Global surface temperature change detection: Differences between the long-term mean of 1950-1970 and 1990-2010

Merlin Unterfinger, Geography UZH
Olivier Niklaus, Geography UZH

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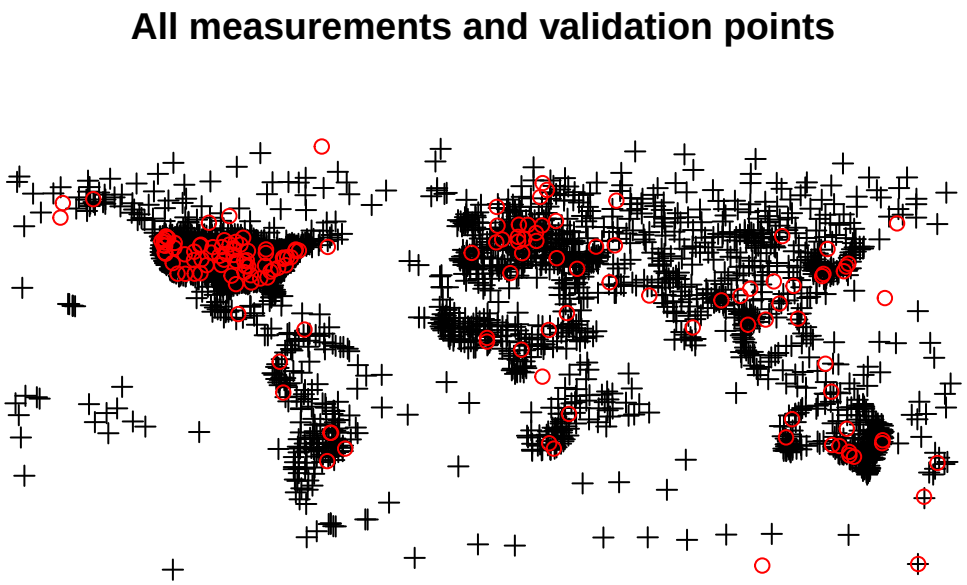
Abstract

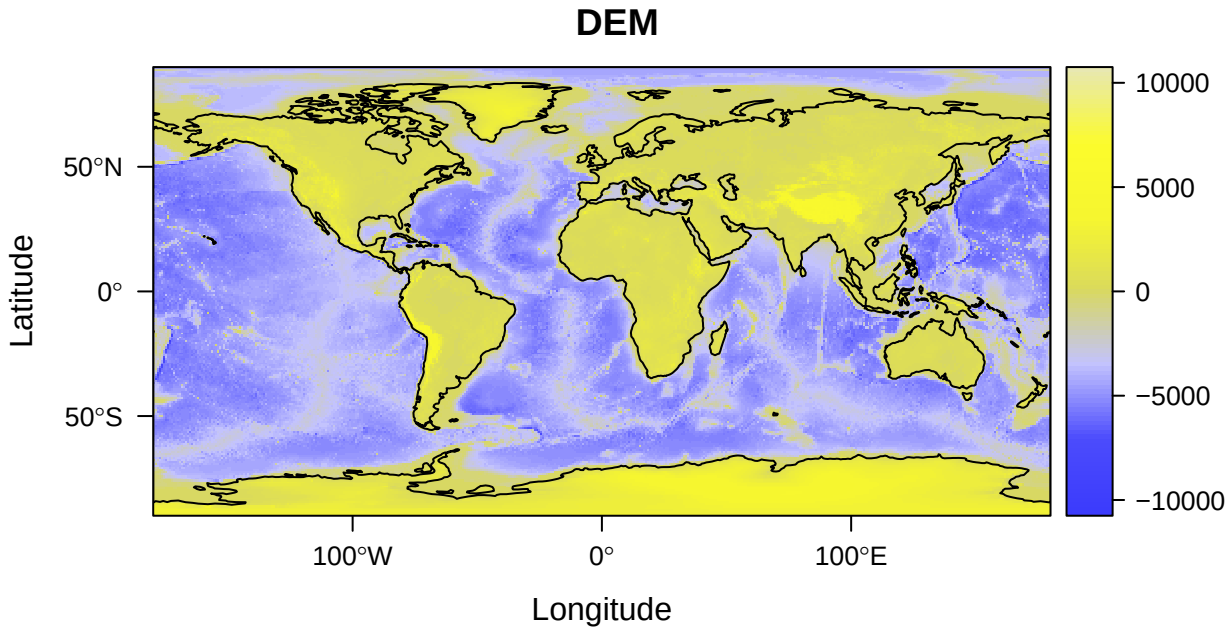
Spatial continuity of global temperature point measurements is analysed by creating H-scatterplots, autocovariance plots and variograms. Universal Kriging is applied to interpolate global temperature maps from the point measurements. Global layers of elevation, sun inclination angle, atmospheric distance and continentality are created and used in the Universal Kriging as explaining variables. Afterwards difference images are calculated and interpreted.

Contents

1 Data



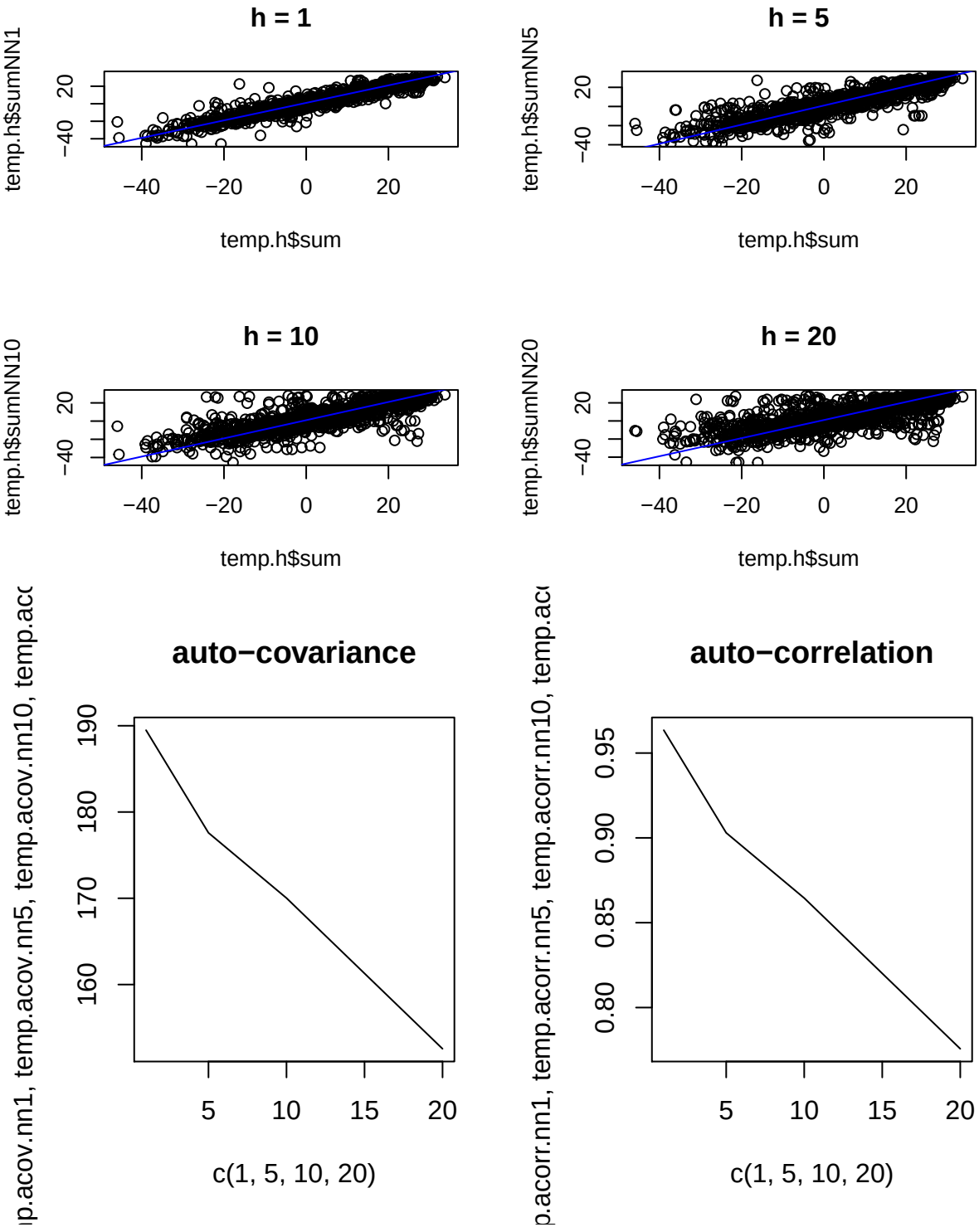
id	meanWi_before1970	meanSu_before1970	meanWi_after1990	meanSu_after1990	elev
1	11.83	23.27	13.09	24.75	7
2	10.21	22.43	11.35	23.94	4
3	10.83	22.78	11.32	24.76	25
4	10.30	22.00	11.44	24.02	2
5	6.13	22.37	7.00	24.56	694
6	8.14	24.90	9.35	26.15	715



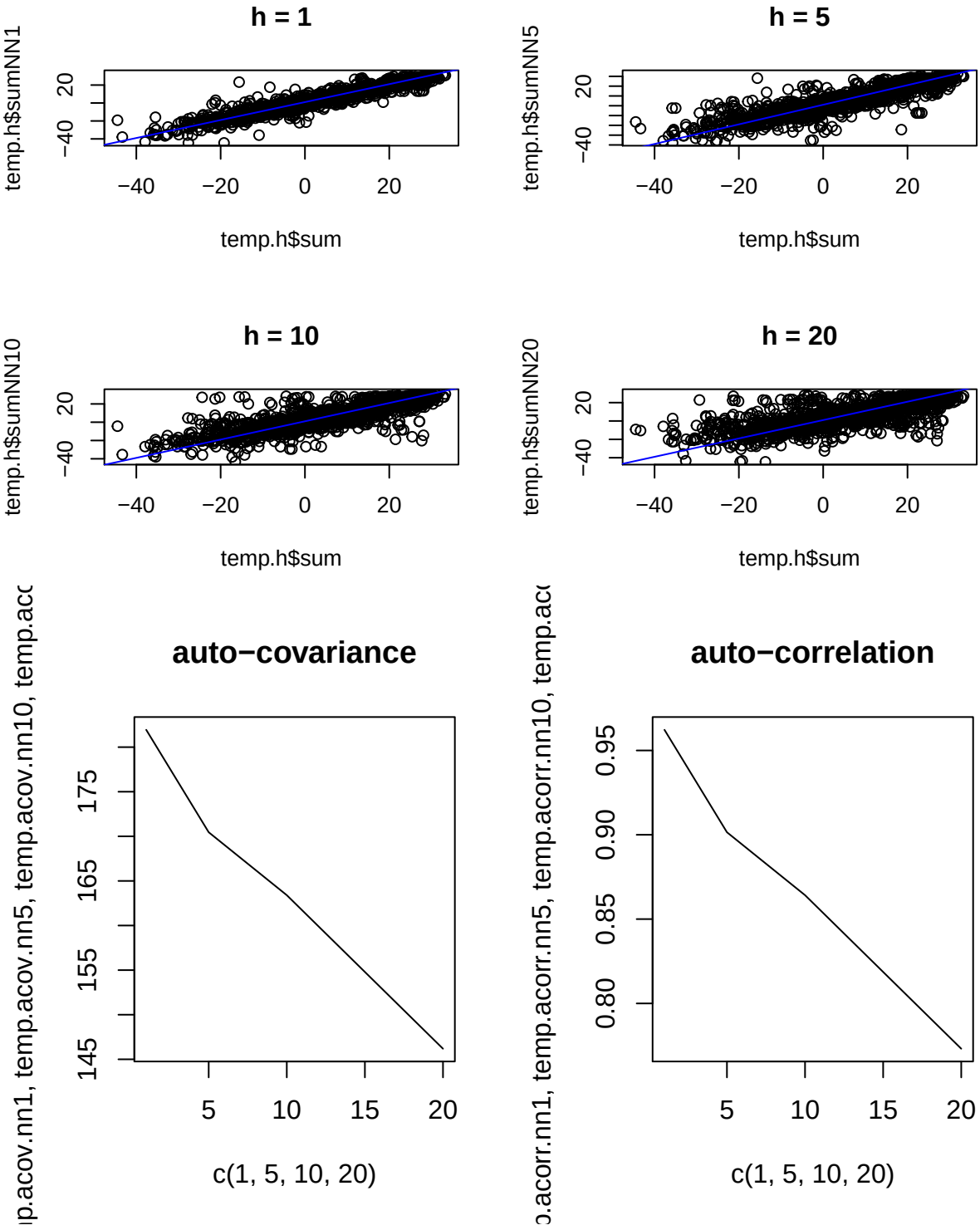
2 Spatial continuity

2.1 H-scatterplots and autocovariance

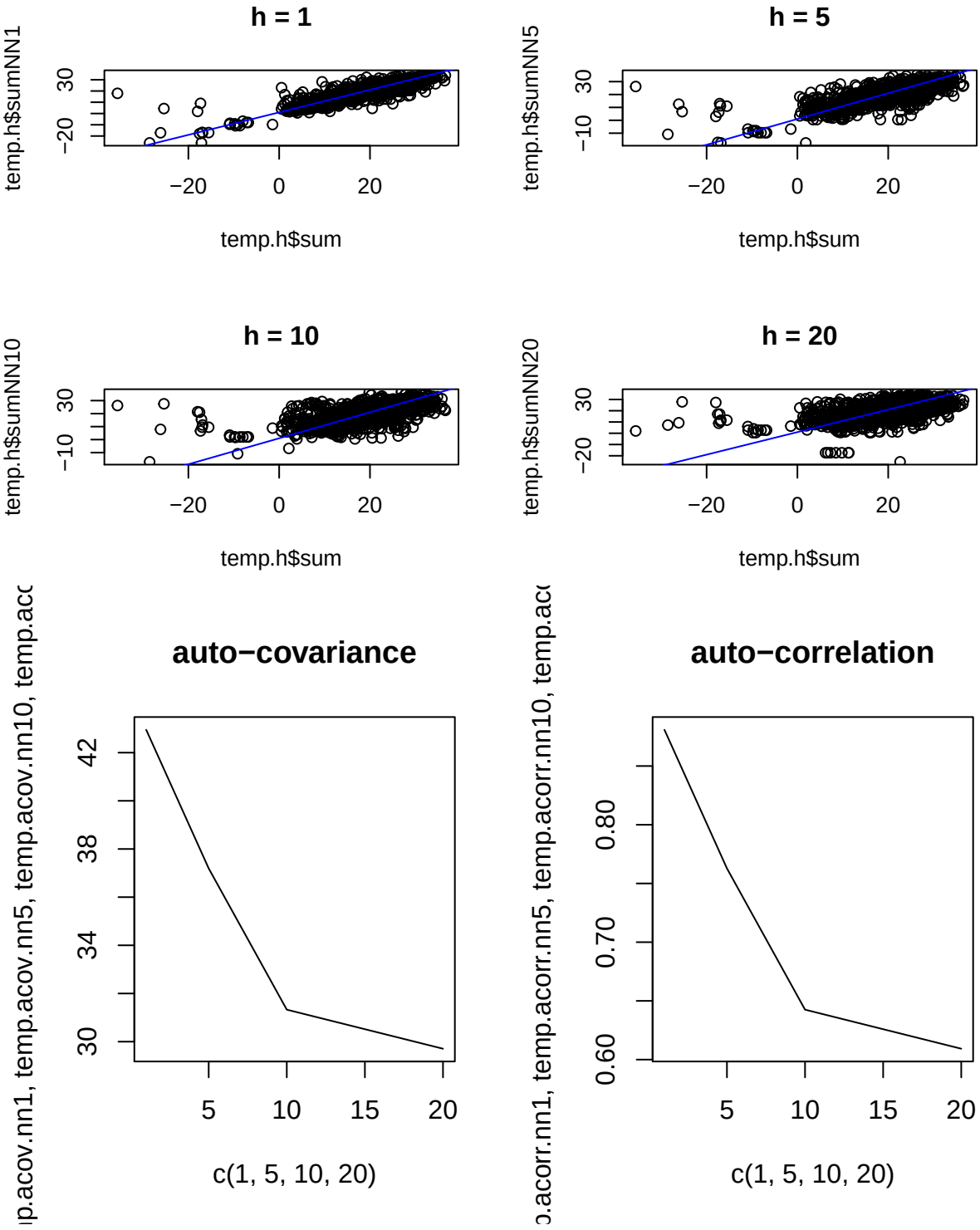
2.1.1 Winter before 1970



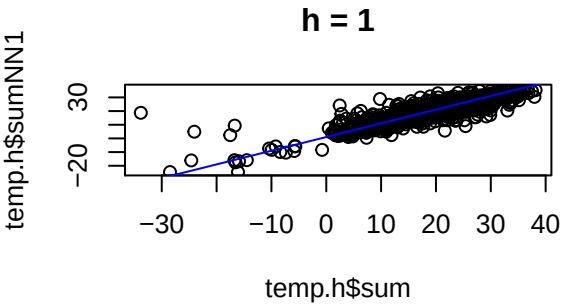
2.1.2 Winter after 1990

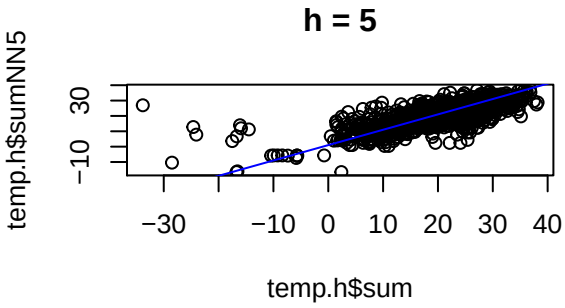


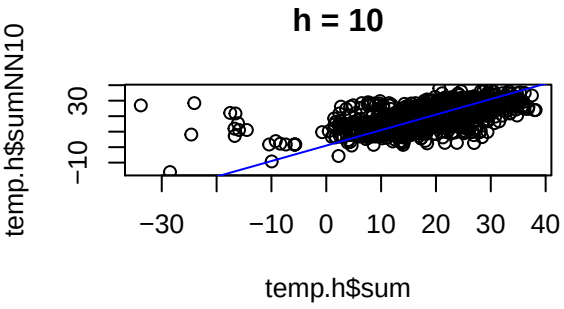
2.1.3 Summer before 1970

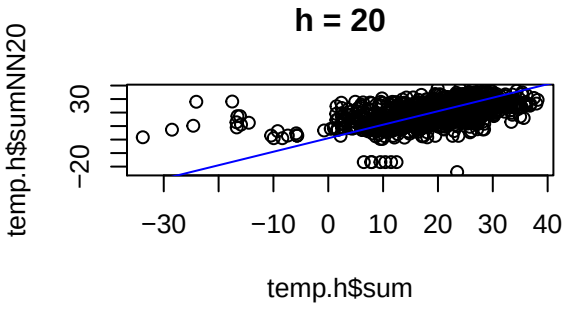


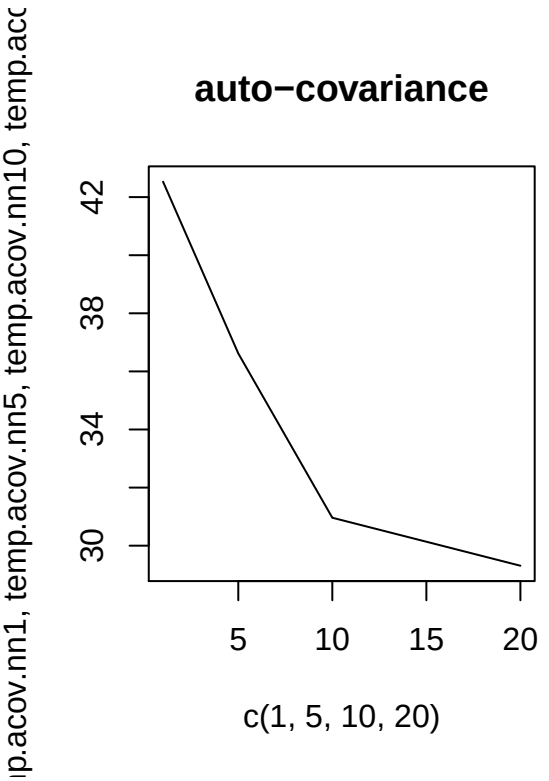
2.1.4 Summer after 1990

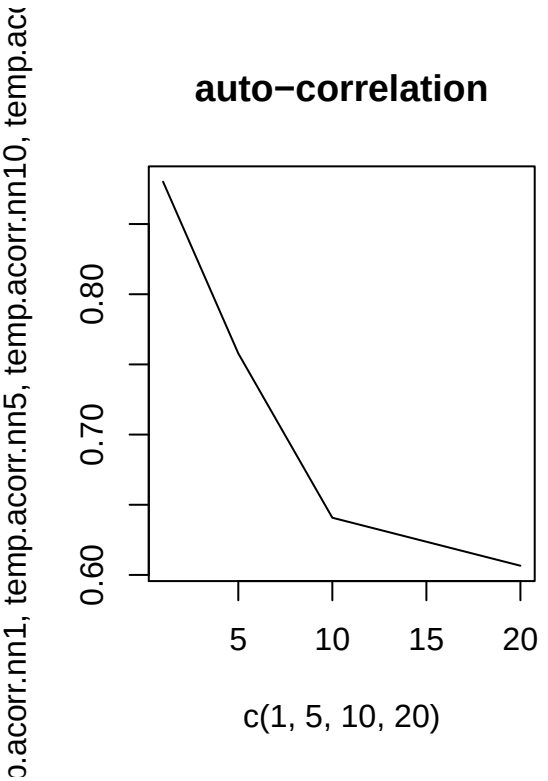






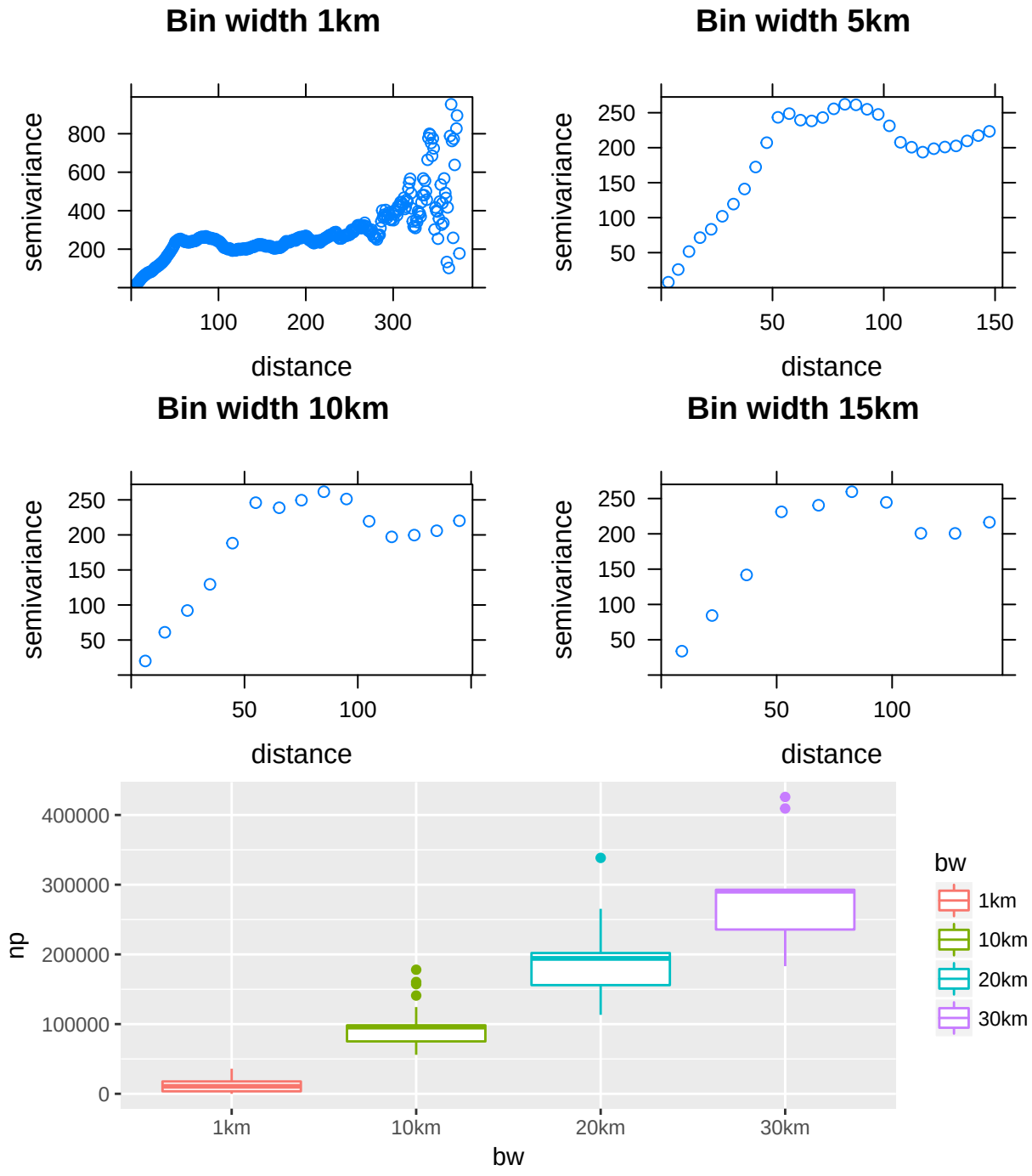




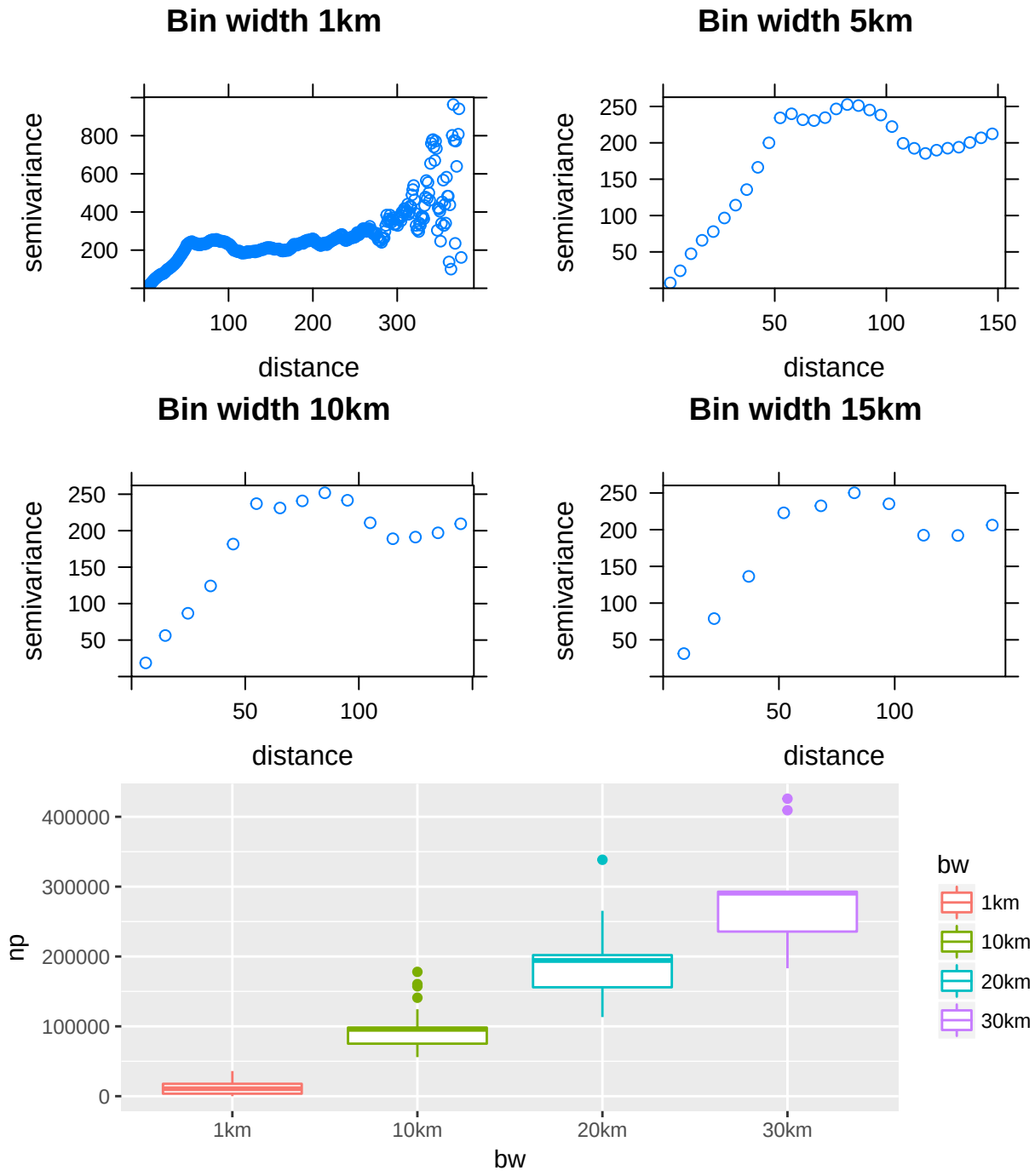


2.2 Empirical Variogram

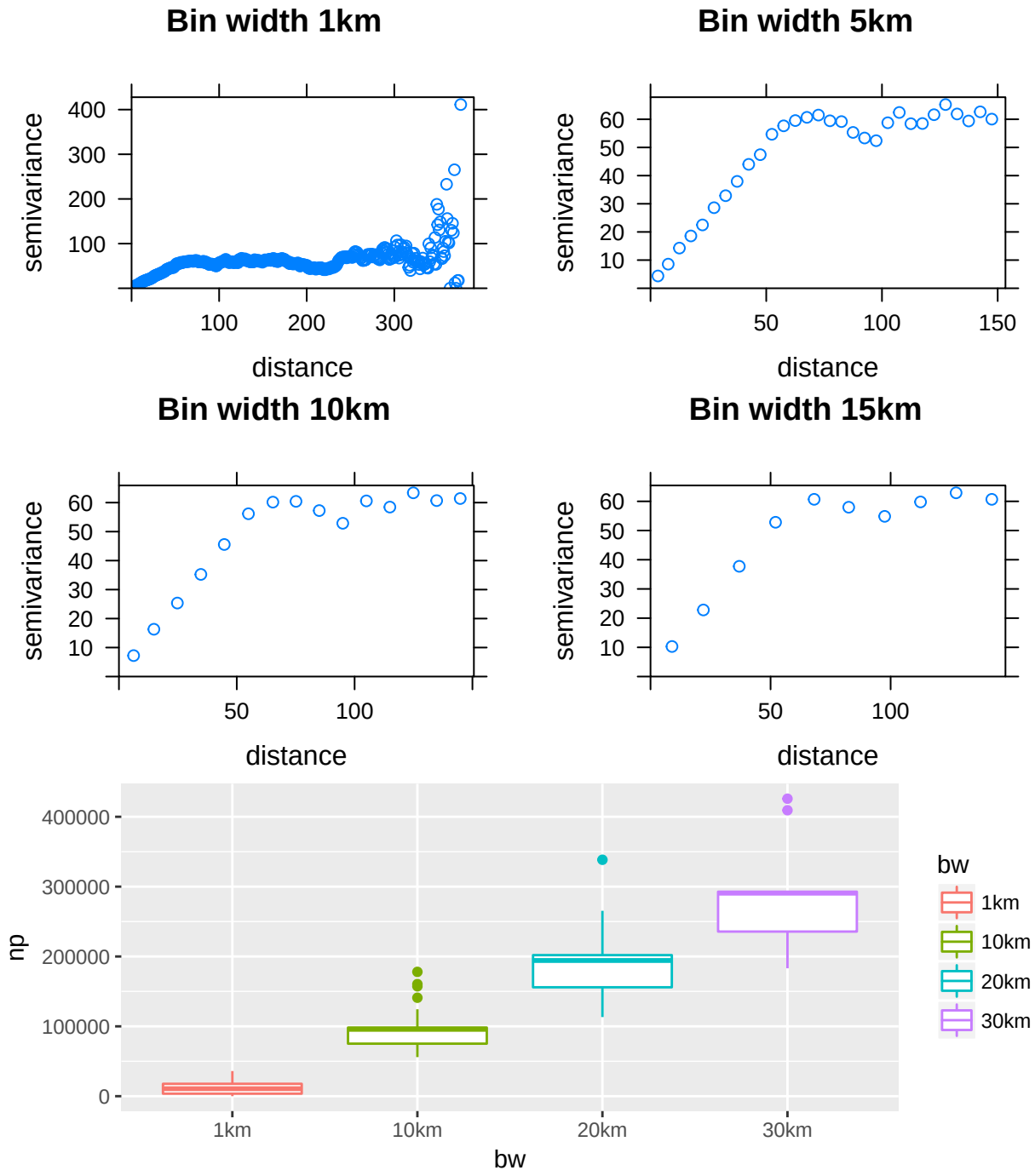
2.2.1 Winter before 1970



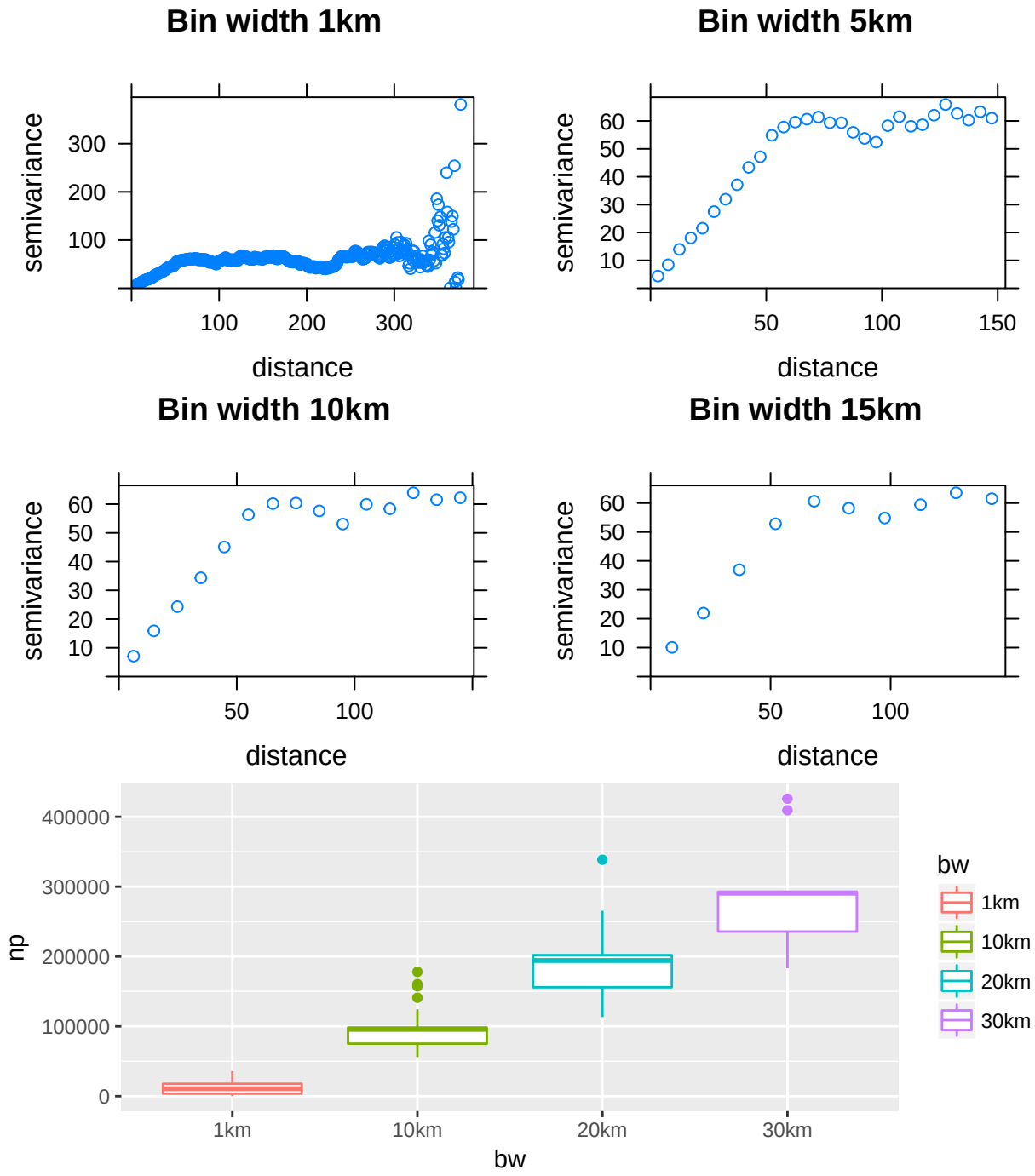
2.2.2 Winter after 1990



2.2.3 Summer before 1970

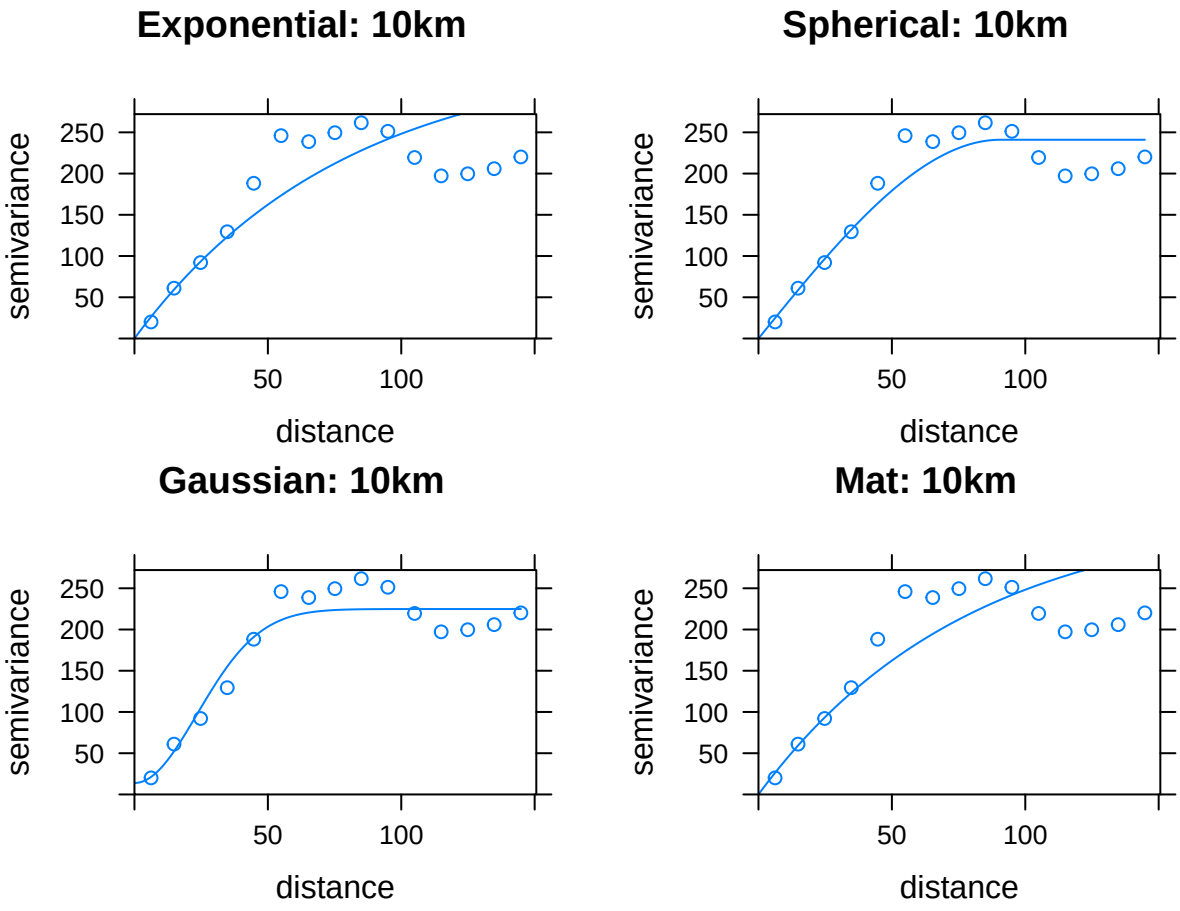


2.2.4 Summer after 1990

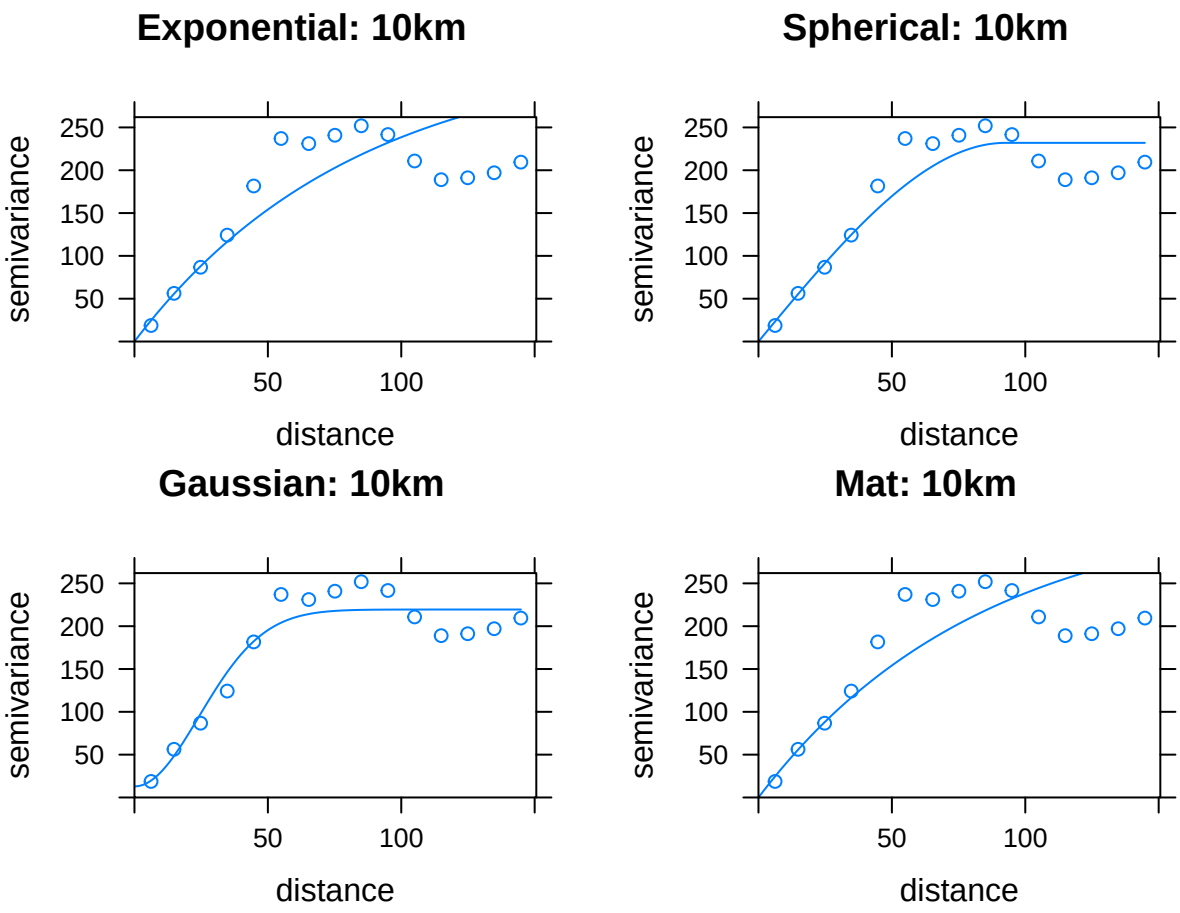


2.3 Fitted Semivariogram

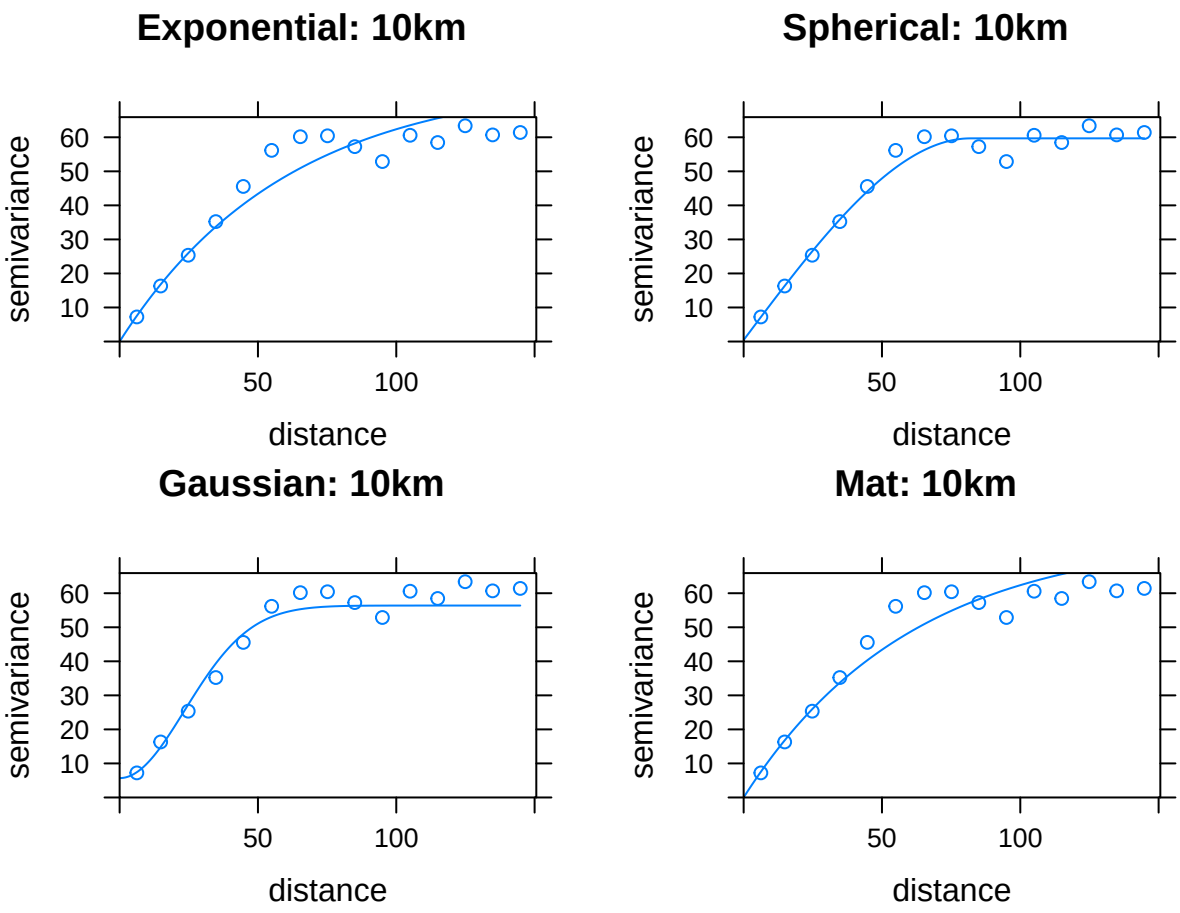
2.3.1 Winter before 1970



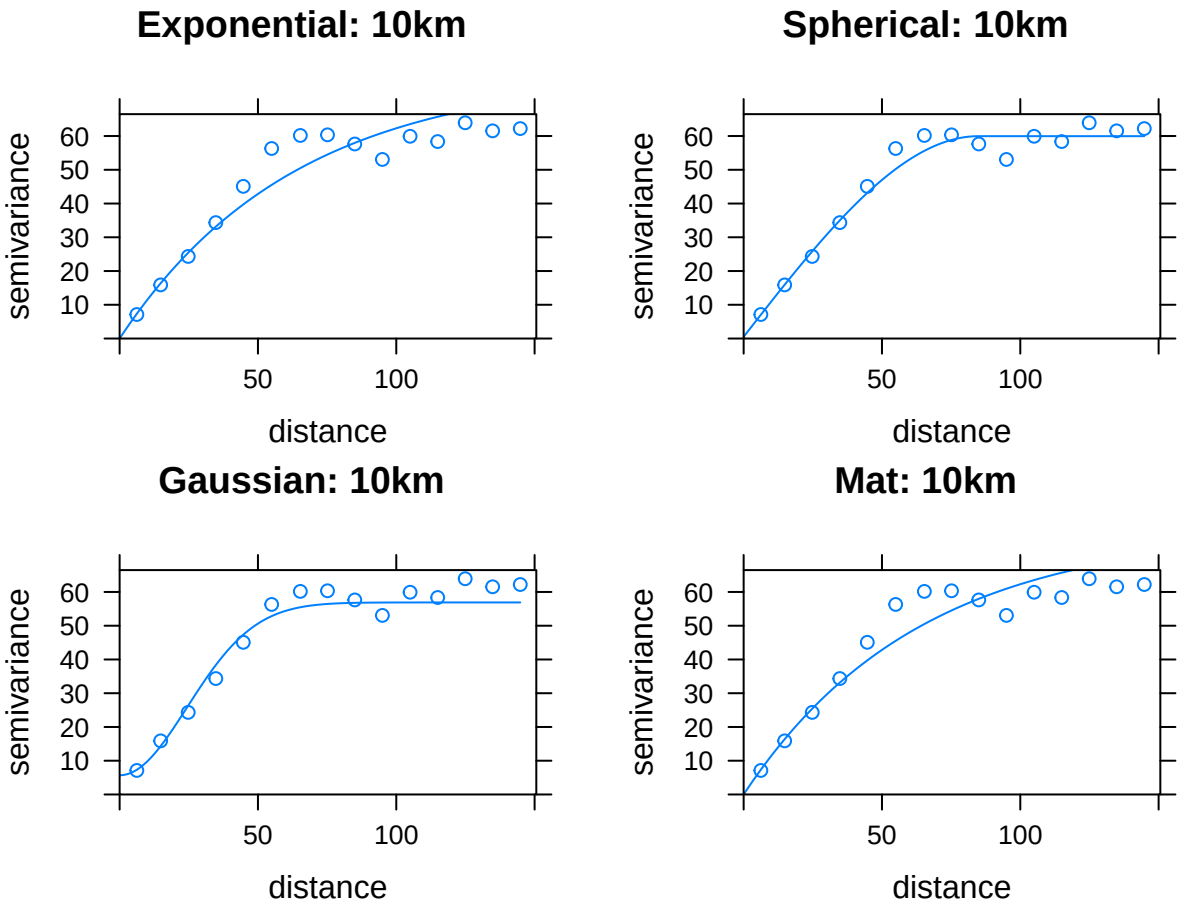
2.3.2 Winter after 1990



2.3.3 Summer before 1970

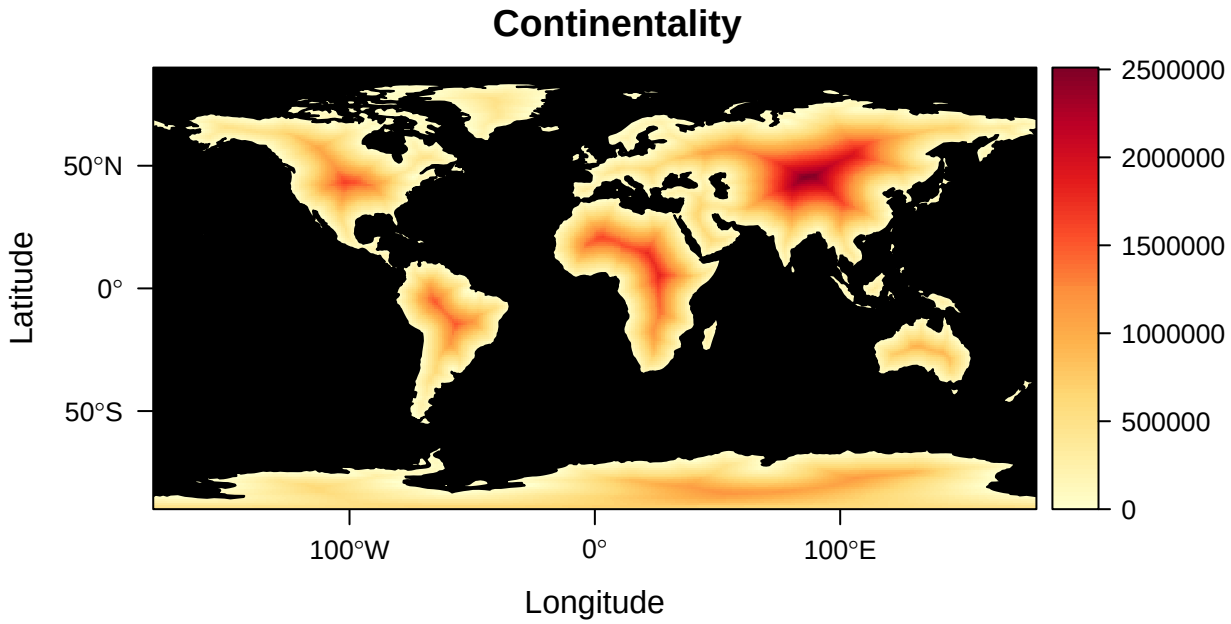


2.3.4 Summer after 1990

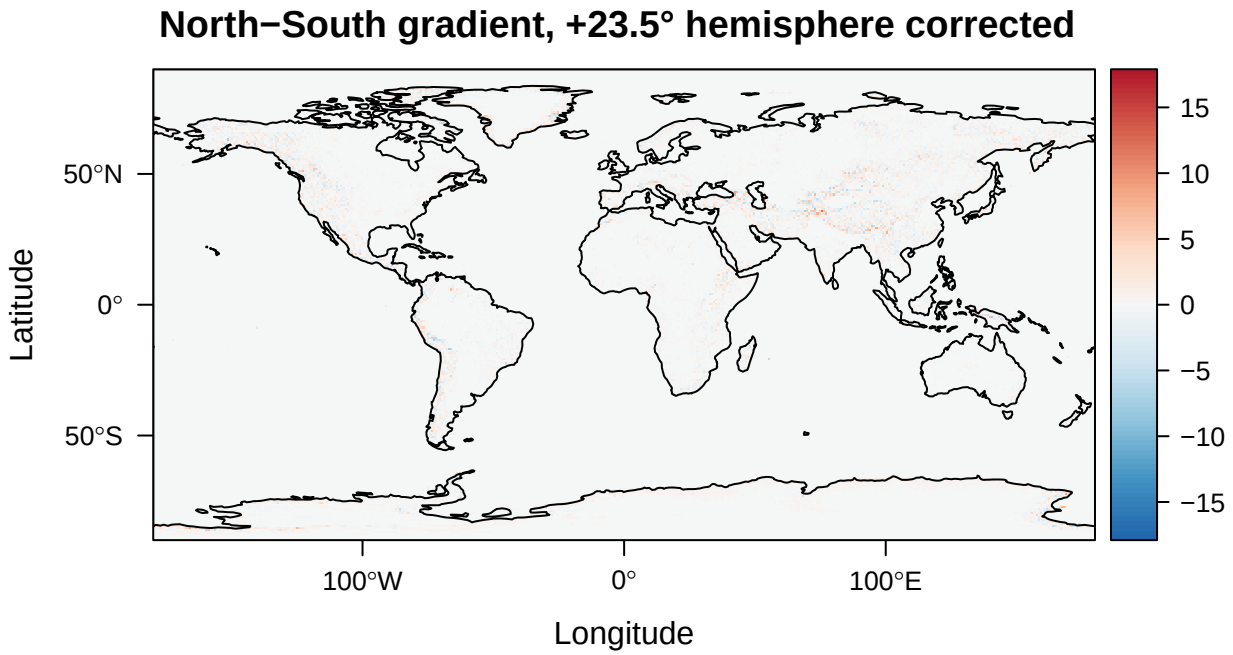


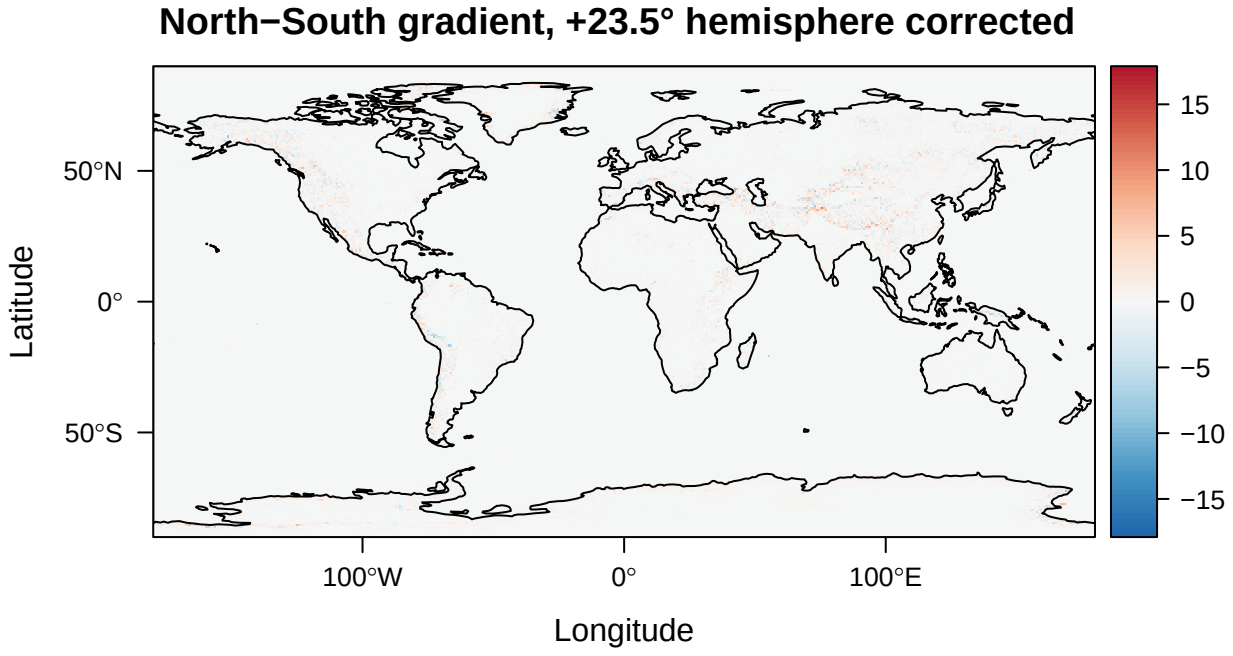
3 Universal Kriging

3.1 Continentality

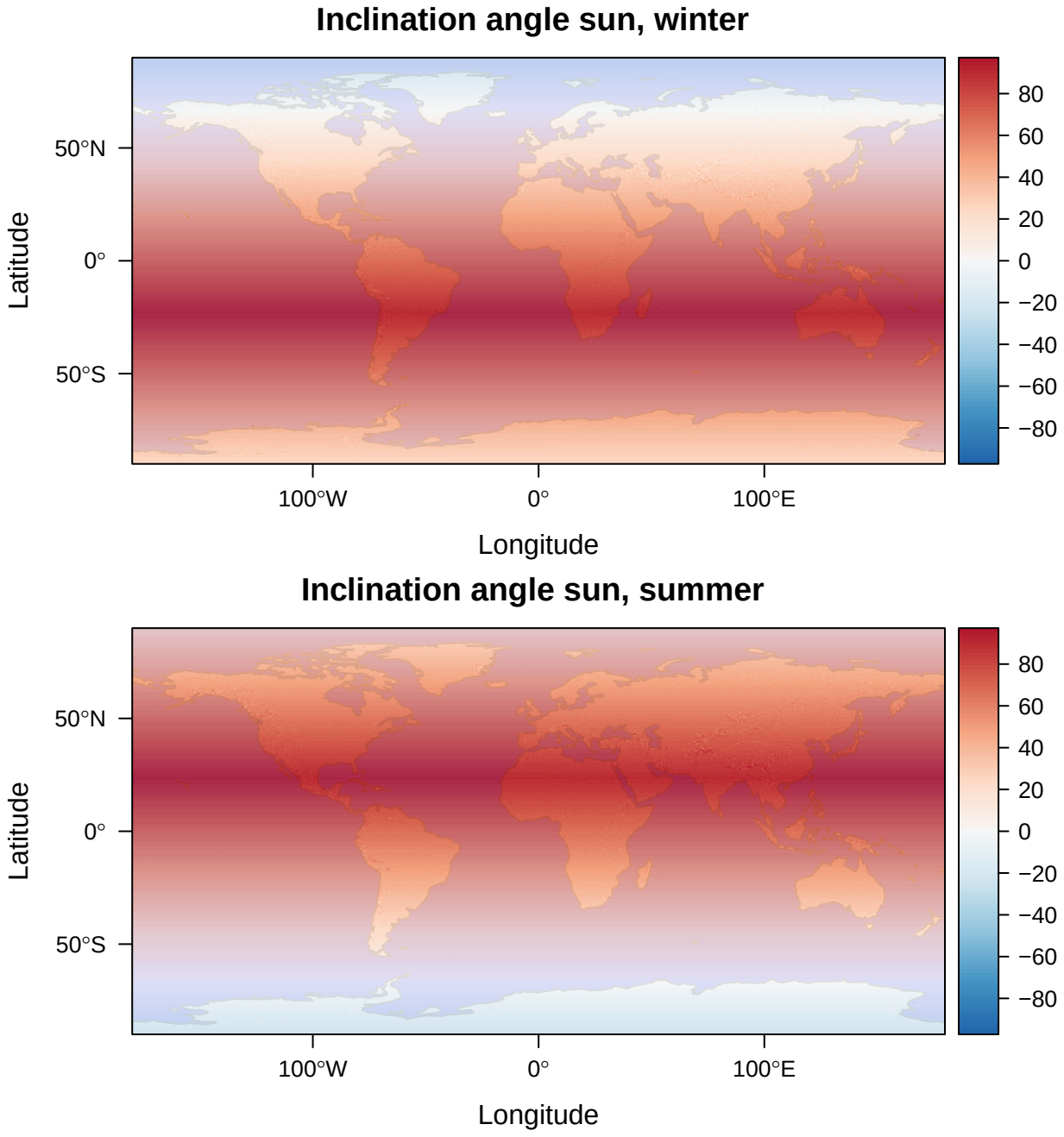


3.2 Surface gradient (North-South)

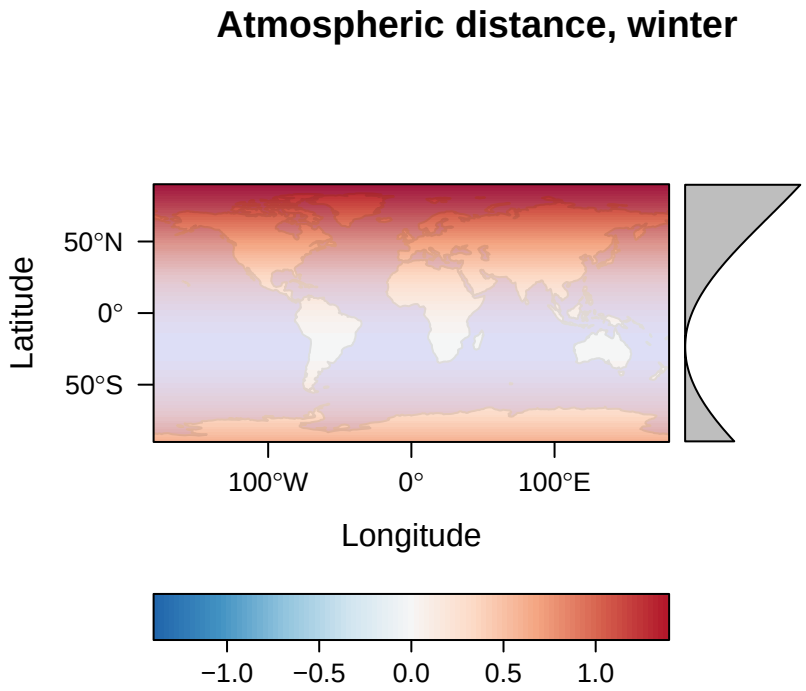


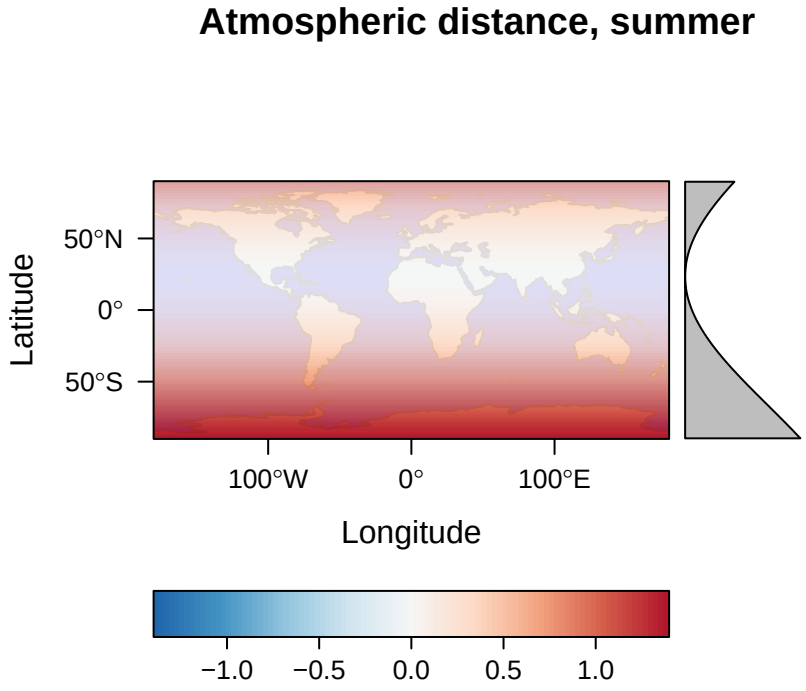


3.3 Sun inclination angle



3.4 Atmospheric distance

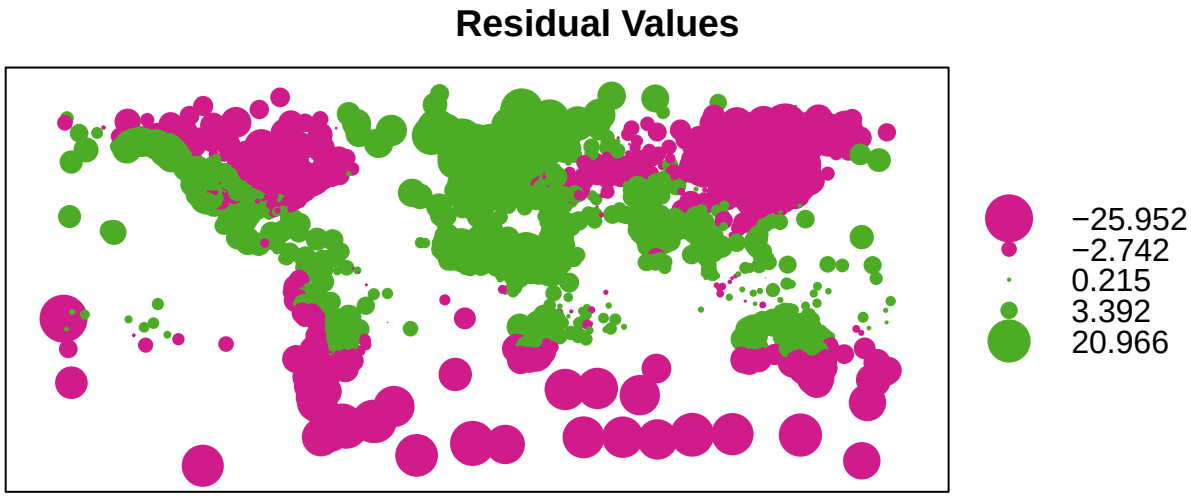


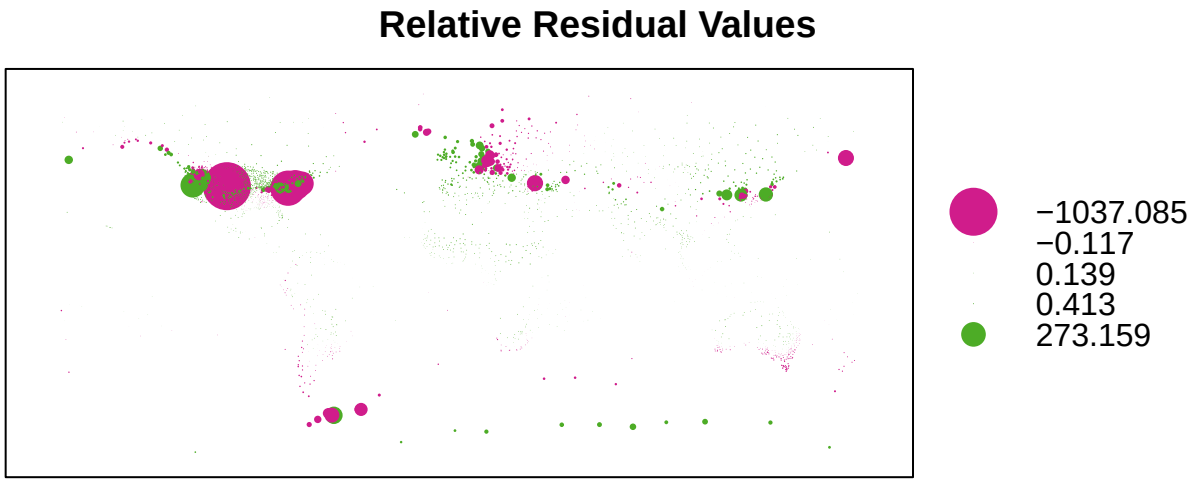


3.5 Interpolation

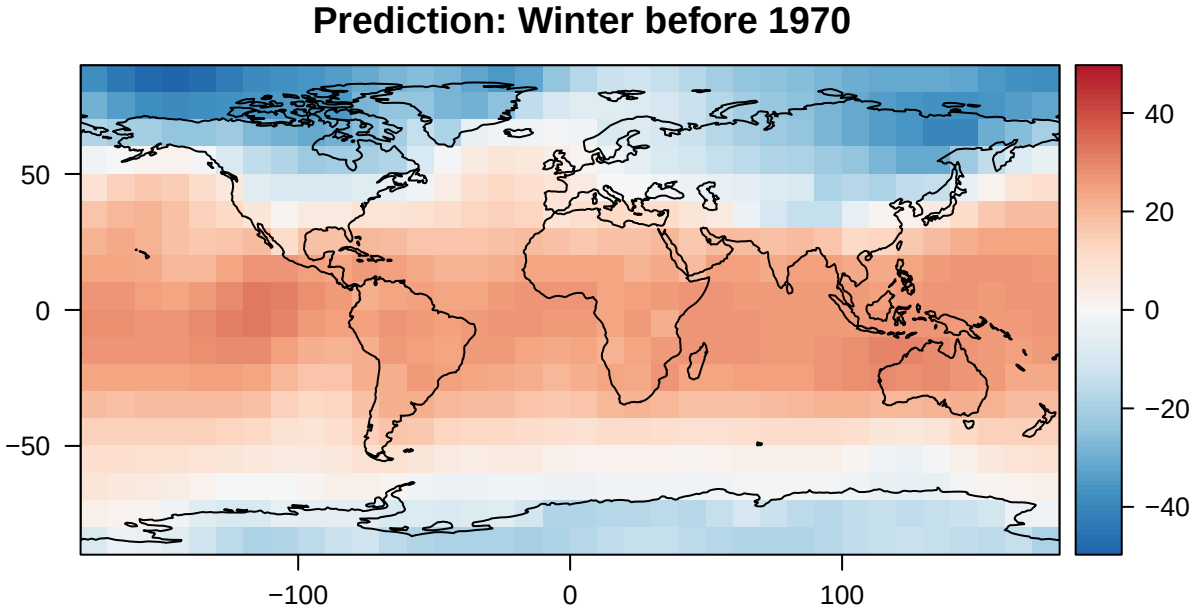
3.5.1 Winter before 1970

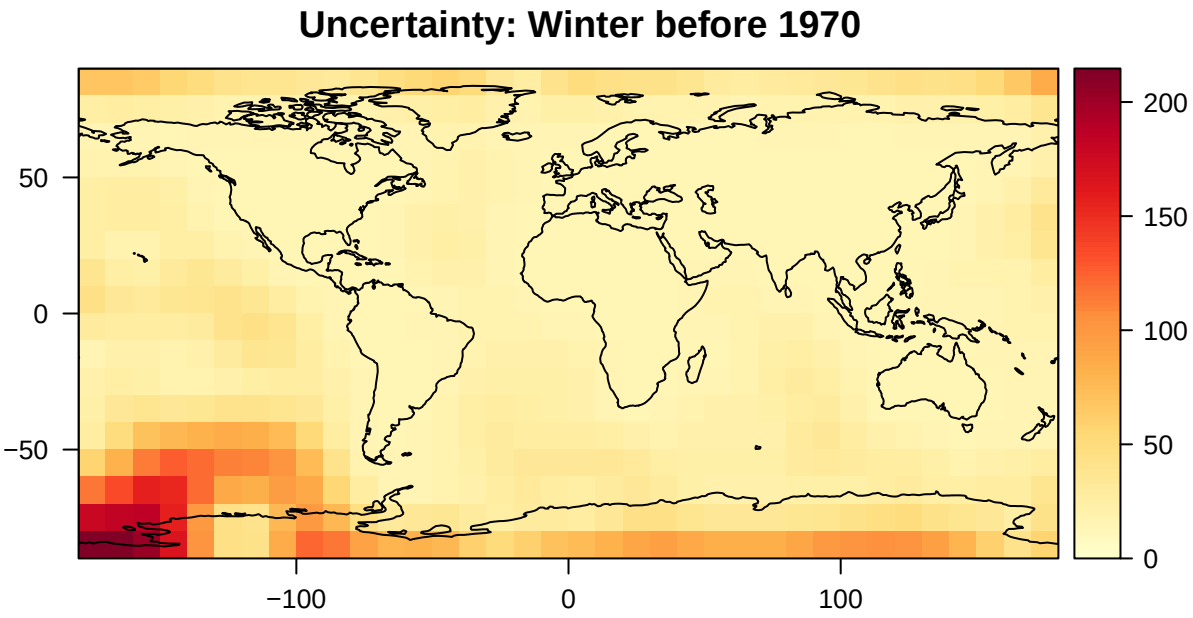
```
##
## Call:
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp1970w@data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.9521  -2.7425   0.2153   3.3919  20.9661
##
## Coefficients:
##                  Estimate    Std. Error t value Pr(>|t|)
## (Intercept)  52.946267789   1.555124585   34.05   <2e-16 ***
## elev         -0.002415947   0.000194905  -12.40   <2e-16 ***
## cont         -0.000004784   0.000000247  -19.37   <2e-16 ***
## hsun         -0.317743109   0.020169562  -15.75   <2e-16 ***
## dist        -72.185938885   1.777533469  -40.61   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 5.361 on 2873 degrees of freedom
## Multiple R-squared:  0.8541, Adjusted R-squared:  0.8539
## F-statistic:  4203 on 4 and 2873 DF,  p-value: < 2.2e-16
```





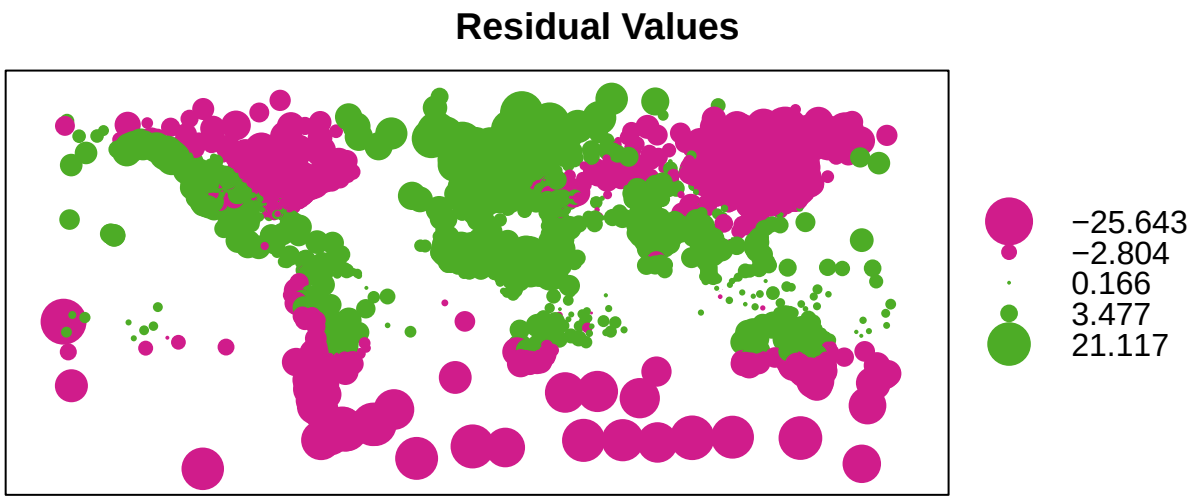

```
## [1] "Observed autocorrelation:  0.200347415811005"
## [1] "P-value of H0 (residuals are randomly distributed):  0"
## [using universal kriging]
## [1] "Observed RMSE (5% validation data): 4.39°C"
```

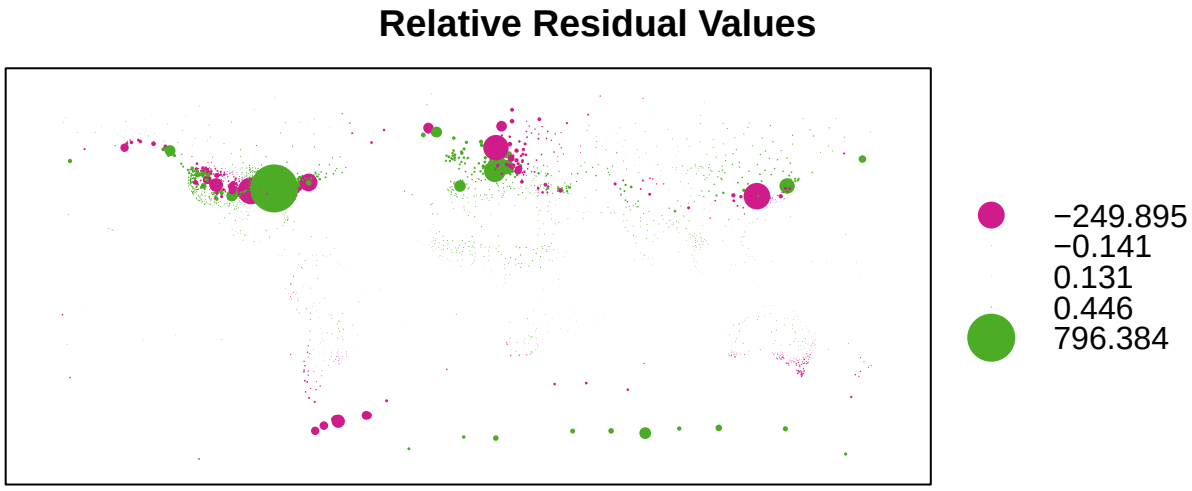



Uncertainty: Winter before 1970
50
0
−50
−100
0
100
200
150
100
50
0

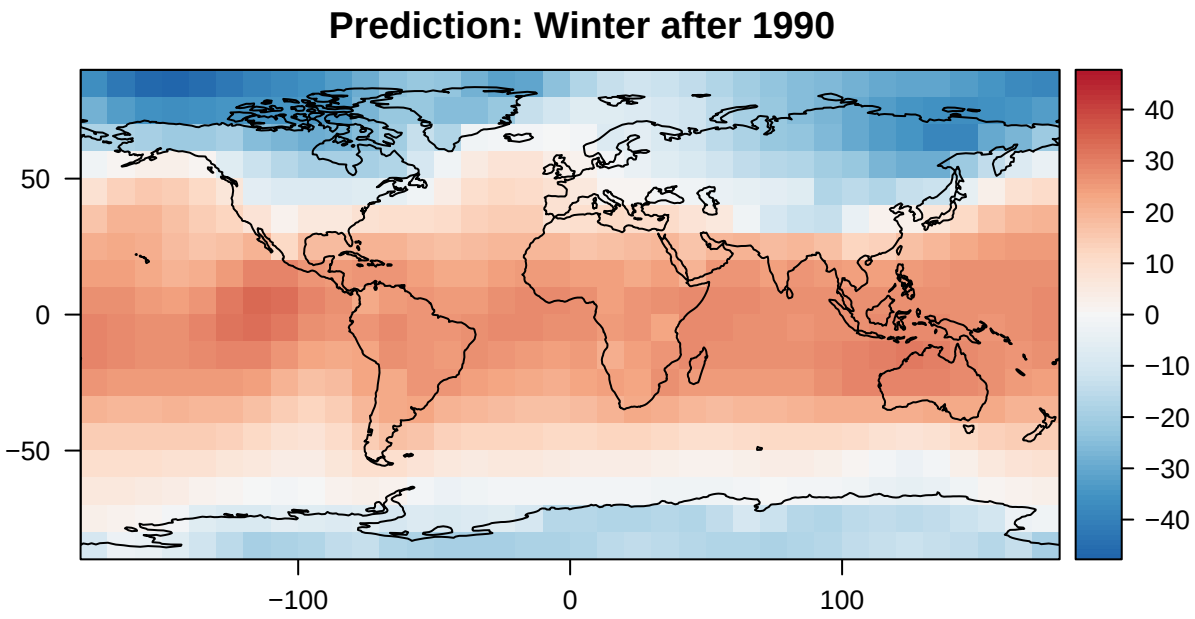
3.5.2 Winter after 1990

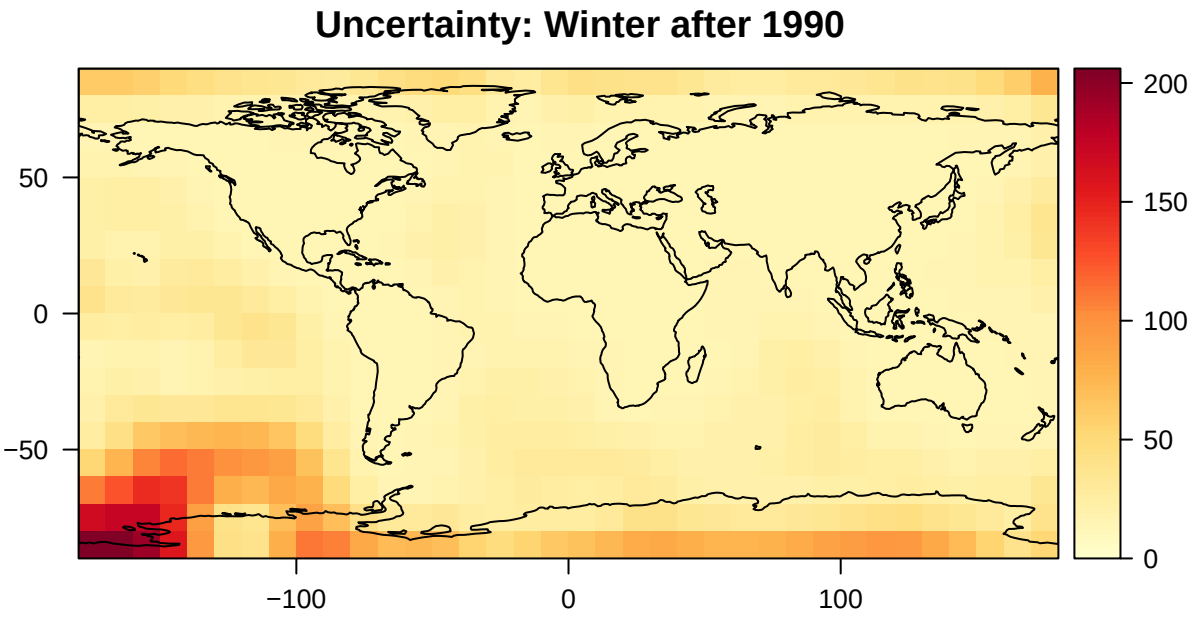
```
##
## Call:
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp2010w@data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.6428  -2.8042   0.1663   3.4773  21.1174
##
## Coefficients:
##                   Estimate     Std. Error t value Pr(>|t|)
## (Intercept)  51.2642919827   1.5443238593   33.20   <2e-16 ***
## elev         -0.0024294349   0.0001935508  -12.55   <2e-16 ***
## cont         -0.0000045061   0.0000002453  -18.37   <2e-16 ***
## hsun         -0.2910942578   0.0200294794  -14.53   <2e-16 ***
## dist        -69.0585594032   1.7651880583  -39.12   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 5.324 on 2873 degrees of freedom
## Multiple R-squared:  0.8503, Adjusted R-squared:  0.8501
## F-statistic:  4080 on 4 and 2873 DF,  p-value: < 2.2e-16
```





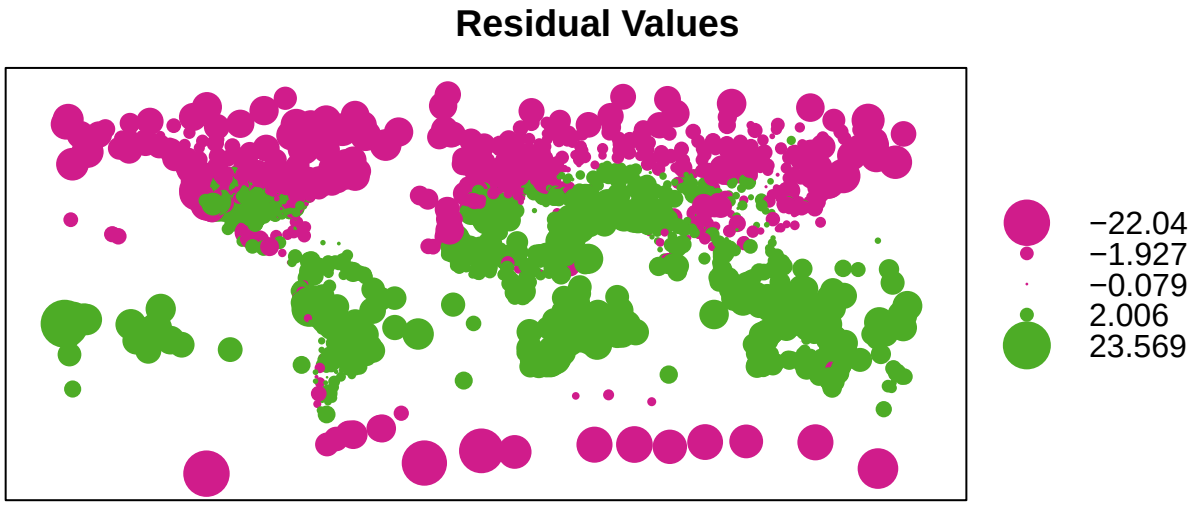

```
## [1] "Observed autocorrelation:  0.201337381282231"
## [1] "P-value of H0 (residuals are randomly distributed):  0"
## [using universal kriging]
## [1] "Observed RMSE (5% validation data): 4.37°C"
```

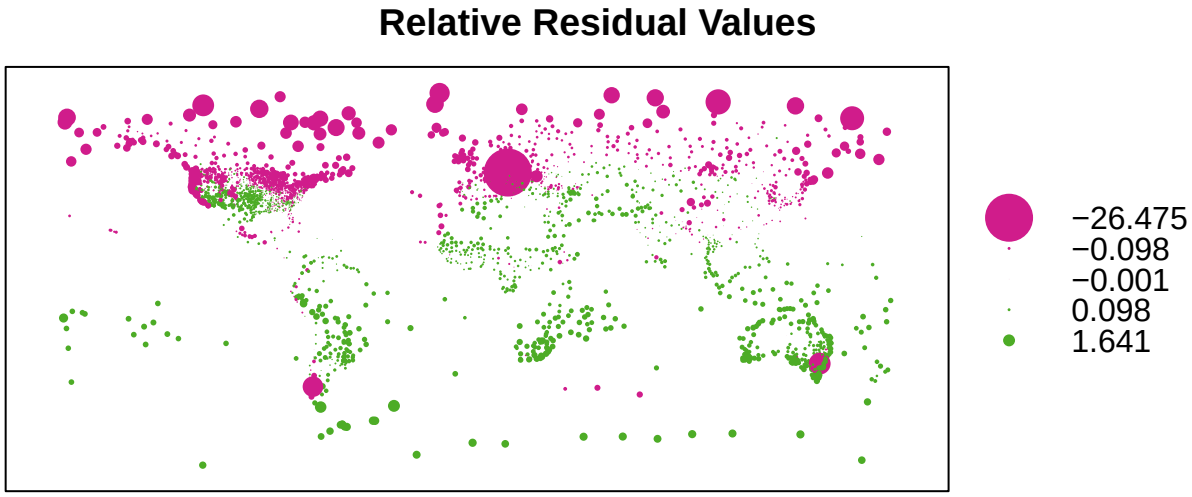



Uncertainty: Winter after 1990
50
0
−50
−100
0
100
200
150
100
50
0

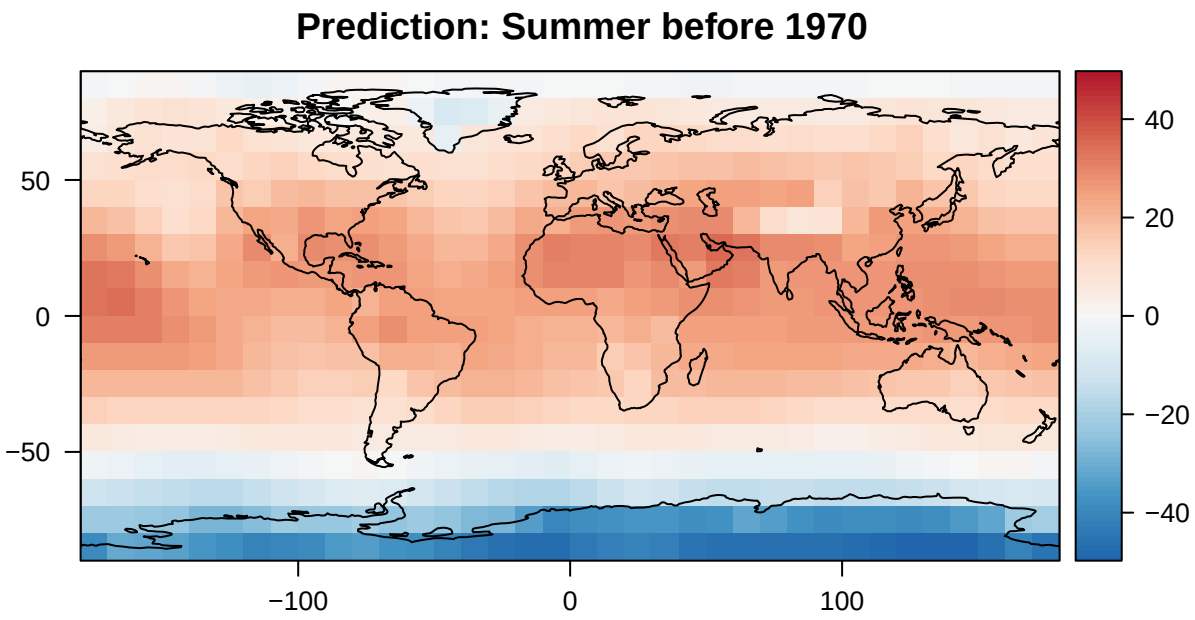
3.5.3 Summer before 1970

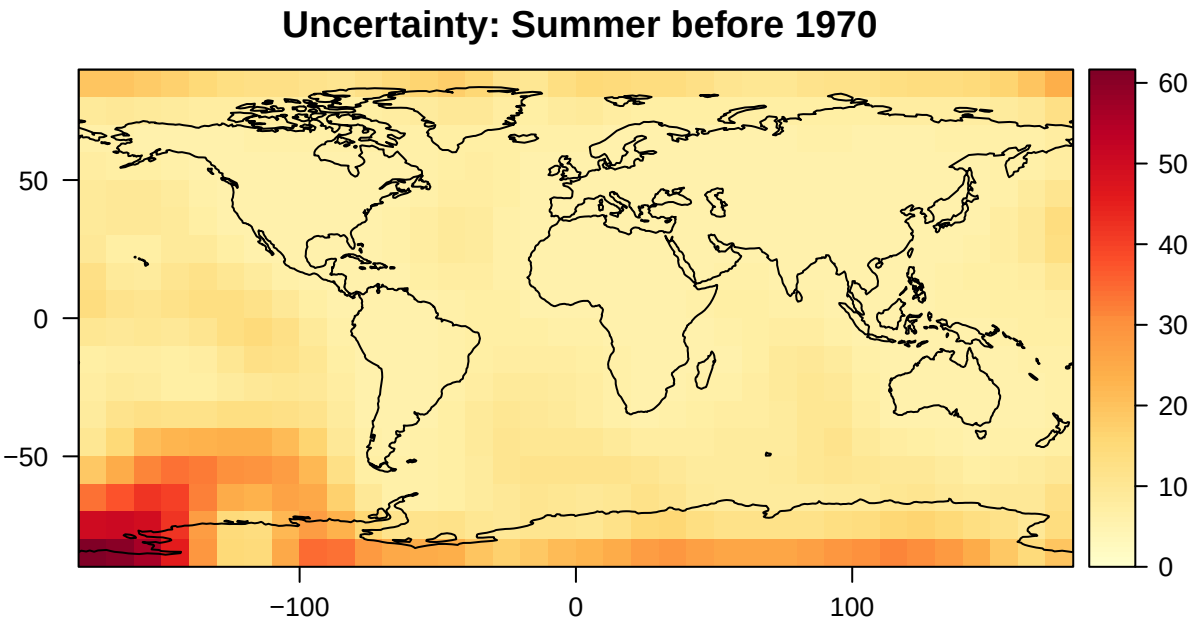
```
##
## Call:
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp1970s@data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -22.0397  -1.9267  -0.0793   2.0064  23.5689
##
## Coefficients:
##                   Estimate    Std. Error t value       Pr(>|t|)
## (Intercept)  2.3838400870  1.2237549749   1.948         0.0515 .
## elev        -0.0031050856  0.0001287024 -24.126        < 2e-16 ***
## cont         0.0000010166  0.0000001633   6.226 0.000000000548 ***
## hsun         0.2921664256  0.0154431009  18.919        < 2e-16 ***
## dist        -6.3330076998  1.5961749986  -3.968 0.000074370811 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.542 on 2873 degrees of freedom
## Multiple R-squared:  0.743,  Adjusted R-squared:  0.7426
## F-statistic:  2076 on 4 and 2873 DF,  p-value: < 2.2e-16
```





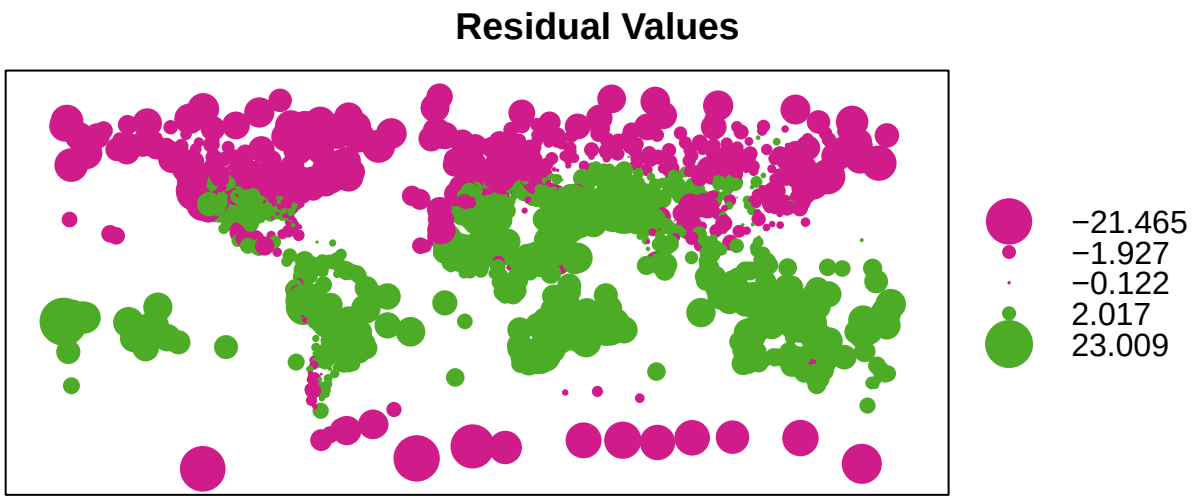

```
## [1] "Observed autocorrelation:  0.153299833387528"
## [1] "P-value of H0 (residuals are randomly distributed):  0"
## [using universal kriging]
## [1] "Observed RMSE (5% validation data): 3.75°C"
```

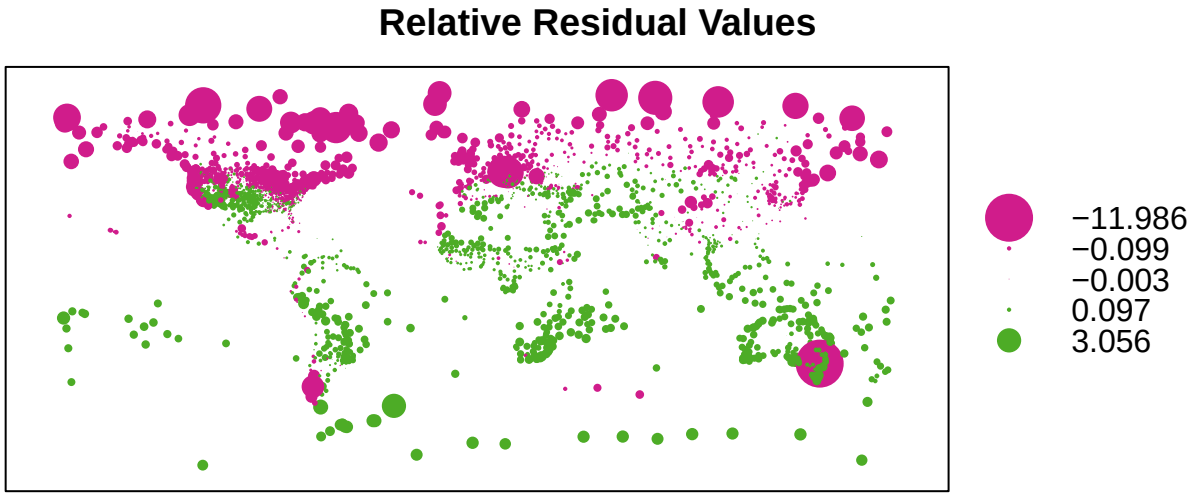



Uncertainty: Summer before 1970
50
0
−50
−100
0
100
60
50
40
30
20
10
0

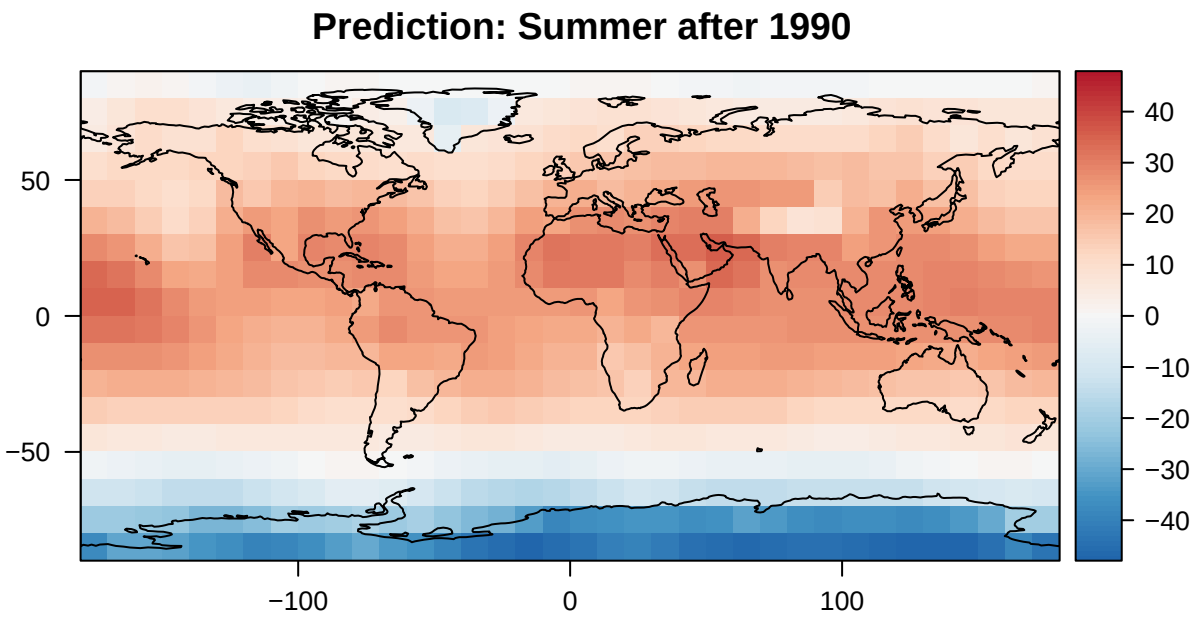
3.5.4 Summer after 1990

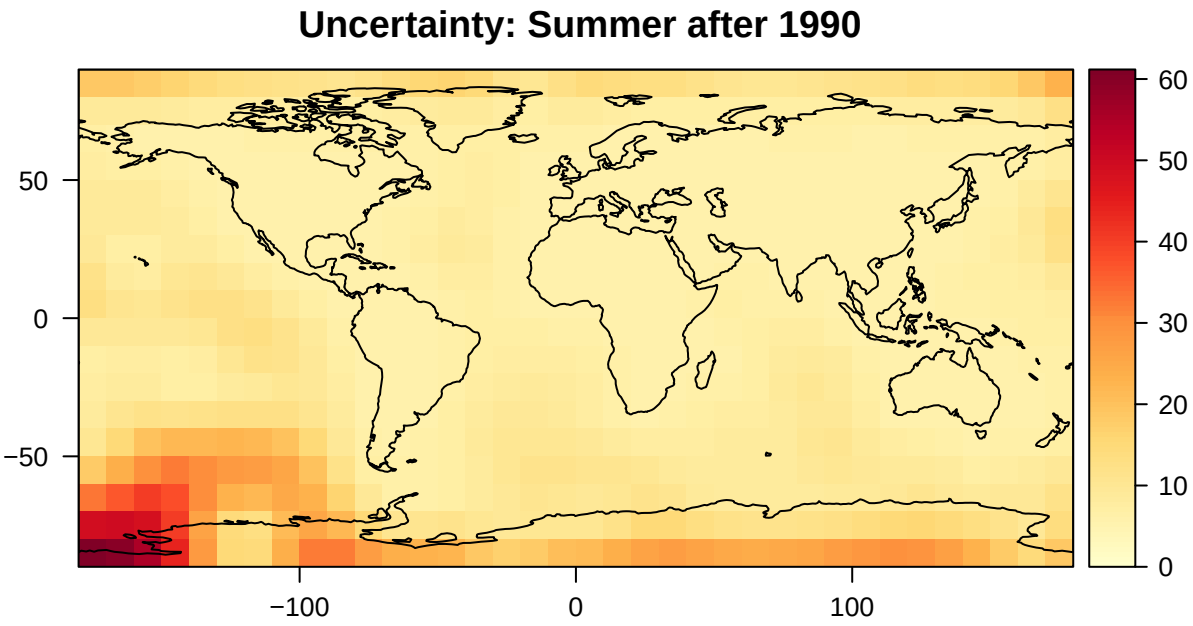
```
##
## Call:
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp2010s@data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -21.4651  -1.9268  -0.1217   2.0172  23.0091
##
## Coefficients:
##                   Estimate    Std. Error t value   Pr(>|t|)
## (Intercept)  3.7912617324  1.2331059228   3.075    0.00213 **
## elev        -0.0029389353  0.0001296858 -22.662    < 2e-16 ***
## cont         0.0000006733  0.0000001645   4.092 0.00004397 ***
## hsun         0.2827975342  0.0155611046  18.173    < 2e-16 ***
## dist        -7.1857437495  1.6083716798  -4.468 0.00000821 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 3.57 on 2873 degrees of freedom
## Multiple R-squared:  0.7367, Adjusted R-squared:  0.7363
## F-statistic:  2009 on 4 and 2873 DF,  p-value: < 2.2e-16
```





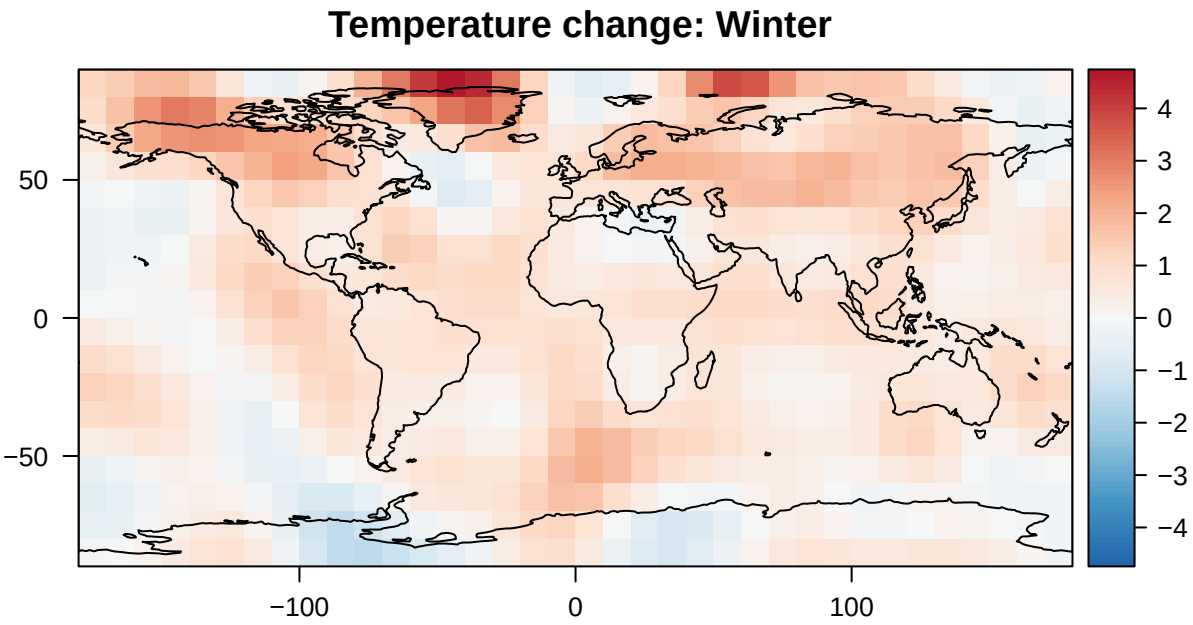

```
## [1] "Observed autocorrelation:  0.160028805439165"
## [1] "P-value of H0 (residuals are randomly distributed):  0"
## [using universal kriging]
## [1] "Observed RMSE (5% validation data): 3.84°C"
```




Uncertainty: Summer after 1990
50
0
−50
−100
0
100
60
50
40
30
20
10
0

4 Difference images

4.1 Winter



4.2 Summer