exNGT: an overview of various correlation and other analyses

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Introduction

This document summarises various analyses of the NGT firn core stack:

- comparison of the NGT stack with other temperature data sets from the Arctic2k compilation and weather station measurements;
- comparison of individual NGT firn cores with the Arctic2k data set;
- comparison of the mean temperature anomalies derived from the NGT stack between the recent 15 year period and the reference period 1961-1990 as well as the entire 20th century.

Prepare data

Load relevant source files and packages:

```
source("init.R")
```

Set the running mean filter window size (yr) and the isotope–temperature slope (K/‰):

```
filter.window <- 11
permil2temperature <- 1 / 0.67
```

Load the NGT data, filter it and calculate the isotope stack:

```
stackedNGT <- processNGT() %>%
  stackNGT()

filteredStackedNGT <- processNGT() %>%
  filterData(window = filter.window) %>%
  stackNGT()
```

Load the Arctic2k and weather station data and filter it:

```
Arctic2k <- readArctic2k() %>%
  extendWithHadCrut()

filteredExtendedArctic2k <- Arctic2k %>%
  filterData(window = filter.window)

filteredArctic2k <- readArctic2k() %>%
  filterData(window = filter.window)

filteredDMI <- readDMI() %>%
  makeAnomalies() %>%
  filterData(window = filter.window)
```

Convert the NGT stack data to temperature:

```
stackedTemperatureNGT <- stackedNGT %>%
  dplyr::mutate(stack = permil2temperature * stack)

filteredStackedTemperatureNGT <- filteredStackedNGT %>%
  dplyr::mutate(stack = permil2temperature * stack)
```

Comparison of NGT-2012 temperature stack with Arctic2k

- Overall correlation between NGT-2012 temperature stack and Arctic2k compilation from 1000 CE onwards with and without including HadCrut extension:

```
analysis.period <- 2011 : 1000
res <- estimateCorrelation(stackedTemperatureNGT,
                           filteredStackedTemperatureNGT, filteredExtendedArctic2k,
                           filter.window = filter.window,
                           analysis.period = analysis.period,
                           nmc = 10000)
sprintf("r = %1.2f (p = %1.4f)", res$r, res$p)
#> [1] "r = 0.59 (p = 0.0000)"

analysis.period <- 2000 : 1000
res <- estimateCorrelation(stackedTemperatureNGT,
                           filteredStackedTemperatureNGT, filteredArctic2k,
                           filter.window = filter.window,
                           analysis.period = analysis.period,
                           nmc = 10000)
sprintf("r = %1.2f (p = %1.4f)", res$r, res$p)
#> [1] "r = 0.58 (p = 0.0000)"
```

- Correlation between NGT temperature stack and Arctic2k compilation for the 20th century and for the 20th century including up to 2011 CE:

```
analysis.period <- 2000 : 1901
res <- estimateCorrelation(stackedTemperatureNGT,
                           filteredStackedTemperatureNGT, filteredArctic2k,
                           filter.window = filter.window,
                           analysis.period = analysis.period,
                           nmc = 10000)
sprintf("r = %1.2f (p = %1.3f)", res$r, res$p)
#> [1] "r = 0.29 (p = 0.160)"

analysis.period <- 2011 : 1901
res <- estimateCorrelation(stackedTemperatureNGT,
                           filteredStackedTemperatureNGT, filteredExtendedArctic2k,
                           filter.window = filter.window,
                           analysis.period = analysis.period,
                           nmc = 10000)
sprintf("r = %1.2f (p = %1.3f)", res$r, res$p)
#> [1] "r = 0.34 (p = 0.121)"
```

- Linear trends (in degree Celsius / 100 years) of Arctic2k and NGT-2012 stack over pre-industrial and industrial era:

```r
t1 <- 1800 : 1000
t2 <- 2011 : 1800

regressionData <- list(
  data.frame(x = t1, y = subsetData(stackedTemperatureNGT, t1, "stack")),
  data.frame(x = t2, y = subsetData(stackedTemperatureNGT, t2, "stack")),
  data.frame(x = t1, y = subsetData(Arctic2k, t1, "TempAnomaly")),
  data.frame(x = t2, y = subsetData(Arctic2k, t2, "TempAnomaly"))
)

regressionSlopes <- regressionData %>%
  sapply(function(df) {unname(coef(summary(lm(y ~ x, df)))[2, 1 : 2])})
```

```r
# NGT 1000-1800 CE:
(regressionSlopes[1, 1] * 100) %>% round(digits = 2)
#> [1] -0.06
# +/-
(regressionSlopes[2, 1] * 100) %>% round(digits = 2)
#> [1] 0.01

# Arctic2k 1000-1800 CE:
(regressionSlopes[1, 3] * 100) %>% round(digits = 2)
#> [1] -0.12
# +/-
(regressionSlopes[2, 3] * 100) %>% round(digits = 2)
#> [1] 0.01

# NGT 1800-2011 CE:
(regressionSlopes[1, 2] * 100) %>% round(digits = 2)
#> [1] 0.73
# +/-
(regressionSlopes[2, 2] * 100) %>% round(digits = 2)
#> [1] 0.11

# Arctic2k 1800-2011 CE:
(regressionSlopes[1, 4] * 100) %>% round(digits = 2)
#> [1] 1.11
# +/-
(regressionSlopes[2, 4] * 100) %>% round(digits = 2)
#> [1] 0.06
```

Comparison of individual NGT firn core records with Arctic2k

We here use those NGT records which are also part of the Arctic2k compilation to assess the extent to which these records contribute to the overall Arctic2k temperature reconstruction. These firn cores are GRIP, GISP2, NGRIP, B16, B18 and B21 and we use the merged versions when redrilled cores are available.

```r
mergedFilteredNGT <- processNGT() %>%
  filterData(window = filter.window) %>%
  stackNGT(stack = FALSE)

t <- 2000 : 1000
a2k <- subsetData(filteredArctic2k, t, "TempAnomaly")
```

```r
grip <- subsetData(mergedFilteredNGT, t, "GRIP")
gisp2 <- subsetData(mergedFilteredNGT, t, "GISP2")
ngrip <- subsetData(mergedFilteredNGT, t, "NGRIP")
b16 <- subsetData(mergedFilteredNGT, t, "B16")
b18 <- subsetData(mergedFilteredNGT, t, "B18")
b21 <- subsetData(mergedFilteredNGT, t, "B21")
```

```r
cor(grip, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0
```

```r
cor(gisp2, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0.29
```

```r
cor(ngrip, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0.19
```

```r
cor(b16, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0.39
```

```r
cor(b18, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0.37
```

```r
cor(b21, a2k, use = "pairwise") %>%
  round(digits = 2)
#> [1] 0.49
```

Comparison of NGT isotope stack with DMI temperature data

We calculate the correlations of the NGT isotope stack with the temperature data from three coastal Greenland weather stations for the time period 1901–2011.

```r
pituffik <- dplyr::select(filteredDMI, "Year", "Pituffik")
upernavik <- dplyr::select(filteredDMI, "Year", "Upernavik")
danmarkshavn <- dplyr::select(filteredDMI, "Year", "Danmarkshavn")
```

- Correlation of NGT isotope stack and Pituffik weather station temperature:

  ```r
  res <- estimateCorrelation(stackedNGT, filteredStackedNGT, pituffik,
                             filter.window = filter.window,
                             analysis.period = 2011 : 1901,
                             nmc = 10000)
  sprintf("r = %1.2f (p = %1.3f)", res$r, res$p)
  #> [1] "r = 0.88 (p = 0.002)"
  ```

- Correlation of NGT isotope stack and Upernavik weather station temperature:

  ```r
  res <- estimateCorrelation(stackedNGT, filteredStackedNGT, upernavik,
                             filter.window = filter.window,
                             analysis.period = 2011 : 1901,
  ```

```
                               nmc = 10000)
sprintf("r = %1.2f (p = %1.3f)", res$r, res$p)
#> [1] "r = 0.76 (p = 0.002)"
```

- Correlation of NGT isotope stack and Danmarkshavn weather station temperature:

```
res <- estimateCorrelation(stackedNGT, filteredStackedNGT, danmarkshavn,
                           filter.window = filter.window,
                           analysis.period = 2011 : 1901,
                           nmc = 10000)
sprintf("r = %1.2f (p = %1.3f)", res$r, res$p)
#> [1] "r = 0.86 (p = 0.005)"
```

Temperature increase of recent 11 years relative to past

We compare the mean temperature over the recent 11 years of the NGT stack with the mean value of the 1961-1990 period and the mean value of the 20th century (1901–2000). We do this assuming the standard spatial isotope–temperature slope for Greenland as well as assuming stronger and weaker values from the temporal slopes derived by Vinther et al. (2009) and Masson-Delmotte et al. (2015).

Get NGT temperature stack data for the alternative isotope–temperature slopes:

```
permil2temperature.max <- 2.1     # Vinther et al. (2009)
permil2temperature.min <- 1 / 1.1 # Masson-Delmotte et al. (2015)

maxStackedTemperatureNGT <- stackedNGT %>%
  dplyr::mutate(stack = permil2temperature.max * stack)

minStackedTemperatureNGT <- stackedNGT %>%
  dplyr::mutate(stack = permil2temperature.min * stack)
```

- Recent 11 years versus 1961-1990 reference period:

```
t1 <- 2011 : 2001
t2 <- 1990 : 1961

# spatial slope
(mean(subsetData(stackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(stackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 1.9

# minimum slope
(mean(subsetData(minStackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(minStackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 1.1

# maximum slope
(mean(subsetData(maxStackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(maxStackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 2.6
```

- Recent 11 years versus 20th century (1901-2000):

```r
t1 <- 2011 : 2011
t2 <- 2000 : 1901

# spatial slope
(mean(subsetData(stackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(stackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 2.2

# minimum slope
(mean(subsetData(minStackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(minStackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 1.3

# maximum slope
(mean(subsetData(maxStackedTemperatureNGT, t1, var = "stack")) -
 mean(subsetData(maxStackedTemperatureNGT, t2, var = "stack"))) %>%
  round(digits = 1)
#> [1] 3.1
```

References

Masson-Delmotte, V., Steen-Larsen, H. C., Ortega, P., Swingedouw, D., Popp, T., Vinther, B. M., Oerter, H., Sveinbjornsdottir, A. E., Gudlaugsdottir, H., Box, J. E., Falourd, S., Fettweis, X., Gallée, H., Garnier, E., Gkinis, V., Jouzel, J., Landais, A., Minster, B., Paradis, N., Orsi, A., Risi, C., Werner, M. and White, J. W. C., Recent changes in north-west Greenland climate documented by NEEM shallow ice core data and simulations, and implications for past-temperature reconstructions, The Cryosphere, 9(4), 1481–1504, https://doi.org/10.5194/tc-9-1481-2015, 2015.

Vinther, B. M., Buchardt, S. L., Clausen, H. B., Dahl-Jensen, D., Johnsen, S. J., Fisher, D. A., Koerner, R. M., Raynaud, D., Lipenkov, V., Andersen, K. K., Blunier, T., Rasmussen, S. O., Steffensen, J. P. and Svensson, A. M., Holocene thinning of the Greenland ice sheet, Nature, 461(7262), 385–388, https://doi.org/10.1038/nature08355, 2009.