Tidy Data

EES 4891/5891

Probability & Statistics for Geosciences

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Learning Goals

Learning Goals

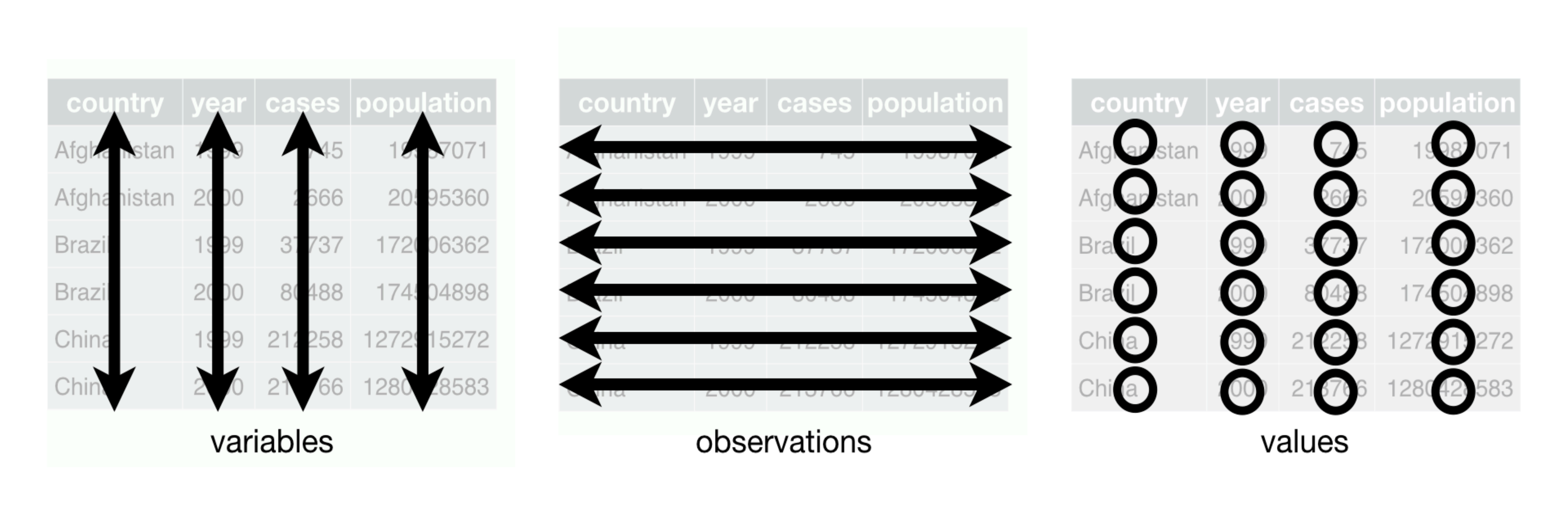
- Understand the principles of tidy data
- Learn about *cleaning* and *tidying* data
- Learn about *pivoting* data:
  - *Lengthening* data
  - *Widening* data

Tidy Data

Organizing Data in Tables

- There are many ways to organize data in a table
  - There is no best way.
  - Different questions call for different organization
- Common Principles:

1. Each column is a variable
2. Each row is an observation
3. Each cell is a value



Example

Tuberculosis incidence, reported by World Health Organization

country	year	cases	population
Afghanistan	2,000	2,666	20,595,360
Afghanistan	2,010	12,947	28,397,812
Brazil	2,000	80,488	174,504,898
Brazil	2,010	70,848	195,210,154
China	2,000	213,766	1,280,428,583
China	2,010	869,092	1,359,821,465

country	year	type	count
Afghanistan	2,000	cases	2,666
Afghanistan	2,000	population	20,595,360
Afghanistan	2,010	cases	12,947
Afghanistan	2,010	population	28,397,812
Brazil	2,000	cases	80,488
Brazil	2,000	population	174,504,898
Brazil	2,010	cases	70,848
Brazil	2,010	population	195,210,154
China	2,000	cases	213,766
China	2,000	population	1,280,428,583
China	2,010	cases	869,092
China	2,010	population	1,359,821,465

country	year	rate
Afghanistan	2000	12.94
Afghanistan	2010	45.59
Brazil	2000	46.12
Brazil	2010	36.29
China	2000	16.69
China	2010	63.91

Rate = cases per 100,000 population.

Tidy Data Principles

- Principles:
  1. Each column is a variable
  2. Each row is an observation
  3. Each cell is a value
- Advantages:
  - Consistency makes it easier to do analysis
    - You can reuse analysis code and methods
  - It's more efficient for R to work with *vectors* of data, and that's how columns are stored

Digression: R data types

- R has many data types.
- Important categories:
  - **Atomic data:** one number, character string, etc.
    - `3.7`, `"foo"`
  - **Vectors:** multiple atoms, all of the same type:
    - `c(3.7, 4.2, 17.6)`, `c("foo", "bar")`
  - **Lists:** multiple atoms, vectors, or lists, which can be different types:
    - `list(1, 2, "three")`, `list(c(1, 2, 3), c("one", "two", "three"))`
  - **Data frames:** are lists of vectors. Each column is a vector.
- Vectors and lists can have named elements:

```
x <- c(height = 7.2, mass = 10.3, volume =
        327)
y <- c(surname = "Jones", given = "Sam")
z <- list(sample_id = "S12.3", pH = 6.3,
          salinity = 10.3,
          contaminants = c("As", "Cd", "Pb"))
```

- Indexing contents:
  - **vectors:**
    - `x["height"]`, `y["surname"]`, or `x[1]`, `y[2]`
    - `x[c("height", "mass")]`, `x[1:3]`
  - **lists:**
    - `z[["sample_id"]]` or `z[[2]]` or `z$salinity`
    - `z[c("sample_id", "pH")]`
    - Single brace `[` returns a list, double braces `[[` and `$` return a bare element

Vectors, Lists, and Data Frames

- R operates more efficiently on vectors than lists
- Data frames are lists of vectors. Each column is a vector.
  - `sum()`, `mean()`, `median()`, `sd()` work much faster on vectors,
    - Getting summary statistics of a column is fast & efficient

Jura Data

Jura Data

- Soil samples from Swiss Jura, with concentrations of contaminants

```
library(gstat)
data(jura)
jura <- as_tibble(jura.val)
```

```
glimpse(jura)
```

```
## Rows: 100
## Columns: 13
## $ Xloc    <dbl> 2.672, 3.589, 4.010, 2…
## $ Yloc    <dbl> 3.558, 4.443, 4.713, 3…
## $ long    <dbl> 6.854080, 6.865951, 6.…
## $ lat     <dbl> 47.14342, 47.15144, 47…
## $ Landuse <fct> Meadow, Meadow, Pastur…
## $ Rock    <fct> Quaternary, Argovian, …
## $ Cd      <dbl> 1.570, 2.045, 1.203, 0…
## $ Co      <dbl> 8.28, 10.80, 12.00, 10…
## $ Cr      <dbl> 37.12, 40.80, 53.20, 2…
## $ Cu      <dbl> 18.600, 11.480, 13.040…
## $ Ni      <dbl> 18.60, 21.52, 23.92, 1…
## $ Pb      <dbl> 38.20, 33.36, 26.56, 2…
## $ Zn      <dbl> 65.20, 112.80, 91.60, …
```

- Remove columns `Xloc` and `Yloc`

```
jura <- jura |> select(-c(Xloc:Yloc))

print(jura)
```

```
## # A tibble: 100 × 11
##     long   lat Landuse Rock            Cd    Co    Cr    Cu    Ni    Pb    Zn
##    <dbl> <dbl> <fct>   <fct>        <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
##  1  6.85  47.1 Meadow  Quaternary   1.57   8.28  37.1 18.6   18.6  38.2  65.2
##  2  6.87  47.2 Meadow  Argovian     2.04  10.8   40.8 11.5   21.5  33.4 113. 
##  3  6.87  47.2 Pasture Argovian     1.20  12     53.2 13.0   23.9  26.6  91.6
##  4  6.86  47.1 Pasture Quaternary   0.49  10.9   23.4  5.64  14.6  25.9  41.2
##  5  6.84  47.1 Meadow  Sequanian    0.692  8.12  27.2 10.3   14.6  31.2  50.4
##  6  6.87  47.1 Forest  Kimmeridgian 1.75   9.12  35.5  8.36  26.4  37.7  63.2
##  7  6.85  47.1 Forest  Kimmeridgian 0.415  9.12  30.3  4.44  24.2  41    53.2
##  8  6.87  47.1 Pasture Sequanian    0.685 11.7   31.9 10.9   13.1  30.8  49.3
##  9  6.85  47.1 Meadow  Kimmeridgian 0.92  10.6   49.0 30.3   31.5  68.1 103. 
## 10  6.87  47.1 Forest  Kimmeridgian 2.12   6.36  23    7.35  14.5  54.4  72.4
## # ℹ 90 more rows
```

Cleaning and Wrangling Data

Cleaning and Wrangling Data

- When you get data from someone else, it's probably not in an easy format to work with.
- Example: Records of monthly CO_2 measurements from Mauna Loa Observatory:
    - Begins with 54 lines of comments
    - Column names are spread over 3 lines, with names and units.
    - Missing values are indicated by `-99.99`

```
"-------------------------------------------------------------------------------------------"
" Atmospheric CO2 concentrations (ppm) derived from in situ air measurements                "
" at Mauna Loa, Observatory, Hawaii: Latitude 19.5°N Longitude 155.6°W Elevation 3397m      "
"                                                                                           "
" Source: R. F. Keeling, S. J. Walker, S. C. Piper and A. F. Bollenbacher                   "
" Scripps CO2 Program ( http://scrippsco2.ucsd.edu )                                        "
" Scripps Institution of Oceanography (SIO)                                                 "
" University of California                                                                  "
" La Jolla, California USA 92093-0244                                                       "
"                                                                                           "
" Status of data and correspondence:                                                        "
"                                                                                           "
" These data are subject to revision based on recalibration of standard gases. Questions    "
" about the data should be directed to Dr. Ralph Keeling (rkeeling@ucsd.edu), Stephen Walker"
" (sjwalker@ucsd.edu) and Stephen Piper (scpiper@ucsd.edu), Scripps CO2 Program.            "
"                                                                                           "
" Baseline data in this file through 03-Aug-2017 from archive dated 04-Aug-2017 14:36:38    "
"                                                                                           "
"-------------------------------------------------------------------------------------------"
"                                                                                           "
" Please cite as:                                                                           "
"                                                                                           "
" C. D. Keeling, S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and       "
" H. A. Meijer, Exchanges of atmospheric CO2 and 13CO2 with the terrestrial biosphere and   "
" oceans from 1978 to 2000.  I. Global aspects, SIO Reference Series, No. 01-06, Scripps    "
" Institution of Oceanography, San Diego, 88 pages, 2001.                                   "
"                                                                                           "
" If it is necessary to cite a peer-reviewed article, please cite as:                       "
"                                                                                           "
" C. D. Keeling, S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and       "
" H. A. Meijer, Atmospheric CO2 and 13CO2 exchange with the terrestrial biosphere and       "
" oceans from 1978 to 2000: observations and carbon cycle implications, pages 83-113,       "
" in "A History of Atmospheric CO2 and its effects on Plants, Animals, and Ecosystems",     "
" editors, Ehleringer, J.R., T. E. Cerling, M. D. Dearing, Springer Verlag,                 "
" New York, 2005.                                                                           "
"                                                                                           "
"-------------------------------------------------------------------------------------------"
"                                                                                           "
" The data file below contains 10 columns.  Columns 1-4 give the dates in several redundant "
" formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per   "
" mole (ppm), reported on the 2008A SIO manometric mole fraction scale.  This is the        "
" standard version of the data most often sought.  The monthly values have been adjusted   "
" to 24:00 hours on the 15th of each month.  Column 6 gives the same data after a seasonal  "
" adjustment to remove the quasi-regular seasonal cycle.  The adjustment involves           "
" subtracting from the data a 4-harmonic fit with a linear gain factor.  Column 7 is a      "
" smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic "
" functions with linear gain.  Column 8 is the same smoothed version with the seasonal      "
" cycle removed.  Column 9 is identical to Column 5 except that the missing values from     "
" Column 5 have been filled with values from Column 7.  Column 10 is identical to Column 6  "
" except missing values have been filled with values from Column 8.  Missing values are     "
" denoted by -99.99                                                                         "
"                                                                                           "
" CO2 concentrations are measured on the '08A' calibration scale                            "
"                                                                                           "
  Yr, Mn,    Date,      Date,     CO2,seasonally,        fit,  seasonally,      CO2, seasonally
    ,   ,        ,          ,        ,  adjusted,           ,adjusted fit,   filled,adjusted filled
    ,   ,   Excel,          ,   [ppm],    [ppm] ,      [ppm],    [ppm],       [ppm],    [ppm]
1958, 01,   21200, 1958.0411,   -99.99,   -99.99,     -99.99,   -99.99,     -99.99,   -99.99
1958, 02,   21231, 1958.1260,   -99.99,   -99.99,     -99.99,   -99.99,     -99.99,   -99.99
1958, 03,   21259, 1958.2027,   315.69,   314.43,     316.19,   314.90,     315.69,   314.43
1958, 04,   21290, 1958.2877,   317.46,   315.15,     317.30,   314.98,     317.46,   315.15
1958, 05,   21320, 1958.3699,   317.51,   314.73,     317.84,   315.06,     317.51,   314.73
1958, 06,   21351, 1958.4548,   -99.99,   -99.99,     317.23,   315.14,     317.23,   315.14
1958, 07,   21381, 1958.5370,   315.86,   315.18,     315.88,   315.22,     315.86,   315.18
1958, 08,   21412, 1958.6219,   314.93,   316.17,     314.02,   315.29,     314.93,   316.17
1958, 09,   21443, 1958.7068,   313.21,   316.06,     312.48,   315.36,     313.21,   316.06
1958, 10,   21473, 1958.7890,   -99.99,   -99.99,     312.45,   315.41,     312.45,   315.41
1958, 11,   21504, 1958.8740,   313.33,   315.20,     313.62,   315.47,     313.33,   315.20
1958, 12,   21534, 1958.9562,   314.67,   315.44,     314.76,   315.52,     314.67,   315.44
1959, 01,   21565, 1959.0411,   315.58,   315.56,     315.61,   315.57,     315.58,   315.56
```

GISS Temperature Data

- Example: Records of global temperature anomalies from NASA Goddard Institute for Space Studies
  - Begins with 1 line of comments
  - Column names are straigntforward, but each month is a different column, which makes it hard to look at the whole time series.
  - Missing values are indicated by `***`.

```
Land-Ocean: Global Means
Year,Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sep,Oct,Nov,Dec,J-D,D-N,DJF,MAM,JJA,SON
1880,-.20,-.25,-.09,-.16,-.09,-.22,-.19,-.09,-.15,-.22,-.22,-.19,-.17,***,***,-.11,-.17,
1881,-.20,-.15,.02,.04,.07,-.19,.01,-.04,-.16,-.22,-.18,-.07,-.09,-.10,-.18,.05,-.07,-.1
1882,.16,.14,.05,-.16,-.13,-.22,-.16,-.07,-.14,-.23,-.17,-.36,-.11,-.08,.07,-.08,-.15,-.
1883,-.29,-.36,-.12,-.18,-.18,-.07,-.07,-.14,-.22,-.11,-.24,-.11,-.18,-.20,-.34,-.16,-.0
1884,-.13,-.08,-.36,-.40,-.33,-.35,-.31,-.28,-.27,-.25,-.33,-.31,-.28,-.27,-.11,-.37,-.3
1885,-.58,-.34,-.27,-.42,-.45,-.43,-.33,-.31,-.28,-.23,-.24,-.10,-.33,-.35,-.41,-.38,-.3
1886,-.44,-.51,-.43,-.28,-.24,-.34,-.18,-.31,-.24,-.28,-.28,-.26,-.31,-.30,-.35,-.32,-.2
1887,-.72,-.57,-.36,-.35,-.31,-.25,-.26,-.36,-.26,-.36,-.26,-.33,-.36,-.36,-.52,-.34,-.2
```

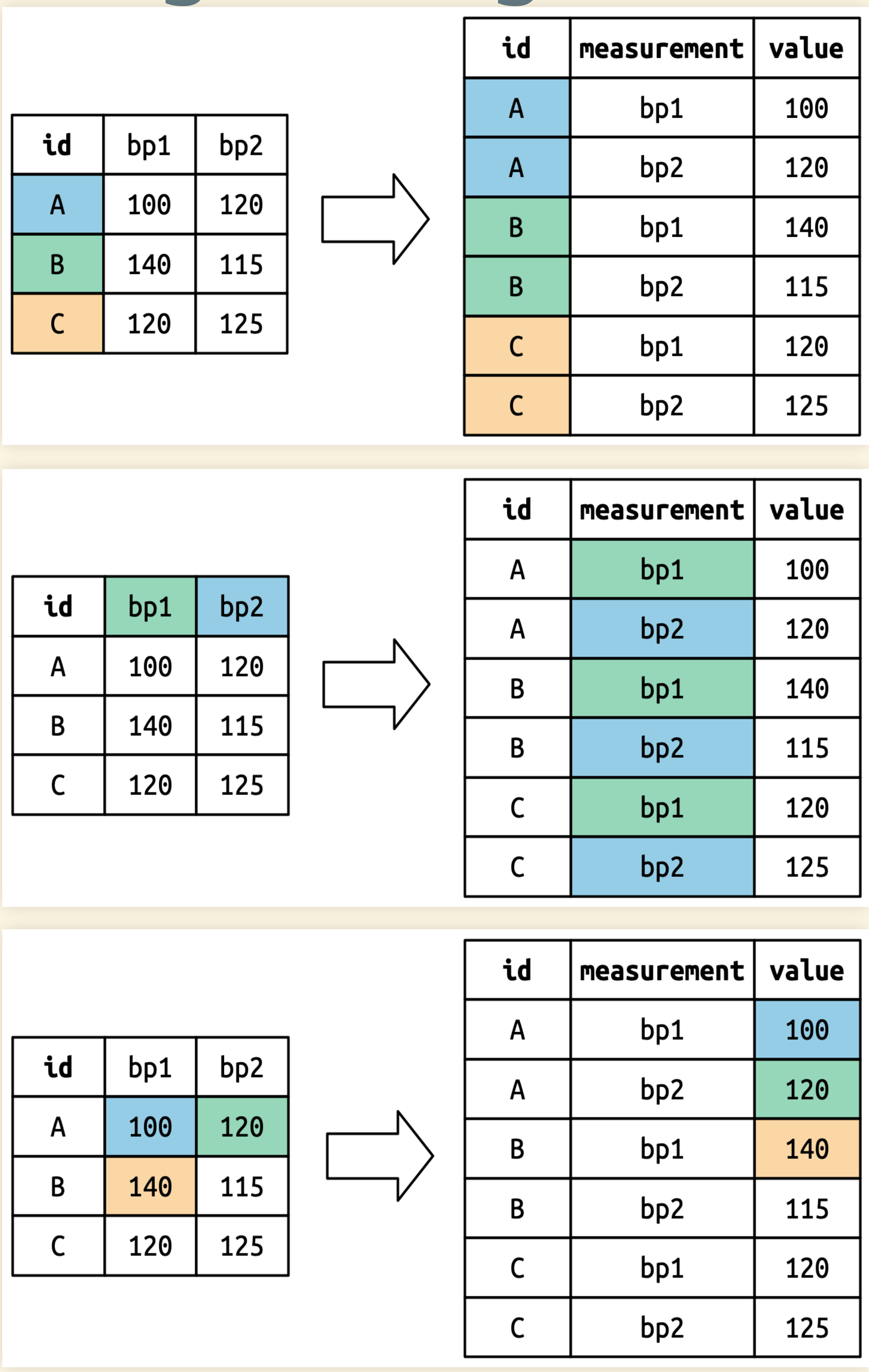
Cleaning and Wrangling Data

- A large part of any statistical analysis project is
  - **Reading the data** into R,
  - **Cleaning the data:**
    - Managing missing data, identifying and fixing transcription errors, etc.)
  - **Wrangling the data:**
    - Transforming the data and organizing it into a convenient form for analysis (*Tidying* the data)
- We'll talk about reading data in and *cleaning* it on Tuesday
- Today, we're looking at *tidying* it.

Pivoting Data

- Pivoting is reorganizing data by changing the row-column structure
  - **Lengthening:** Combine several columns into one, with each column going into a different row.
    - Final table has fewer columns and more rows, so it's *longer*.
  - **Widening:** Splitting one column into several columns, with multiple rows from that column being moved into several columns of a single row.
    - Final table has more columns and fewer rows, so it's *wider*.

- Lengthening Data:



Lengthening Data

Lengthening Data

Wide data frame

```
jura
```

```
## # A tibble: 100 × 11
##     long   lat Landuse Rock            Cd    Co    Cr    Cu    Ni    Pb    Zn
##    <dbl> <dbl> <fct>   <fct>        <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
##  1  6.85  47.1 Meadow  Quaternary   1.57   8.28  37.1 18.6   18.6  38.2  65.2
##  2  6.87  47.2 Meadow  Argovian     2.04  10.8   40.8 11.5   21.5  33.4 113. 
##  3  6.87  47.2 Pasture Argovian     1.20  12     53.2 13.0   23.9  26.6  91.6
##  4  6.86  47.1 Pasture Quaternary   0.49  10.9   23.4  5.64  14.6  25.9  41.2
##  5  6.84  47.1 Meadow  Sequanian    0.692  8.12  27.2 10.3   14.6  31.2  50.4
##  6  6.87  47.1 Forest  Kimmeridgian 1.75   9.12  35.5  8.36  26.4  37.7  63.2
##  7  6.85  47.1 Forest  Kimmeridgian 0.415  9.12  30.3  4.44  24.2  41    53.2
##  8  6.87  47.1 Pasture Sequanian    0.685 11.7   31.9 10.9   13.1  30.8  49.3
##  9  6.85  47.1 Meadow  Kimmeridgian 0.92  10.6   49.0 30.3   31.5  68.1 103. 
## 10  6.87  47.1 Forest  Kimmeridgian 2.12   6.36  23    7.35  14.5  54.4  72.4
## # ℹ 90 more rows
```

```
dim(jura)
```

```
## [1] 100  11
```

Long data frame

```
jura_long <- jura |>
  pivot_longer(Cd:Zn, names_to = "element",
               values_to = "conc")
jura_long
```

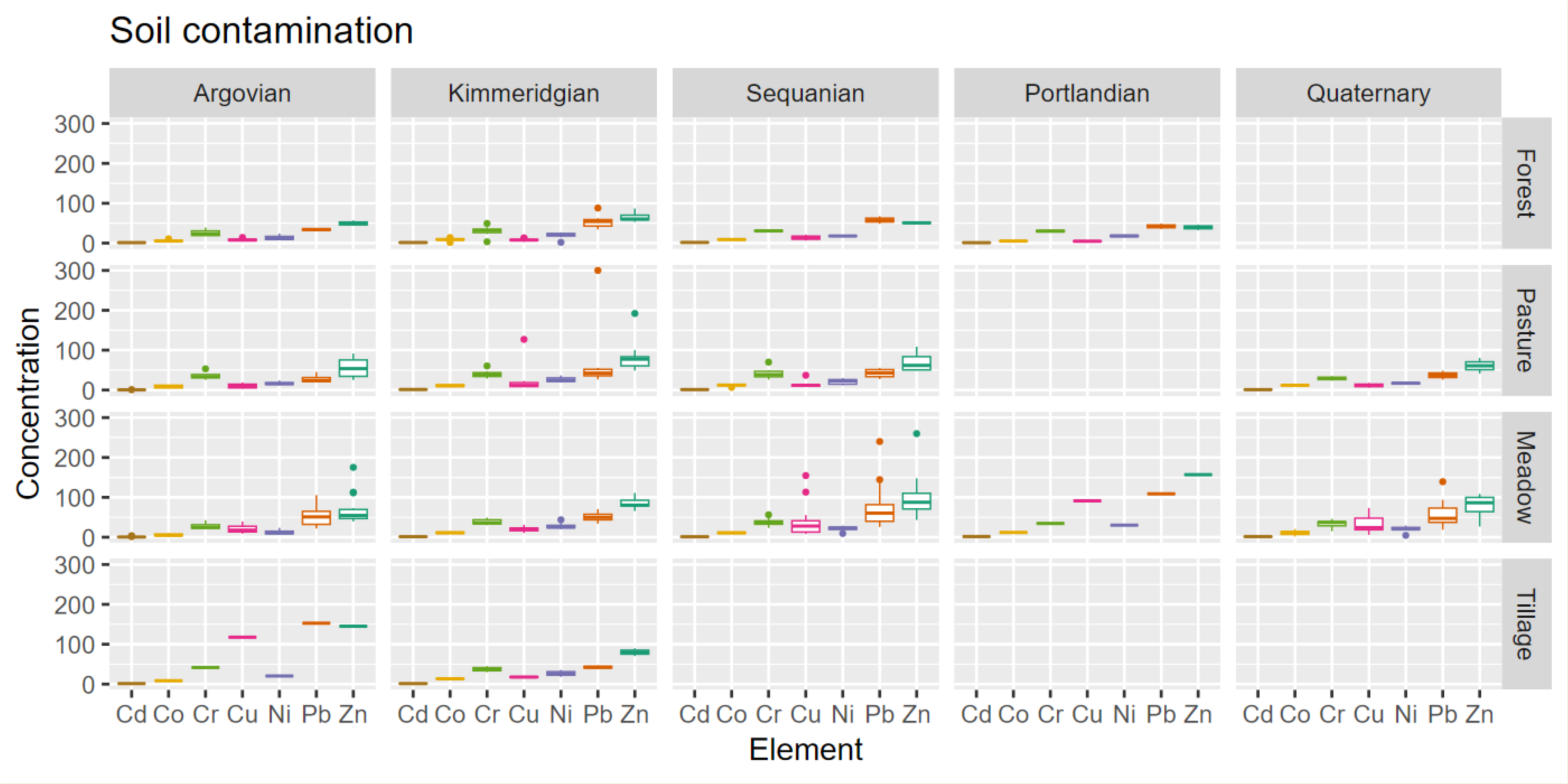
```
## # A tibble: 700 × 6
##     long   lat Landuse Rock       element  conc
##    <dbl> <dbl> <fct>   <fct>      <chr>   <dbl>
##  1  6.85  47.1 Meadow  Quaternary Cd       1.57
##  2  6.85  47.1 Meadow  Quaternary Co       8.28
##  3  6.85  47.1 Meadow  Quaternary Cr      37.1 
##  4  6.85  47.1 Meadow  Quaternary Cu      18.6 
##  5  6.85  47.1 Meadow  Quaternary Ni      18.6 
##  6  6.85  47.1 Meadow  Quaternary Pb      38.2 
##  7  6.85  47.1 Meadow  Quaternary Zn      65.2 
##  8  6.87  47.2 Meadow  Argovian   Cd       2.04
##  9  6.87  47.2 Meadow  Argovian   Co      10.8 
## 10  6.87  47.2 Meadow  Argovian   Cr      40.8 
## # ℹ 690 more rows
```

```
dim(jura_long)
```

```
## [1] 700   6
```

Using Long Data

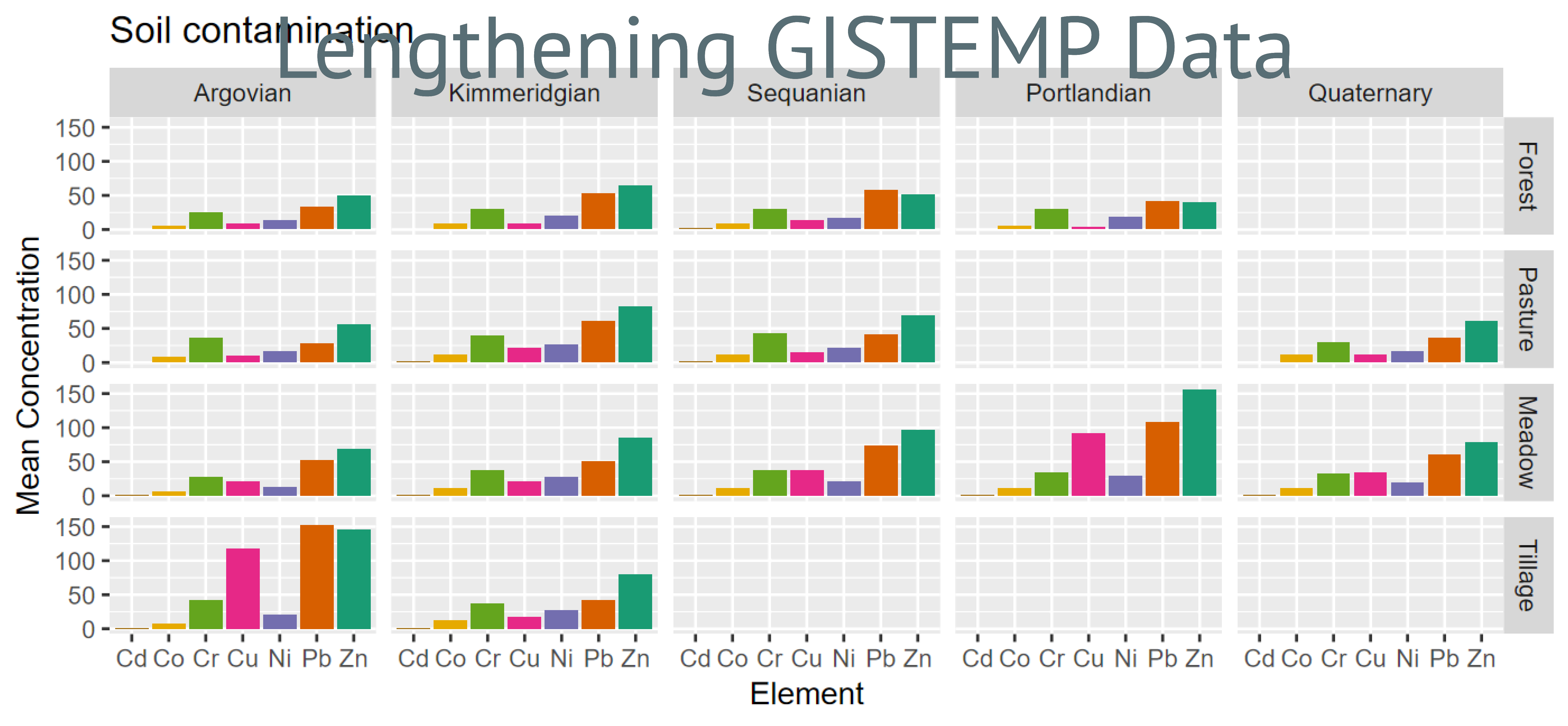
```
ggplot(jura_long, aes(x = element, y = conc, color = element)) +
  geom_boxplot() +
  labs(x = "Element", y = "Concentration", title = "Soil contamination") +
  facet_grid(Landuse ~ Rock)
```



Using Long Data

```
jura_long |>
  summarize(conc = mean(conc), .by = c("Landuse", "Rock", "element")) |>
  ggplot(aes(x = element, y = conc, fill = element)) +
  geom_col() +
  labs(x = "Element", y = "Mean Concentration", title = "Soil
        contamination") +
  facet_grid(Landuse ~ Rock)
```

Lengthening GISTEMP Data



- Wide format:

```
gistemp_data
```

```
## # A tibble: 145 × 19
##     Year   Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep   Oct   Nov   Dec `J-D` `D-N`   DJF   MAM   JJA
SON
##    <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
<dbl>
## 1  1880 -0.2  -0.25 -0.09 -0.16 -0.09 -0.22 -0.19 -0.09 -0.15 -0.22 -0.22 -0.19 -0.17 NA    NA    -0.11 -0.17
-0.2
## 2  1881 -0.2  -0.15  0.02  0.04  0.07 -0.19  0.01 -0.04 -0.16 -0.22 -0.18 -0.07 -0.09 -0.1  -0.18  0.05 -0.07
-0.19
## 3  1882  0.16  0.14  0.05 -0.16 -0.13 -0.22 -0.16 -0.07 -0.14 -0.23 -0.17 -0.36 -0.11 -0.08  0.07 -0.08 -0.15
-0.18
## 4  1883 -0.29 -0.36 -0.12 -0.18 -0.18 -0.07 -0.07 -0.14 -0.22 -0.11 -0.24 -0.11 -0.18 -0.2  -0.34 -0.16 -0.09
-0.19
## 5  1884 -0.13 -0.08 -0.36 -0.4  -0.33 -0.35 -0.31 -0.28 -0.27 -0.25 -0.33 -0.31 -0.28 -0.27 -0.11 -0.37 -0.31
-0.28
## # ℹ 140 more rows
```

- Long format:

```
print(gistemp_data_long, n = 7)
```

```
## # A tibble: 1,740 × 3
##     Year month anomaly
##    <dbl> <chr>   <dbl>
## 1  1880 Jan     -0.2
## 2  1880 Feb     -0.25
## 3  1880 Mar     -0.09
## 4  1880 Apr     -0.16
## 5  1880 May     -0.09
## 6  1880 Jun     -0.22
## 7  1880 Jul     -0.19
## # ℹ 1,733 more rows
```

Fancier Lengthening

- `billboard` data set of songs on the Billboard top-100 charts for 2000
  - 79 columns, with chart position for weeks 1–79 after it entered the top 100.

```
## # A tibble: 317 × 79
##   artist      track date.entered   wk1   wk2   wk3
wk4
##   <chr>       <chr> <date>       <dbl> <dbl> <dbl>
<dbl>
## 1 2 Pac       Baby… 2000-02-26      87    82    72
77
## 2 2Ge+her     The … 2000-09-02      91    87    92
NA
## 3 3 Doors D… Kryp… 2000-04-08      81    70    68
67
## 4 3 Doors D… Loser 2000-10-21      76    76    72
69
## 5 504 Boyz    Wobb… 2000-04-15      57    34    25
17
## 6 98^0        Give… 2000-08-19      51    39    34
26
## 7 A*Teens     Danc… 2000-07-08      97    97    96
95
## 8 Aaliyah     I Do… 2000-01-29      84    62    51
41
## # ℹ 309 more rows
## # ℹ 72 more variables: wk5 <dbl>, wk6 <dbl>, …
```

- We want to lengthen this to put all the chart positions into one column, and the week in

```
billboard_long <- billboard |>
  pivot_longer( cols = starts_with("wk"),
                names_to = "week", values_to = "rank")
head(billboard_long)
```

```
## # A tibble: 6 × 5
##   artist track                   date.entered week
rank
##   <chr>  <chr>                   <date>       <chr>
<dbl>
## 1 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk1
87
## 2 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk2
82
## 3 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk3
72
## 4 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk4
77
## 5 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk5
87
## 6 2 Pac  Baby Don't Cry (Keep... 2000-02-26   wk6
94
```

```
dim(billboard_long)
```

```
## [1] 24092     5
```

```
billboard_long <- billboard |>
  pivot_longer( cols = starts_with("wk"),
                names_to = "week", values_to = "rank",
                values_drop_na = TRUE)
dim(billboard_long)
```

```
## [1] 5307    5
```

Lengthening with Multiple Variables

- `who2` data on tuberculosis cases
  - Column names: `<diagnosis>_<sex>_<age group>`

```
## # A tibble: 7,240 × 58
##    country  year sp_m_014 sp_m_1524 sp_m_2534
sp_m_3544
##    <chr>   <dbl>    <dbl>     <dbl>     <dbl>
<dbl>
##  1 Afghan…  1980       NA        NA        NA
NA
##  2 Afghan…  1981       NA        NA        NA
NA
##  3 Afghan…  1982       NA        NA        NA
NA
##  4 Afghan…  1983       NA        NA        NA
NA
##  5 Afghan…  1984       NA        NA        NA
NA
##  6 Afghan…  1985       NA        NA        NA
NA
##  7 Afghan…  1986       NA        NA        NA
NA
##  8 Afghan…  1987       NA        NA        NA
NA
##  9 Afghan…  1988       NA        NA        NA
NA
## 10 Afghan…  1989       NA        NA        NA
NA
## 11 Afghan…  1990       NA        NA        NA
NA
## 12 Afghan…  1991       NA        NA        NA
NA
```

```r
who_long <- who2 |>
  pivot_longer(cols = !(country:year),
               names_to = c("diagnosis", "sex", "age"),
               names_sep = "_",
               values_to = "count")
print(who_long, n = 15)
```

```
## # A tibble: 405,440 × 6
##    country      year diagnosis sex   age   count
##    <chr>       <dbl> <chr>     <chr> <chr> <dbl>
##  1 Afghanistan  1980 sp        m     014      NA
##  2 Afghanistan  1980 sp        m     1524     NA
##  3 Afghanistan  1980 sp        m     2534     NA
##  4 Afghanistan  1980 sp        m     3544     NA
##  5 Afghanistan  1980 sp        m     4554     NA
##  6 Afghanistan  1980 sp        m     5564     NA
##  7 Afghanistan  1980 sp        m     65       NA
##  8 Afghanistan  1980 sp        f     014      NA
##  9 Afghanistan  1980 sp        f     1524     NA
## 10 Afghanistan  1980 sp        f     2534     NA
## 11 Afghanistan  1980 sp        f     3544     NA
## 12 Afghanistan  1980 sp        f     4554     NA
## 13 Afghanistan  1980 sp        f     5564     NA
## 14 Afghanistan  1980 sp        f     65       NA
## 15 Afghanistan  1980 sn        m     014      NA
## # ℹ 405,425 more rows
```

Widening Data

Widening Data

- Widening `jura_long`

```
## # A tibble: 700 × 6
##     long   lat Landuse Rock        element   conc
##    <dbl> <dbl> <fct>   <fct>       <chr>    <dbl>
##  1  6.85  47.1 Meadow  Quaternary Cd         1.57
##  2  6.85  47.1 Meadow  Quaternary Co         8.28
##  3  6.85  47.1 Meadow  Quaternary Cr        37.1
##  4  6.85  47.1 Meadow  Quaternary Cu        18.6
##  5  6.85  47.1 Meadow  Quaternary Ni        18.6
##  6  6.85  47.1 Meadow  Quaternary Pb        38.2
##  7  6.85  47.1 Meadow  Quaternary Zn        65.2
##  8  6.87  47.2 Meadow  Argovian   Cd         2.04
##  9  6.87  47.2 Meadow  Argovian   Co        10.8
## 10  6.87  47.2 Meadow  Argovian   Cr        40.8
## 11  6.87  47.2 Meadow  Argovian   Cu        11.5
## 12  6.87  47.2 Meadow  Argovian   Ni        21.5
## 13  6.87  47.2 Meadow  Argovian   Pb        33.4
## 14  6.87  47.2 Meadow  Argovian   Zn       113.
## 15  6.87  47.2 Pasture Argovian   Cd         1.20
## 16  6.87  47.2 Pasture Argovian   Co        12
## 17  6.87  47.2 Pasture Argovian   Cr        53.2
## 18  6.87  47.2 Pasture Argovian   Cu        13.0
## 19  6.87  47.2 Pasture Argovian   Ni        23.9
## 20  6.87  47.2 Pasture Argovian   Pb        26.6
## 21  6.87  47.2 Pasture Argovian   Zn        91.6
## 22  6.86  47.1 Pasture Quaternary Cd         0.49
## 23  6.86  47.1 Pasture Quaternary Co        10.9
## # ℹ 677 more rows
```

```
jura_sum <- jura_long |>
  summarize(conc = mean(conc, na.rm = TRUE),
            .by = c("Landuse", "Rock"))
head(jura_sum)
```

```
## # A tibble: 6 × 3
##   Landuse Rock          conc
##   <fct>   <fct>        <dbl>
## 1 Meadow  Quaternary    34.2
## 2 Meadow  Argovian      27.2
## 3 Pasture Argovian      22.5
## 4 Pasture Quaternary    24.1
## 5 Meadow  Sequanian     40.0
## 6 Forest  Kimmeridgian  26.7
```

```
jura_wide <- jura_sum |>
  pivot_wider(names_from = "Landuse", values_from =
          "conc")
head(jura_wide)
```

```
## # A tibble: 5 × 5
##   Rock         Meadow Pasture Forest Tillage
##   <fct>         <dbl>   <dbl>  <dbl>   <dbl>
## 1 Quaternary     34.2    24.1   NA      NA
## 2 Argovian       27.2    22.5   20.0    69.6
## 3 Sequanian      40.0    29.2   25.9    NA
## 4 Kimmeridgian   33.5    34.5   26.7    31.3
## 5 Portlandian    62.2    NA     20.1    NA
```