Parent material and climate interact to control soil carbon dynamics on timescales from years to centuries

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Contents

Introduction

- Parent material key factor affecting radiocarbon content of bulk soil
- Development and persistence of poorly crystalline minerals associated with depleted ^{14}C content of soil organic matter, i.e. soil C persistence
- Decomposition rates increase with temperature, suggesting ^{14}C of heterotrophically respired CO_2 will be closer to atmospheric ^{14}C in warmer sites than in colder sites
- Climate and parent material interact on geologic timescales: weathering leads to formation of poorly crystalline minerals but eventually to degradation of these minerals over time, e.g. poorly crystalline mineral content is highest in intermediate stages of soil development
- How do these interactions affect the balance of C stocks stored in soils?

[NB: should show C stocks, i.e. context for 14C trends]

Hypotheses

1. Parent material will explain more of the variance in the change over time for bulk soil $\Delta^{14}C$ than climate, because parent material controls $\Delta^{14}C$ of the slow cycling soil C that dominates the bulk $\Delta^{14}C$ signal.
2. Climate will explain more of the variance in the change over time for respired soil $\Delta^{14}C$-CO_2 than parent material, as climate controls $\Delta^{14}C$ of the fast cycling soil C that dominates the respired $\Delta^{14}C$-CO_2 signal.
3. Change in bulk soil $\Delta^{14}C$ over time will be greatest in soils developed on granite soils and least in soils developed on andesite (GR > BS > AN)
4. Change in respired $\Delta^{14}C$-CO_2 over time will be greatest in the warm climate sites and least in the cold climate sites (warm > cool > cold)
5. Parent material will not affect the change in respired $\Delta^{14}C$-CO_2 over time (AN = BS = GR)

Methods

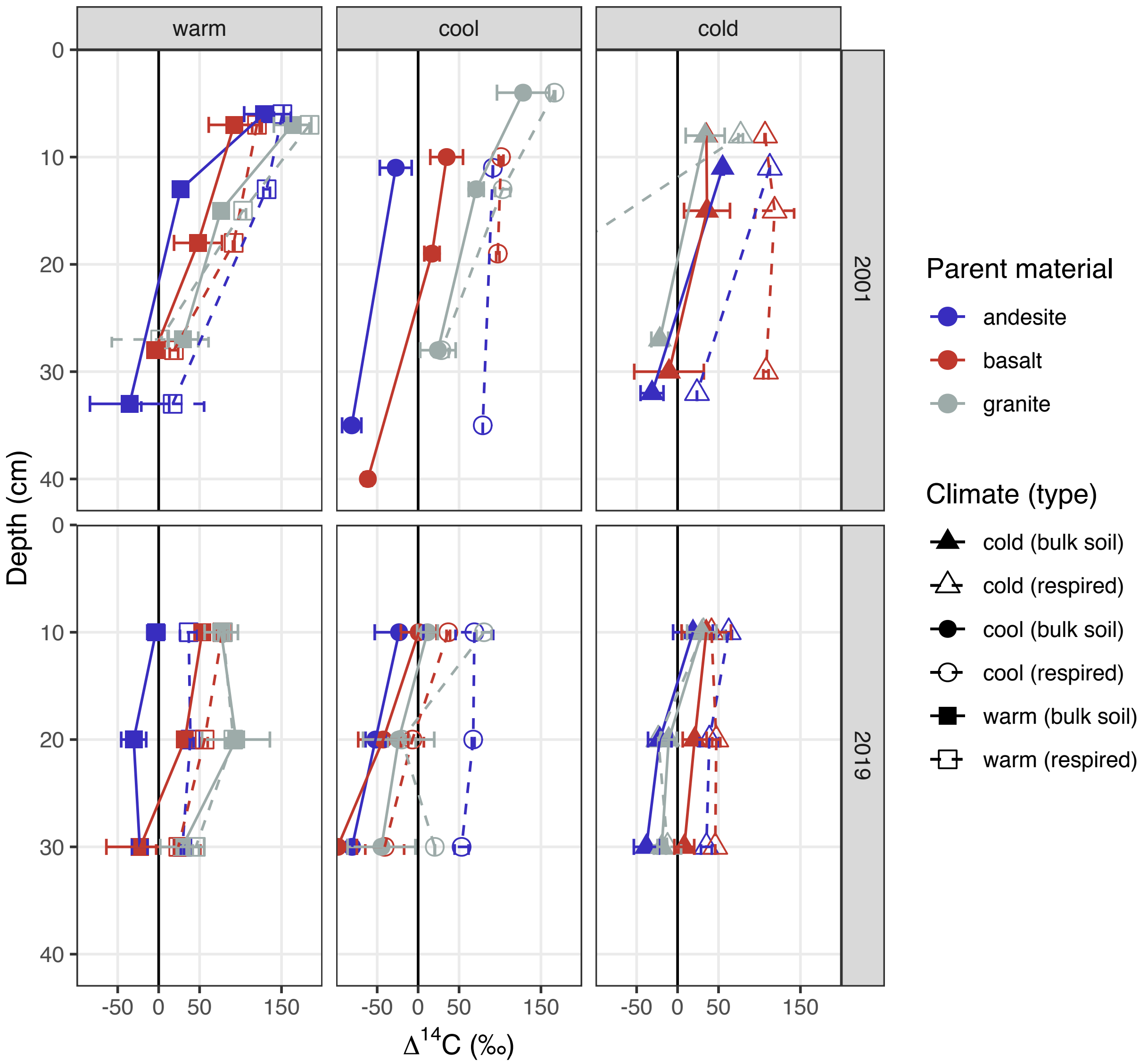
I constructed linear models for $\Delta^{14}C$ of bulk soil C and heterotrophically respired CO_2 as function of parent material (PM), climate (CL), and year. I considered both the two-way and three-way interactions, using models of the form: lm(d14c ~ PM * CL * year). Prior to modeling I interpolated the 2001 and 2009 $\Delta^{14}C$ data to the 2019 sampling depths using a mass-preserving spline weighted by carbon stocks. In order to simplify the analysis and focus on the change in $\Delta^{14}C$ over time as a function of parent material and climate, I modeled each depth increment separately. I focused on the top 30cm only (i.e. 0-10cm, 10-20cm, and 20-30cm depth increments) owing to a lack of data from the 2001 sampling for depths below this depth.

Results

Depth profiles

Fig. 1. Depth profiles of $\Delta^{14}C$ of bulk soil and respired CO_2

Bulk soil points show the mean of three replicate profiles. We composited the profile replicates prior to incubation, and respired data points show the mean of laboratory duplicates. Error bars show ±1 SD for bulk soils and the min. and max. for respired CO_2. Respired CO_2 from the cold granite soil was extremely depleted in $\Delta^{14}C$ and thus is excluded for display purposes.



ANOVA

Bulk soil

Both parent material and climate are significant factors for explaining the variance in bulk soil $\Delta^{14}C$ at all depths (Table 1, Table 2, Table 3). Climate explains more of the variance at the surface (0-10cm) than does parent material (31.4% and 14.1%, for climate and parent material, respectively) (Table 1). Below 10cm in depth the relative importance of these two factors reverses, with parent material explaining more variance than climate (Table 2). At the deepest depth (20-30cm) parent material explains 25% of variance in bulk soil Δ^{14}C compared to 11.4% for climate (Table 3). The two-way interaction between parent material and climate is signficant in the top 20cm ($p < 0.05$), but not at the deepest depth.

Year is highly significant at the surface ($p < 0.0001$, Table 1), but is only marginally significant in the deeper soil layers ($p < 0.10$) (Table 2, Table 3). Interestingly, the two-way interaction between climate and year is much more significant than the interaction between parent material and year at all depths. This appears to be driven by the strong decrease in cool site Δ^{14}C over time relative to the warm or cold sites (**Fig. 16b**).

Overall, the models explains less of the variance in the data deeper in the soil: 73%, 61%, and 56% for 0-10cm, 10-20cm, and 20-30cm, respectively (Table 1, Table 2, Table 3).

NB in subsequent tables "ECO" = climate

0-10cm

Table 1. ANOVA: Bulk soil, 0-10cm

```
## Analysis of Variance Table
##
## Response: d14c
##             Df Sum Sq Mean Sq F value        Pr(>F)
## PM           2  15008  7503.8 13.0156 0.00003627015 ***
## ECO          2  33394 16696.8 28.9612 0.00000000942 ***
## year         1  19132 19132.2 33.1856 0.00000075761 ***
## PM:ECO       4  14680  3669.9  6.3656     0.0003934 ***
## PM:year      2   2690  1344.9  2.3328     0.1089146
## ECO:year     2   6715  3357.4  5.8236     0.0057044 **
## PM:ECO:year  4  10691  2672.7  4.6360     0.0032831 **
## Residuals   44  25367   576.5
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

10-20cm

Table 2. ANOVA: Bulk soil, 10-20cm

```
## Analysis of Variance Table
##
## Response: d14c
##             Df Sum Sq Mean Sq F value       Pr(>F)
## PM           2  33732 16865.9 21.6126 0.0000002896 ***
## ECO          2  23144 11572.1 14.8289 0.0000119436 ***
## year         1   3155  3155.0  4.0430      0.05051 .
## PM:ECO       4  11619  2904.7  3.7222      0.01077 *
## PM:year      2    755   377.5  0.4838      0.61969
## ECO:year     2   4390  2195.0  2.8128      0.07087 .
## PM:ECO:year  4   9617  2404.2  3.0809      0.02542 *
## Residuals   44  34336   780.4
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

20-30cm

Table 3. ANOVA: Bulk soil, 20-30cm

```
## Analysis of Variance Table
##
## Response: d14c
##              Df Sum Sq Mean Sq F value      Pr(>F)
## PM            2  26591 13295.6 17.2538 0.000002937 ***
## ECO           2  12157  6078.6  7.8882   0.0011812 **
## year          1   2840  2839.8  3.6852   0.0613973 .
## PM:ECO        4   4880  1220.0  1.5832   0.1955863
## PM:year       2   4623  2311.4  2.9996   0.0600877 .
## ECO:year      2  13699  6849.5  8.8886   0.0005724 ***
## PM:ECO:year   4   7525  1881.3  2.4413   0.0607447 .
## Residuals    44  33906   770.6
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Respired CO_2

The relative importance of parent material and climate for explaining the variance in $\Delta^{14}C\text{-}CO_2$ changes with depth in a similar manner as it does for bulk soil. Climate explains more of the variance in $\Delta^{14}C\text{-}CO_2$ at the surface (0-10cm) than does parent material (Table 4). Unlike bulk soil, however, parent material is not significant for $\Delta^{14}C\text{-}CO_2$ at the surface at all. Both parent material and climate are significant ($p < 0.0005$) for $\Delta^{14}C\text{-}CO_2$ at the 10-20cm depth, but parent material explains more variance than does climate (Table 5). At the deepest depth (20-30cm) climate is no longer a siginficant predictor of $\Delta^{14}C\text{-}CO_2$ at all, while parent material is strongly siginficant ($p = 0.006$) (Table 6).

Year is highly significant for 0-10cm and 10-20cm ($p < 0.0001$), but not significant at 20-30cm ($p = 0.0950$). The two-way interaction between climate and year is significant at all depths, while the two-way interaction between parent material and year is siginficant below 10cm.

Overall the models explained more variance in respired $\Delta^{14}C\text{-}CO_2$ than in bulk soil $\Delta^{14}C$. The $\Delta^{14}C\text{-}CO_2$ models explained a similar amount of the variance at the 0-10cm and 10-20cm depths (R^2 of 0.86 and 0.89, respectively), and slightly less at the deepest depth ($R^2 = 0.70$).

0-10cm

Table 4. ANOVA: Respired CO_2, 0-10cm

```
## Analysis of Variance Table
##
## Response: d14c
##              Df  Sum Sq Mean Sq  F value         Pr(>F)
## PM            2   242.0   121.0   0.4881       0.621700
## ECO           2  9092.1  4546.1  18.3402 0.000045390627 ***
## year          1 28816.0 28816.0 116.2528 0.000000002769 ***
## PM:ECO        4 12293.8  3073.4  12.3992 0.000051182369 ***
## PM:year       2   384.9   192.4   0.7763       0.474891
## ECO:year      2  2558.1  1279.1   5.1601       0.016927 *
## PM:ECO:year   4  5930.1  1482.5   5.9810       0.003042 **
## Residuals    18  4461.7   247.9
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

10-20cm

Table 5. ANOVA: Respired CO_2, 10-20cm

```
## Analysis of Variance Table
##
## Response: d14c
##             Df  Sum Sq Mean Sq F value      Pr(>F)
## PM           2  9874.1  4937.1 19.0794 0.000058023 ***
## ECO          2  6767.7  3383.9 13.0770   0.0004308 ***
## year         1  9203.2  9203.2 35.5661 0.000019838 ***
## PM:ECO       4 26135.3  6533.8 25.2502 0.000000967 ***
## PM:year      2  5591.0  2795.5 10.8032   0.0010736 **
## ECO:year     2  6143.9  3072.0 11.8717   0.0006900 ***
## PM:ECO:year  4  8375.3  2093.8  8.0917   0.0009112 ***
## Residuals   16  4140.2   258.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

20-30cm

Table 6. ANOVA: Respired CO_2, 20-30cm

```
## Analysis of Variance Table
##
## Response: d14c
##             Df  Sum Sq Mean Sq F value    Pr(>F)
## PM           2 13960.7  6980.3  7.0583 0.0063461 **
## ECO          2  4015.6  2007.8  2.0302 0.1637711
## year         1   174.8   174.8  0.1767 0.6798018
## PM:ECO       4 28563.3  7140.8  7.2206 0.0016036 **
## PM:year      2 21957.6 10978.8 11.1015 0.0009466 ***
## ECO:year     2 15561.6  7780.8  7.8678 0.0041744 **
## PM:ECO:year  4  9420.2  2355.1  2.3814 0.0949814 .
## Residuals   16 15823.2   988.9
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Marginal mean trends: 2001-2019

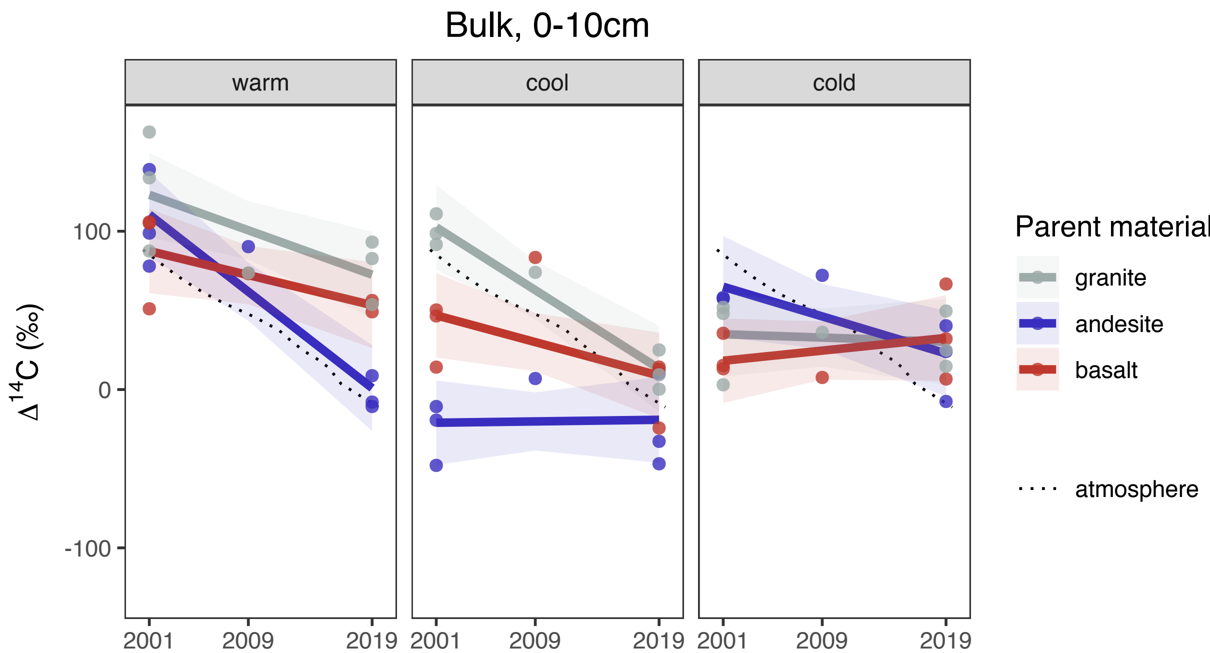
The next set of plots show least-square mean estimates of trends within parent material and climate groups for the time period 2001 to 2019. Plots are shown for each depth increment. The first two plots show the full model with interactions between parent material and climate. The same curves are shown twice, but grouped differently to emphasize differences across each level of the grouping factors. Finally, I show the estimated trend and associated confidence intervals for the change in $\Delta^{14}C$ over time averaged across either parent material or climate. Raw data are shown as points.

Following each plot I show the contrasts for the slope estimates within parent material and climate groups. The first set of numbers show marginal means estimated within groups; second set of numbers show the contrasts, i.e. are the trends over time significantly different between different parent materials or climate conditions?

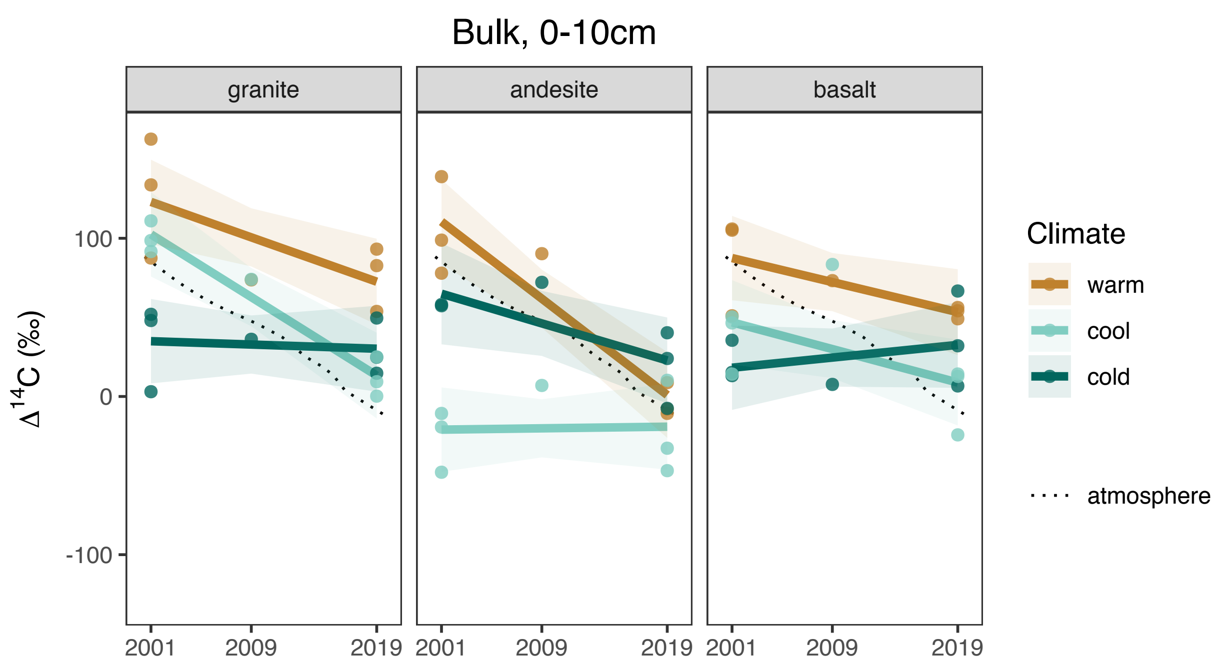
Bulk soil

0-10cm

Fig. 2. [a] **parent material**



[b] **ecosystem**



We can see the strong effect of climate on the temporal trend in bulk soil Δ^{14}C clearly in Fig. 2. [a]. Curves are much steeper at the warm site for all three parent materials, while they are nearly flat at the coldest site. However, at the cool site we can also see the effect of parent material within the climate grouping. The steepest slope and the most enriched Δ^{14}C is seen in the granite soils, while the andesite soils show no change in Δ^{14}C over time and are also much less enriched. Overall, rates of change in granite and basalt soils were not significantly different in any of the ecosystems. However, the andsite soils are changing significantly faster than the basalt soils at the warmest sites and significantly slower than the granite soils at the cool sites (Table 7).

For the andesite soils we see faster changes over time for the warm site relative to the cool and cold sites when considering the contrasts between climates within parent materials ($p = 0.0006$, and $p = 0.0657$ respectively) (Fig. 5b, Table 8). For the granite soils, however, we see significantly ($p = 0.0105$) faster rates of change at the cool sites than at either the warm or the cold sites.

Trends & Contrasts

Table 7. Bulk soil, 0-10cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite      -2.802 1.09 44    -5.00  -0.6088
##  andesite     -6.088 1.09 44    -8.28  -3.8951
##  basalt       -1.899 1.09 44    -4.09   0.2939
##
## ECO = cool:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite      -4.961 1.09 44    -7.15  -2.7679
##  andesite      0.103 1.09 44    -2.09   2.2961
##  basalt       -2.116 1.09 44    -4.31   0.0775
##
## ECO = cold:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite      -0.264 1.09 44    -2.46   1.9294
##  andesite     -2.343 1.21 44    -4.78   0.0911
##  basalt        0.802 1.09 44    -1.39   2.9953
##
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite    3.286 1.54 44  2.135  0.0943
##  granite - basalt     -0.903 1.54 44 -0.587  0.8280
##  andesite - basalt    -4.189 1.54 44 -2.722  0.0246
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite   -5.064 1.54 44 -3.291  0.0055
##  granite - basalt     -2.845 1.54 44 -1.849  0.1658
##  andesite - basalt     2.219 1.54 44  1.442  0.3288
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite    2.079 1.63 44  1.279  0.4144
##  granite - basalt     -1.066 1.54 44 -0.693  0.7690
##  andesite - basalt    -3.145 1.63 44 -1.935  0.1410
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

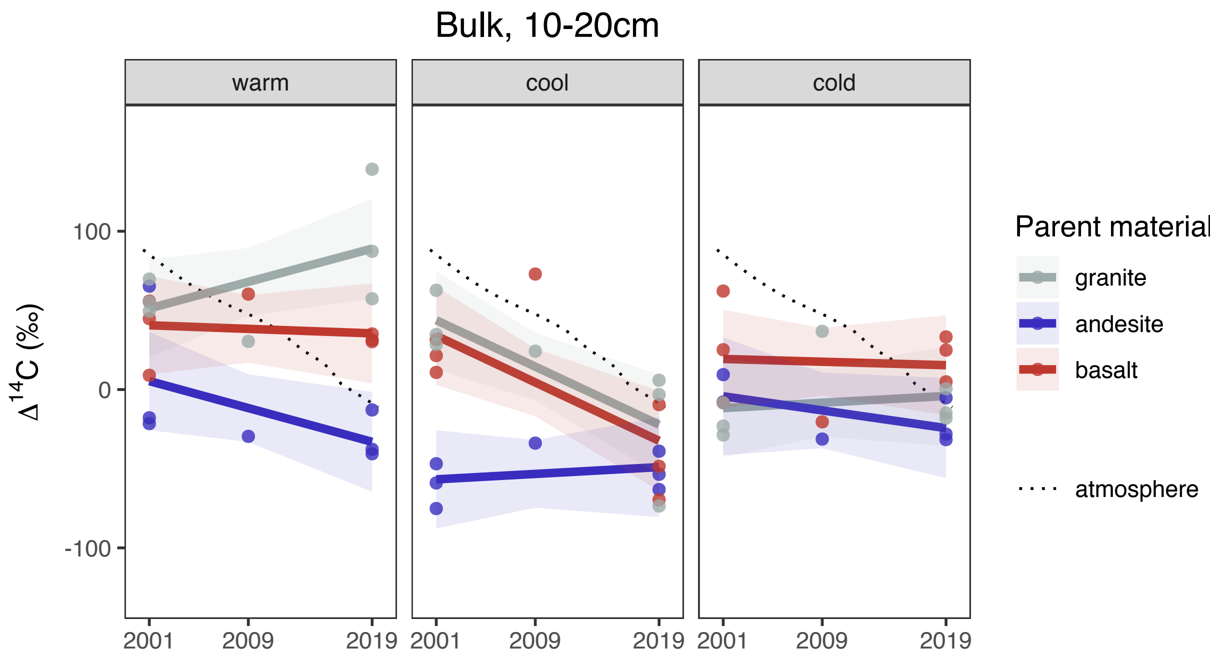
Table 8. Bulk soil, 0-10cm: Climate trends within parent material

```
## [1] "Interactions, ECO | PM"

## $emtrends
## PM = granite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -2.802 1.09 44    -5.00  -0.6088
##  cool     -4.961 1.09 44    -7.15  -2.7679
##  cold     -0.264 1.09 44    -2.46   1.9294
##
## PM = andesite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -6.088 1.09 44    -8.28  -3.8951
##  cool      0.103 1.09 44    -2.09   2.2961
##  cold     -2.343 1.21 44    -4.78   0.0911
##
## PM = basalt:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -1.899 1.09 44    -4.09   0.2939
##  cool     -2.116 1.09 44    -4.31   0.0775
##  cold      0.802 1.09 44    -1.39   2.9953
##
## Confidence level used: 0.95
##
## $contrasts
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool    2.159 1.54 44  1.403  0.3482
##  warm - cold   -2.538 1.54 44 -1.649  0.2362
##  cool - cold   -4.697 1.54 44 -3.052  0.0105
##
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   -6.191 1.54 44 -4.023  0.0006
##  warm - cold   -3.746 1.63 44 -2.304  0.0657
##  cool - cold    2.446 1.63 44  1.504  0.2987
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool    0.216 1.54 44  0.141  0.9892
##  warm - cold   -2.701 1.54 44 -1.755  0.1966
##  cool - cold   -2.918 1.54 44 -1.896  0.1518
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

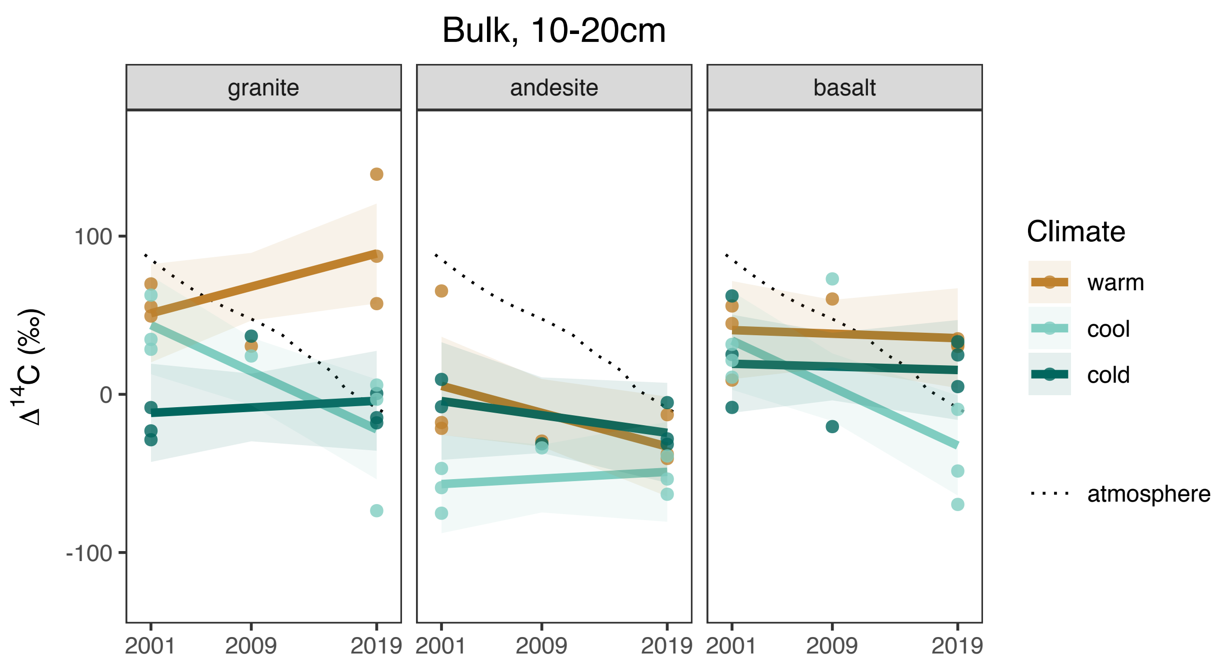
10-20cm

Interaction plots

Fig. 3. a) **parent material**



b) **climate**



text

Trends & Contrasts

Table 9. Bulk soil, 10-20cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite       2.099 1.27 44   -0.452    4.651
##  andesite     -2.133 1.27 44   -4.685    0.418
##  basalt       -0.283 1.27 44   -2.835    2.268
##
## ECO = cool:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite      -3.664 1.27 44   -6.215   -1.112
##  andesite      0.430 1.27 44   -2.122    2.981
##  basalt       -3.686 1.27 44   -6.238   -1.135
##
## ECO = cold:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite       0.424 1.27 44   -2.127    2.976
##  andesite     -1.117 1.40 44   -3.948    1.715
##  basalt       -0.219 1.27 44   -2.770    2.333
##
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite   4.2323 1.79 44   2.364  0.0575
##  granite - basalt     2.3823 1.79 44   1.331  0.3861
##  andesite - basalt   -1.8500 1.79 44  -1.033  0.5601
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite  -4.0935 1.79 44  -2.286  0.0683
##  granite - basalt     0.0223 1.79 44   0.012  0.9999
##  andesite - basalt    4.1158 1.79 44   2.299  0.0665
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite   1.5408 1.89 44   0.815  0.6960
##  granite - basalt     0.6429 1.79 44   0.359  0.9315
##  andesite - basalt   -0.8979 1.89 44  -0.475  0.8835
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

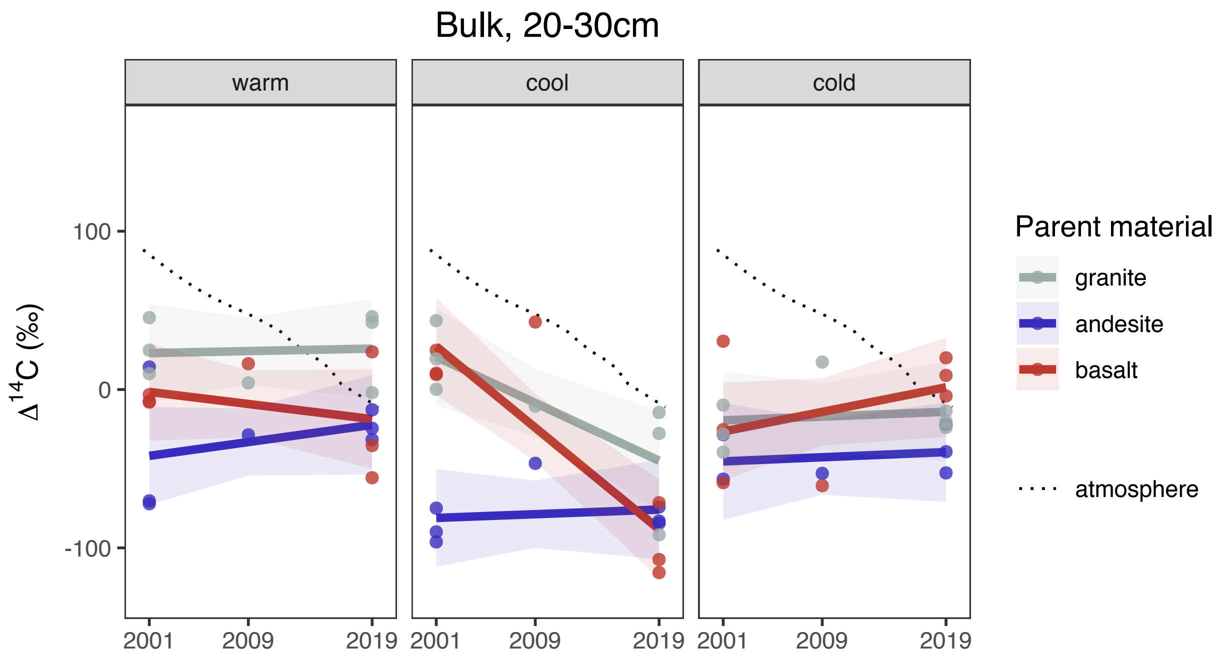
Table 10. Bulk soil, 10-20cm: Climate trends within parent material

```
## [1] "Interactions, ECO | PM"

## $emtrends
## PM = granite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm      2.099 1.27 44   -0.452    4.651
##  cool     -3.664 1.27 44   -6.215   -1.112
##  cold      0.424 1.27 44   -2.127    2.976
##
## PM = andesite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -2.133 1.27 44   -4.685    0.418
##  cool      0.430 1.27 44   -2.122    2.981
##  cold     -1.117 1.40 44   -3.948    1.715
##
## PM = basalt:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -0.283 1.27 44   -2.835    2.268
##  cool     -3.686 1.27 44   -6.238   -1.135
##  cold     -0.219 1.27 44   -2.770    2.333
##
## Confidence level used: 0.95
##
## $contrasts
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   5.7630 1.79 44  3.219  0.0067
##  warm - cold   1.6749 1.79 44  0.935  0.6210
##  cool - cold  -4.0880 1.79 44 -2.283  0.0688
##
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool  -2.5628 1.79 44 -1.431  0.3339
##  warm - cold  -1.0166 1.89 44 -0.538  0.8533
##  cool - cold   1.5462 1.89 44  0.818  0.6942
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   3.4030 1.79 44  1.901  0.1505
##  warm - cold  -0.0645 1.79 44 -0.036  0.9993
##  cool - cold  -3.4675 1.79 44 -1.937  0.1405
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

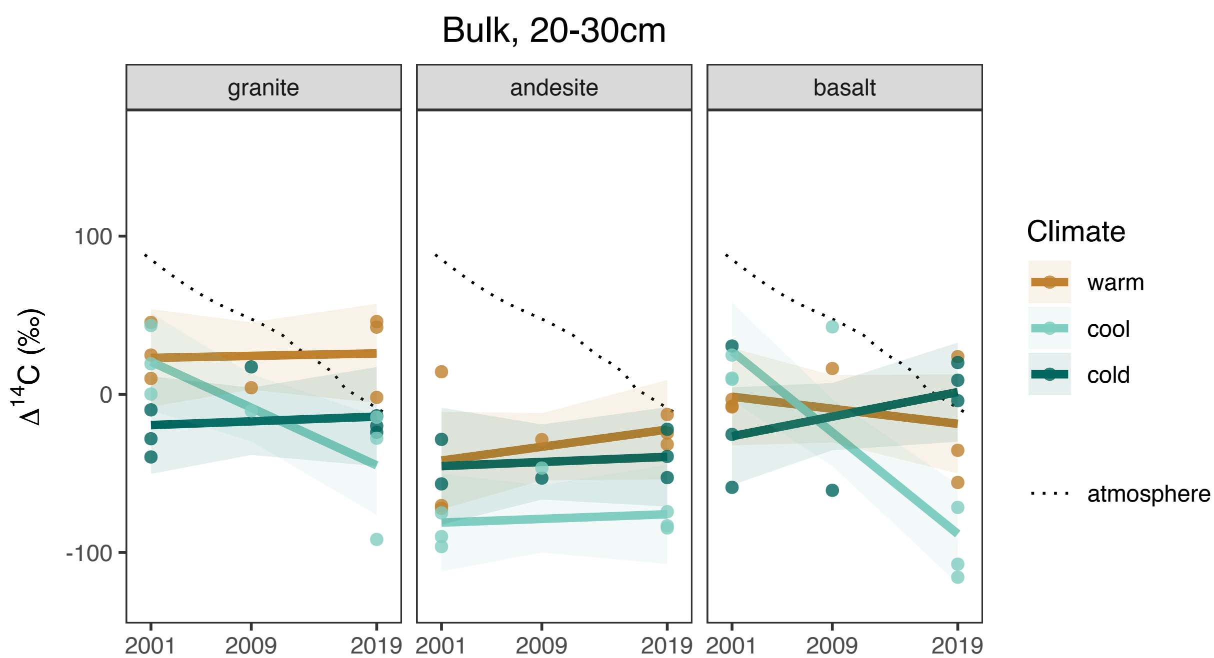
20-30cm

Interaction plots

Fig. 4. a) **parent material**



b) **climate**



text

Trends & Contrasts

Table 11. Bulk soil, 20-30cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite       0.157 1.26 44   -2.378     2.69
##  andesite      1.089 1.26 44   -1.447     3.62
##  basalt       -0.954 1.26 44   -3.490     1.58
##
## ECO = cool:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite      -3.644 1.26 44   -6.180    -1.11
##  andesite      0.293 1.26 44   -2.242     2.83
##  basalt       -6.417 1.26 44   -8.952    -3.88
##
## ECO = cold:
##  PM       year.trend   SE df lower.CL upper.CL
##  granite       0.298 1.26 44   -2.238     2.83
##  andesite      0.326 1.40 44   -2.488     3.14
##  basalt        1.551 1.26 44   -0.985     4.09
##
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite  -0.9313 1.78 44 -0.523  0.8603
##  granite - basalt     1.1118 1.78 44  0.625  0.8073
##  andesite - basalt    2.0431 1.78 44  1.148  0.4900
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite  -3.9373 1.78 44 -2.213  0.0801
##  granite - basalt     2.7726 1.78 44  1.558  0.2743
##  andesite - basalt    6.7099 1.78 44  3.771  0.0014
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  granite - andesite  -0.0284 1.88 44 -0.015  0.9999
##  granite - basalt    -1.2528 1.78 44 -0.704  0.7623
##  andesite - basalt   -1.2243 1.88 44 -0.651  0.7925
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

Table 12. Bulk soil, 20-30cm: Climate trends within parent material

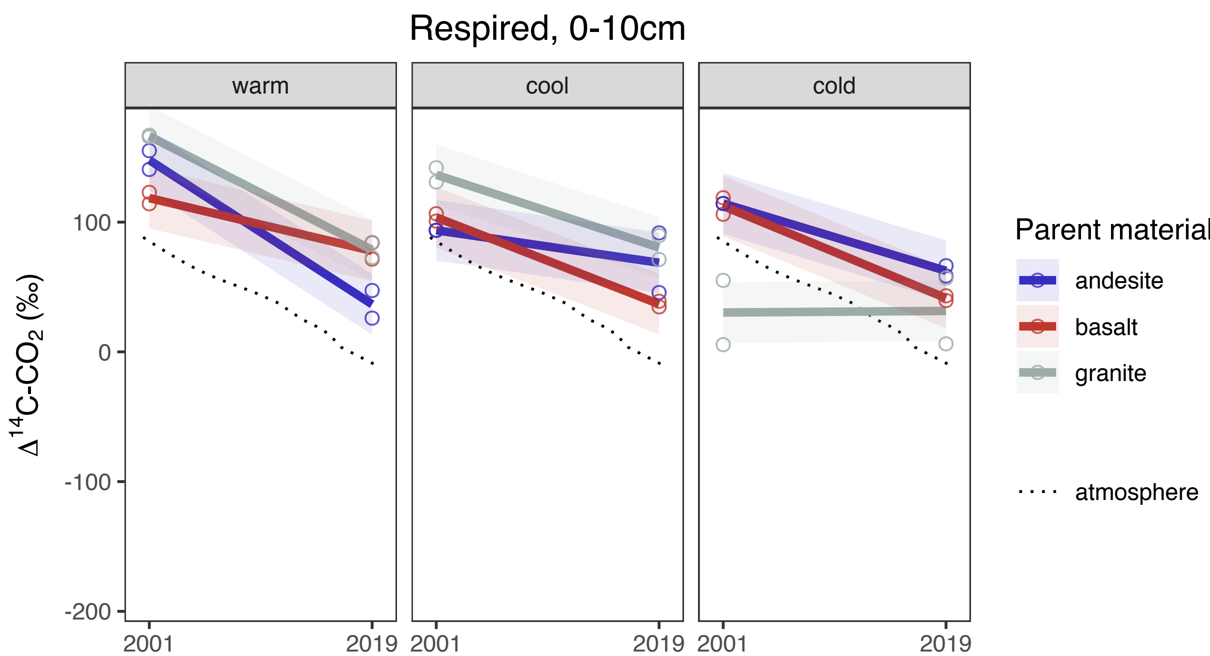
```
## [1] "Interactions, ECO | PM"

## $emtrends
## PM = granite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm      0.157 1.26 44   -2.378     2.69
##  cool     -3.644 1.26 44   -6.180    -1.11
##  cold      0.298 1.26 44   -2.238     2.83
##
## PM = andesite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm      1.089 1.26 44   -1.447     3.62
##  cool      0.293 1.26 44   -2.242     2.83
##  cold      0.326 1.40 44   -2.488     3.14
##
## PM = basalt:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     -0.954 1.26 44   -3.490     1.58
##  cool     -6.417 1.26 44   -8.952    -3.88
##  cold      1.551 1.26 44   -0.985     4.09
##
## Confidence level used: 0.95
##
## $contrasts
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   3.8016 1.78 44  2.137  0.0941
##  warm - cold  -0.1405 1.78 44 -0.079  0.9966
##  cool - cold  -3.9420 1.78 44 -2.216  0.0796
##
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   0.7956 1.78 44  0.447  0.8959
##  warm - cold   0.7625 1.88 44  0.406  0.9134
##  cool - cold  -0.0331 1.88 44 -0.018  0.9998
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   5.4623 1.78 44  3.070  0.0100
##  warm - cold  -2.5050 1.78 44 -1.408  0.3456
##  cool - cold  -7.9674 1.78 44 -4.478  0.0002
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

Respired CO_2

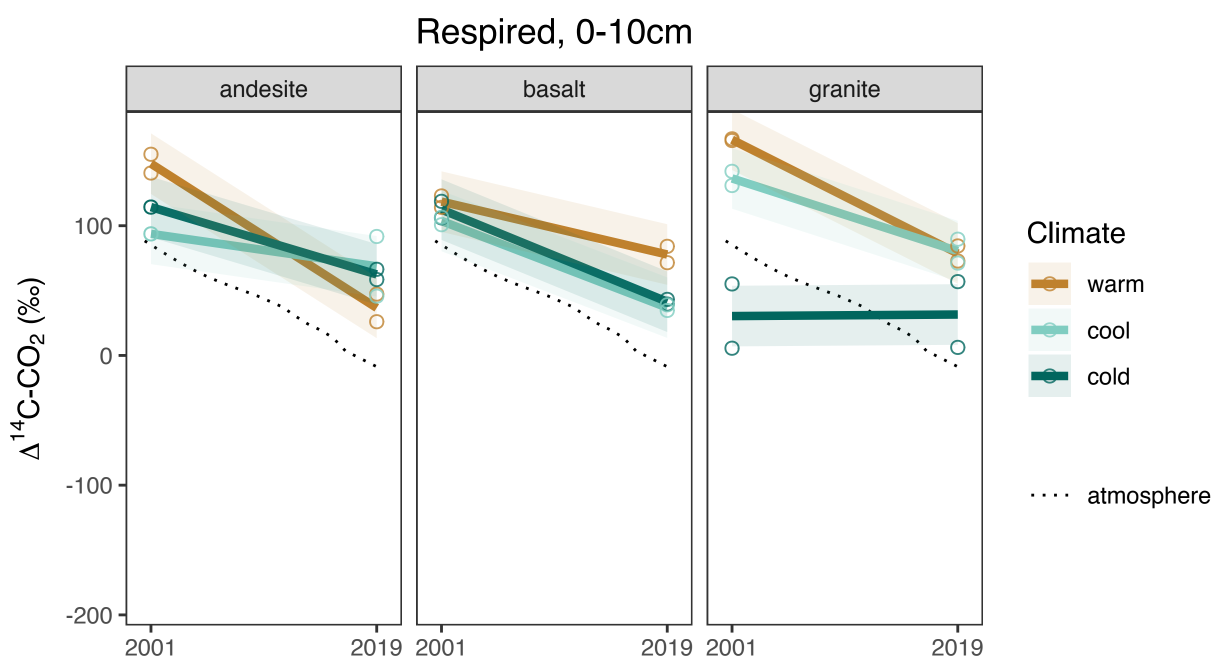
0-10cm

Interaction plots

Fig. 5. a) **parent material**



b) **climate**



text

Trends & Contrasts

Table 13. Respired CO_2, 0-10cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM       year.trend    SE df lower.CL upper.CL
##  andesite     -6.177 0.875 18    -8.01   -4.340
##  basalt       -2.265 0.875 18    -4.10   -0.427
##  granite      -4.873 0.875 18    -6.71   -3.036
##
## ECO = cool:
##  PM       year.trend    SE df lower.CL upper.CL
##  andesite     -1.390 0.875 18    -3.23    0.448
##  basalt       -3.711 0.875 18    -5.55   -1.873
##  granite      -3.114 0.875 18    -4.95   -1.276
##
## ECO = cold:
##  PM       year.trend    SE df lower.CL upper.CL
##  andesite     -2.884 0.875 18    -4.72   -1.046
##  basalt       -3.946 0.875 18    -5.78   -2.108
##  granite       0.067 0.875 18    -1.77    1.905
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt    -3.913 1.24 18 -3.163  0.0142
##  andesite - granite   -1.304 1.24 18 -1.054  0.5535
##  basalt - granite      2.608 1.24 18  2.109  0.1161
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     2.321 1.24 18  1.877  0.1741
##  andesite - granite    1.724 1.24 18  1.394  0.3648
##  basalt - granite     -0.597 1.24 18 -0.483  0.8803
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     1.062 1.24 18  0.859  0.6724
##  andesite - granite   -2.951 1.24 18 -2.385  0.0693
##  basalt - granite     -4.013 1.24 18 -3.244  0.0119
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```

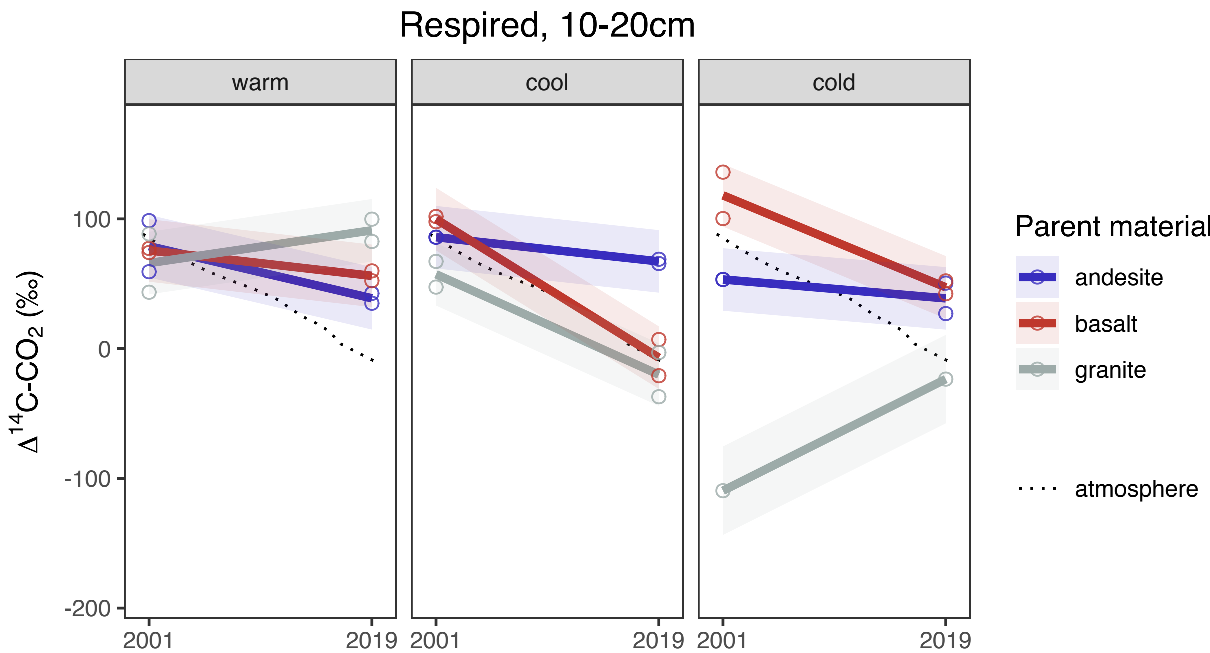
Table 14. Respired CO_2, 0-10cm: Climate trends within parent material

```
## [1] "Interactions, ECO | PM"

## $emtrends
## PM = andesite:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm     -6.177 0.875 18    -8.01   -4.340
##  cool     -1.390 0.875 18    -3.23    0.448
##  cold     -2.884 0.875 18    -4.72   -1.046
##
## PM = basalt:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm     -2.265 0.875 18    -4.10   -0.427
##  cool     -3.711 0.875 18    -5.55   -1.873
##  cold     -3.946 0.875 18    -5.78   -2.108
##
## PM = granite:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm     -4.873 0.875 18    -6.71   -3.036
##  cool     -3.114 0.875 18    -4.95   -1.276
##  cold      0.067 0.875 18    -1.77    1.905
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   -4.788 1.24 18 -3.871  0.0031
##  warm - cold   -3.294 1.24 18 -2.663  0.0401
##  cool - cold    1.494 1.24 18  1.208  0.4638
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool    1.446 1.24 18  1.169  0.4858
##  warm - cold    1.681 1.24 18  1.359  0.3823
##  cool - cold    0.235 1.24 18  0.190  0.9803
##
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   -1.759 1.24 18 -1.422  0.3509
##  warm - cold   -4.940 1.24 18 -3.994  0.0023
##  cool - cold   -3.181 1.24 18 -2.571  0.0481
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```

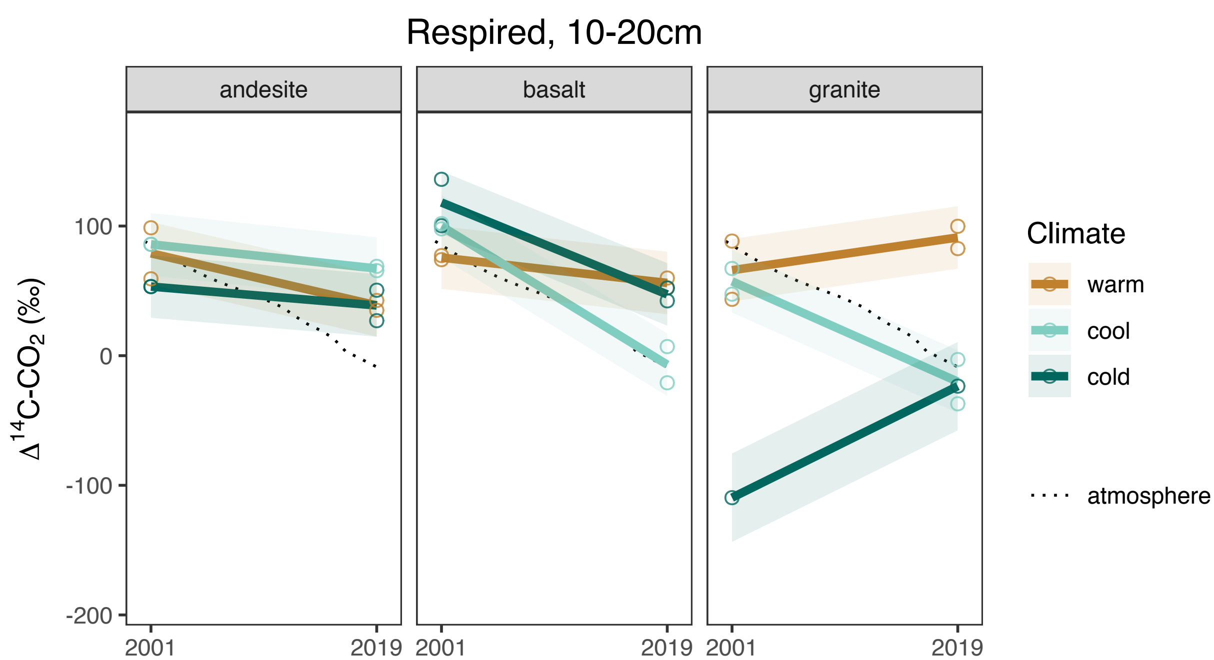
10-20cm

Interaction plots

Fig. 6. [a] **parent material**



[b] **climate**



text

Trends & Contrasts

Table 15. Respired CO_2, 10-20cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM        year.trend    SE df lower.CL upper.CL
##  andesite      -2.231 0.894 16   -4.126   -0.337
##  basalt        -1.086 0.894 16   -2.981    0.808
##  granite        1.404 0.894 16   -0.491    3.298
##
## ECO = cool:
##  PM        year.trend    SE df lower.CL upper.CL
##  andesite      -1.036 0.894 16   -2.930    0.859
##  basalt        -5.933 0.894 16   -7.827   -4.038
##  granite       -4.299 0.894 16   -6.194   -2.405
##
## ECO = cold:
##  PM        year.trend    SE df lower.CL upper.CL
##  andesite      -0.808 0.894 16   -2.703    1.086
##  basalt        -3.939 0.894 16   -5.833   -2.044
##  granite        4.780 1.264 16    2.101    7.459
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     -1.15 1.26 16 -0.906  0.6444
##  andesite - granite    -3.63 1.26 16 -2.876  0.0280
##  basalt - granite      -2.49 1.26 16 -1.970  0.1519
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt      4.90 1.26 16  3.875  0.0036
##  andesite - granite     3.26 1.26 16  2.582  0.0498
##  basalt - granite      -1.63 1.26 16 -1.293  0.4194
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt      3.13 1.26 16  2.477  0.0609
##  andesite - granite    -5.59 1.55 16 -3.610  0.0063
##  basalt - granite      -8.72 1.55 16 -5.633  0.0001
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```

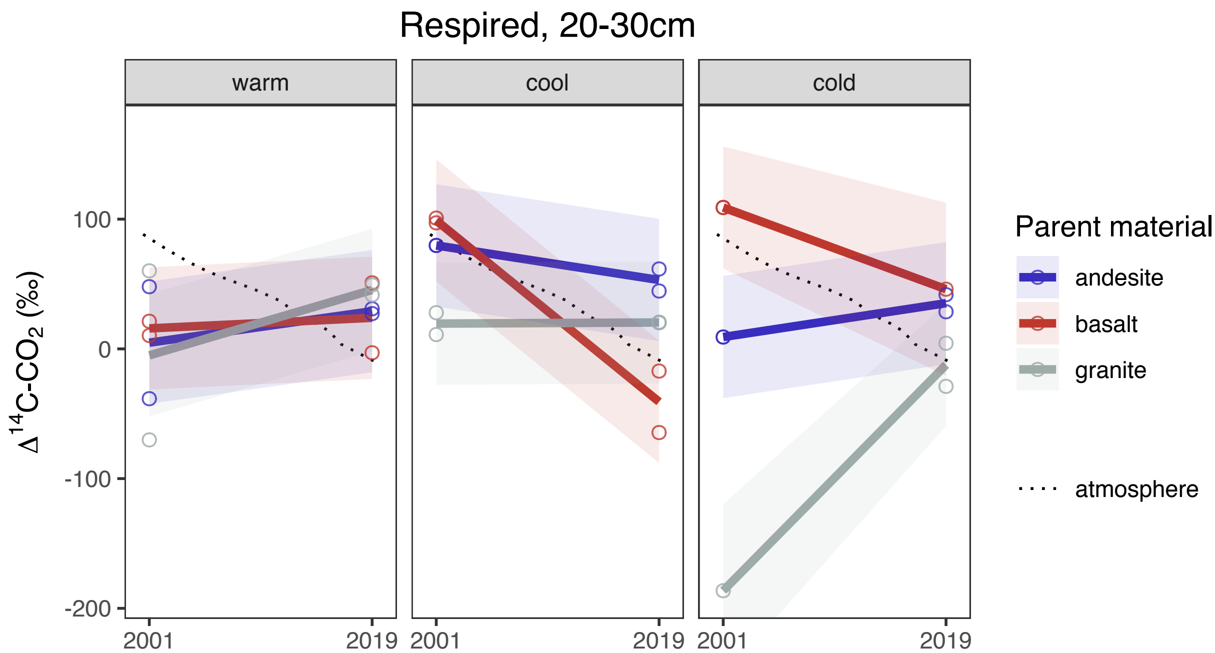
Table 16. Respired CO_2, 10-20cm: Climate trends within parent material

```
## [1] "Interactions, ECO | PM"

## $emtrends
## PM = andesite:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm     -2.231 0.894 16   -4.126   -0.337
##  cool     -1.036 0.894 16   -2.930    0.859
##  cold     -0.808 0.894 16   -2.703    1.086
##
## PM = basalt:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm     -1.086 0.894 16   -2.981    0.808
##  cool     -5.933 0.894 16   -7.827   -4.038
##  cold     -3.939 0.894 16   -5.833   -2.044
##
## PM = granite:
##  ECO  year.trend    SE df lower.CL upper.CL
##  warm      1.404 0.894 16   -0.491    3.298
##  cool     -4.299 0.894 16   -6.194   -2.405
##  cold      4.780 1.264 16    2.101    7.459
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   -1.196 1.26 16 -0.946  0.6201
##  warm - cold   -1.423 1.26 16 -1.126  0.5126
##  cool - cold   -0.228 1.26 16 -0.180  0.9823
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool    4.847 1.26 16  3.835  0.0039
##  warm - cold    2.852 1.26 16  2.257  0.0917
##  cool - cold   -1.994 1.26 16 -1.578  0.2833
##
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool    5.703 1.26 16  4.512  0.0010
##  warm - cold   -3.376 1.55 16 -2.181  0.1051
##  cool - cold   -9.079 1.55 16 -5.866  0.0001
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```

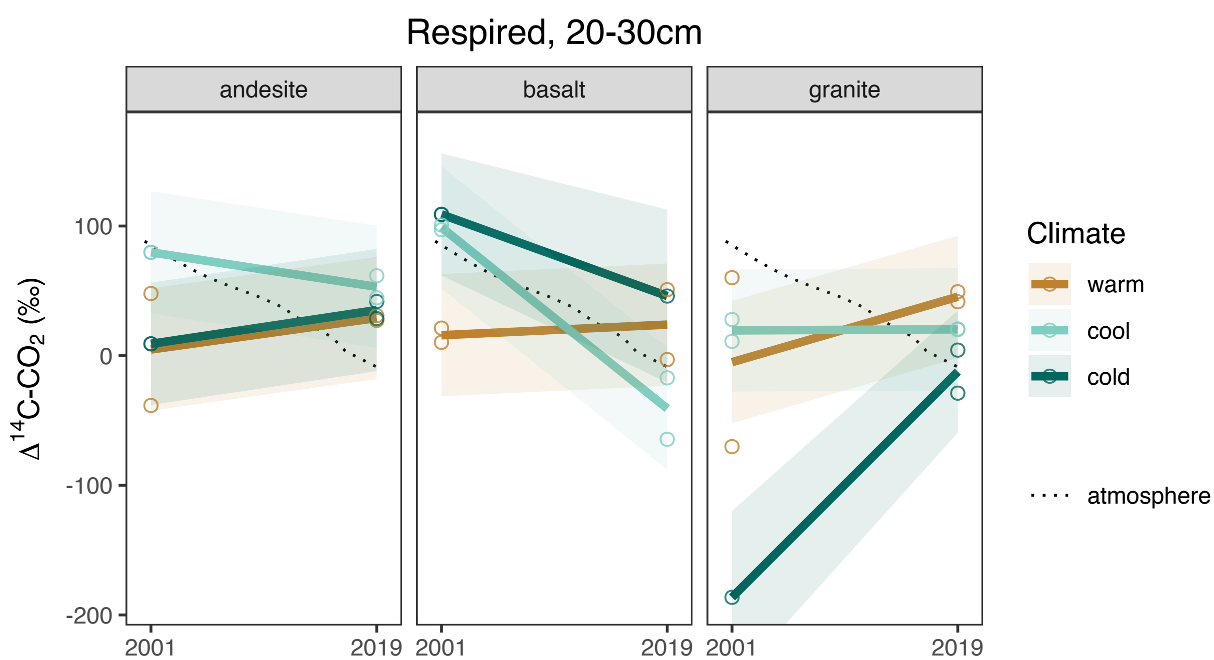
20-30cm

Interaction plots

Fig. 7. [a] **parent material**



[b] **climate**



text

Trends & Contrasts

Table 17. Respired CO_2, 20-30cm: Parent material trends within climate

```
## [1] "Interactions, PM | ECO"

## $emtrends
## ECO = warm:
##  PM        year.trend   SE df lower.CL upper.CL
##  andesite      1.3490 1.75 16   -2.355     5.05
##  basalt        0.4533 1.75 16   -3.250     4.16
##  granite       2.8023 1.75 16   -0.901     6.51
##
## ECO = cool:
##  PM        year.trend   SE df lower.CL upper.CL
##  andesite     -1.4790 1.75 16   -5.183     2.22
##  basalt       -7.7646 1.75 16  -11.468    -4.06
##  granite       0.0487 1.75 16   -3.655     3.75
##
## ECO = cold:
##  PM        year.trend   SE df lower.CL upper.CL
##  andesite      1.4481 1.75 16   -2.256     5.15
##  basalt       -3.4986 2.14 16   -8.035     1.04
##  granite       9.6728 2.14 16    5.137    14.21
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## ECO = warm:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     0.896 2.47 16  0.362  0.9304
##  andesite - granite   -1.453 2.47 16 -0.588  0.8283
##  basalt - granite     -2.349 2.47 16 -0.951  0.6173
##
## ECO = cool:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     6.286 2.47 16  2.544  0.0536
##  andesite - granite   -1.528 2.47 16 -0.618  0.8123
##  basalt - granite     -7.813 2.47 16 -3.162  0.0157
##
## ECO = cold:
##  contrast           estimate   SE df t.ratio p.value
##  andesite - basalt     4.947 2.76 16  1.791  0.2042
##  andesite - granite   -8.225 2.76 16 -2.977  0.0229
##  basalt - granite    -13.171 3.03 16 -4.353  0.0014
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```

Table 18. Respired CO_2, 20-30cm: Climate trends within parent material

```
## [1] "Interactions, ECO | PM"
```

```
## $emtrends
## PM = andesite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     1.3490 1.75 16   -2.355     5.05
##  cool    -1.4790 1.75 16   -5.183     2.22
##  cold     1.4481 1.75 16   -2.256     5.15
##
## PM = basalt:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     0.4533 1.75 16   -3.250     4.16
##  cool    -7.7646 1.75 16  -11.468    -4.06
##  cold    -3.4986 2.14 16   -8.035     1.04
##
## PM = granite:
##  ECO  year.trend   SE df lower.CL upper.CL
##  warm     2.8023 1.75 16   -0.901     6.51
##  cool     0.0487 1.75 16   -3.655     3.75
##  cold     9.6728 2.14 16    5.137    14.21
##
## Results are averaged over the levels of: year
## Confidence level used: 0.95
##
## $contrasts
## PM = andesite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   2.8280 2.47 16  1.145  0.5018
##  warm - cold  -0.0991 2.47 16 -0.040  0.9991
##  cool - cold  -2.9271 2.47 16 -1.185  0.4788
##
## PM = basalt:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   8.2179 2.47 16  3.326  0.0113
##  warm - cold   3.9519 2.76 16  1.431  0.3494
##  cool - cold  -4.2660 2.76 16 -1.544  0.2976
##
## PM = granite:
##  contrast    estimate   SE df t.ratio p.value
##  warm - cool   2.7536 2.47 16  1.114  0.5193
##  warm - cold  -6.8705 2.76 16 -2.487  0.0597
##  cool - cold  -9.6241 2.76 16 -3.484  0.0081
##
## Results are averaged over the levels of: year
## P value adjustment: tukey method for comparing a family of 3 estimates
```