

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

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5 7 2017

Abstract

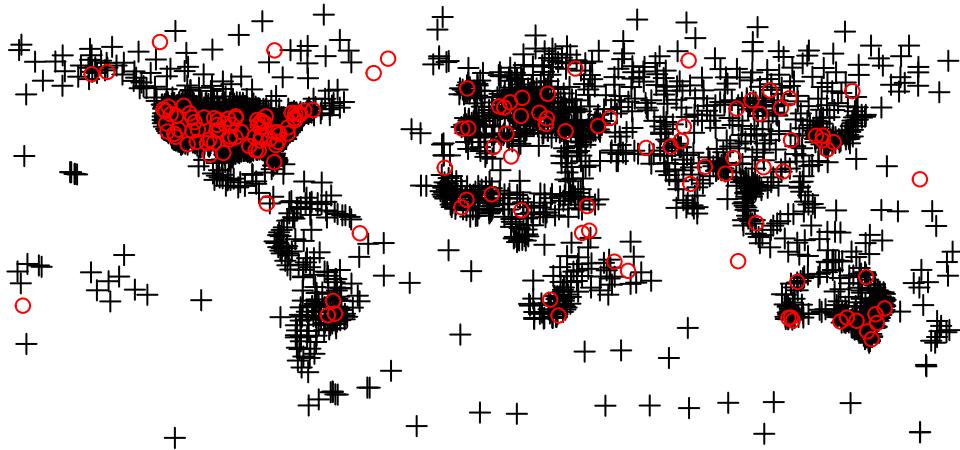
Spatial continuity of global temperature point measurements is analysed by creating H-scatterplots, autocovariance plots and variograms. Universal Kriging is applied to interpolate global temperature maps from the point measurements. Global layers of elevation, sun inclination angle, atmospheric distance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

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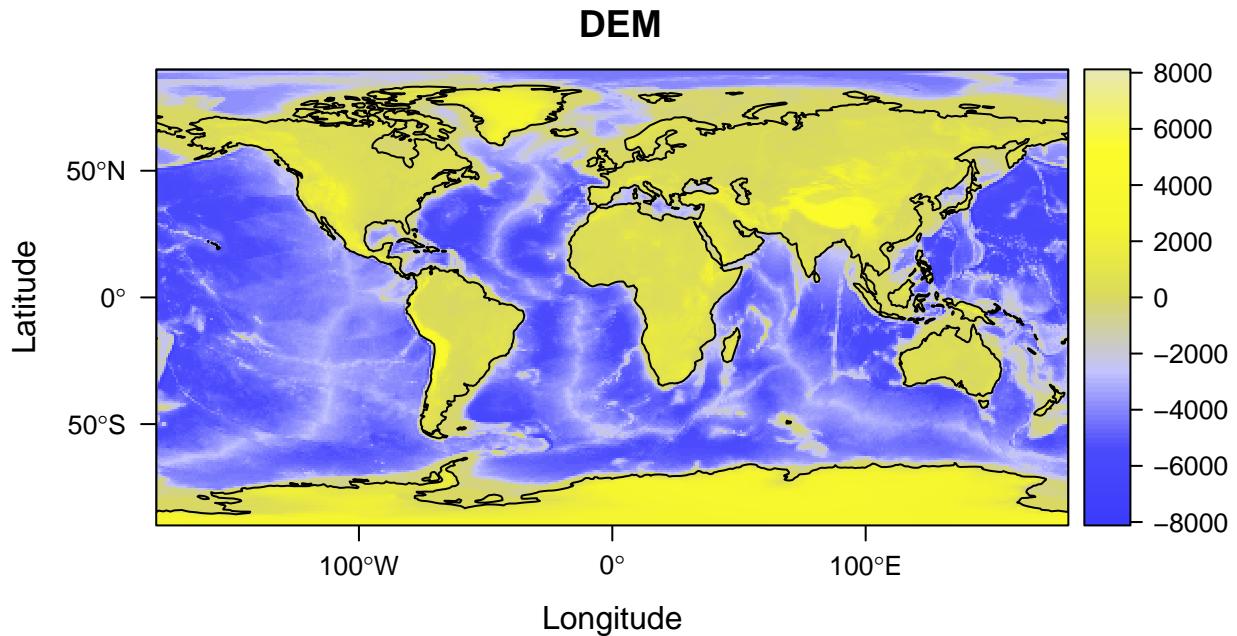
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1 Data

All measurements and validation points



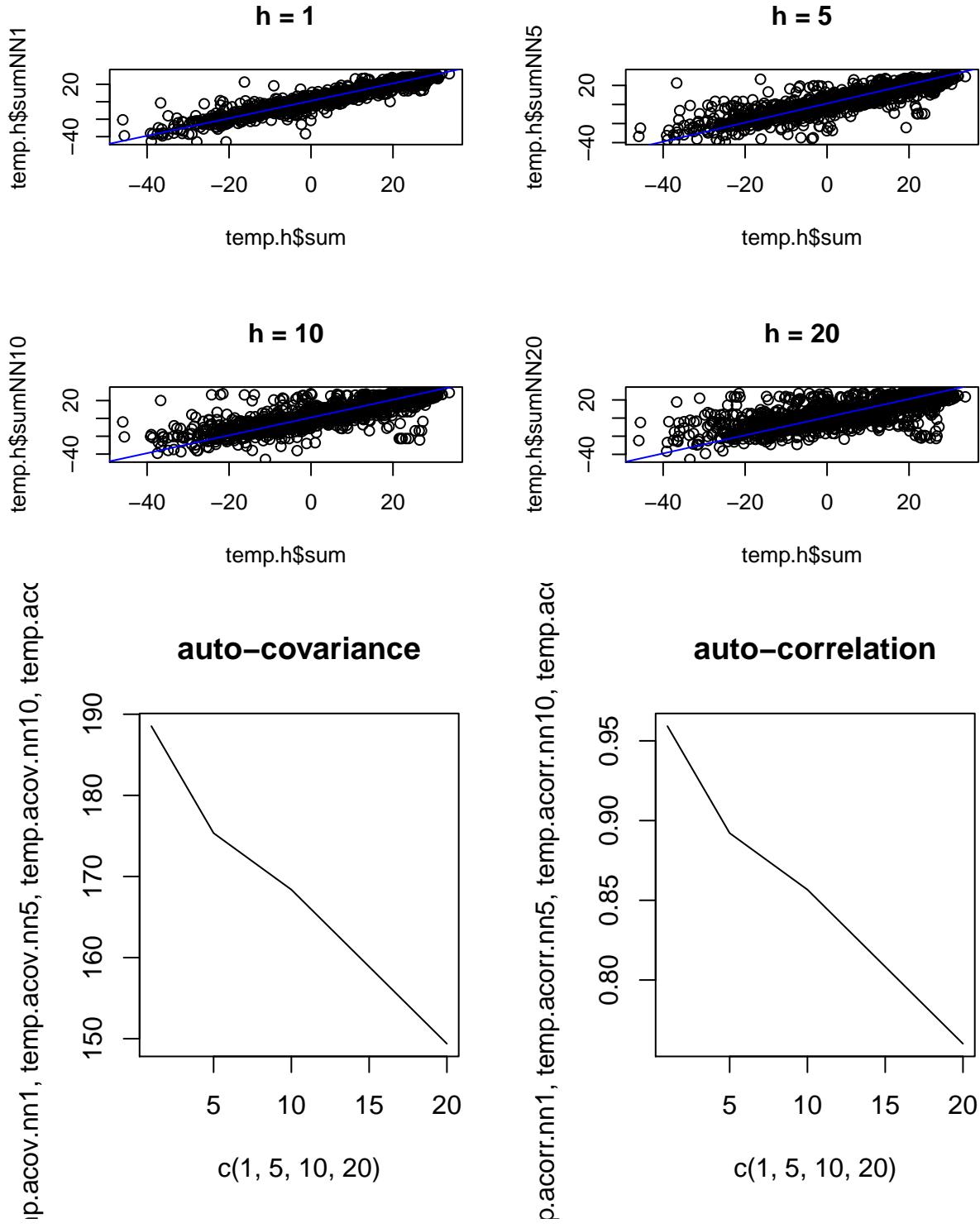
id	meanW	i_before1970	meanS	u_before1970	meanW	i_after1990	meanS	u_after1990	elev
1	1	11.83		23.27		13.09		24.75	7
3	3	10.83		22.78		11.32		24.76	25
4	4	10.30		22.00		11.44		24.02	2
5	5	6.13		22.37		7.00		24.56	694
6	6	8.14		24.90		9.35		26.15	715
7	7	7.49		24.86		7.59		26.09	813



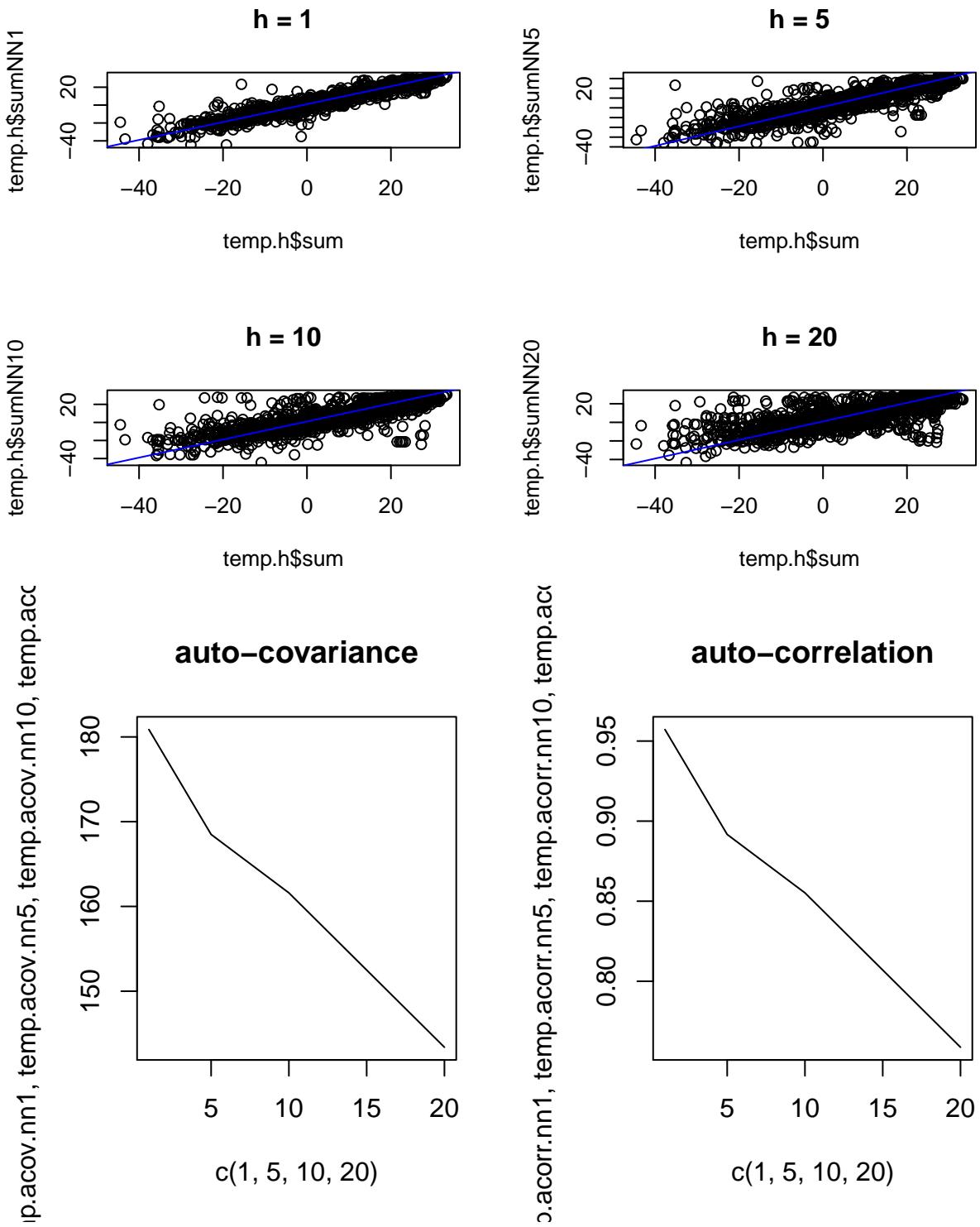
2 Spatial continuity

2.1 H-scatterplots and autocovariance

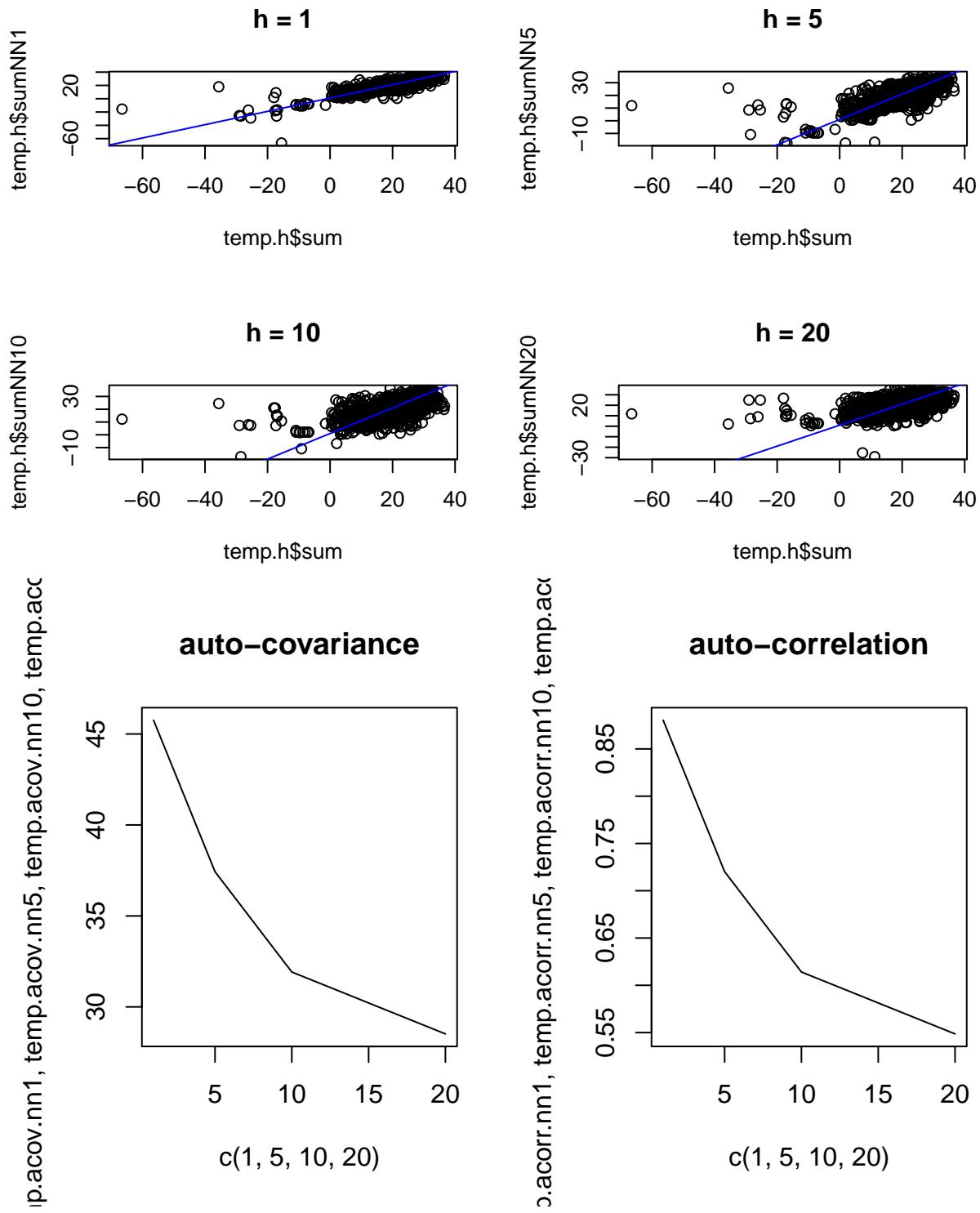
2.1.1 Winter before 1970



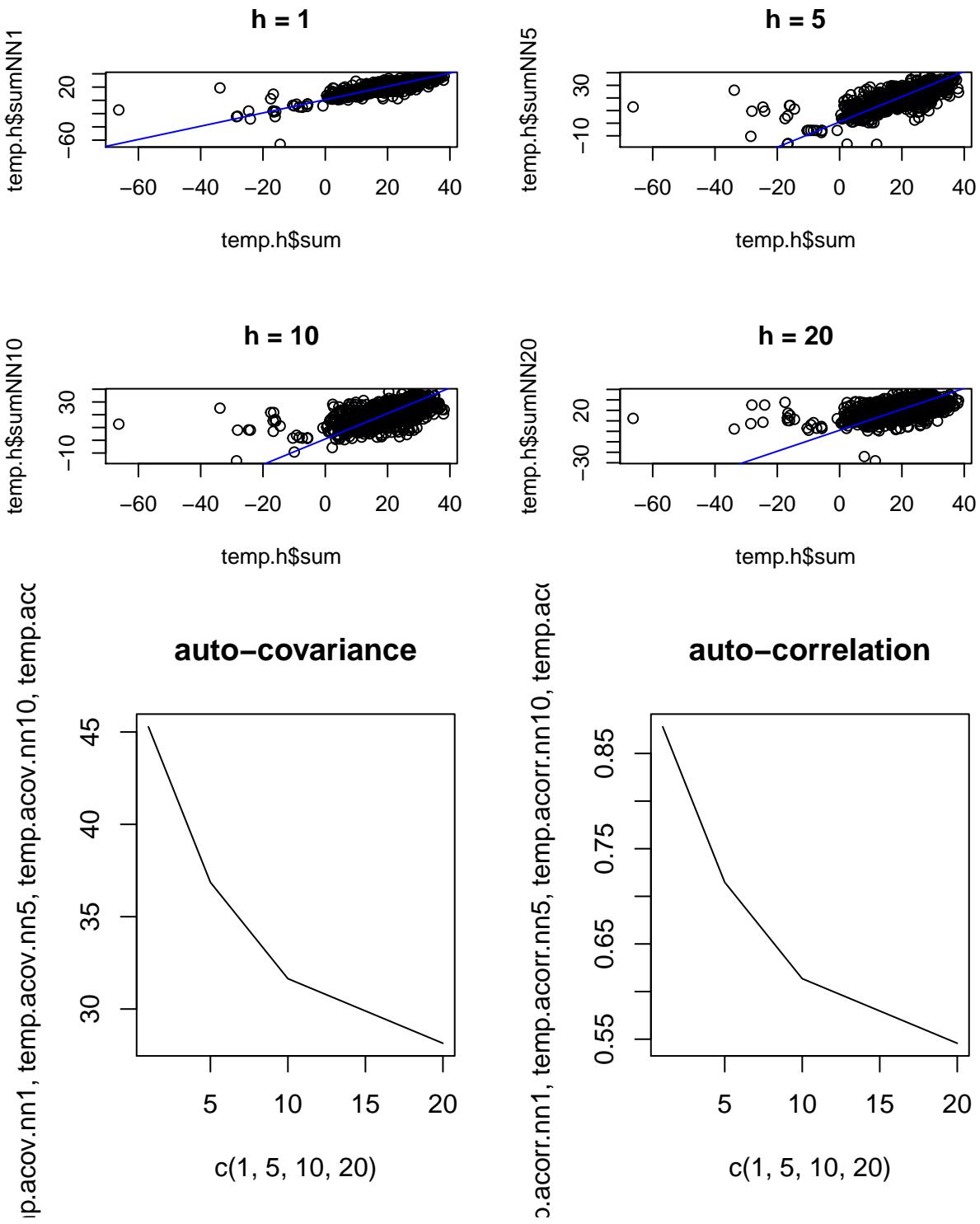
2.1.2 Winter after 1990



2.1.3 Summer before 1970

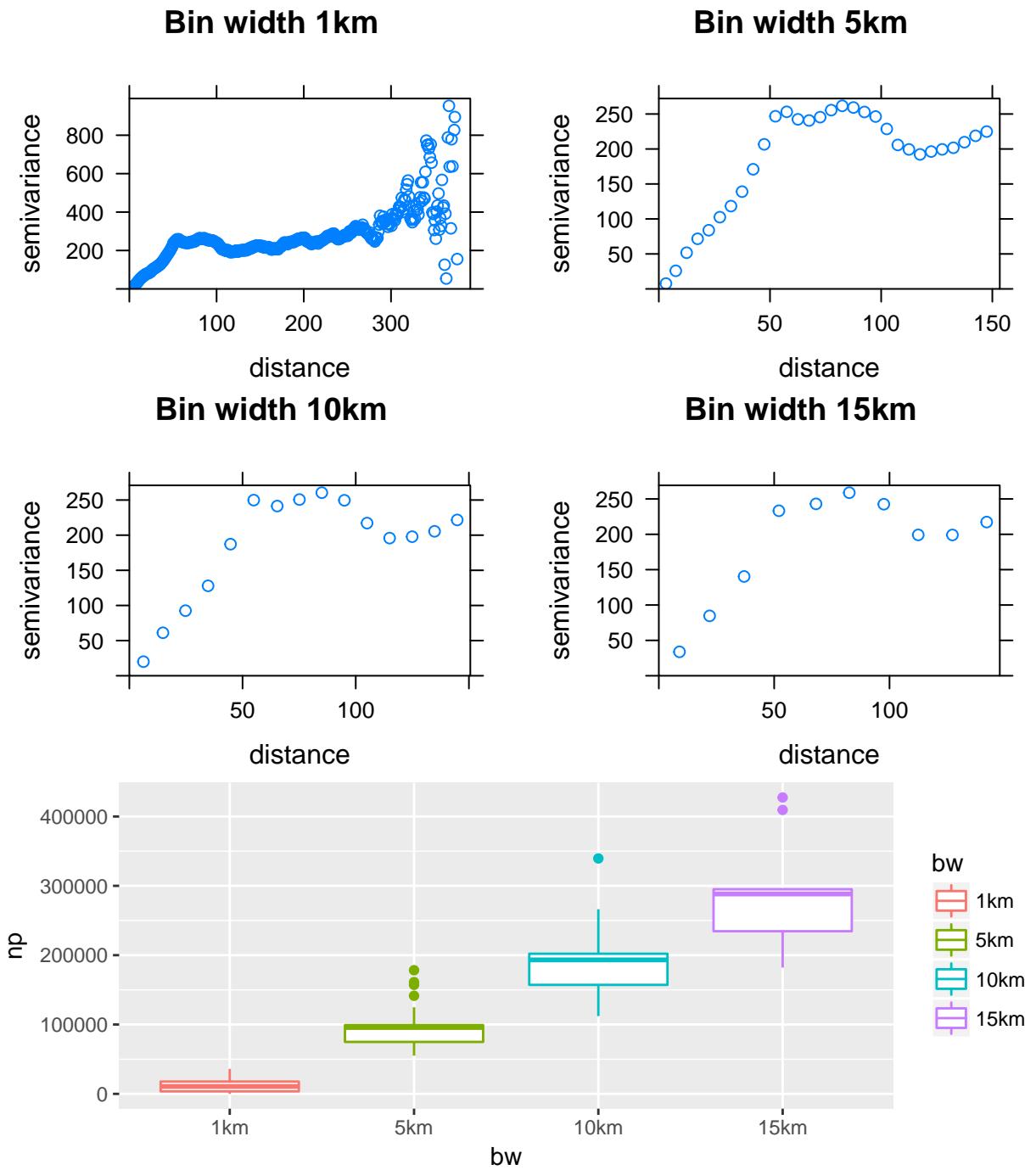


2.1.4 Summer after 1990

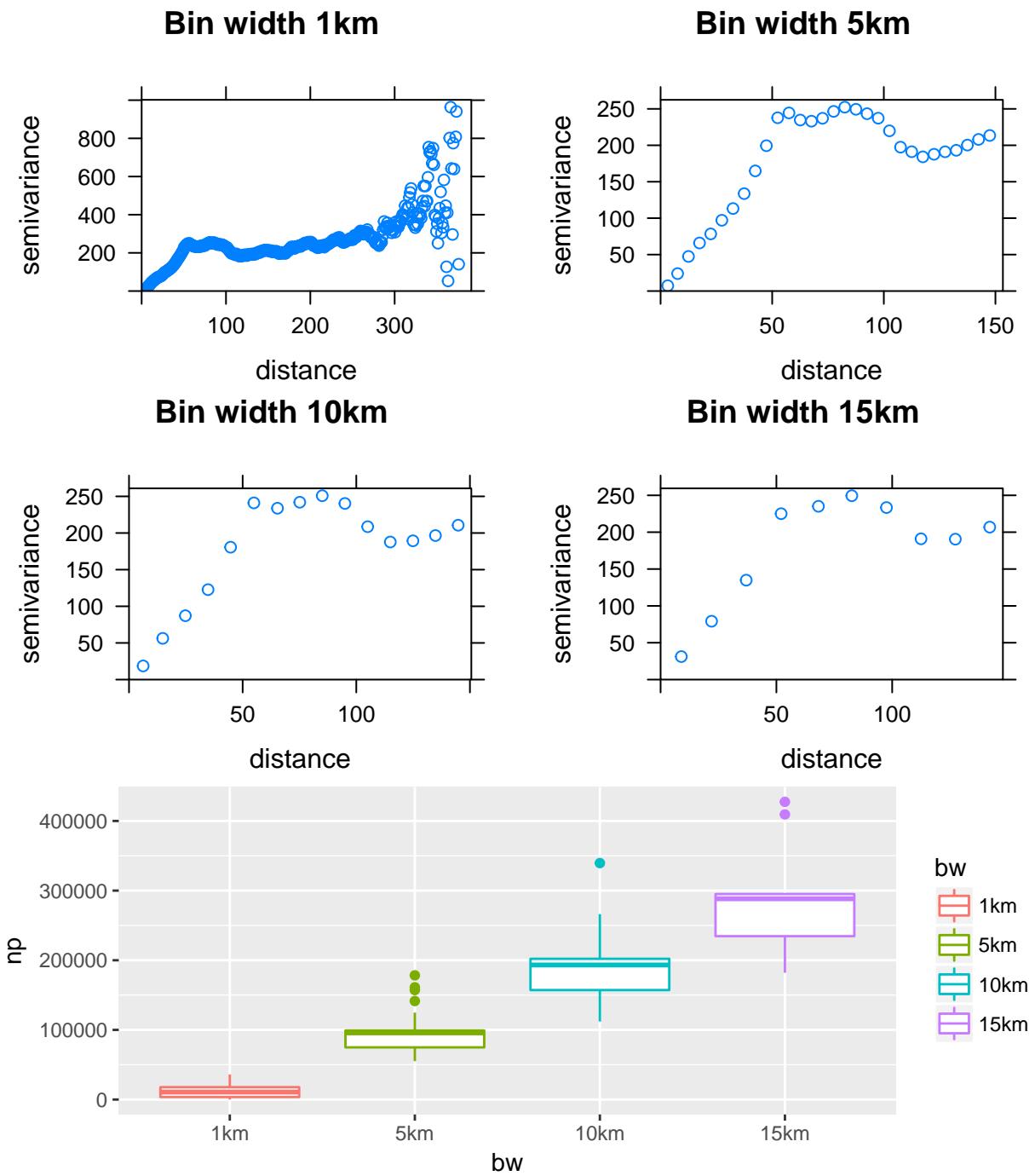


2.2 Empirical Variogram

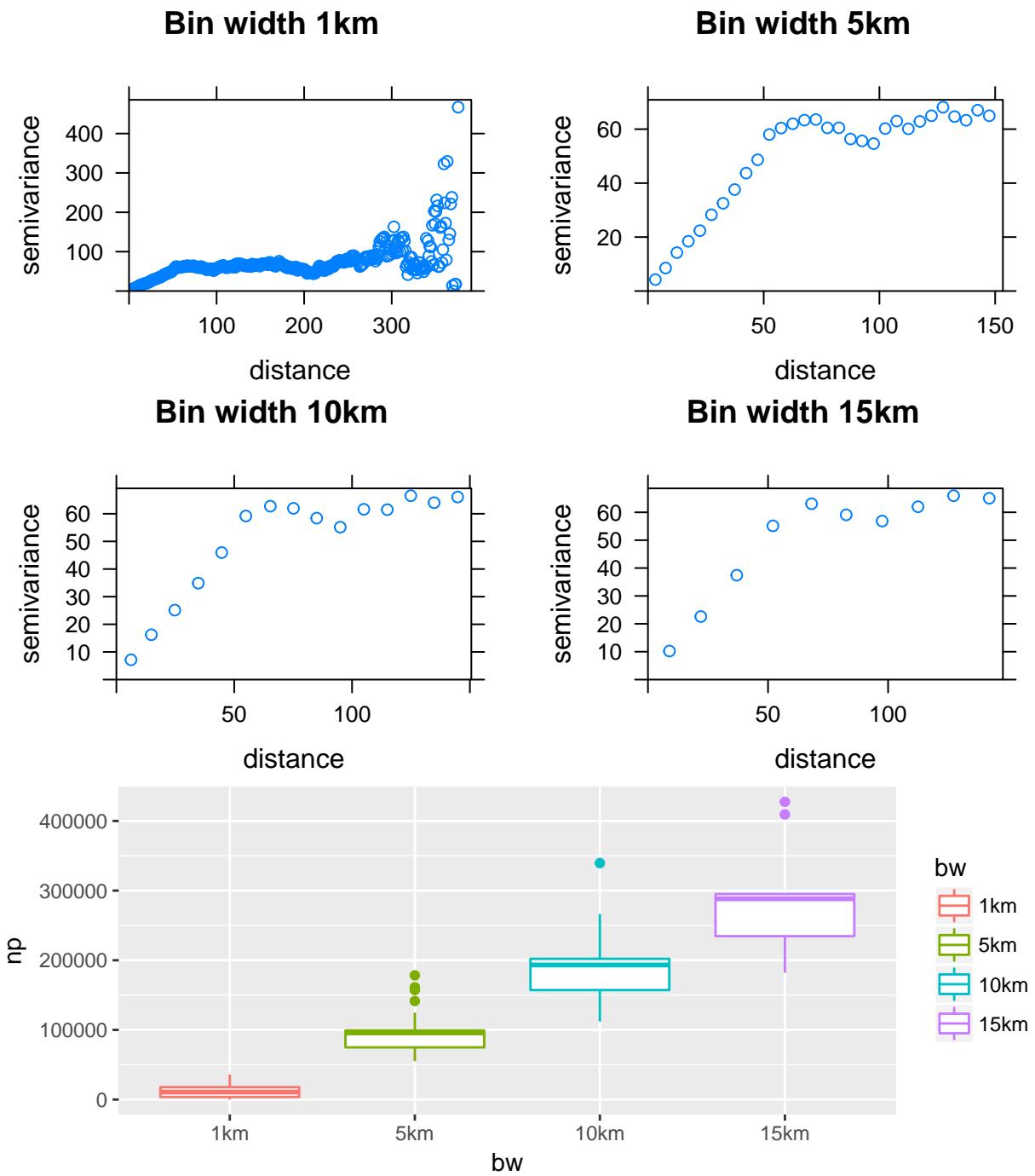
2.2.1 Winter before 1970



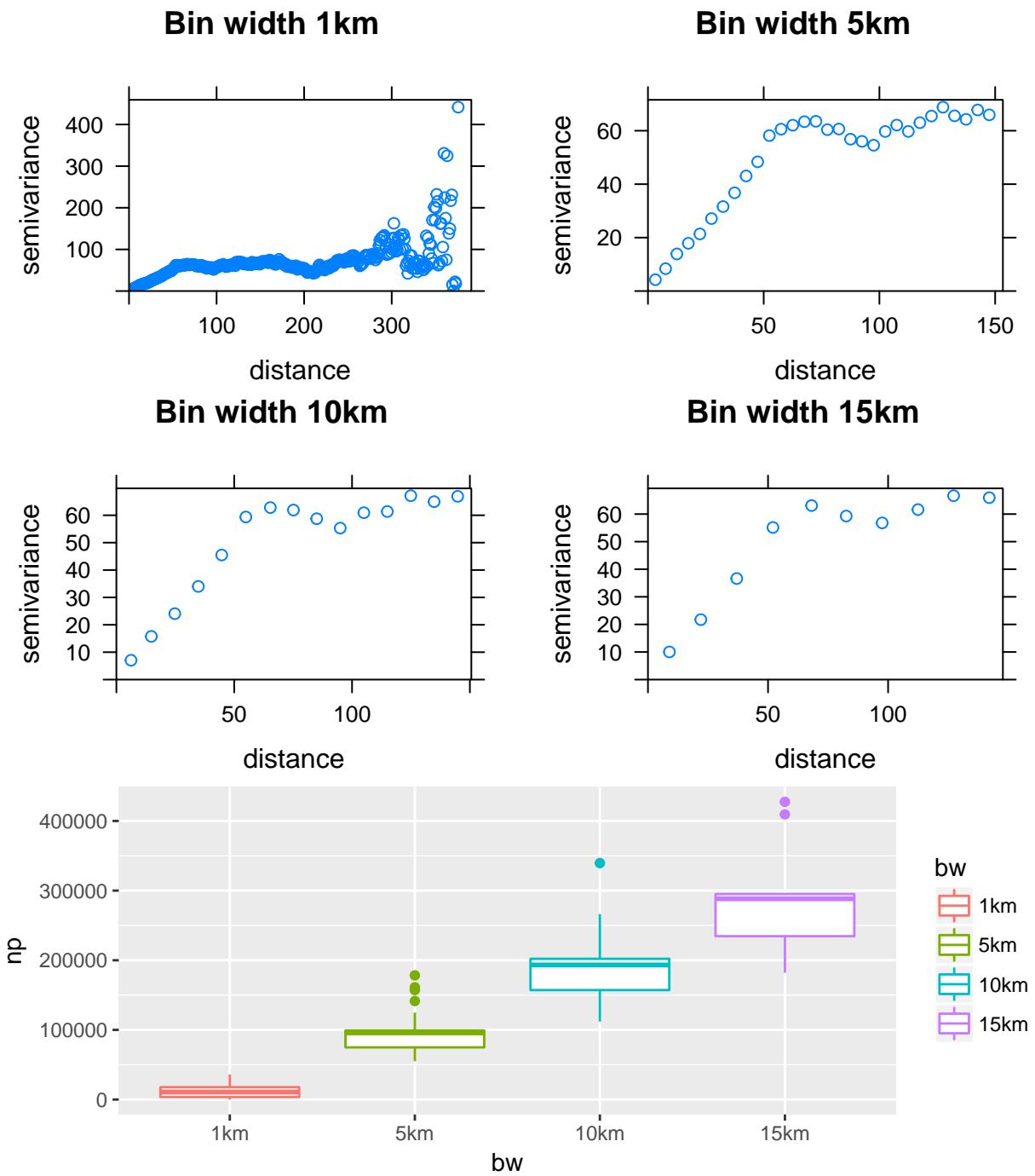
2.2.2 Winter after 1990



2.2.3 Summer before 1970



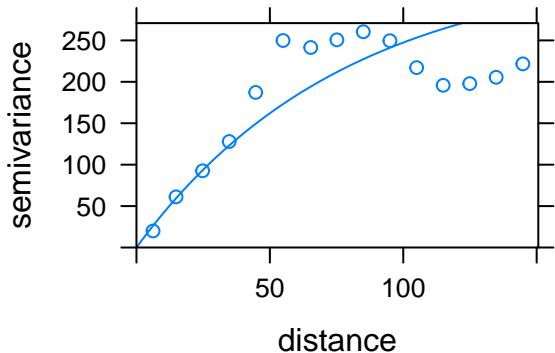
2.2.4 Summer after 1990



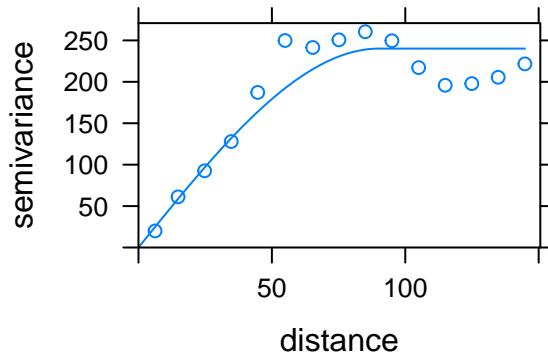
2.3 Fitted Semivariogram

2.3.1 Winter before 1970

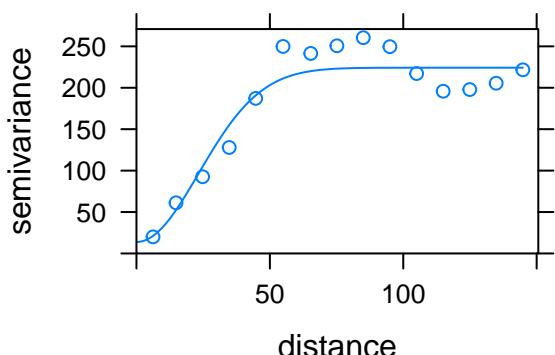
Exponential: 10km



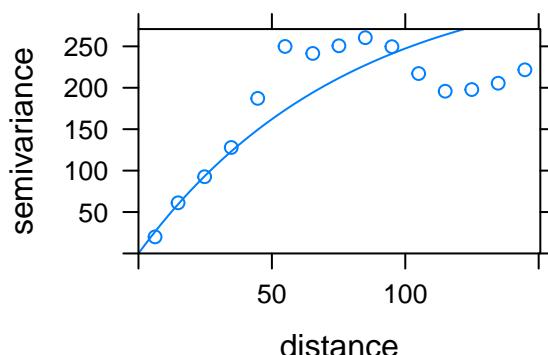
Spherical: 10km



Gaussian: 10km

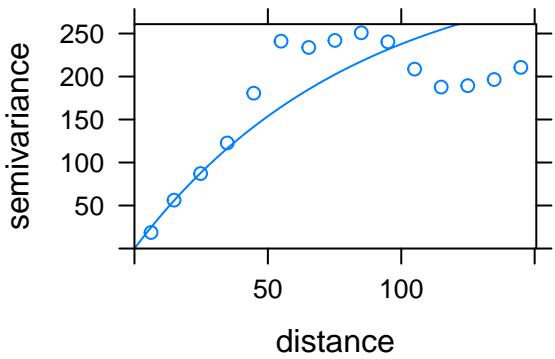


Mat: 10km

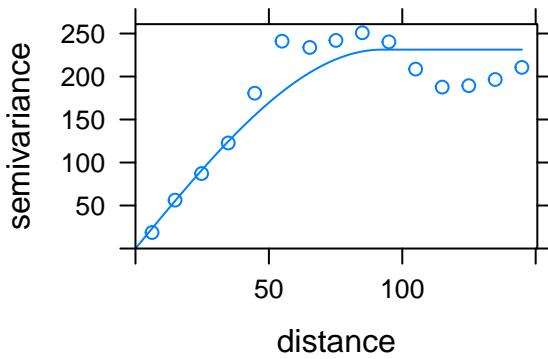


2.3.2 Winter after 1990

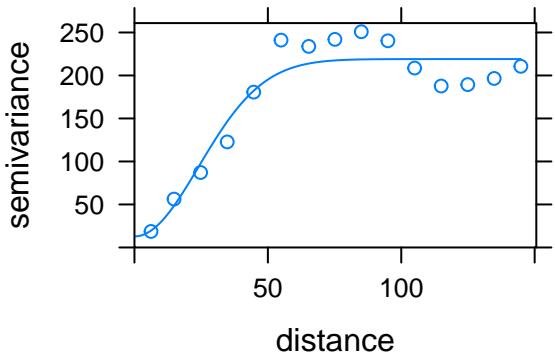
Exponential: 10km



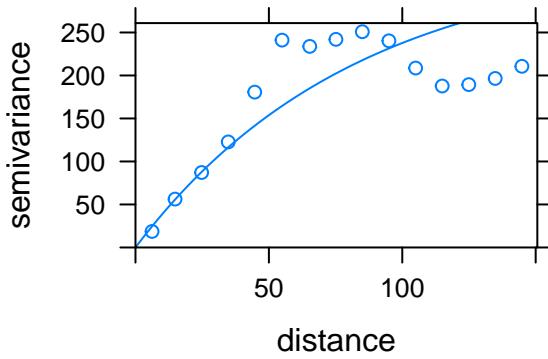
Spherical: 10km



Gaussian: 10km

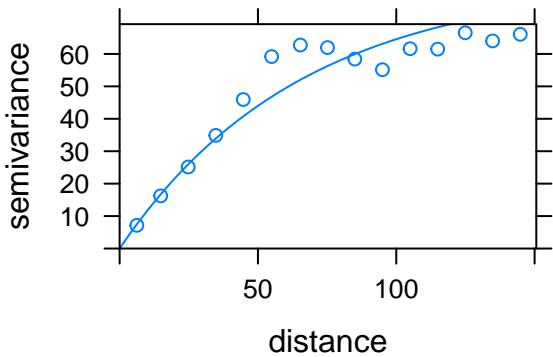


Mat: 10km

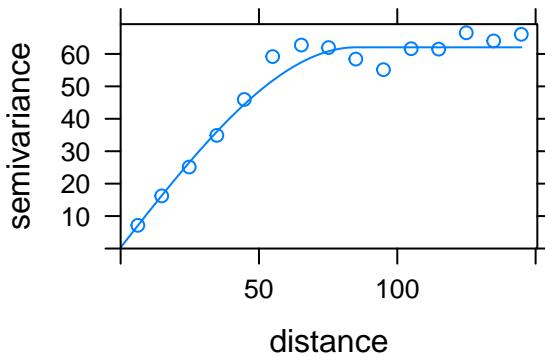


2.3.3 Summer before 1970

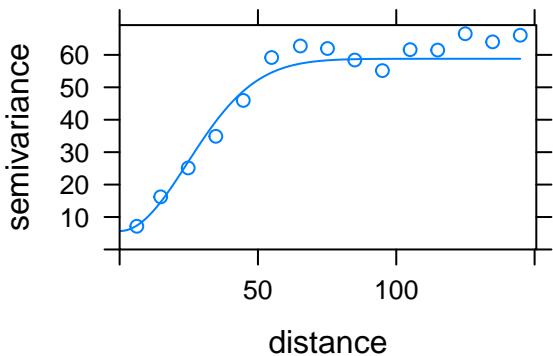
Exponential: 10km



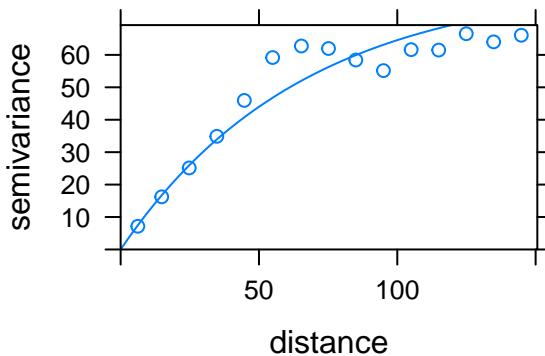
Spherical: 10km



Gaussian: 10km

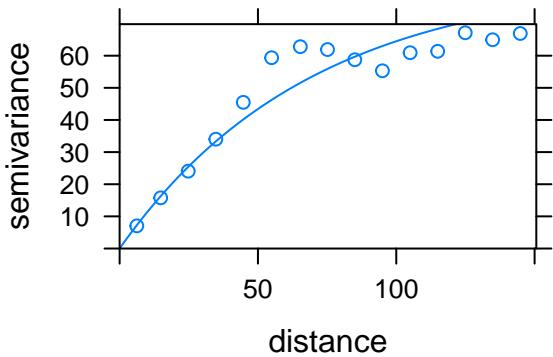


Mat: 10km

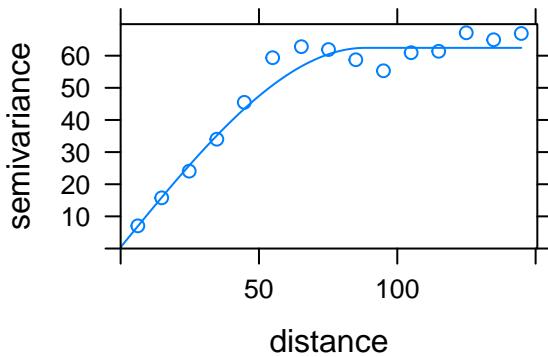


2.3.4 Summer after 1990

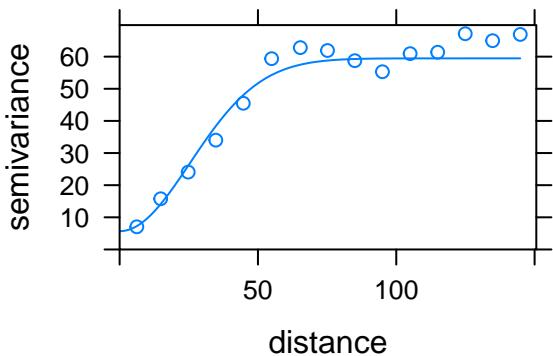
Exponential: 10km



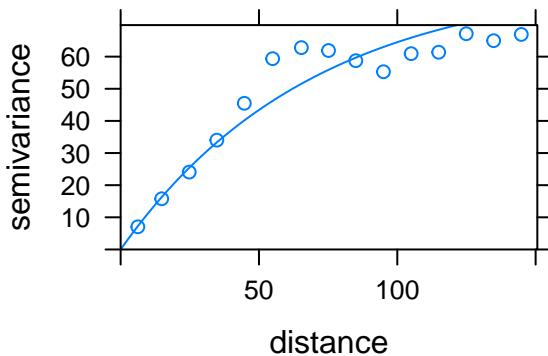
Spherical: 10km



Gaussian: 10km

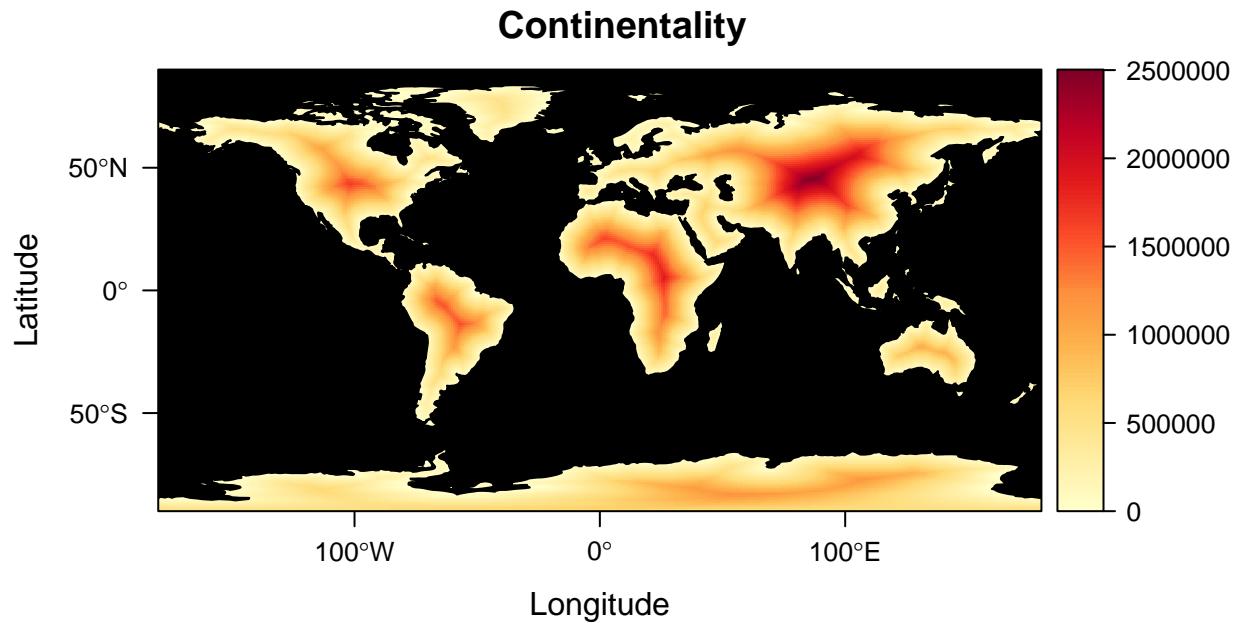


Mat: 10km



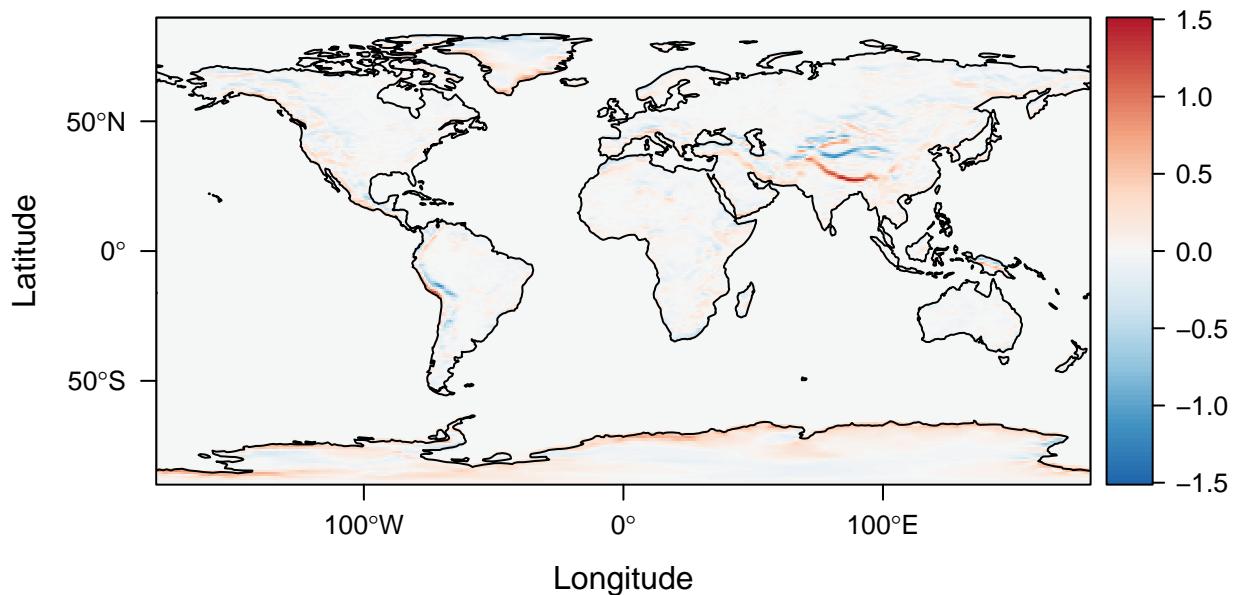
3 Universal Kriging

3.1 Continentiality

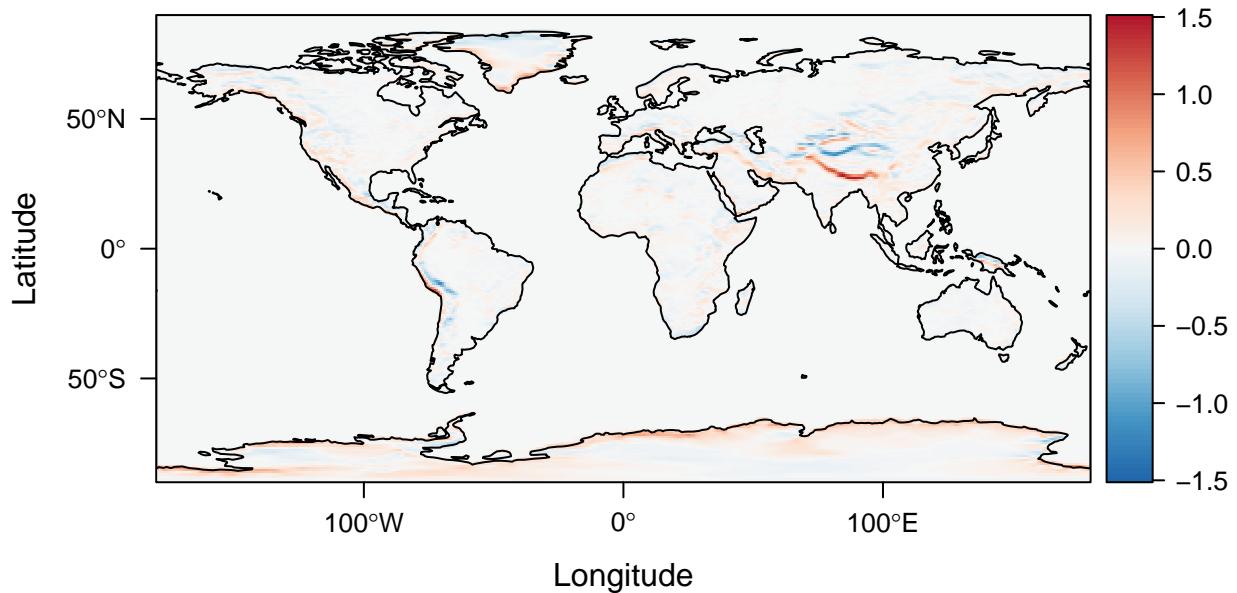


3.2 Surface gradient (North-South)

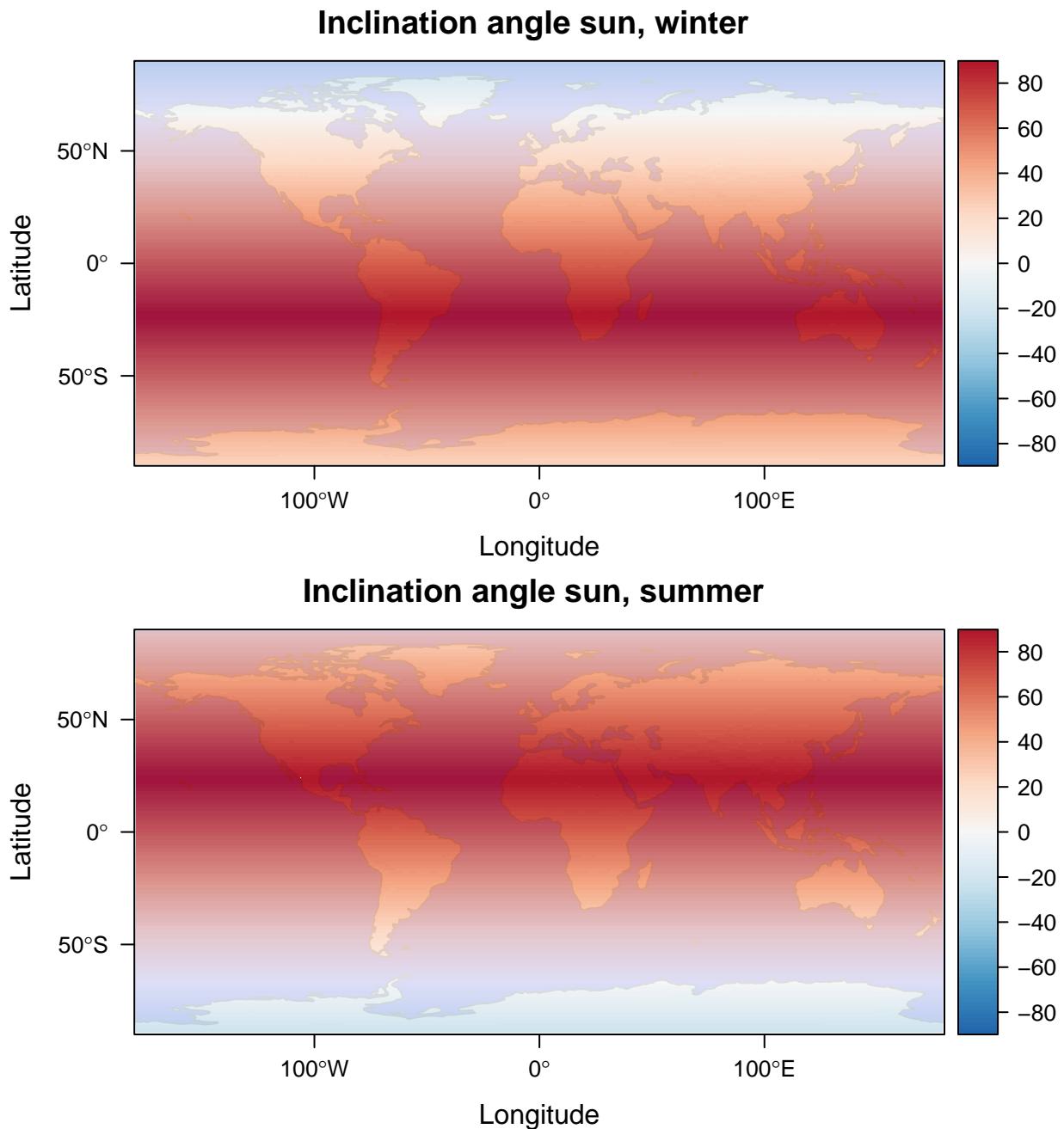
North–South gradient, +23.5° hemisphere corrected



North–South gradient, +23.5° hemisphere corrected

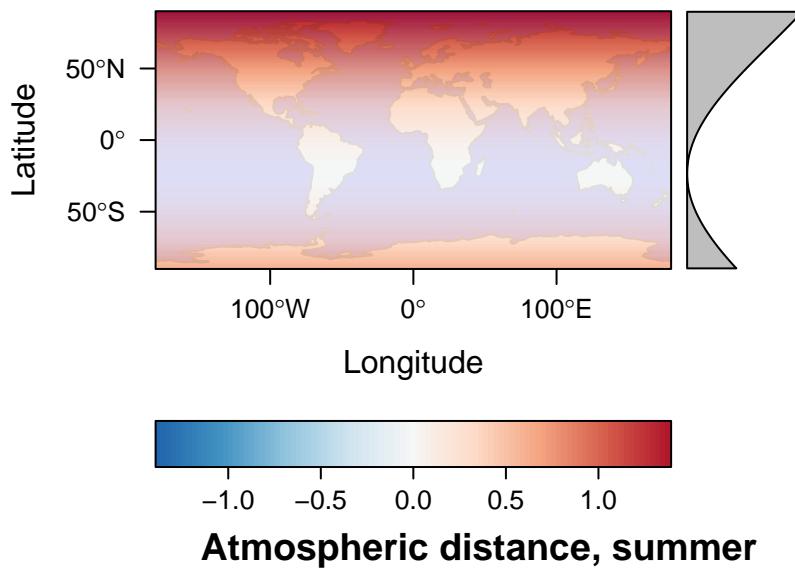


3.3 Sun inclination angle

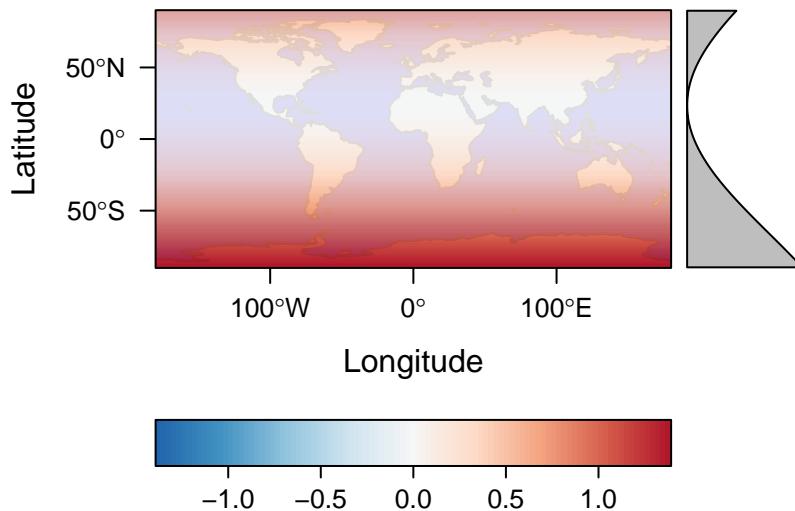


3.4 Atmospheric distance

Atmospheric distance, winter



Atmospheric distance, summer

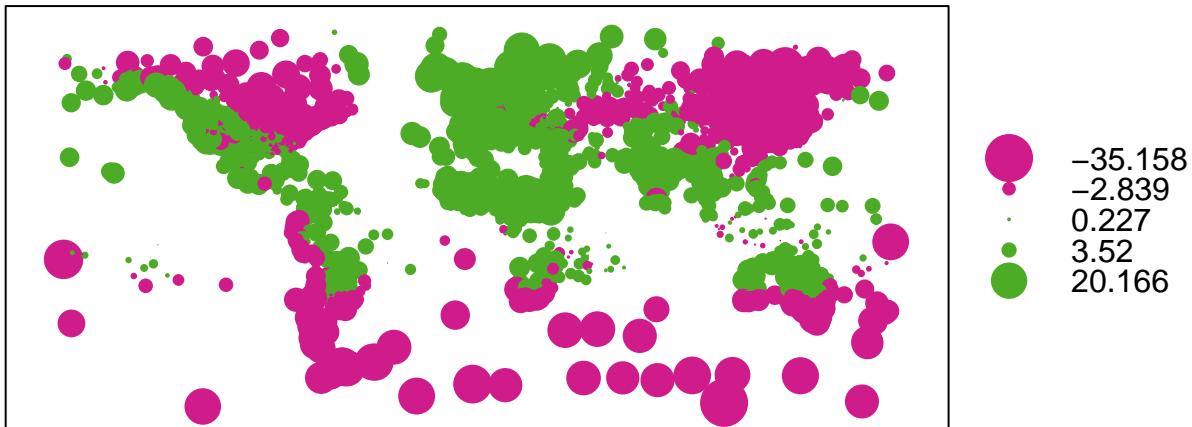


3.5 Interpolation

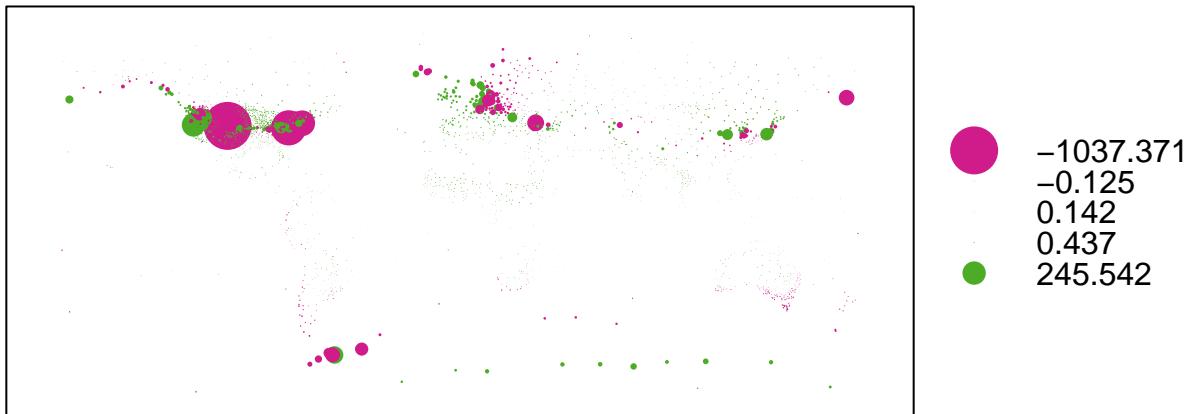
3.5.1 Winter before 1970

```
##  
## Call:  
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp1970w@data)  
##  
## Residuals:  
##      Min       1Q   Median       3Q      Max  
## -35.158  -2.839   0.227   3.520  20.166  
##  
## Coefficients:  
##              Estimate Std. Error t value Pr(>|t|)  
## (Intercept) 50.7880026302 1.5280472410 33.24 <2e-16 ***  
## elev        -0.0021293173 0.0001805316 -11.79 <2e-16 ***  
## cont        -0.00000049136 0.0000002479 -19.82 <2e-16 ***  
## hsun        -0.2894419928 0.0198326683 -14.59 <2e-16 ***  
## dist        -69.4553702382 1.7471717221 -39.75 <2e-16 ***  
## ---  
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1  
##  
## Residual standard error: 5.438 on 2873 degrees of freedom  
## Multiple R-squared: 0.8498, Adjusted R-squared: 0.8495  
## F-statistic: 4062 on 4 and 2873 DF, p-value: < 2.2e-16
```

Residual Values

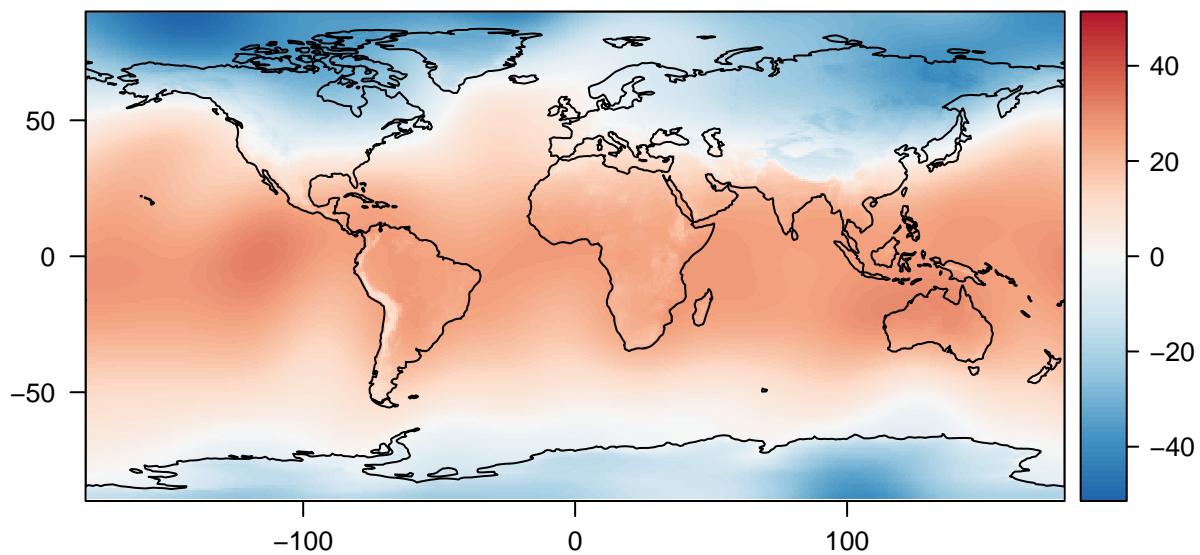


Relative Residual Values

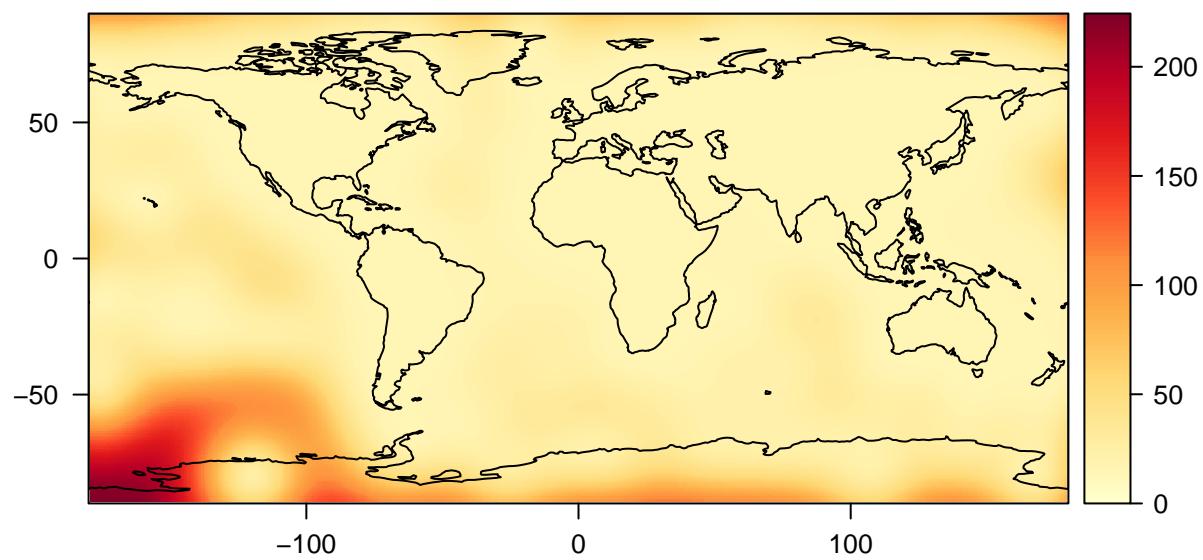


```
## [1] "Observed autocorrelation: 0.195772926952193"  
## [1] "P-value of H0 (residuals are randomly distributed): 0"  
## [using universal kriging]  
## [1] "Observed RMSE (5% validation data): 1.89°C"
```

Prediction: Winter before 1970



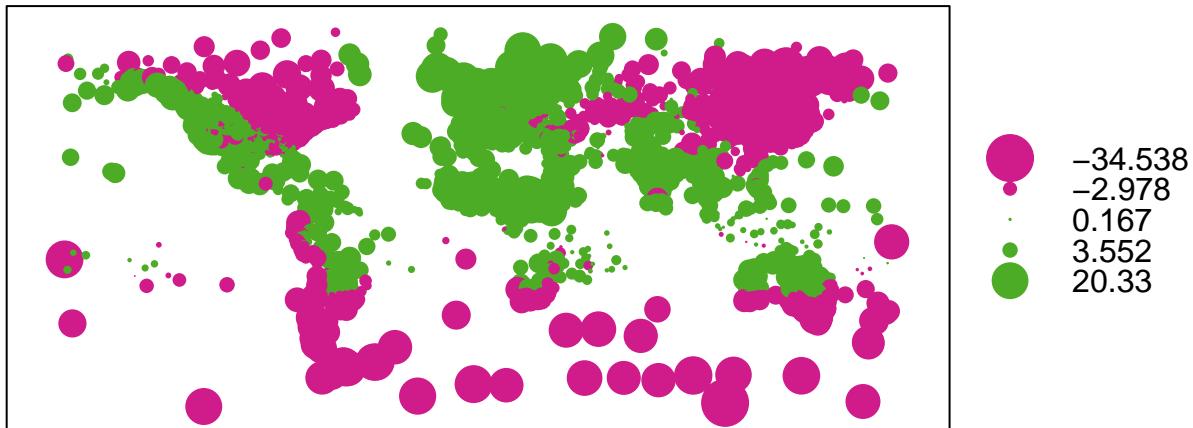
Uncertainty: Winter before 1970



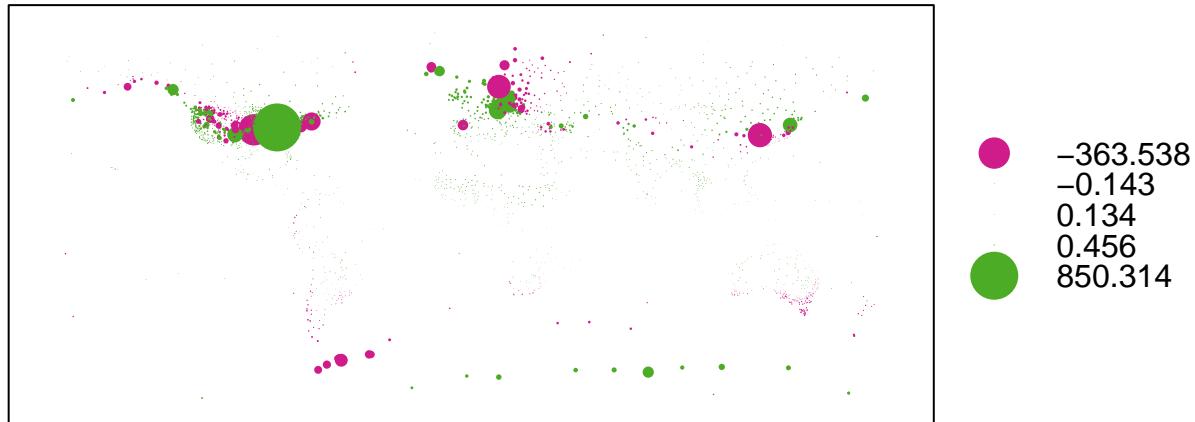
3.5.2 Winter after 1990

```
##  
## Call:  
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp2010w@data)  
##  
## Residuals:  
##      Min       1Q   Median       3Q      Max  
## -34.538  -2.978   0.167   3.552  20.330  
##  
## Coefficients:  
##              Estimate Std. Error t value Pr(>|t|)  
## (Intercept) 49.2119477248 1.5179588200 32.42 <2e-16 ***  
## elev        -0.0021362295 0.0001793397 -11.91 <2e-16 ***  
## cont        -0.0000046426 0.0000002463 -18.85 <2e-16 ***  
## hsun        -0.2642107019 0.0197017297 -13.41 <2e-16 ***  
## dist       -66.4417071505 1.7356366051 -38.28 <2e-16 ***  
## ---  
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1  
##  
## Residual standard error: 5.402 on 2873 degrees of freedom  
## Multiple R-squared:  0.8458, Adjusted R-squared:  0.8456  
## F-statistic: 3939 on 4 and 2873 DF, p-value: < 2.2e-16
```

Residual Values

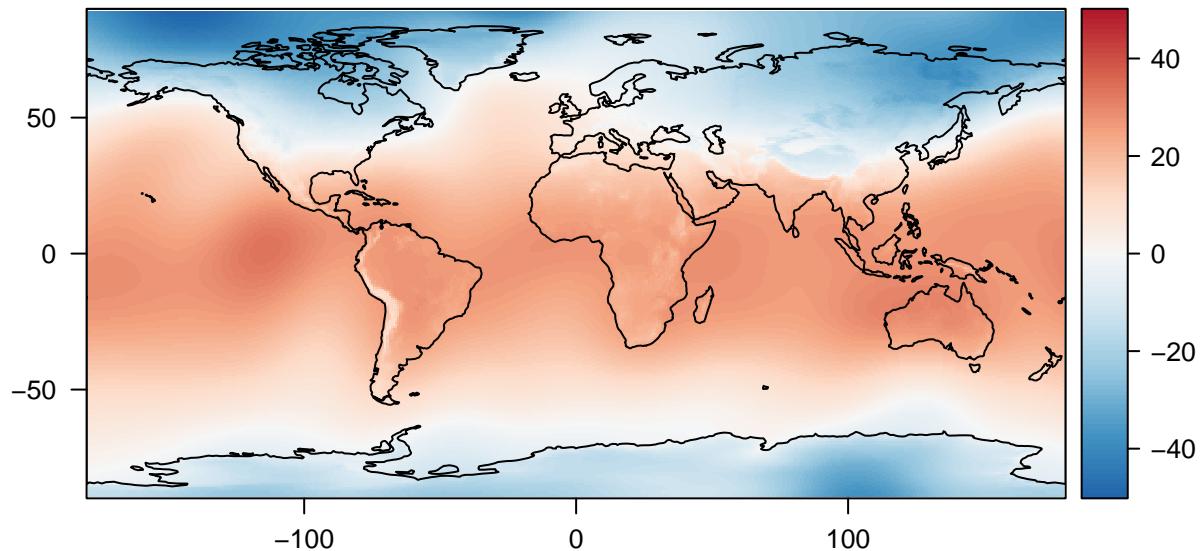


Relative Residual Values

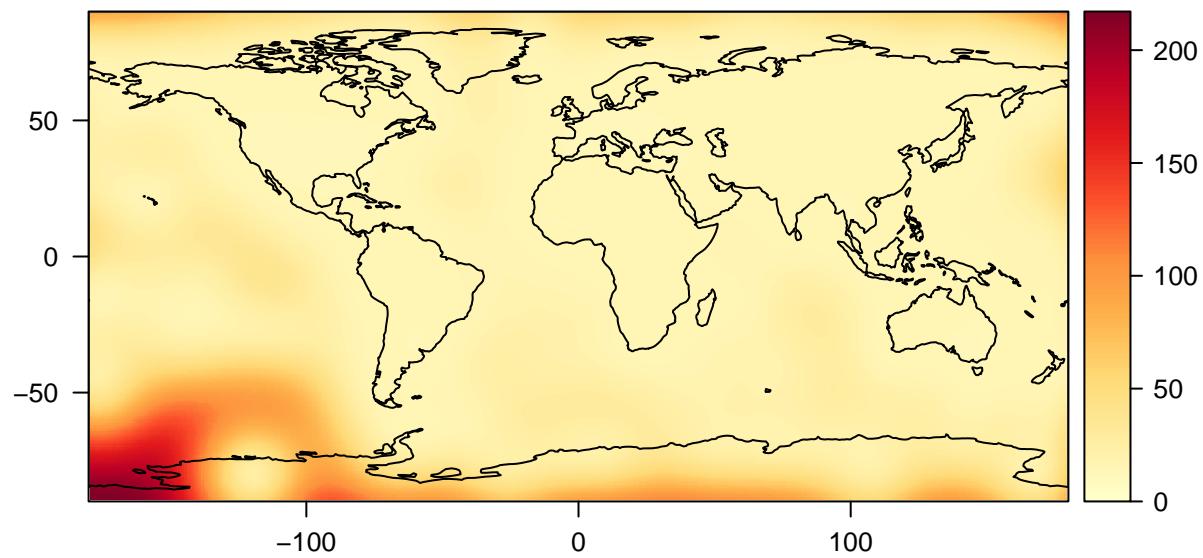


```
## [1] "Observed autocorrelation: 0.197404491338984"  
## [1] "P-value of H0 (residuals are randomly distributed): 0"  
## [using universal kriging]  
## [1] "Observed RMSE (5% validation data): 1.9°C"
```

Prediction: Winter after 1990



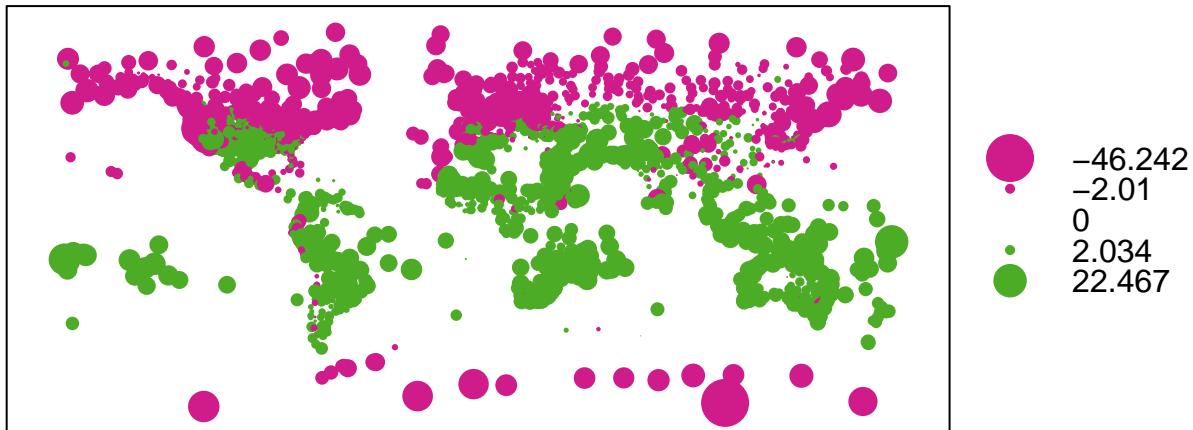
Uncertainty: Winter after 1990



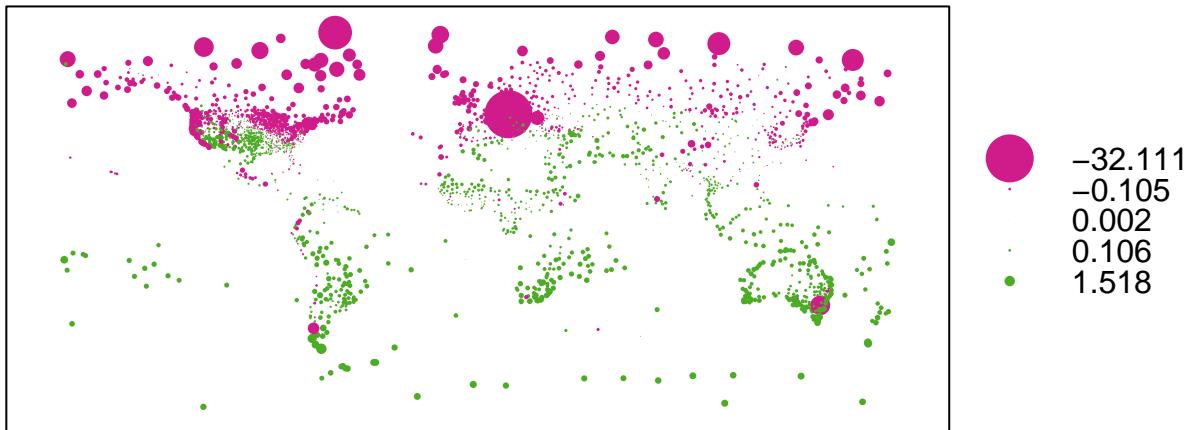
3.5.3 Summer before 1970

```
##  
## Call:  
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp1970s@data)  
##  
## Residuals:  
##      Min       1Q   Median       3Q      Max  
## -46.242  -2.010   0.000   2.034  22.467  
##  
## Coefficients:  
##              Estimate Std. Error t value Pr(>|t|)  
## (Intercept)  7.0478009274  1.1945877513  5.900 4.07e-09 ***  
## elev        -0.0028559282  0.0001227031 -23.275 < 2e-16 ***  
## cont         0.0000007898  0.0000001690   4.673 3.10e-06 ***  
## hsun         0.2355447102  0.0151121464  15.586 < 2e-16 ***  
## dist        -12.8115083677  1.5540386295 -8.244 2.50e-16 ***  
## ---  
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1  
##  
## Residual standard error: 3.696 on 2873 degrees of freedom  
## Multiple R-squared:  0.7376, Adjusted R-squared:  0.7372  
## F-statistic: 2019 on 4 and 2873 DF, p-value: < 2.2e-16
```

Residual Values

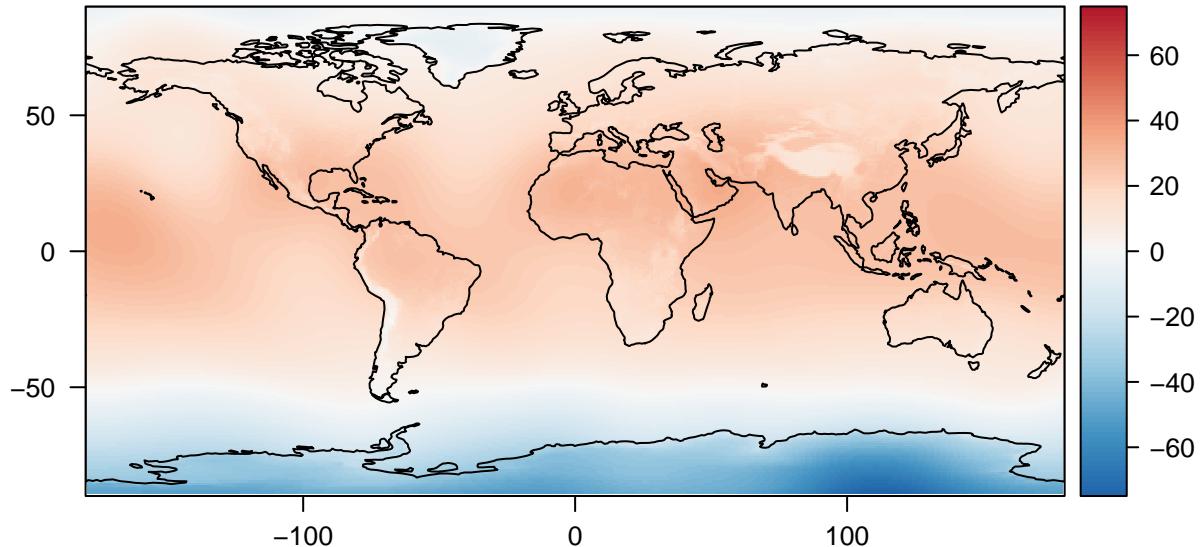


Relative Residual Values

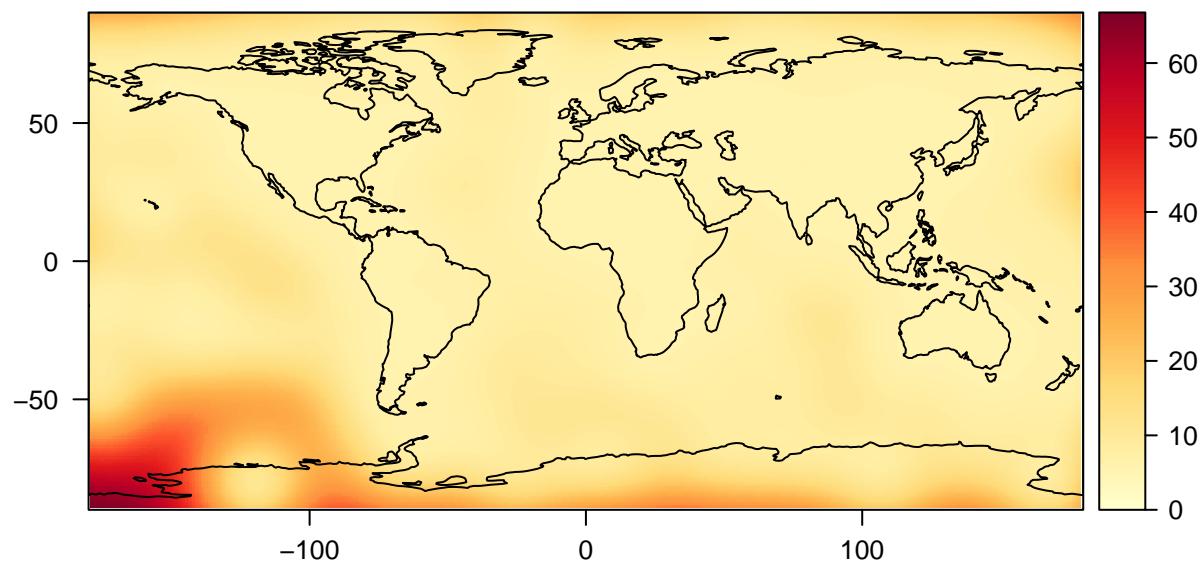


```
## [1] "Observed autocorrelation: 0.149753781631319"  
## [1] "P-value of H0 (residuals are randomly distributed): 0"  
## [using universal kriging]  
## [1] "Observed RMSE (5% validation data): 2.12°C"
```

Prediction: Summer before 1970



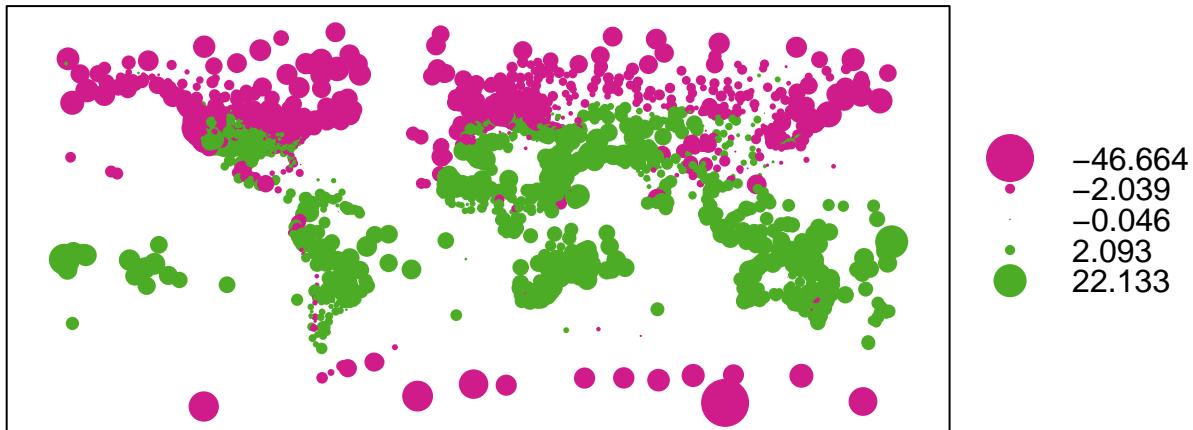
Uncertainty: Summer before 1970



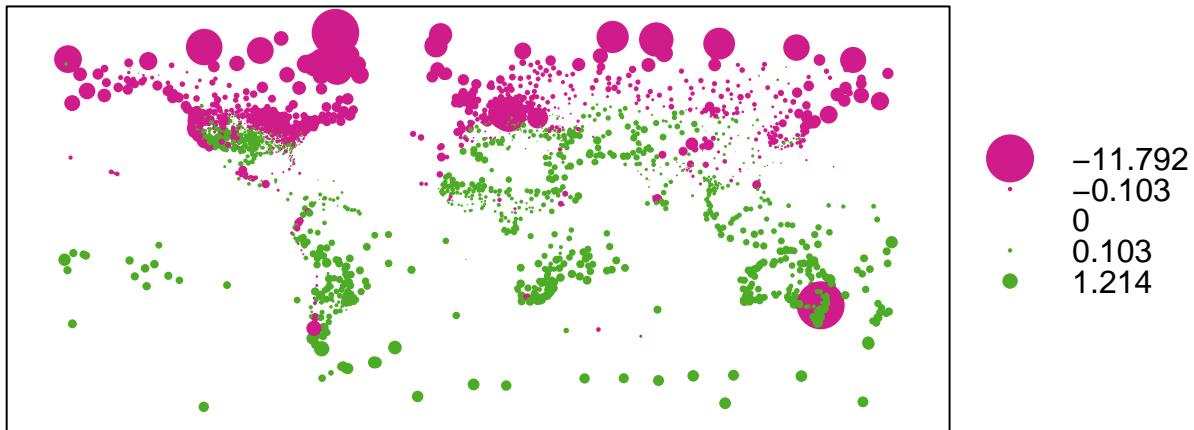
3.5.4 Summer after 1990

```
##
## Call:
## lm(formula = meansum ~ elev + cont + hsun + dist, data = temp2010s@data)
##
## Residuals:
##    Min     1Q Median     3Q    Max 
## -46.664 -2.039 -0.046  2.093 22.133 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 8.3803239729 1.2030231446  6.966 4.02e-12 ***
## elev        -0.0026940625 0.0001235696 -21.802 < 2e-16 ***
## cont         0.0000004357 0.0000001702   2.560  0.0105 *  
## hsun         0.2271410051 0.0152188585  14.925 < 2e-16 ***
## dist        -13.5900666489 1.5650122285 -8.684 < 2e-16 *** 
## ---        
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 
##
## Residual standard error: 3.722 on 2873 degrees of freedom
## Multiple R-squared:  0.7318, Adjusted R-squared:  0.7314 
## F-statistic: 1960 on 4 and 2873 DF,  p-value: < 2.2e-16
```

Residual Values

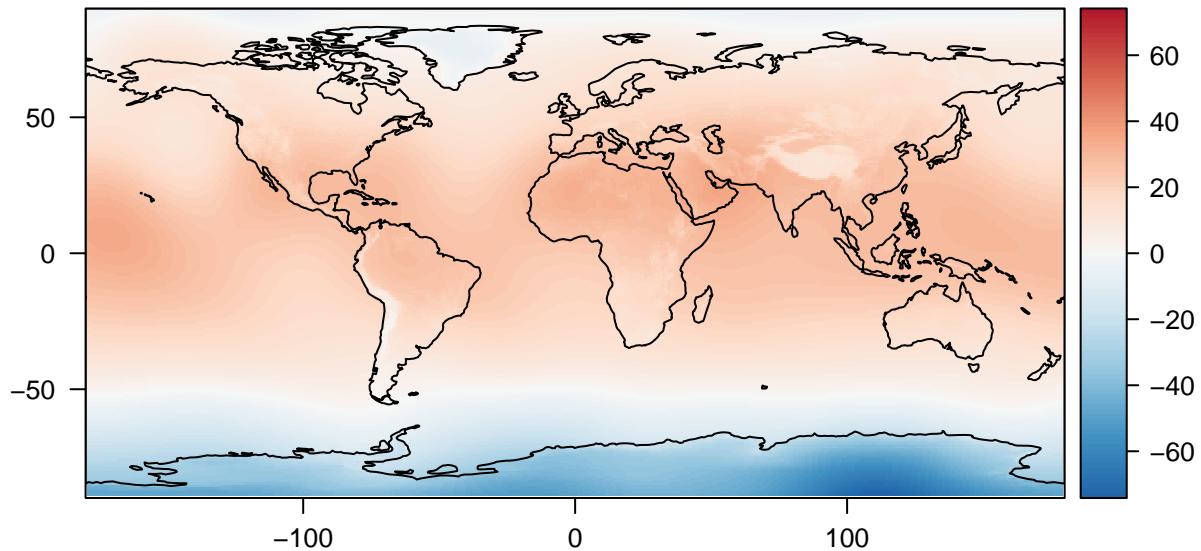


Relative Residual Values

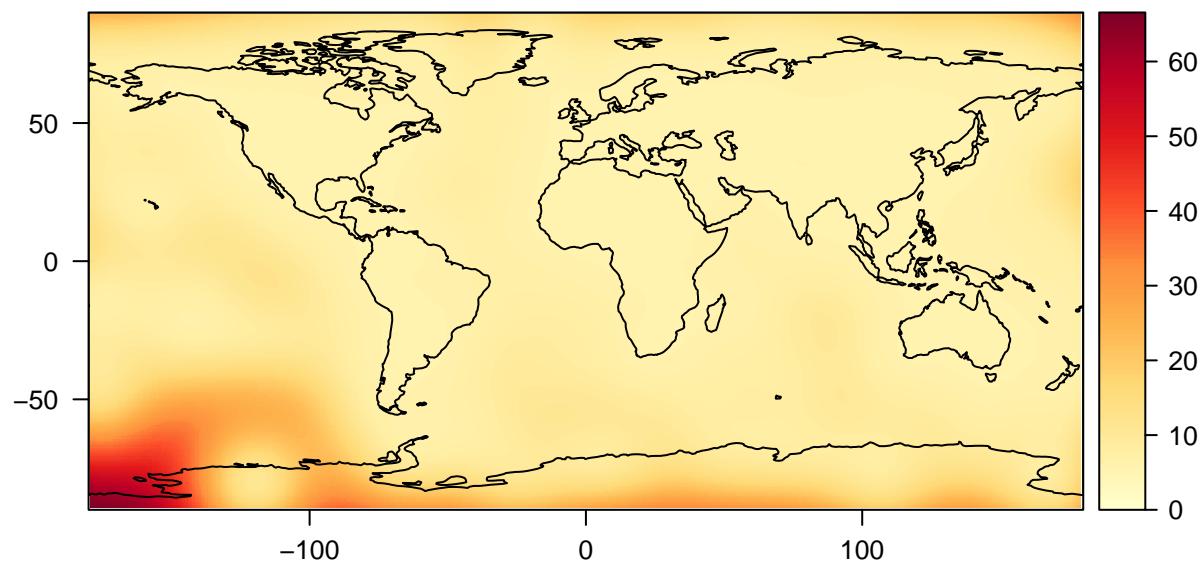


```
## [1] "Observed autocorrelation: 0.155307365448324"  
## [1] "P-value of H0 (residuals are randomly distributed): 0"  
## [using universal kriging]  
## [1] "Observed RMSE (5% validation data): 2.15°C"
```

Prediction: Summer after 1990

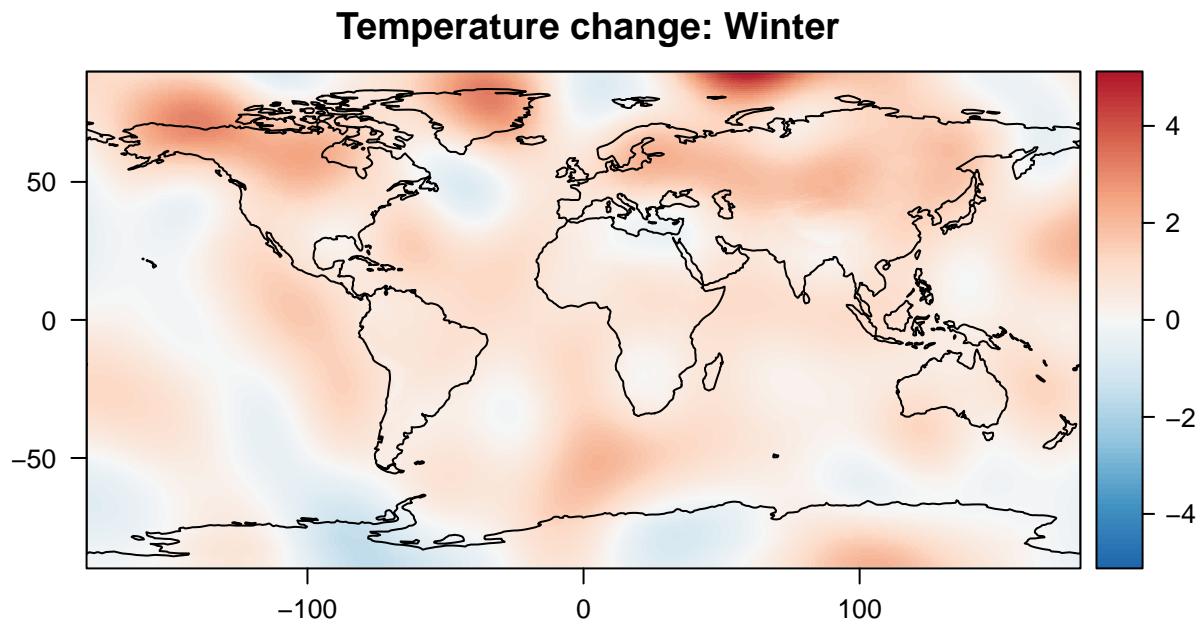


Uncertainty: Summer after 1990



4 Difference images

4.1 Winter



4.2 Summer

