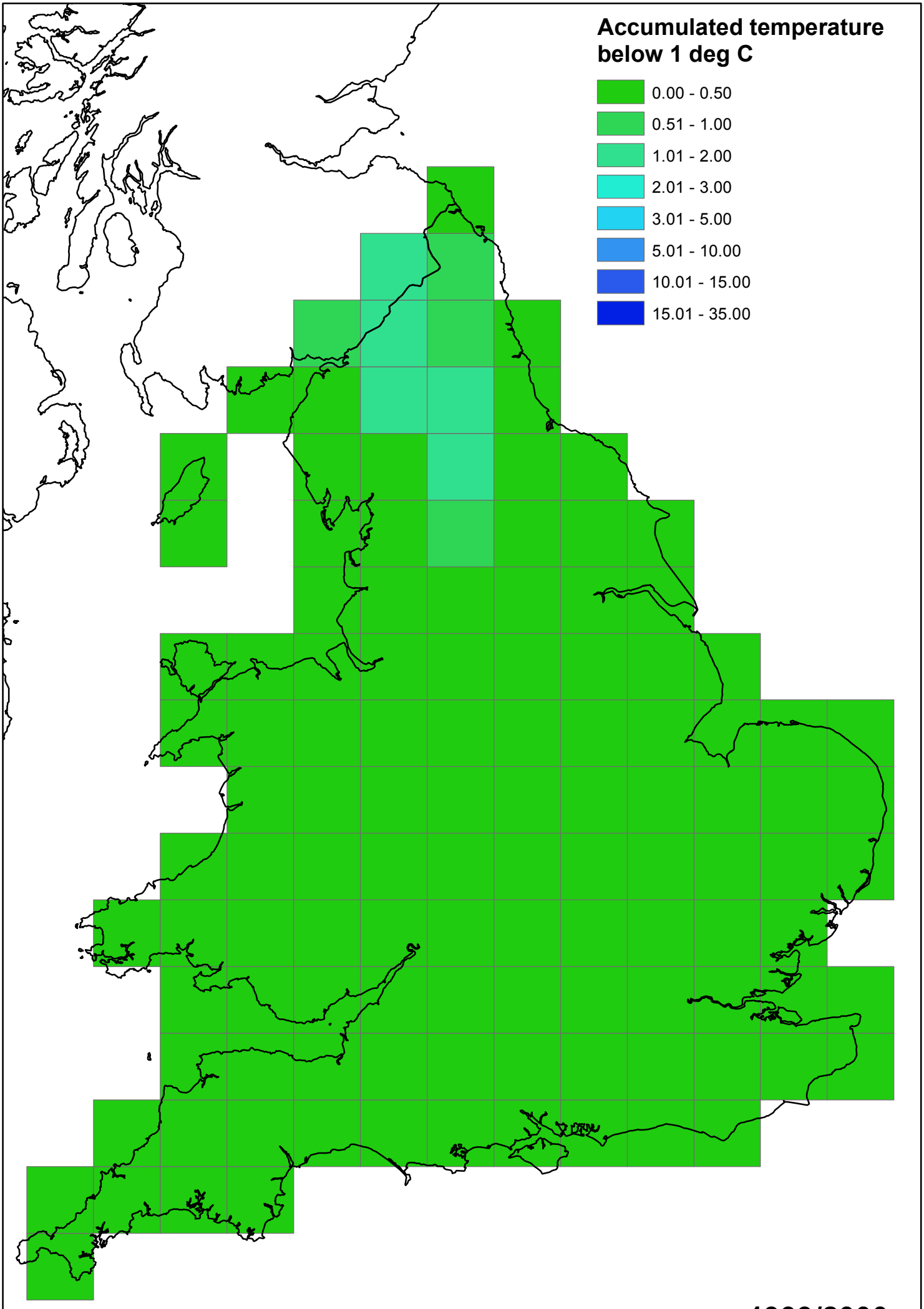

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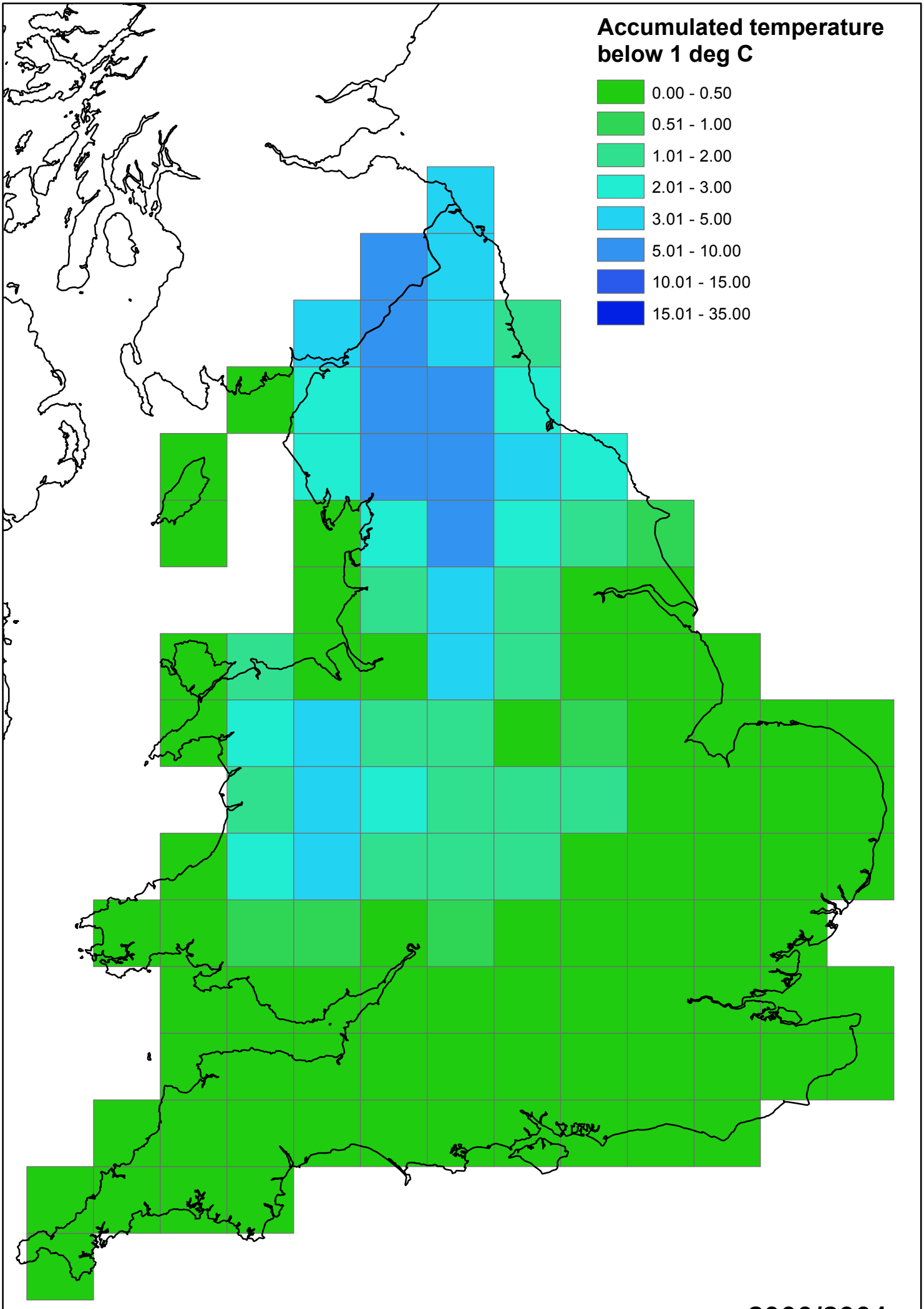

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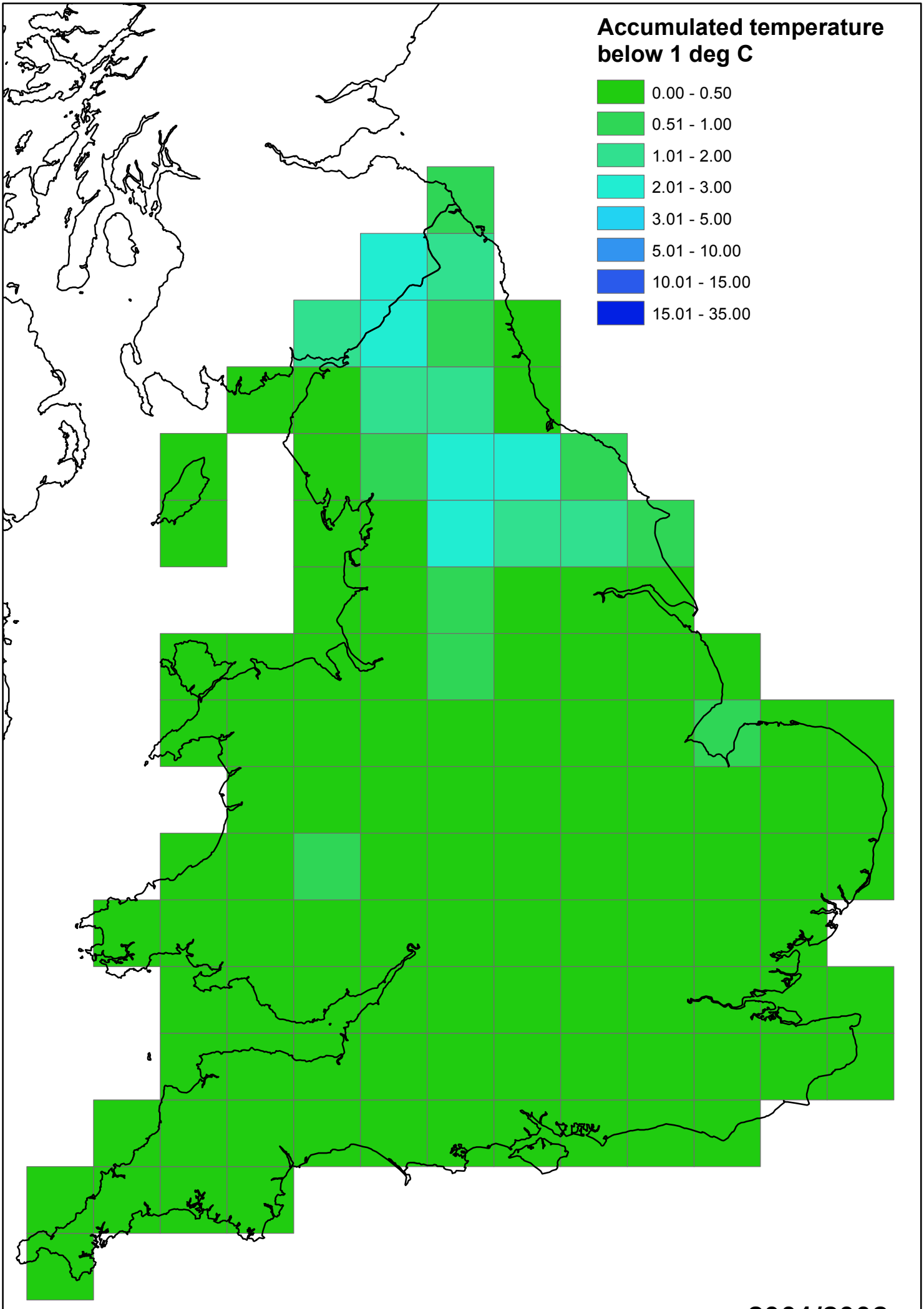

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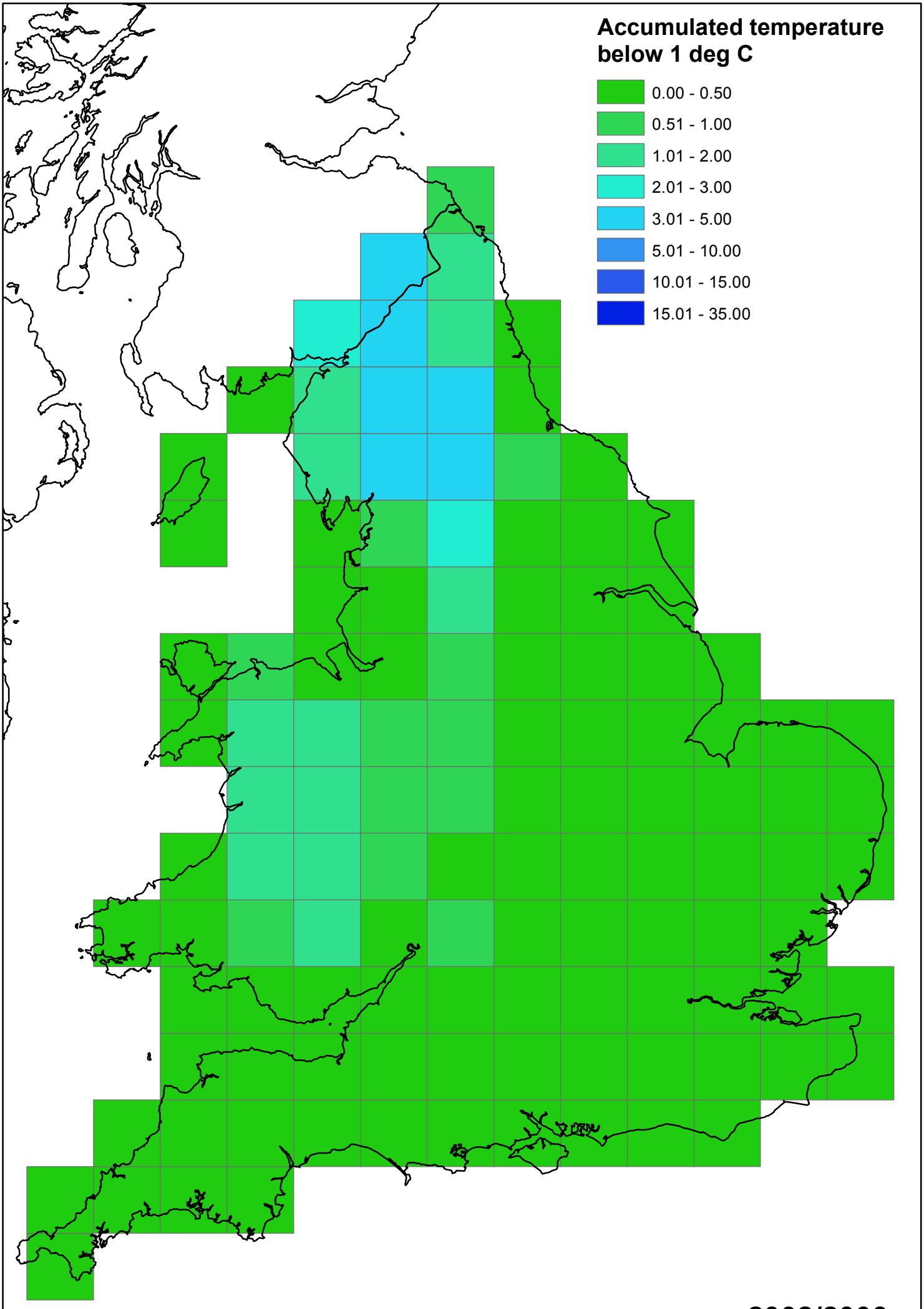

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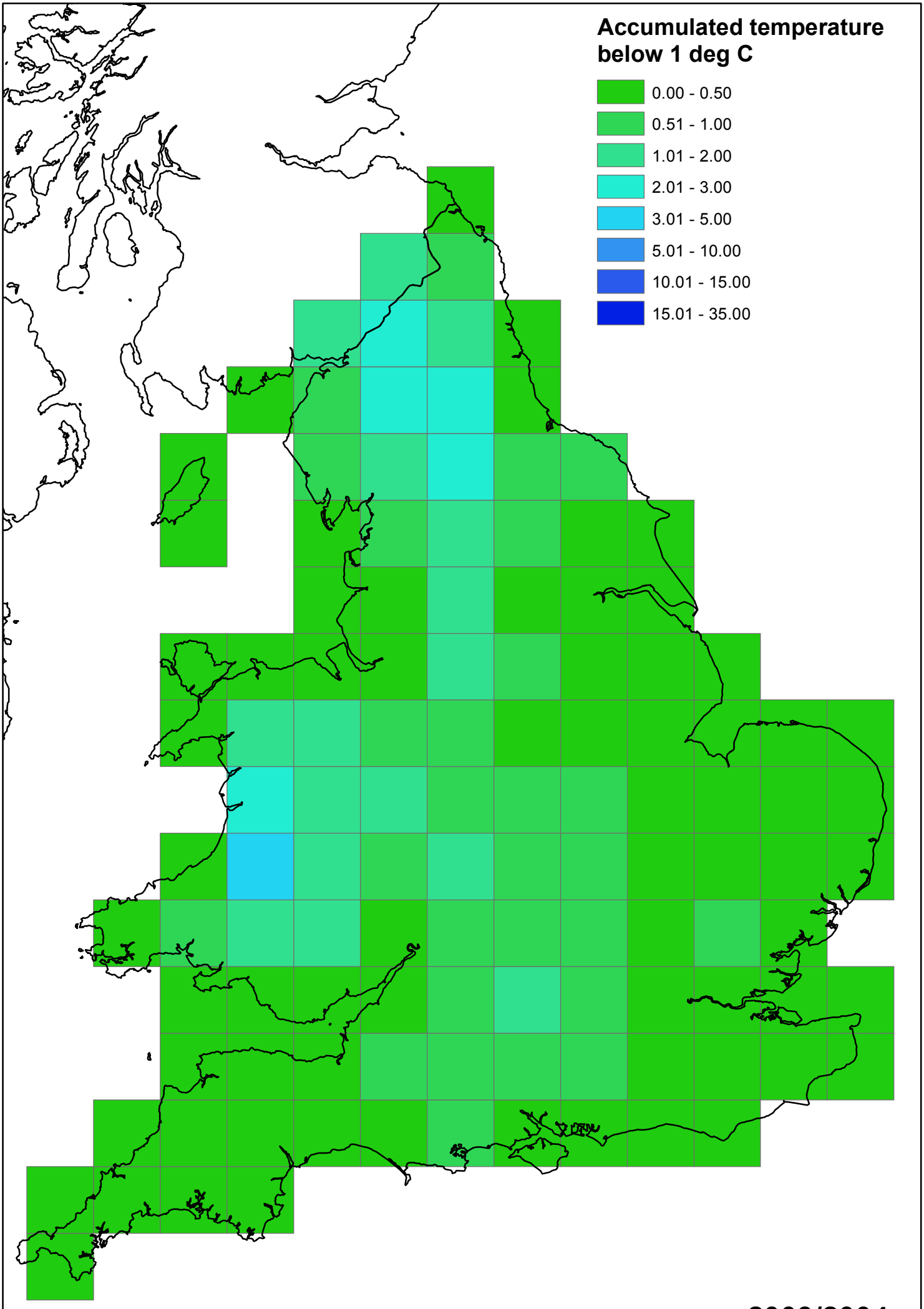

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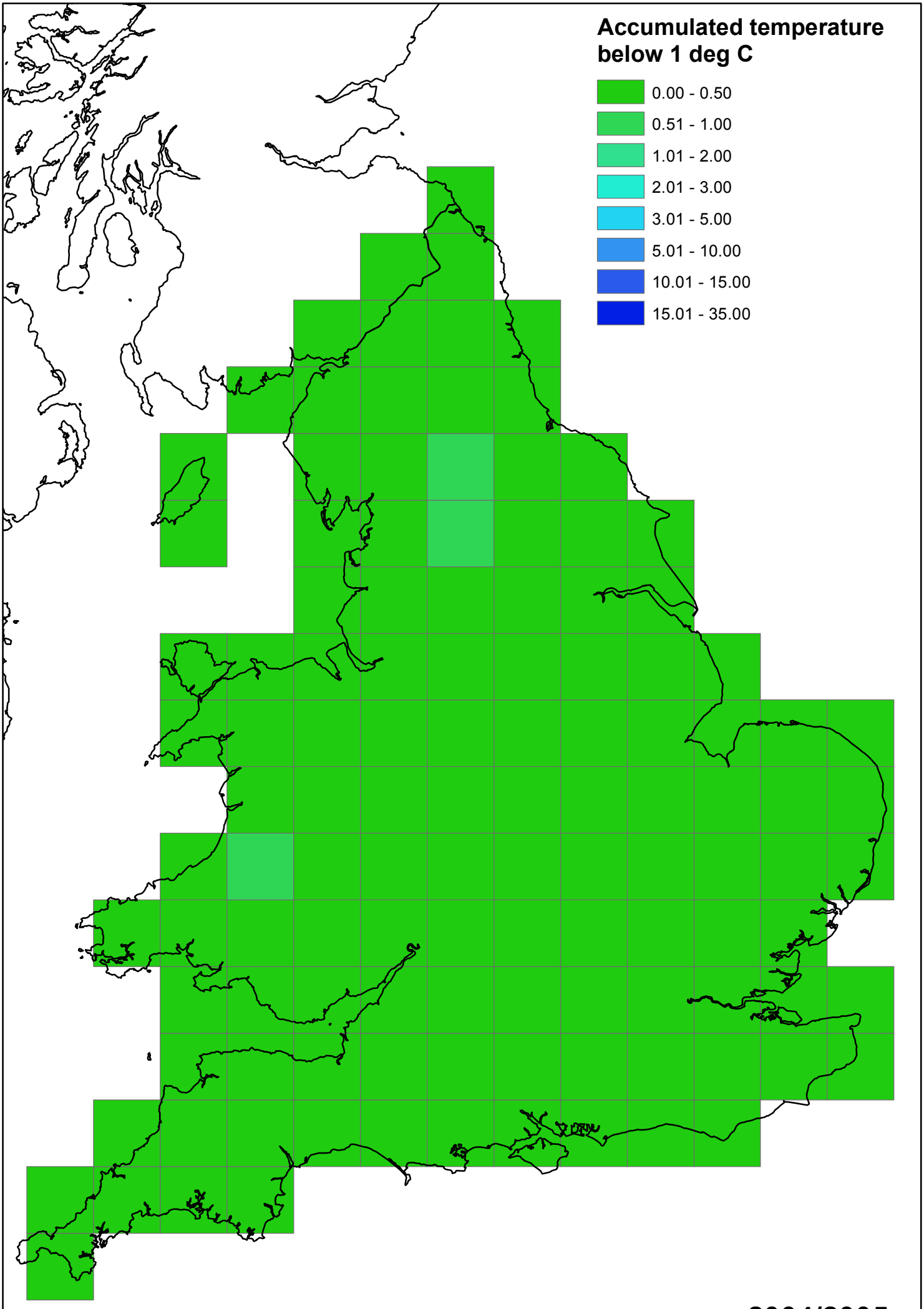

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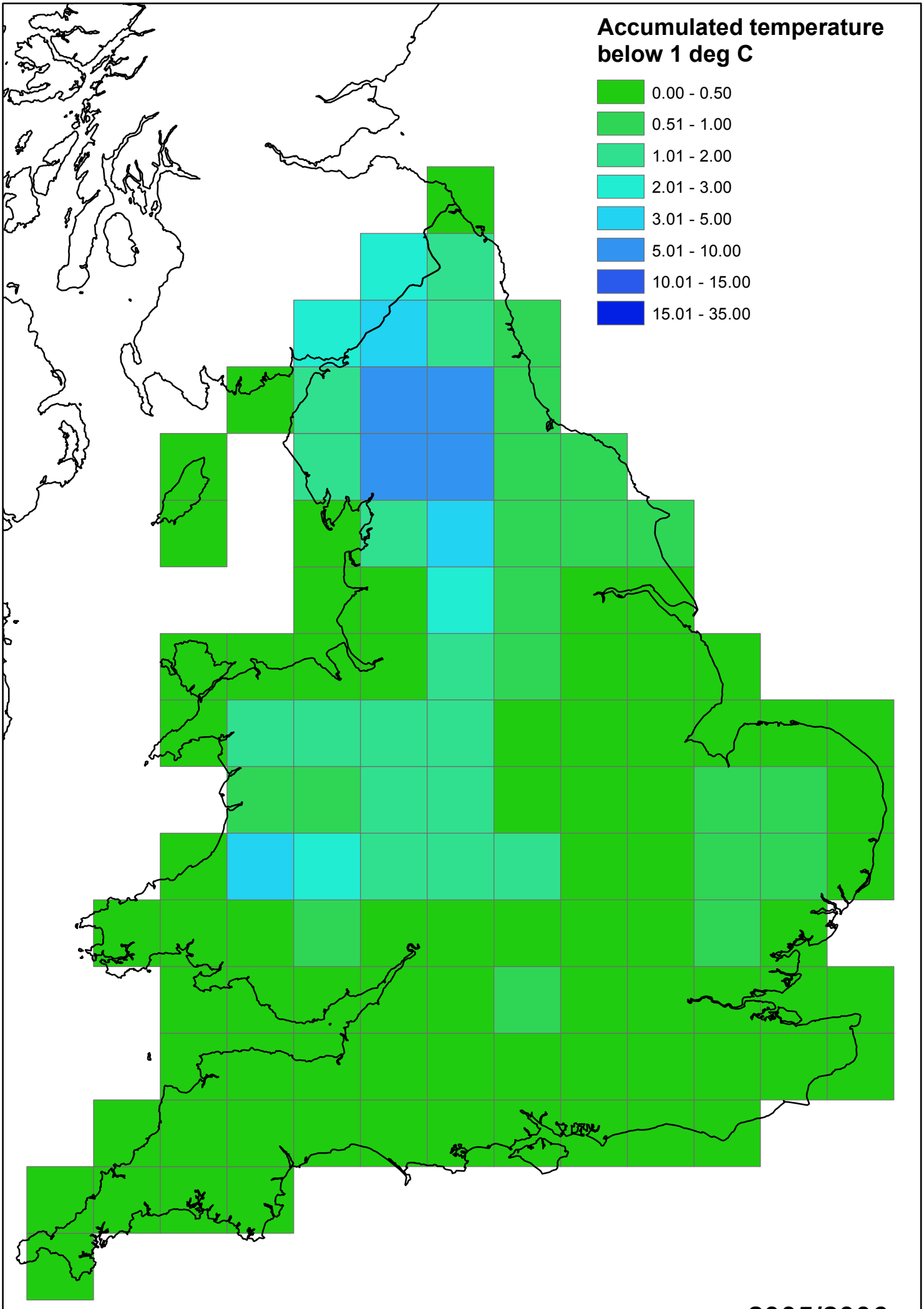

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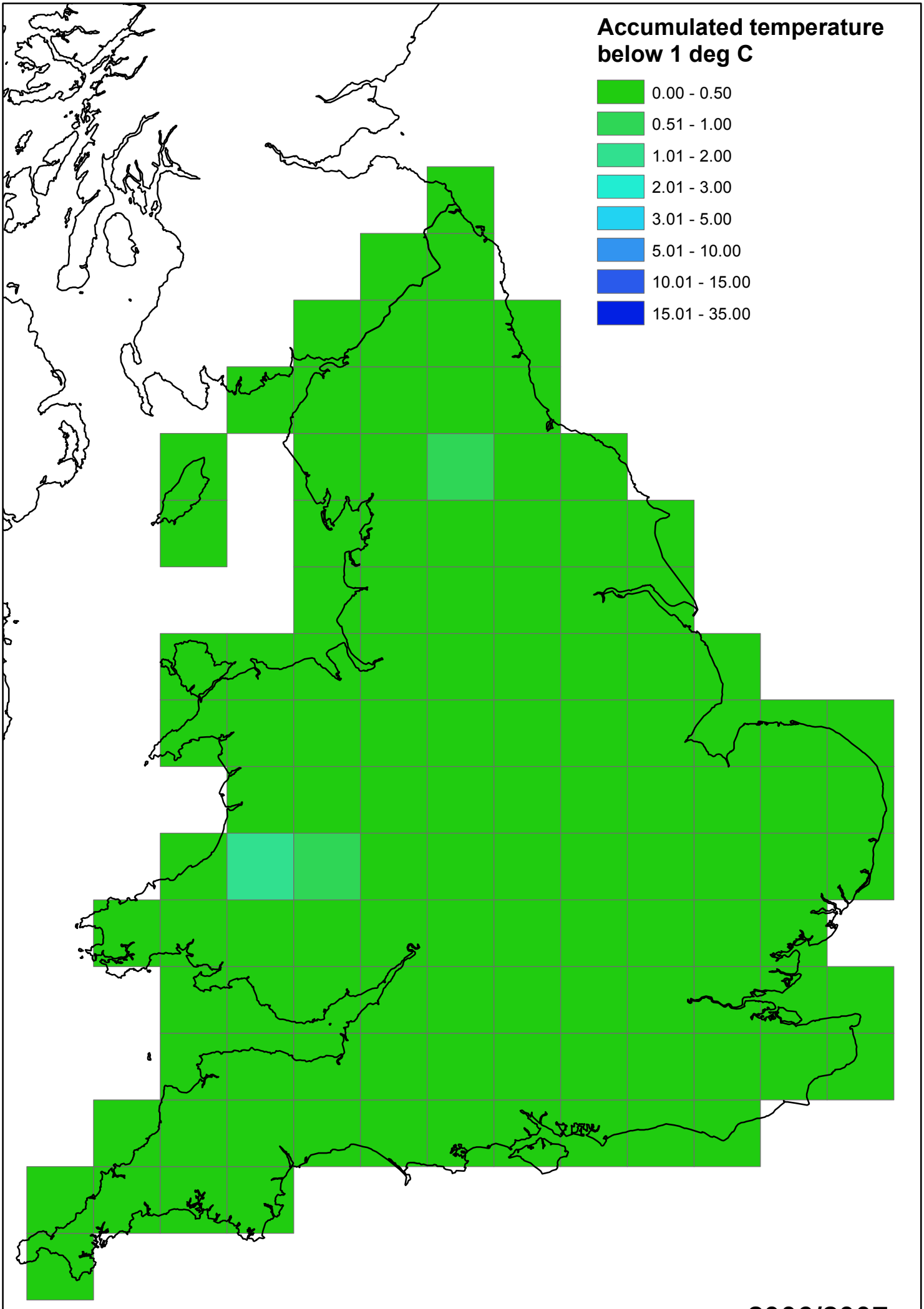

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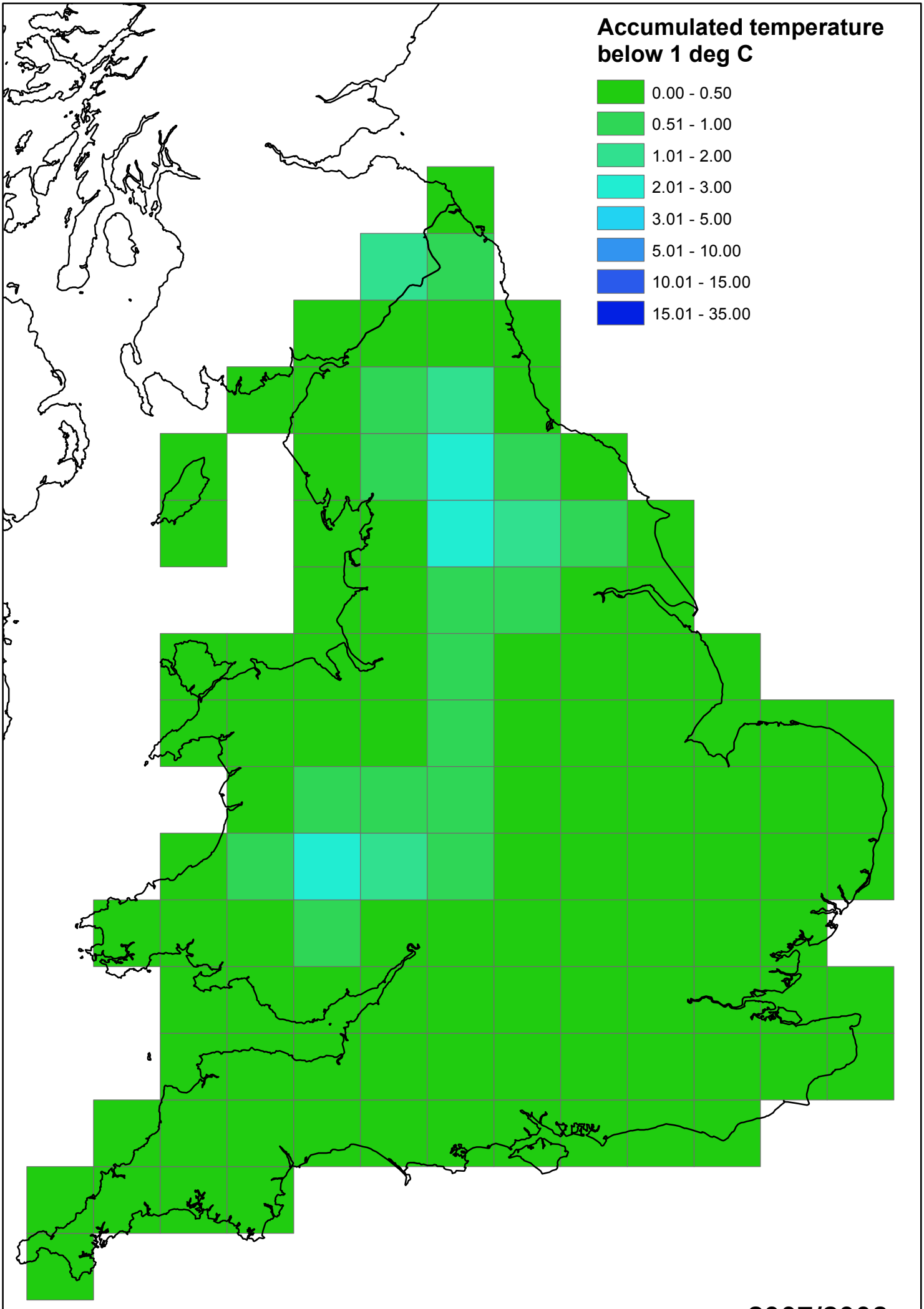

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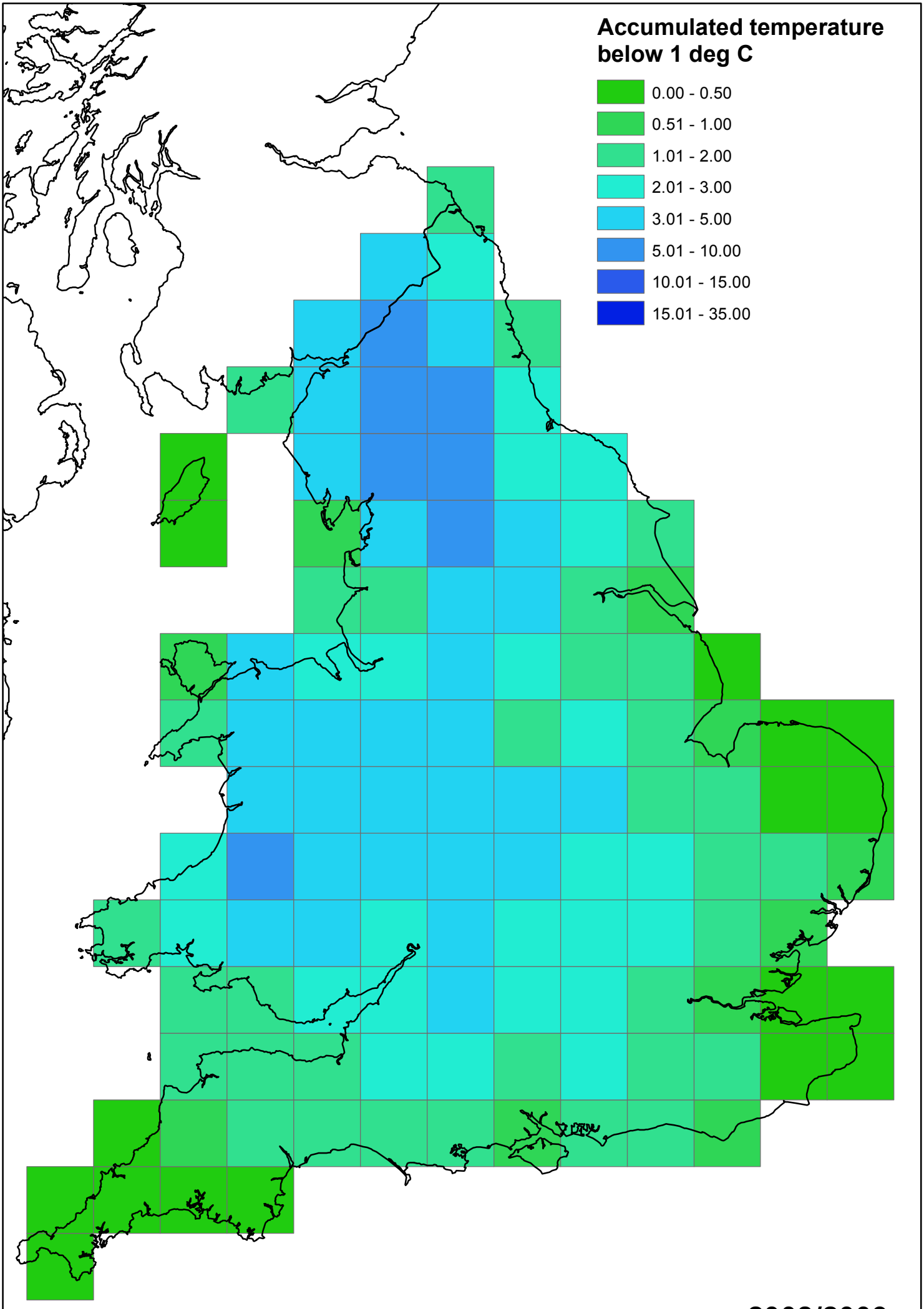

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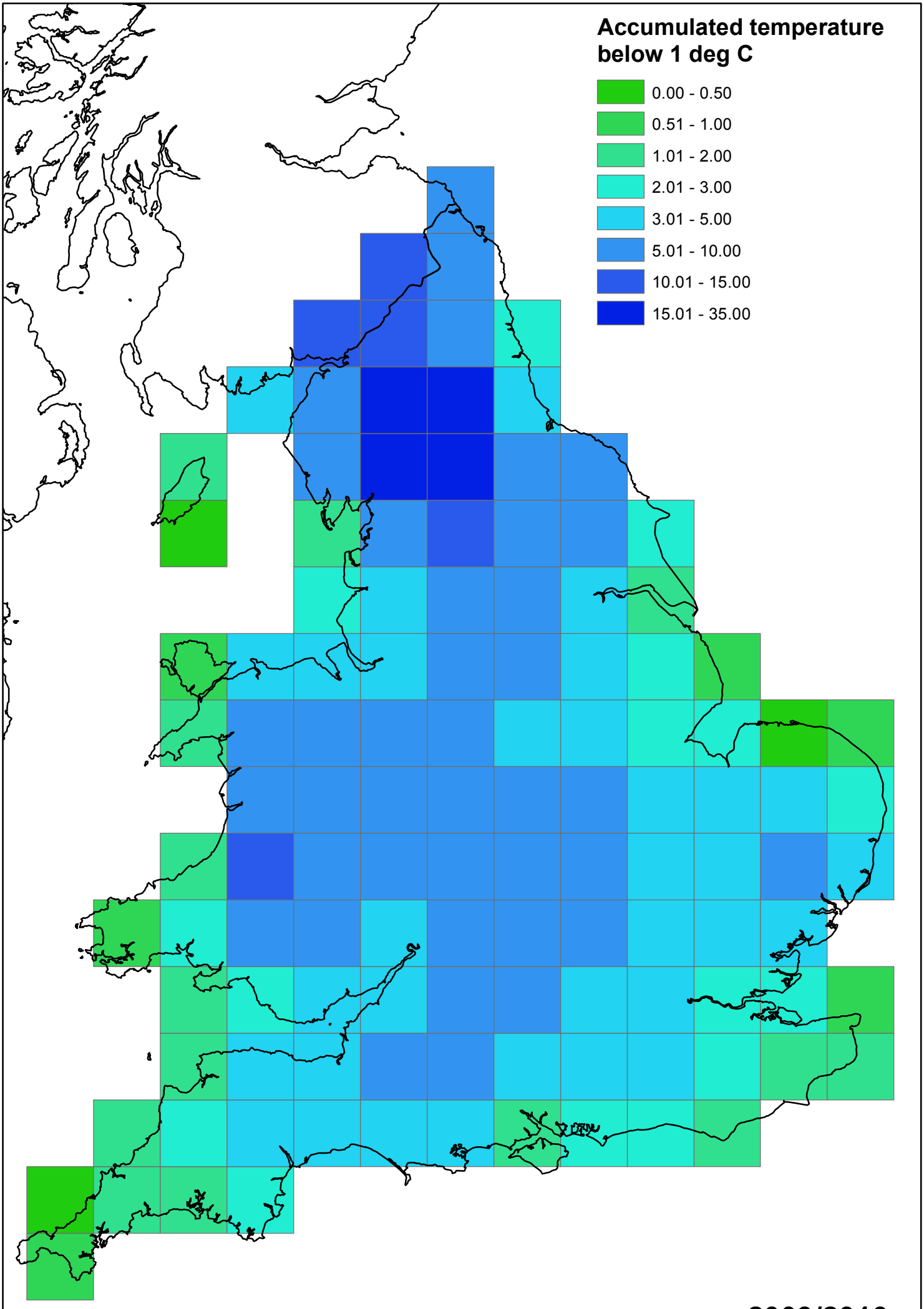

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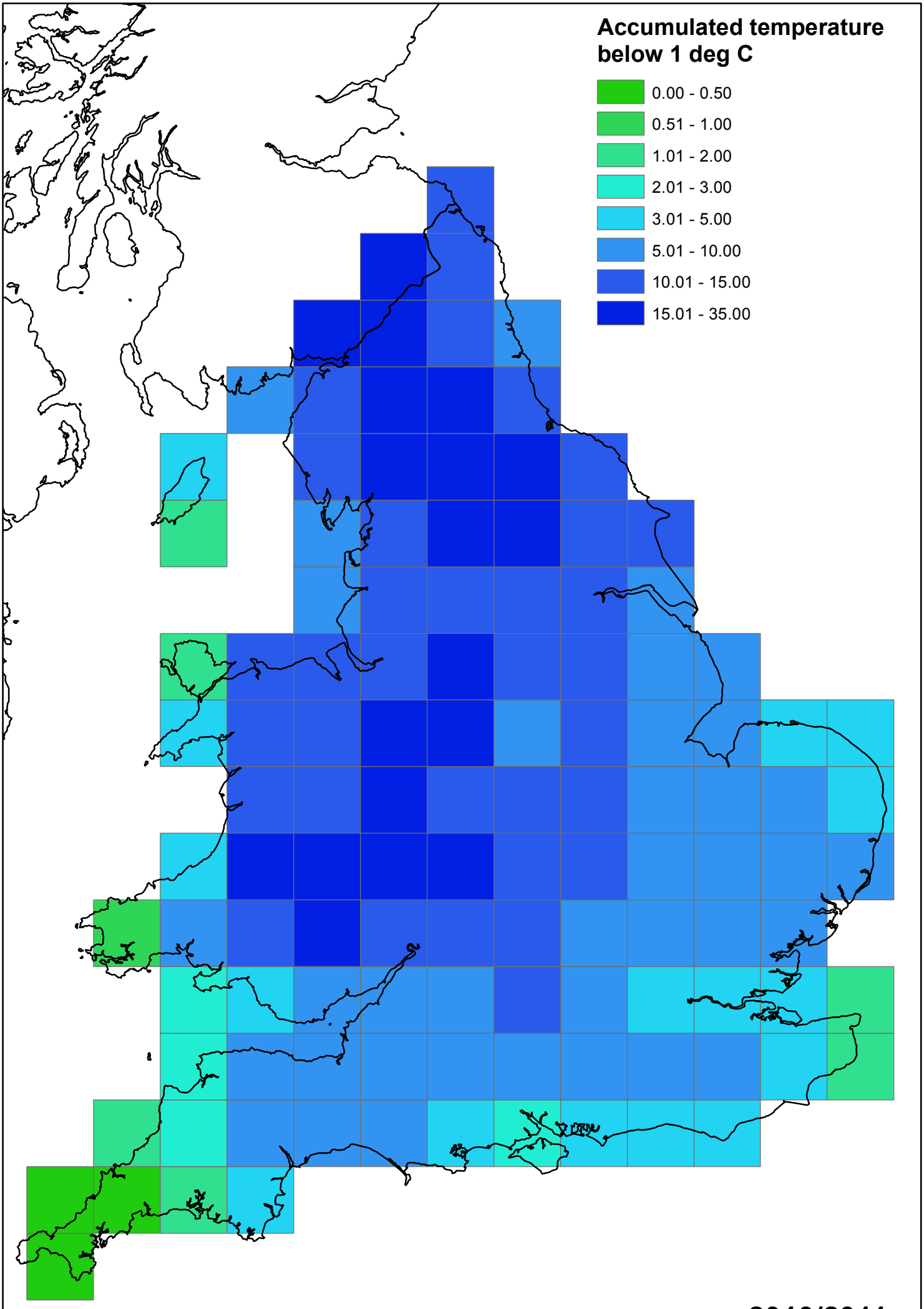

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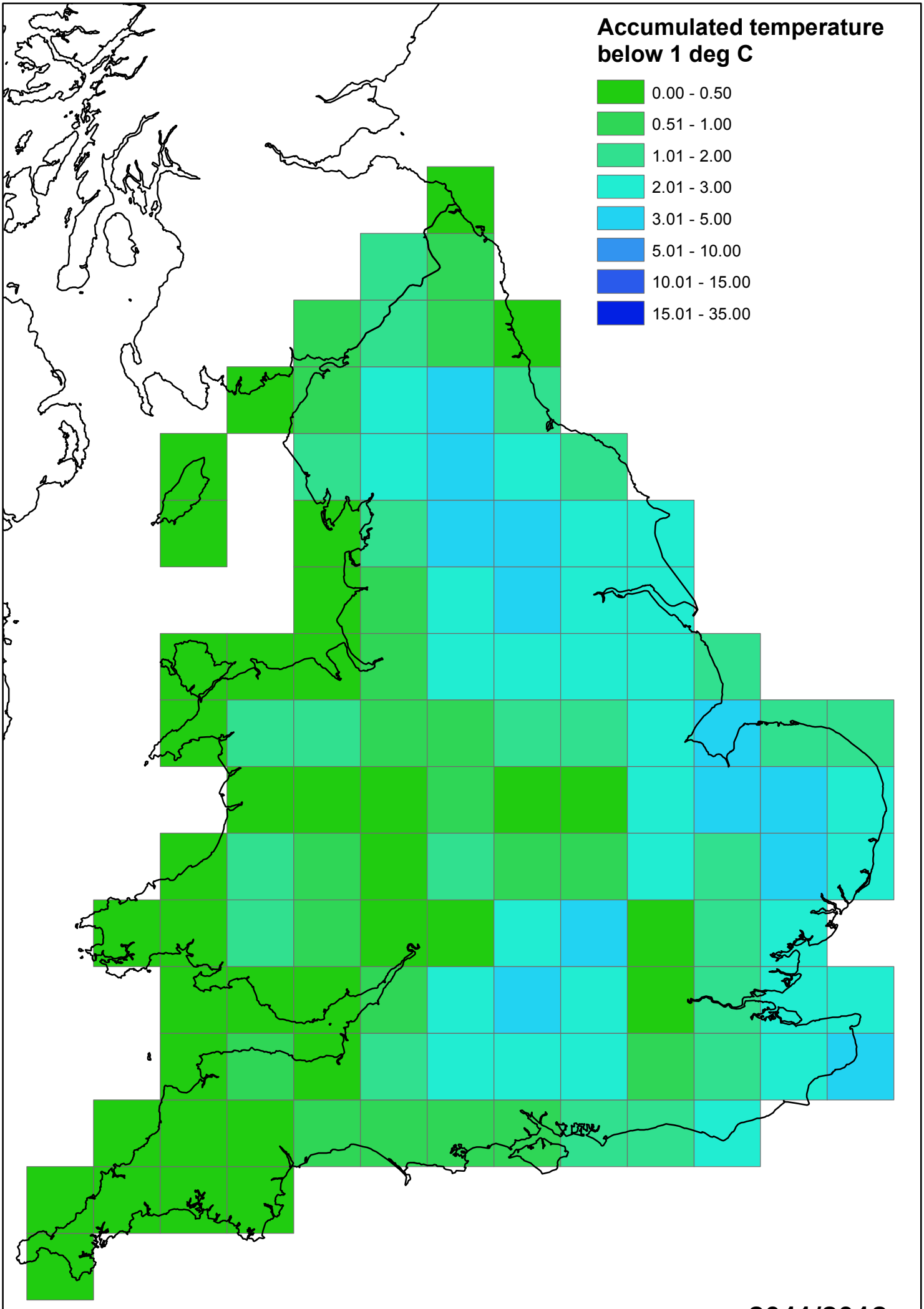

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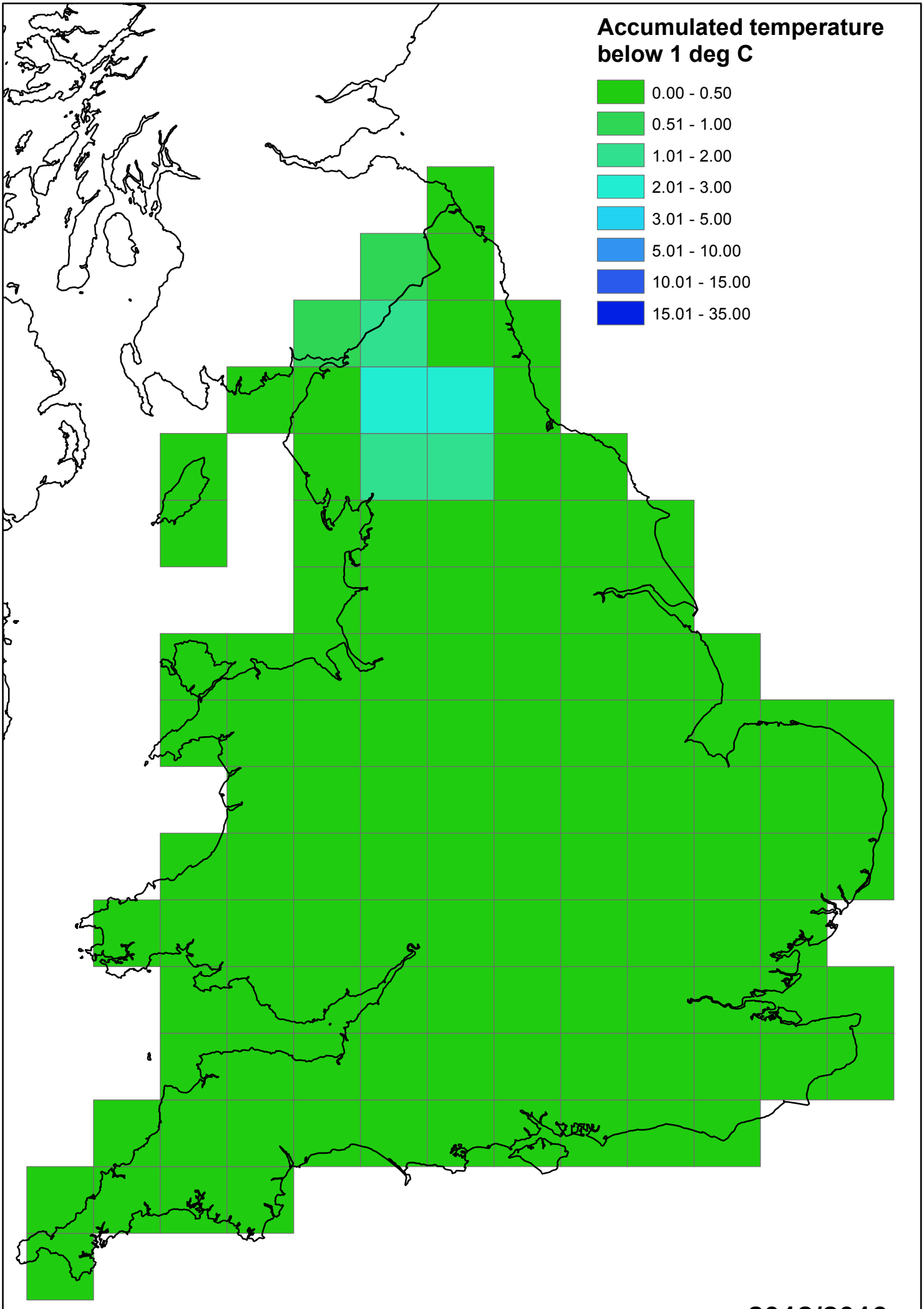

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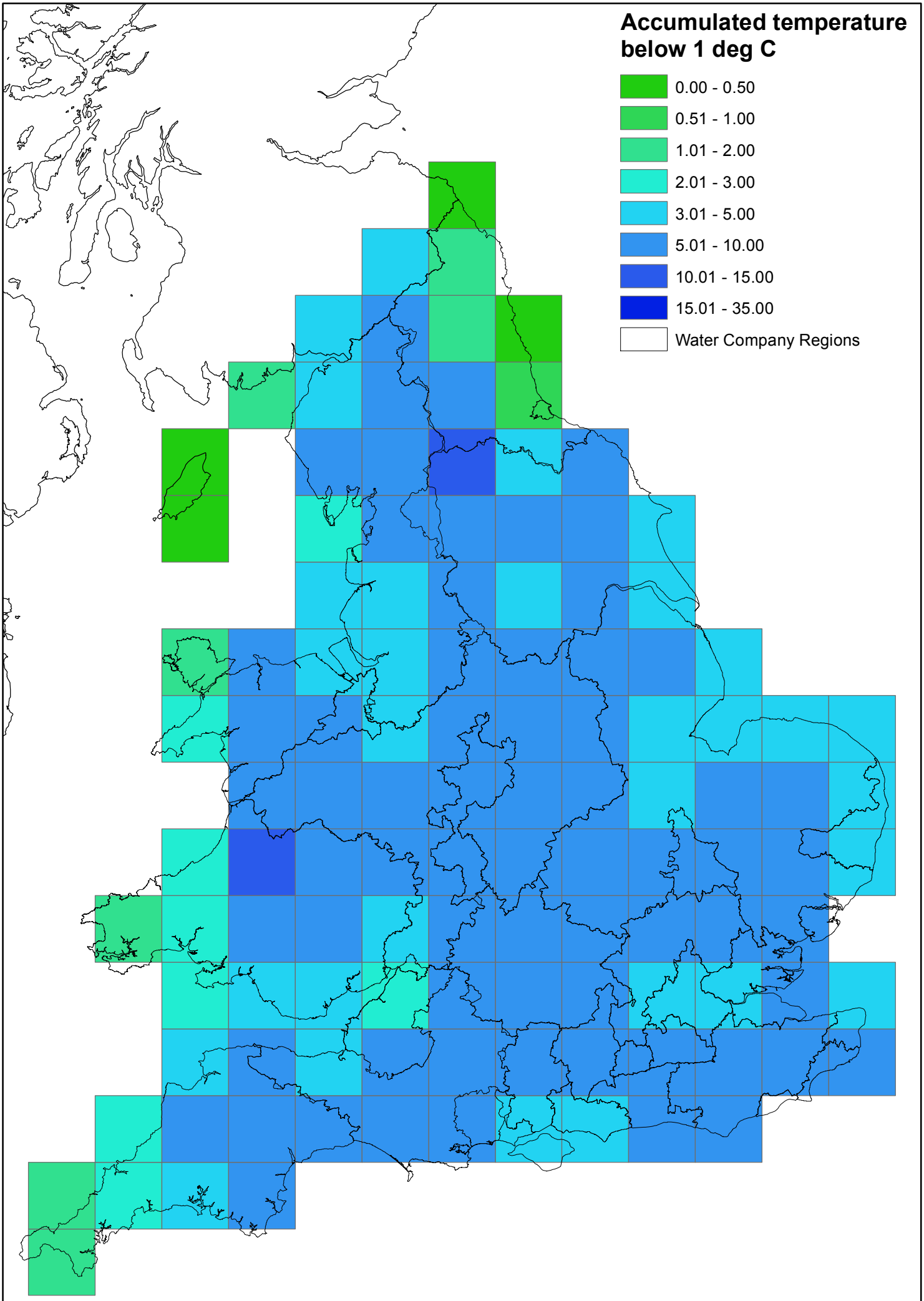

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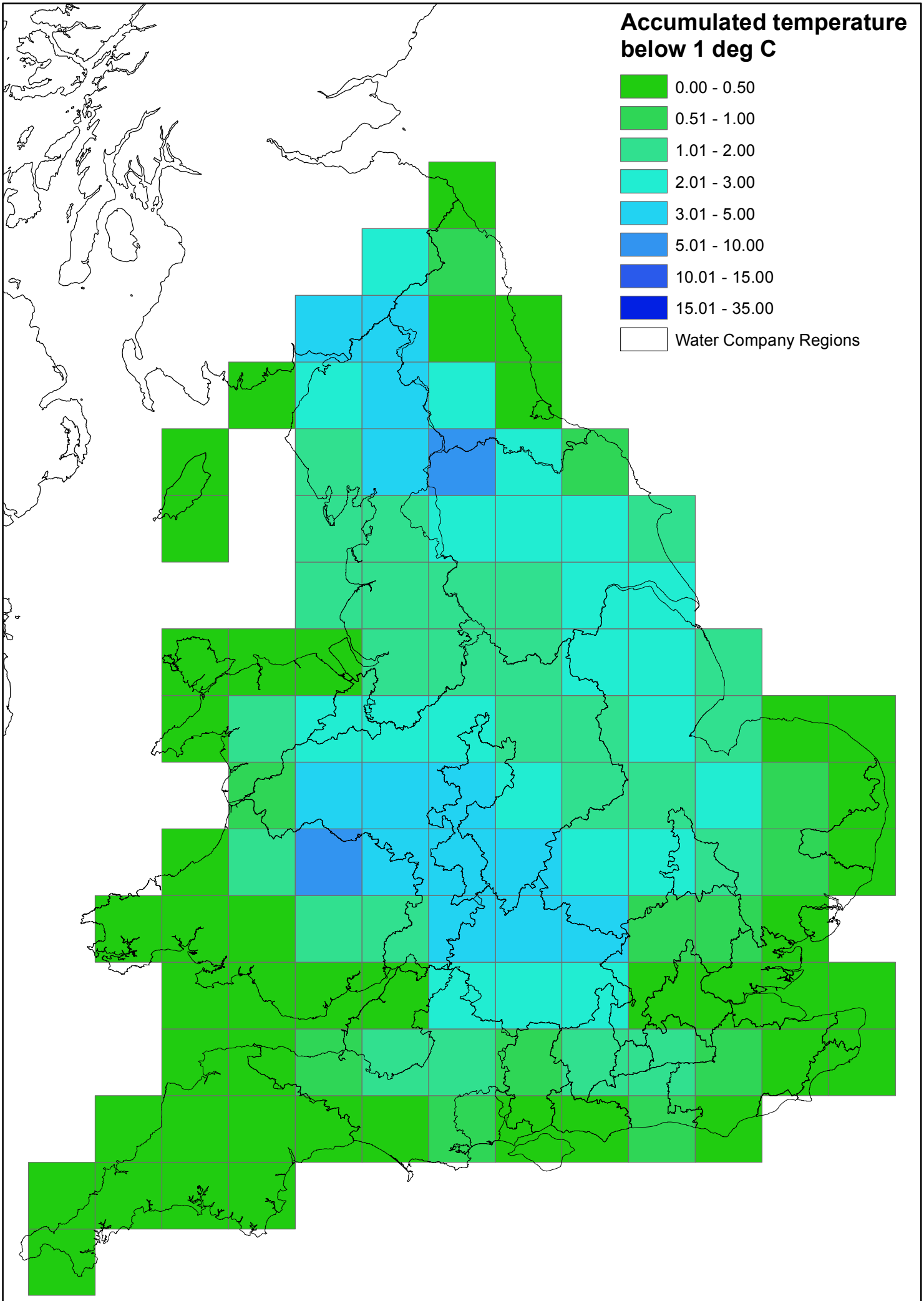

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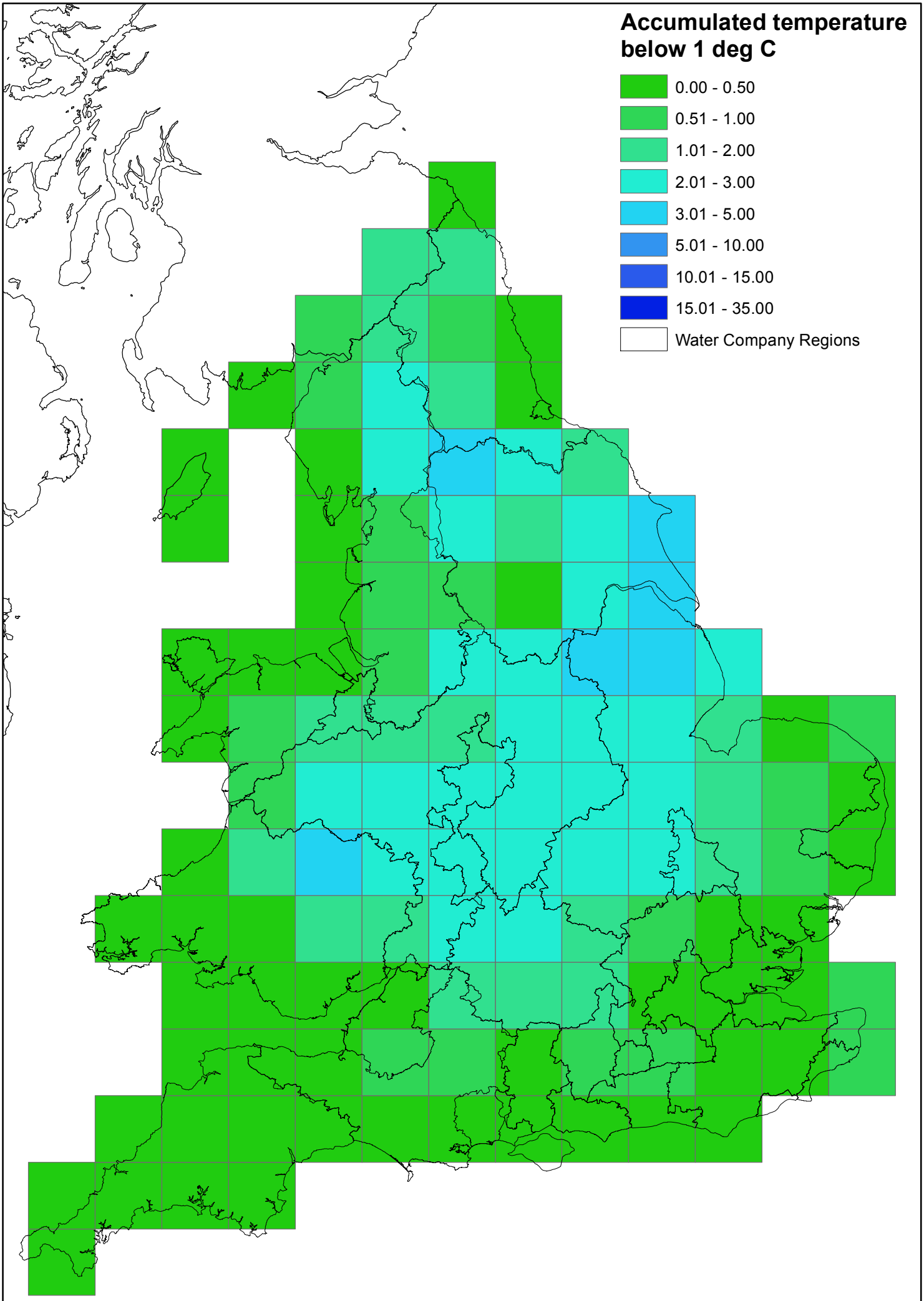

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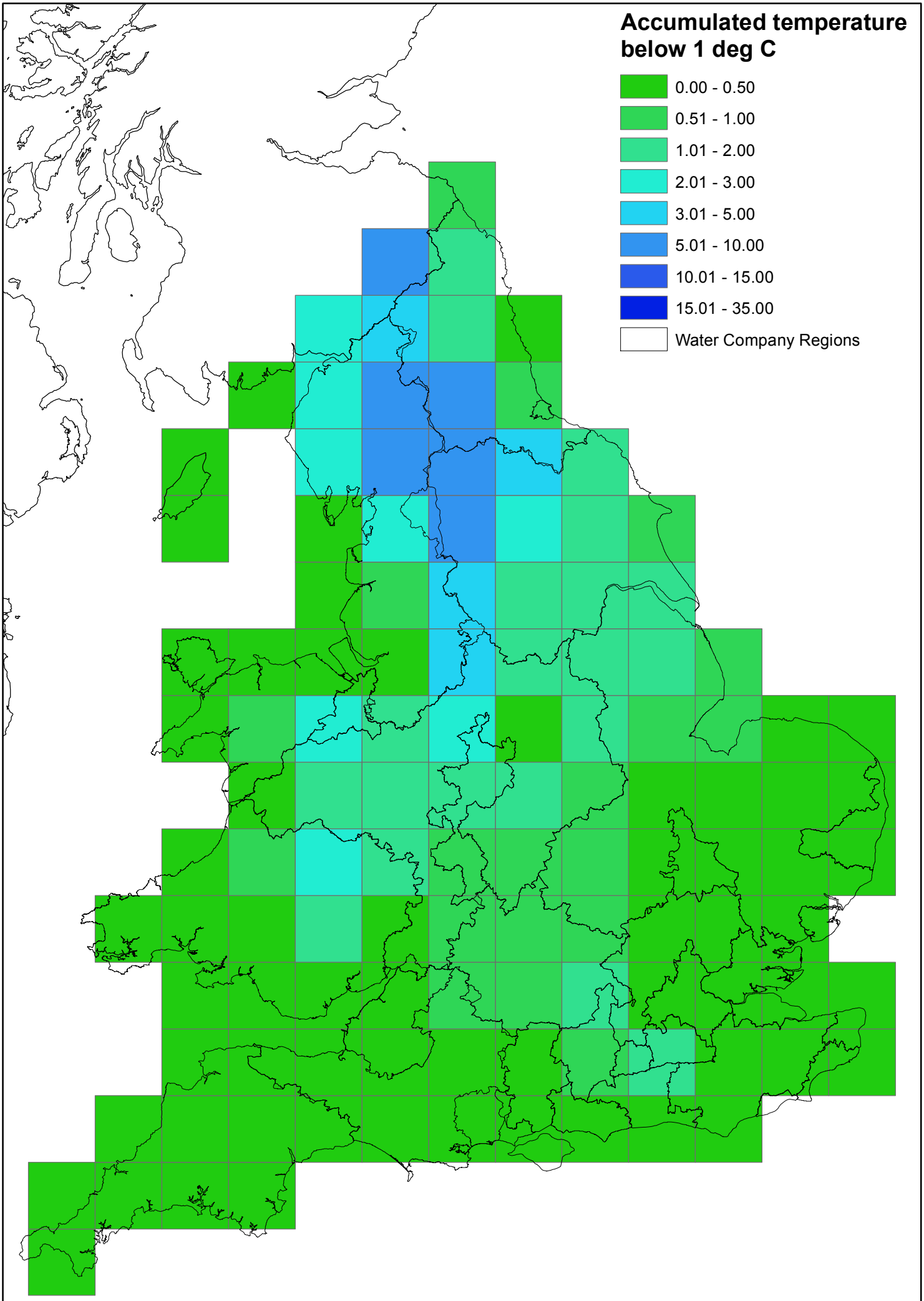

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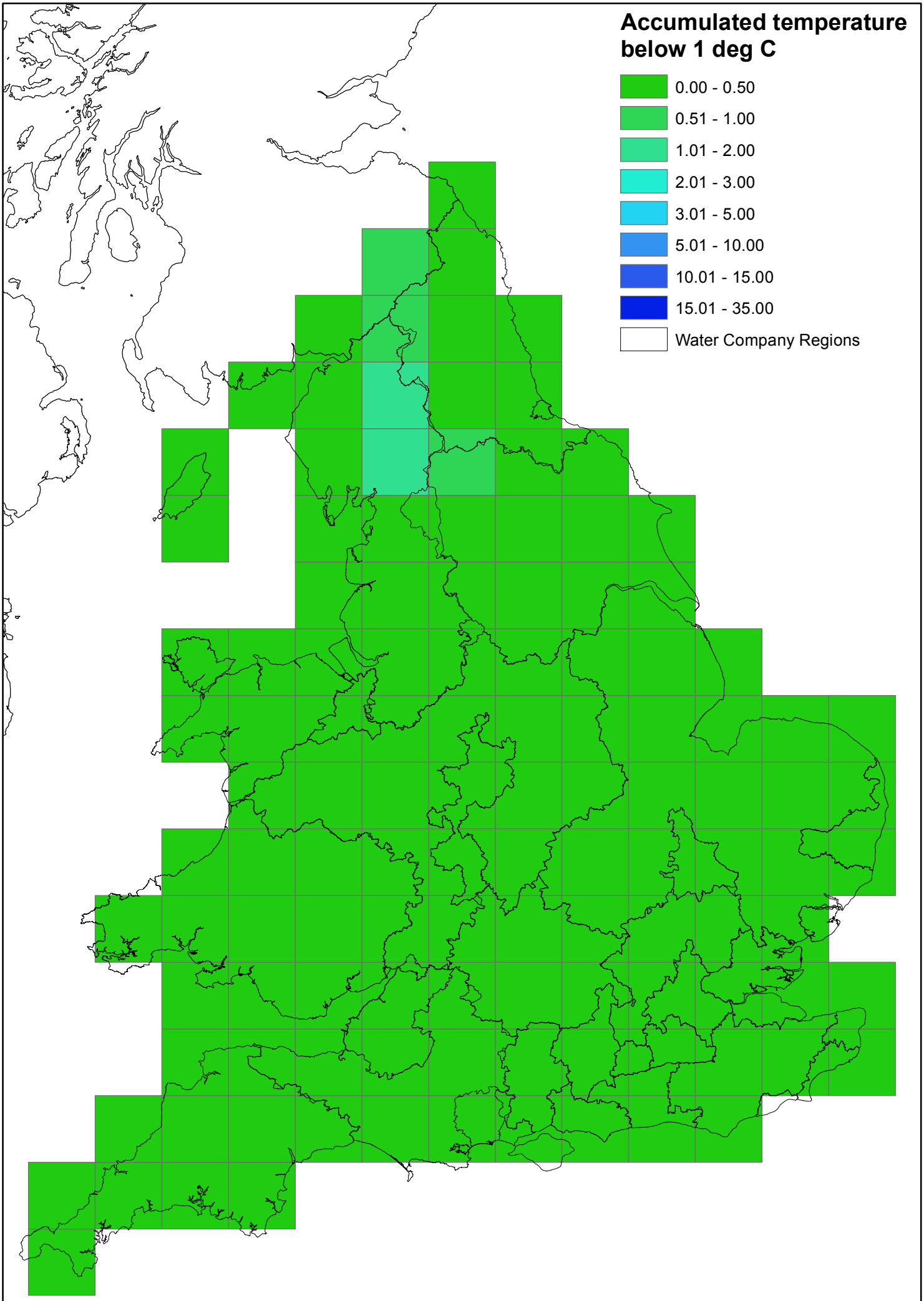

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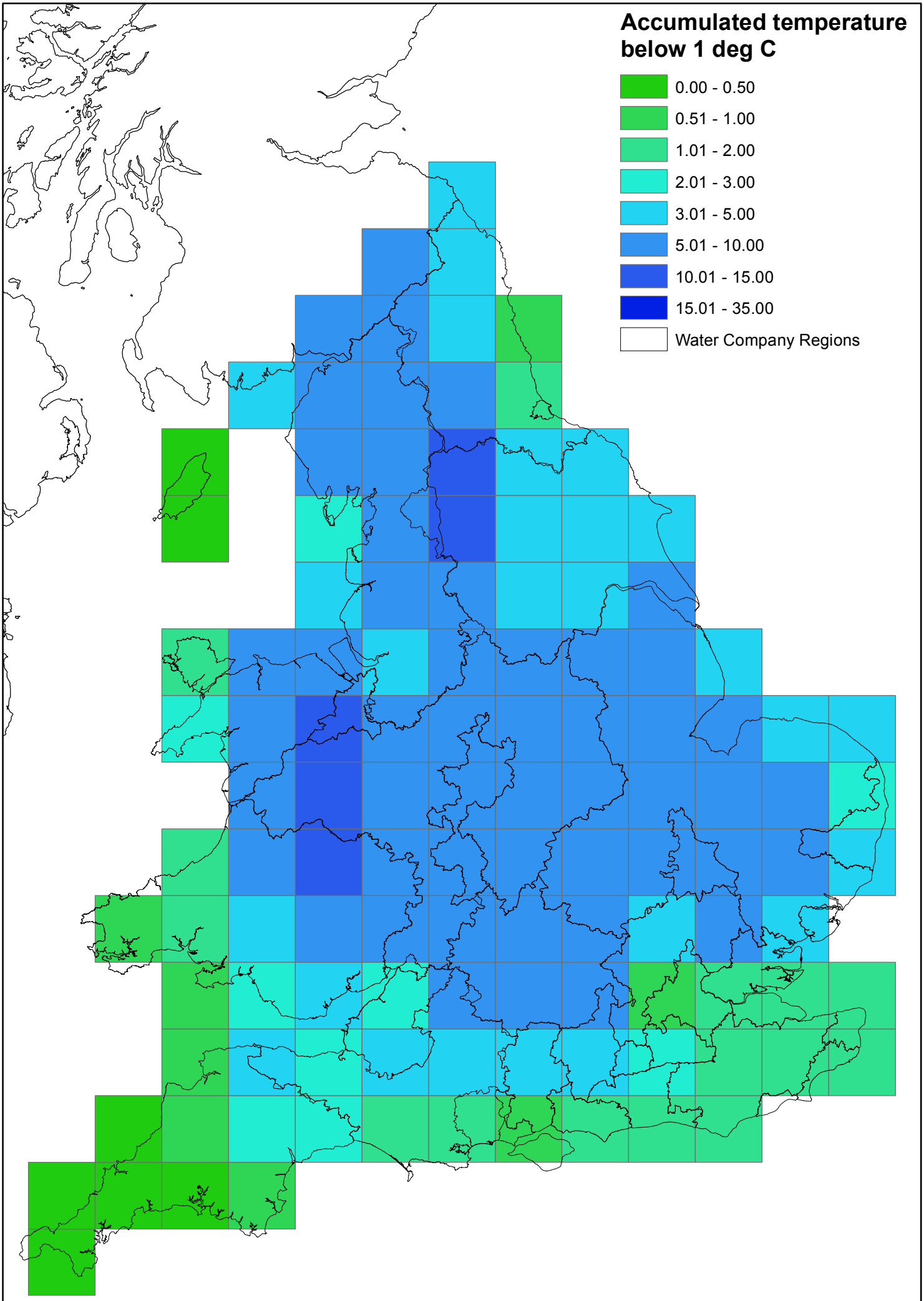

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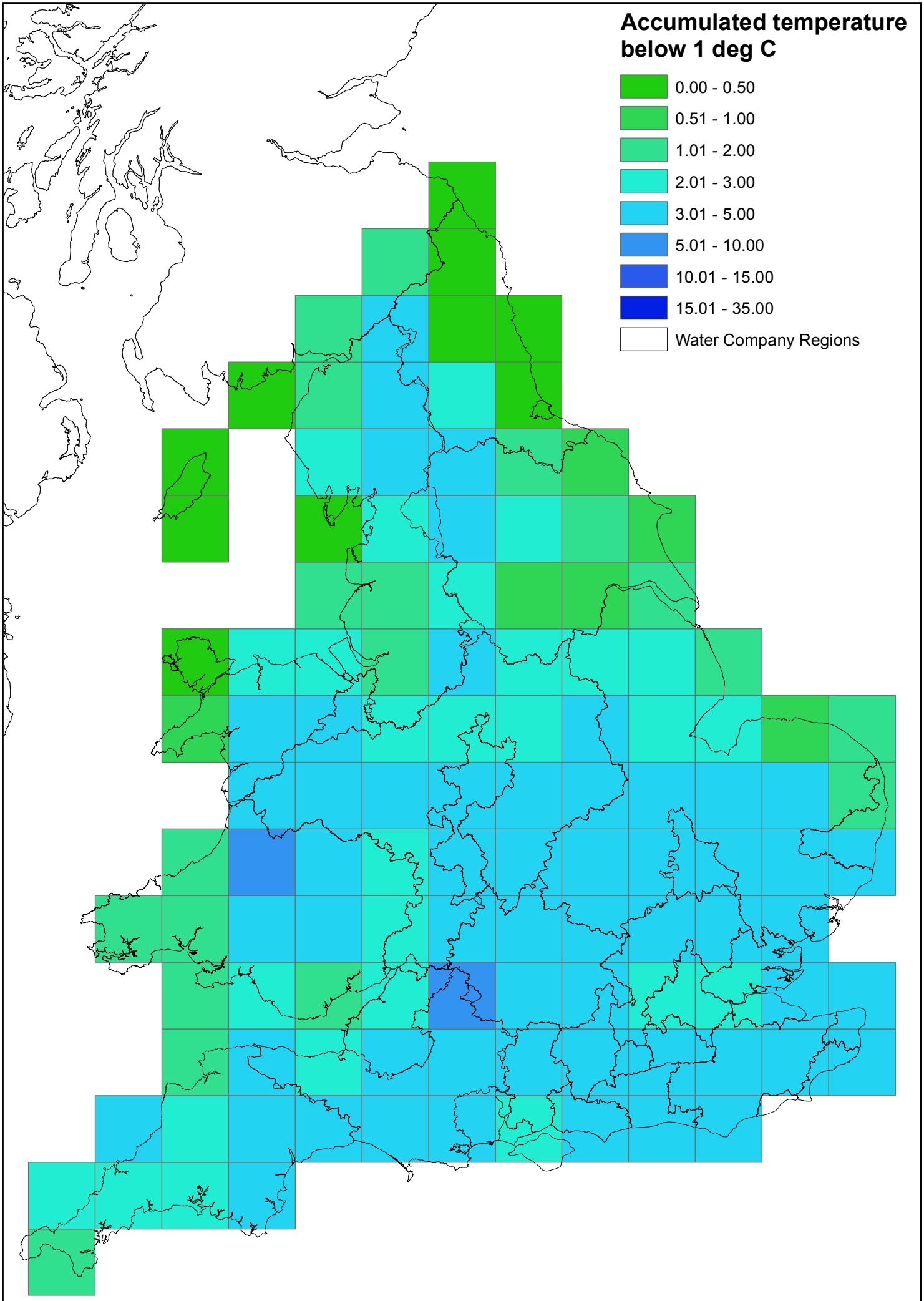

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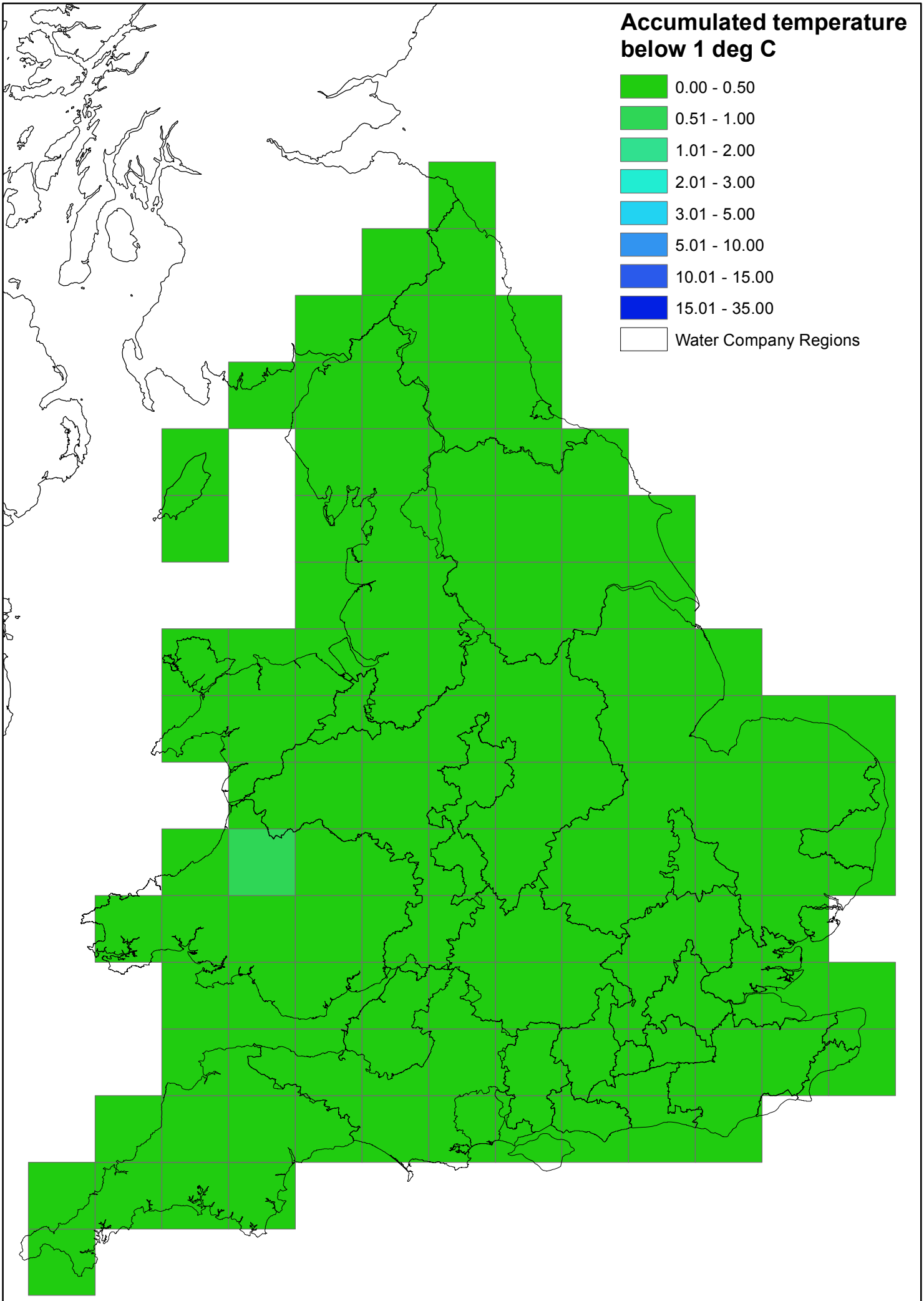

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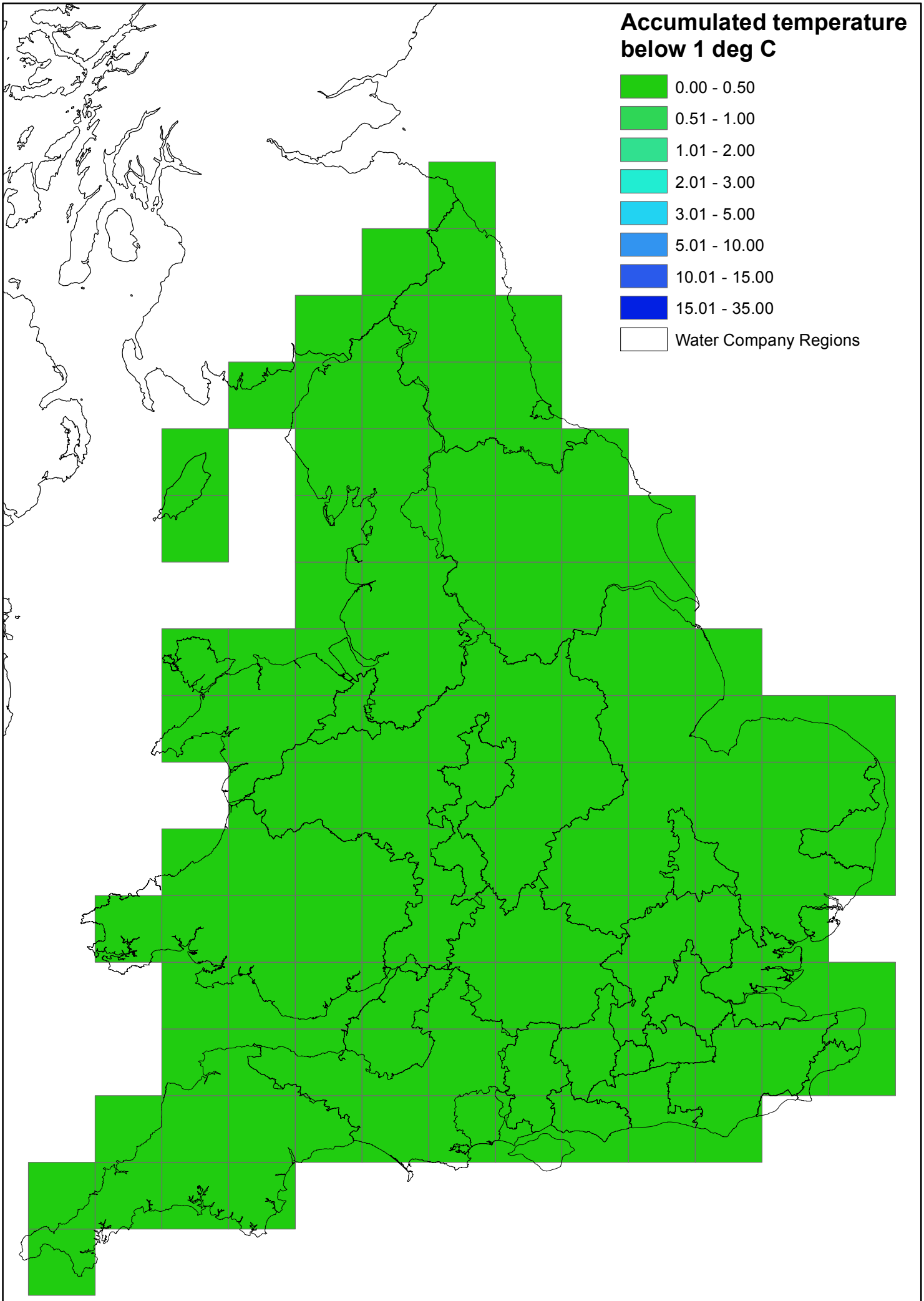

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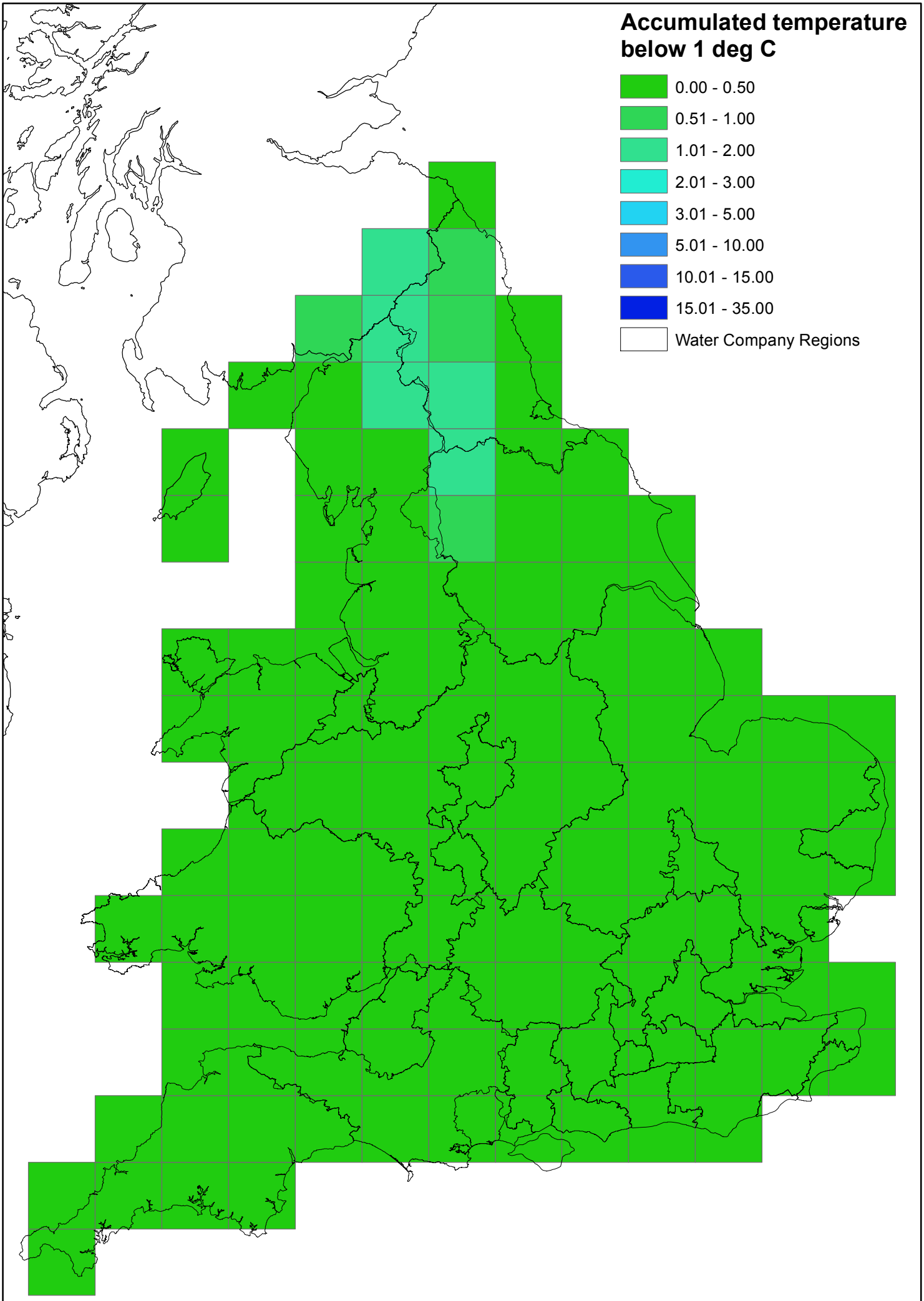

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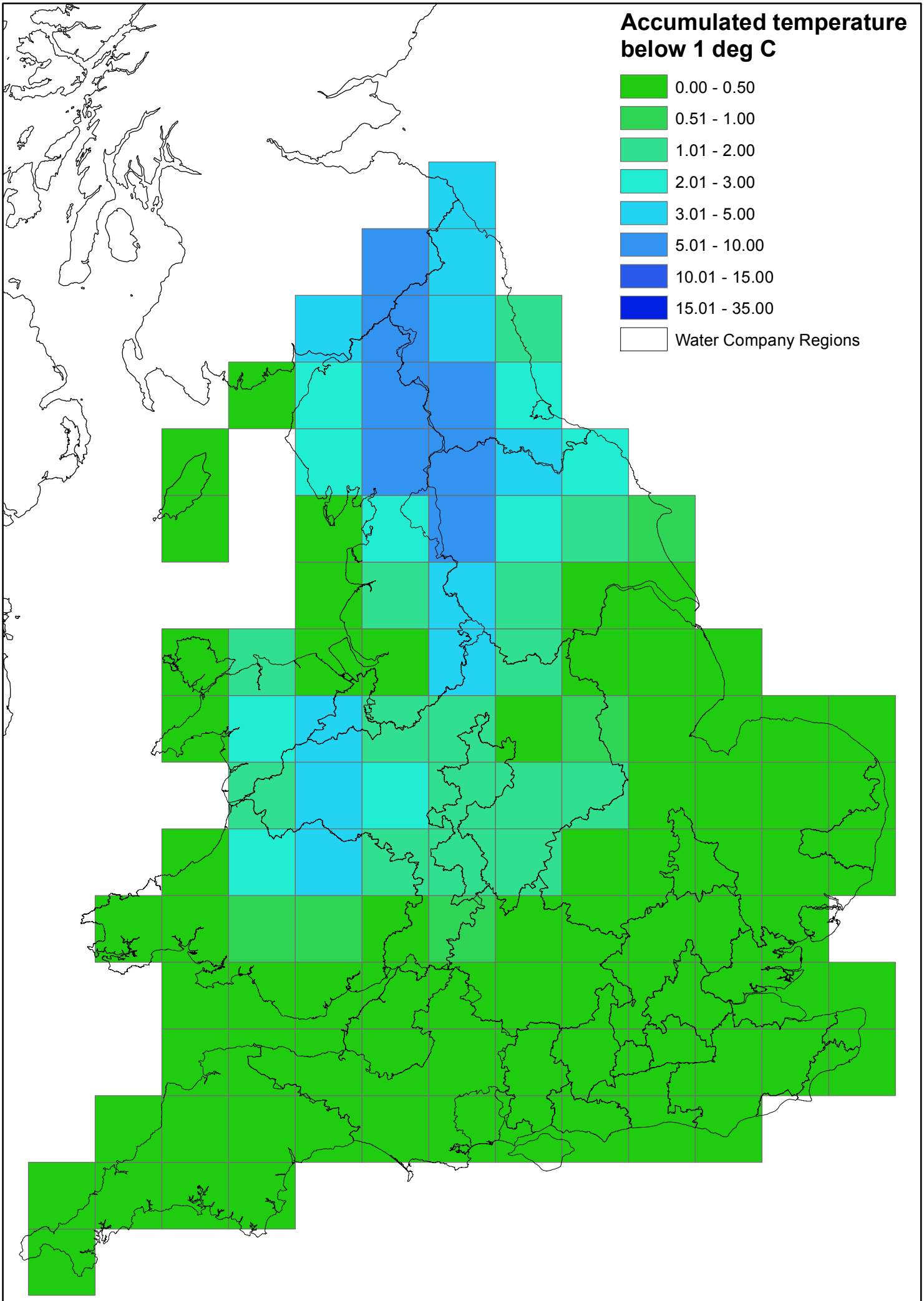

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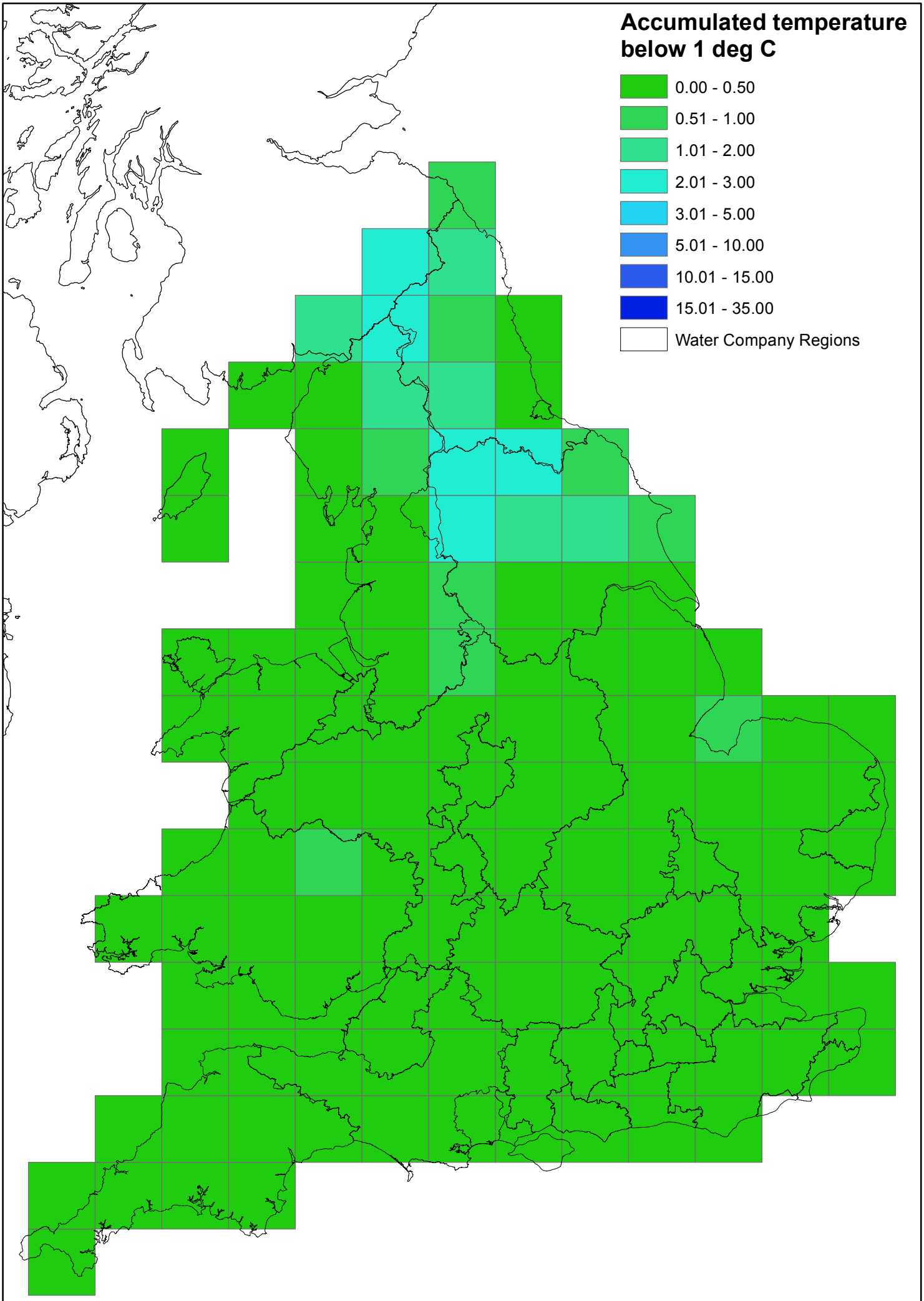

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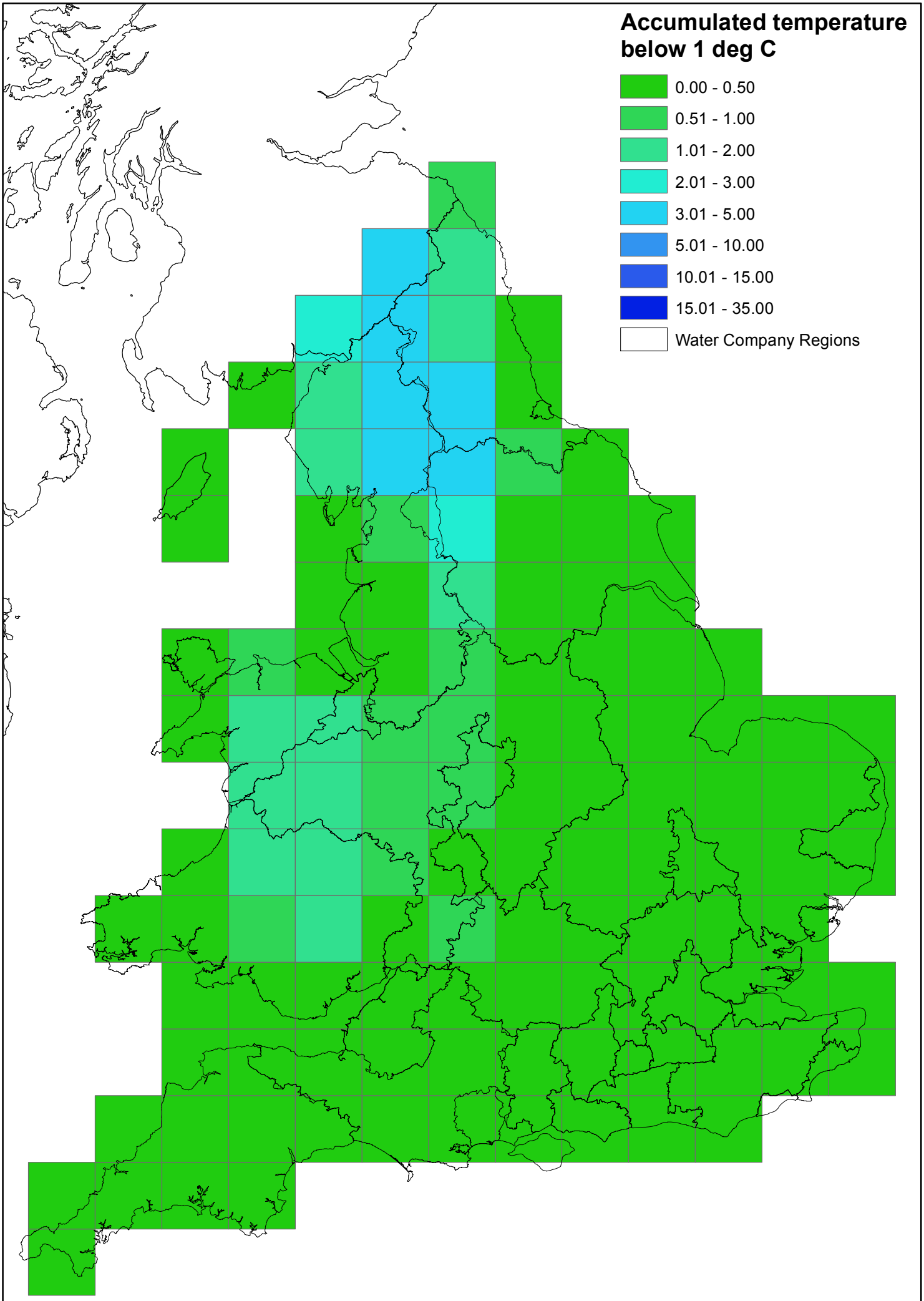

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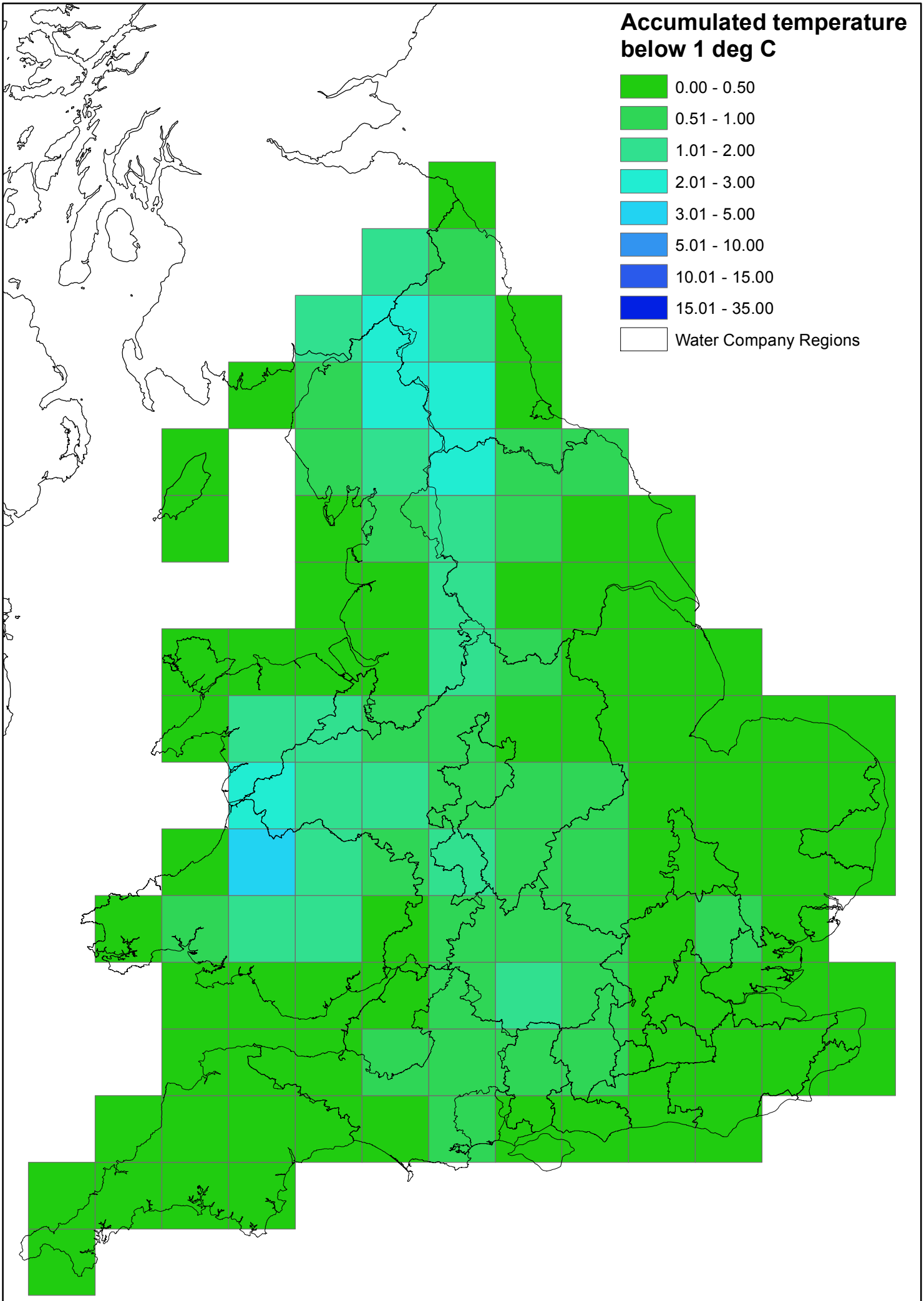

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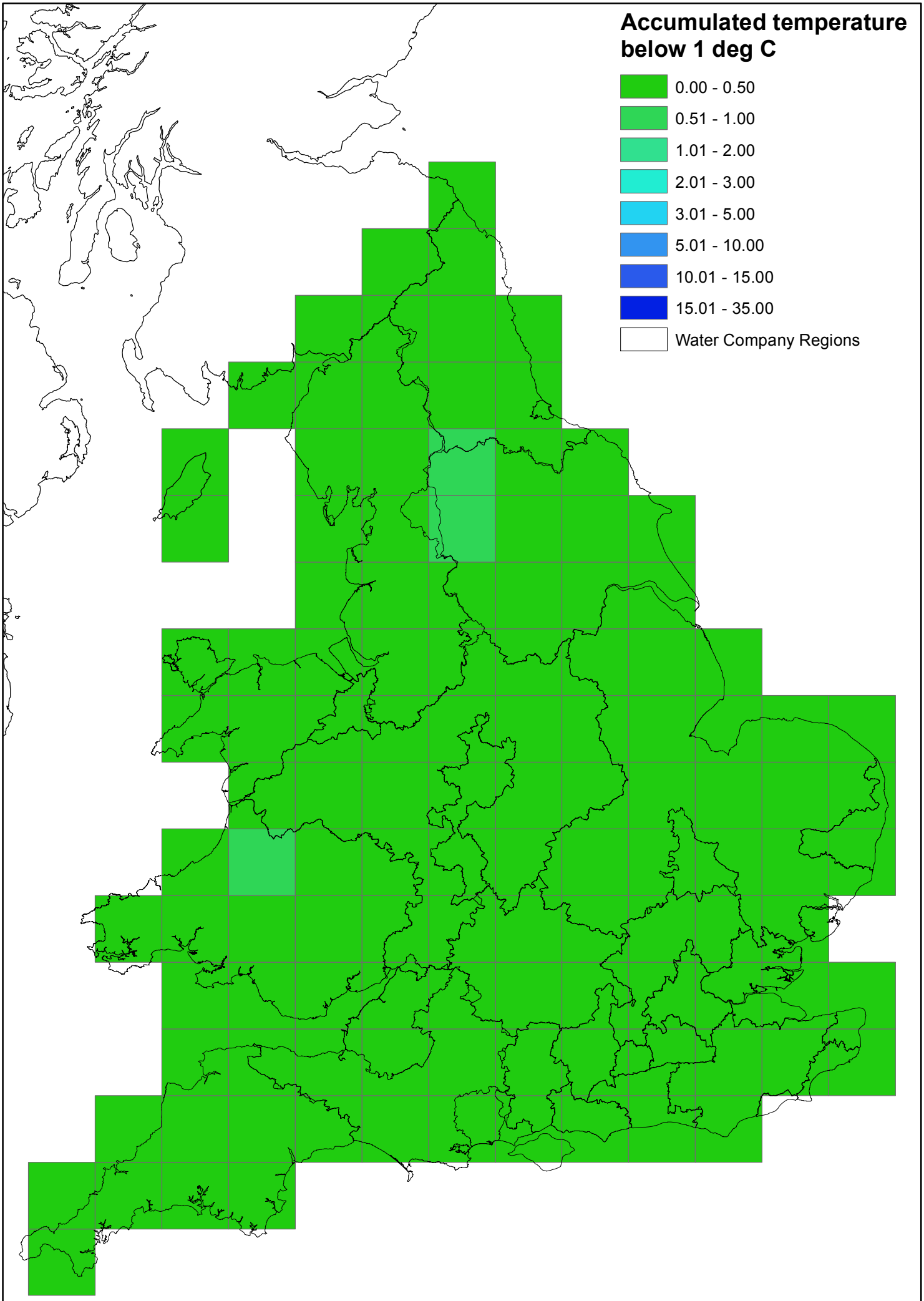

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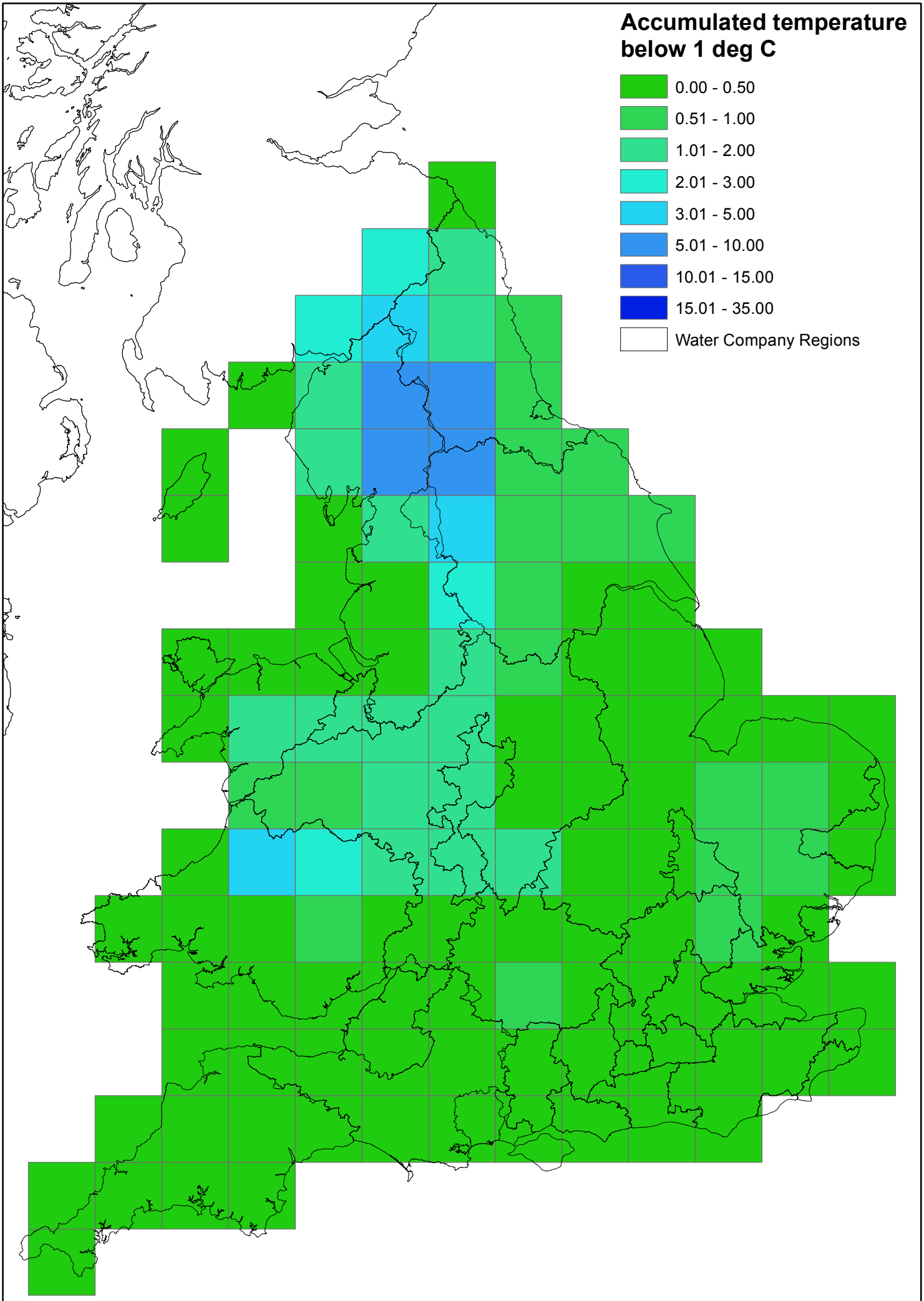

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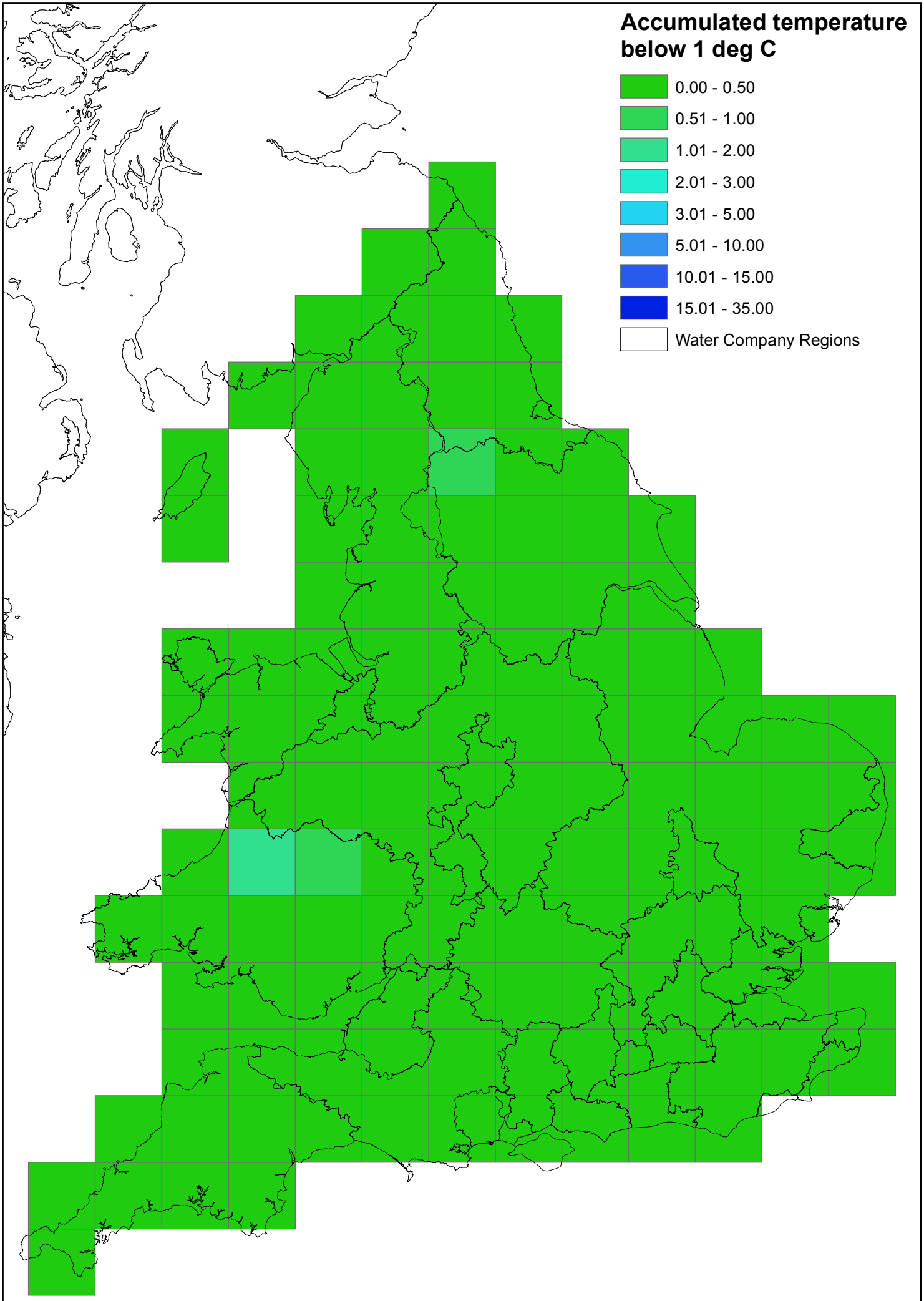

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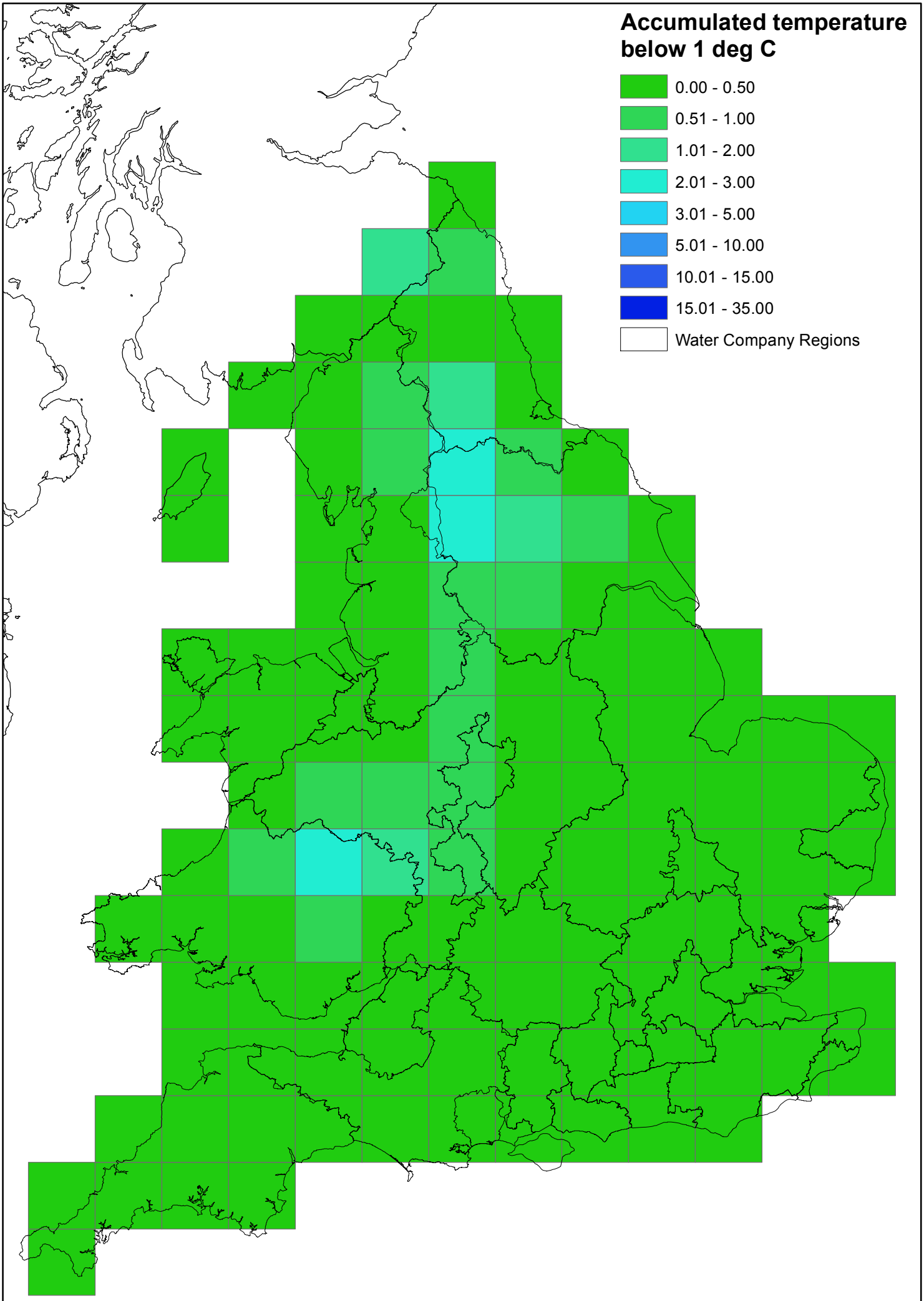

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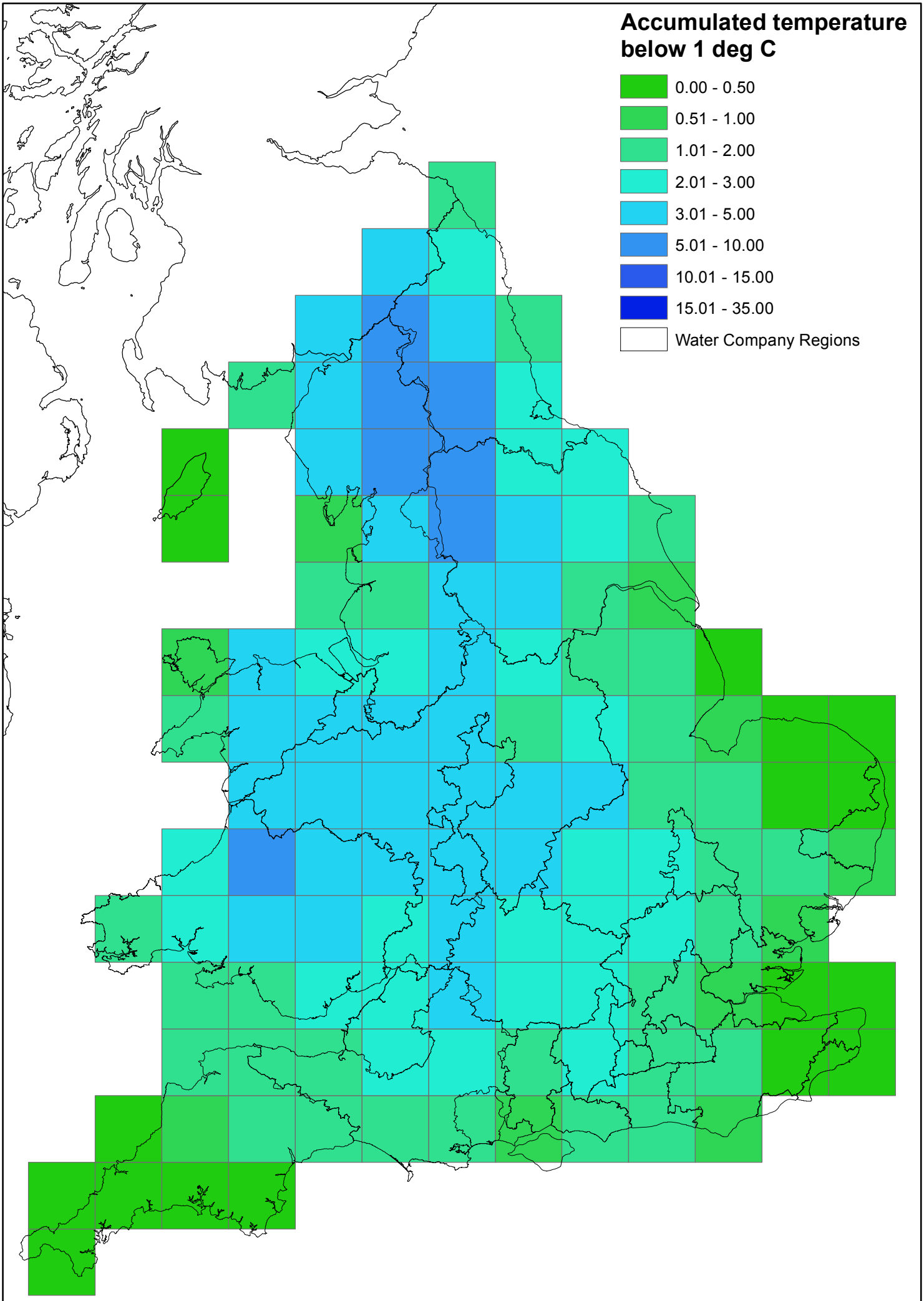

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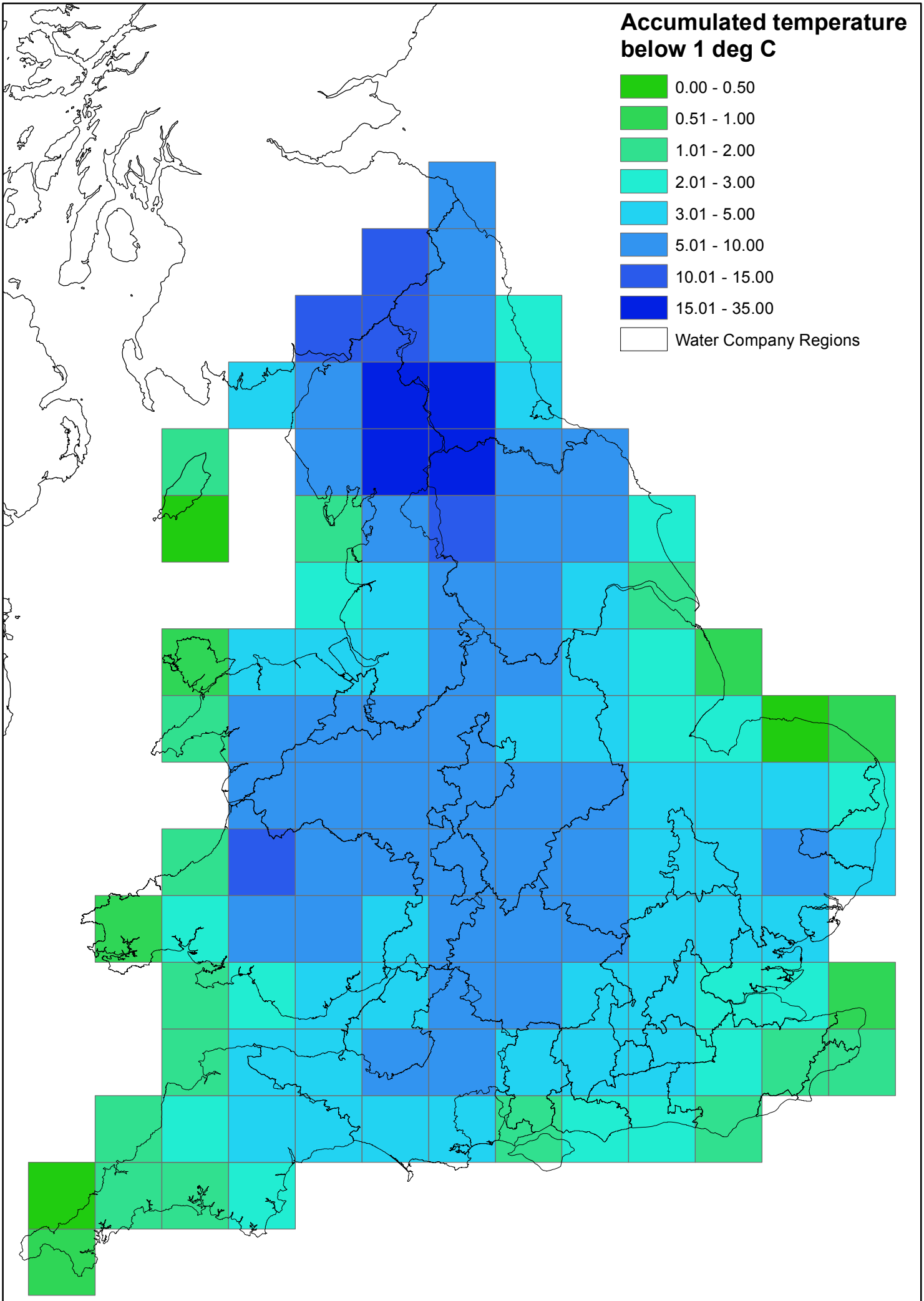

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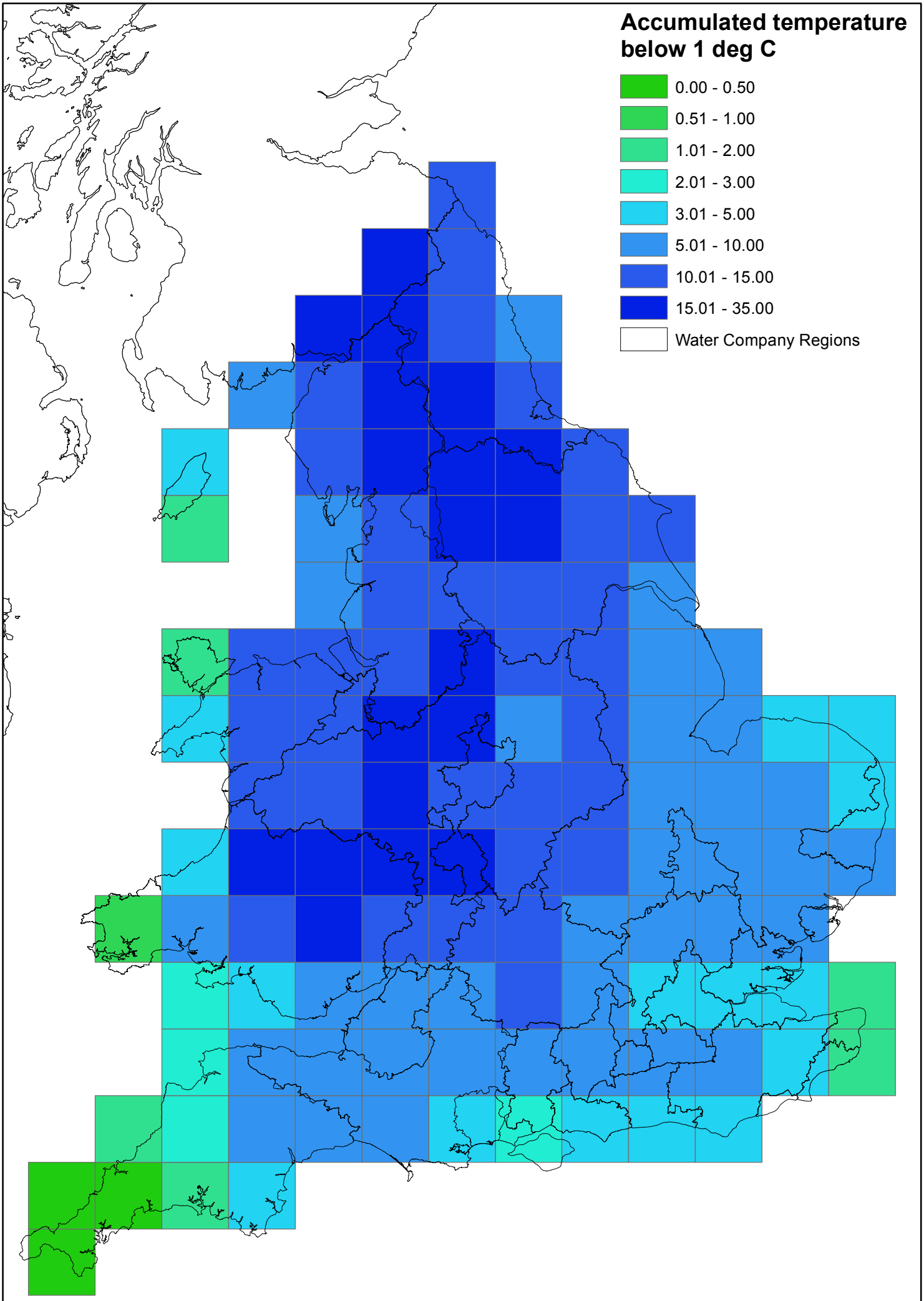

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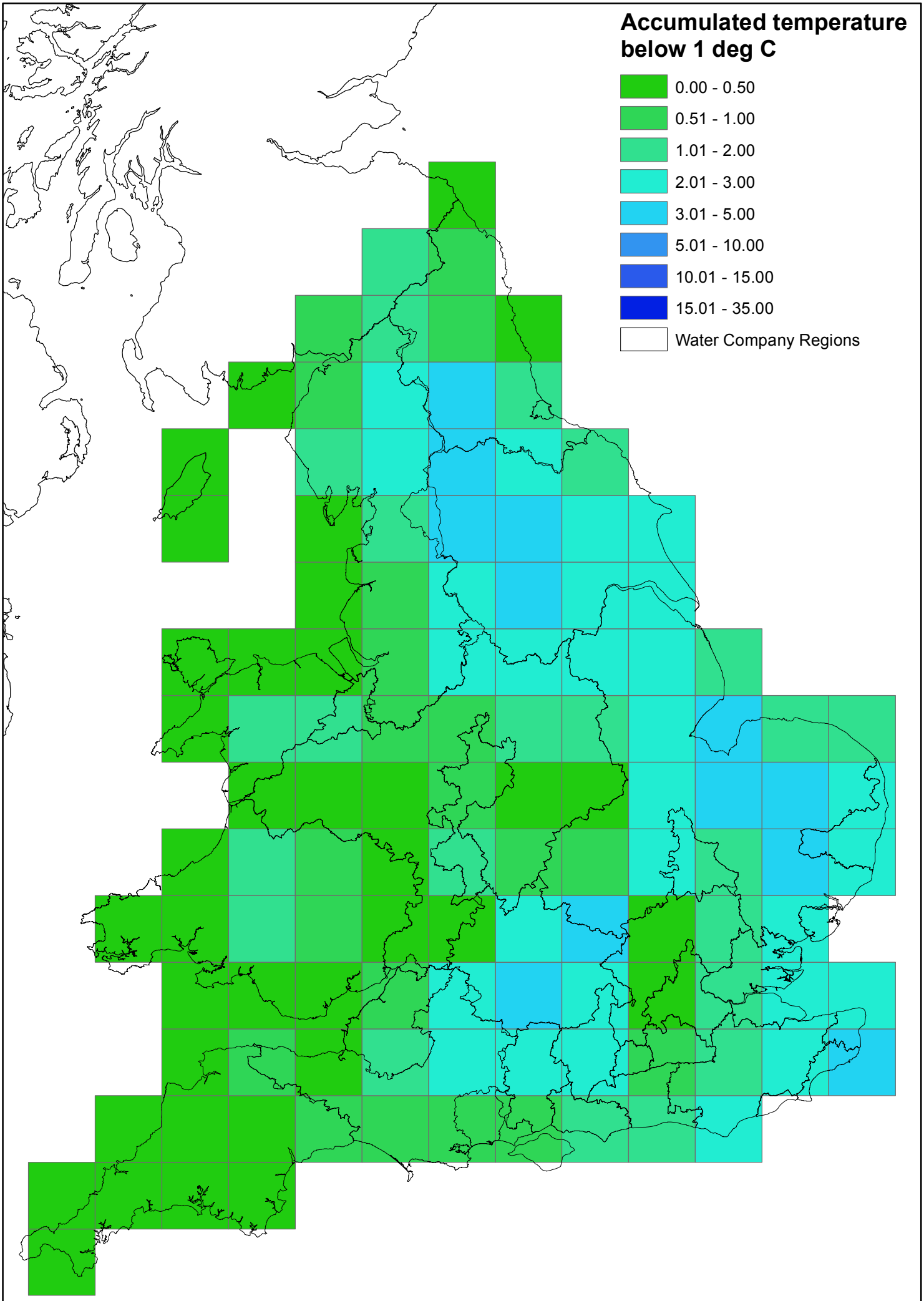

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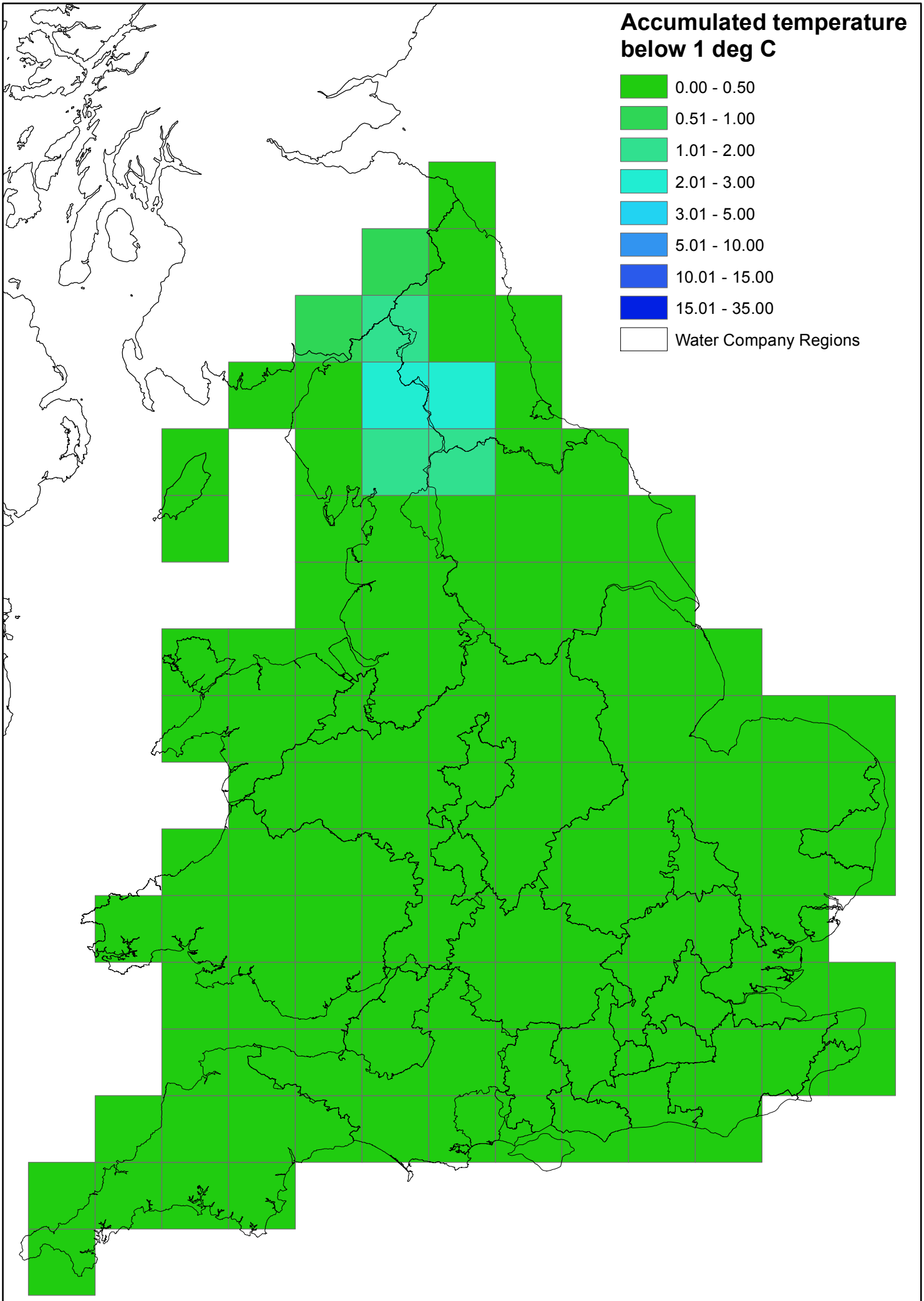

2012/2013