Data Visualization
Discover, Explore and be Skeptical

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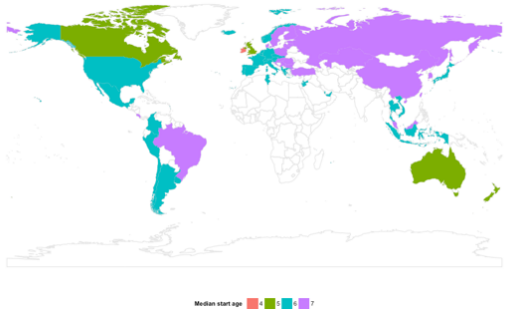
Seminar 1
Exploratory Data Analysis

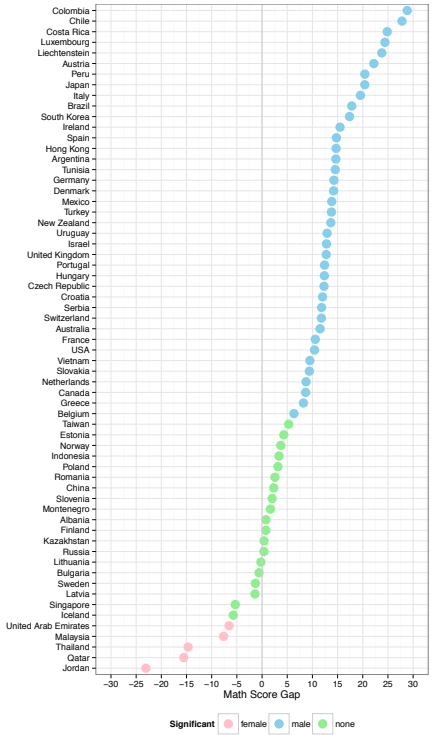


DATA

Results from 2012 OECD PISA tests: "the world's global metric for quality, equity and efficiency in school education".

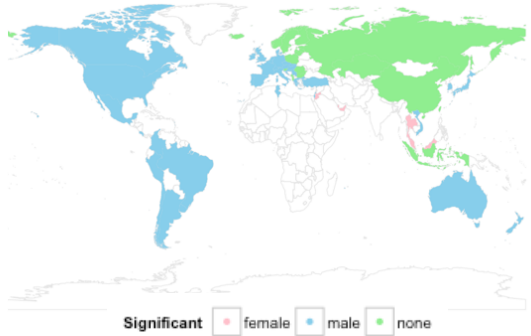
- 485,490 students math, science and reading test scores
- 65 countries, between 100-1500 schools in each
- Student questionnaires about their environment (635 vars)
- Parents surveyed on work, life, income (143 vars)
- Principals provide information about their schools (291 vars)

`http://www.oecd.org/pisa/pisaproducts/datavisualizationcontest.htm`

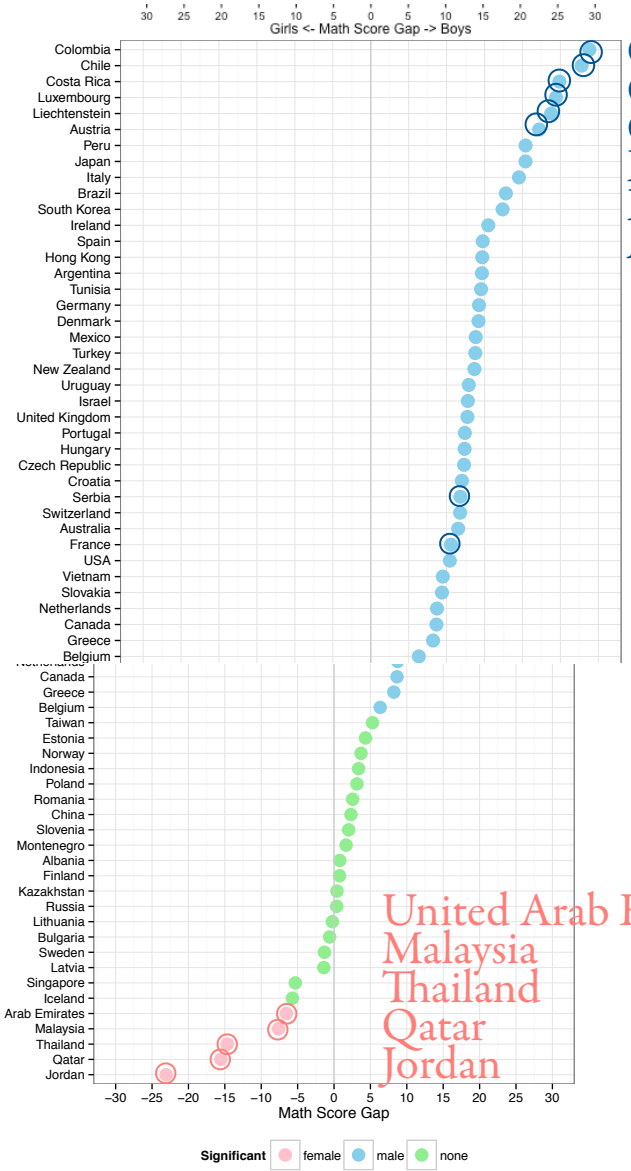


Gender & Math

1. Compute weighted means by country and by gender.
2. Show mean difference by country
3. t-test of difference (unadjusted)



Gender & Math



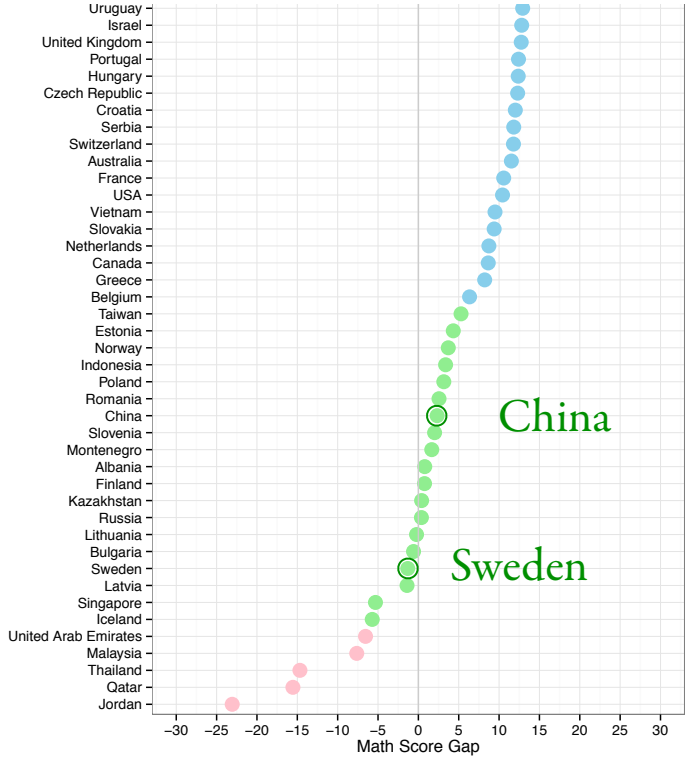
Colombia
Chile
Costa Rica
Luxembourg
Liechtenstein
Austria

Switzerland
USA

United Arab Emirates
Malaysia
Thailand
Qatar
Jordan

Surprise!

Gender & Math



China

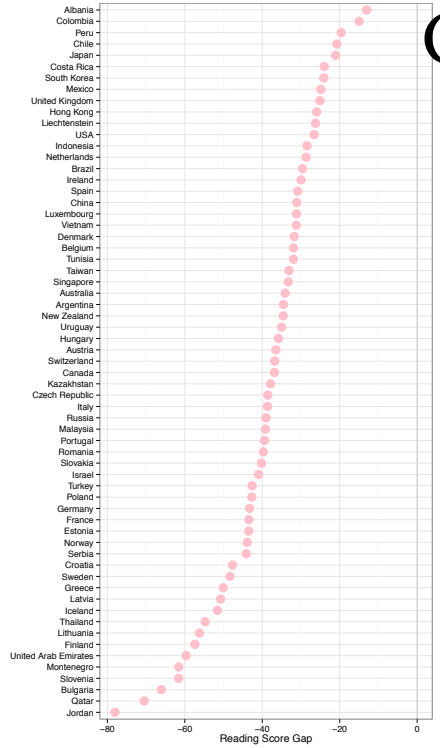
Sweden

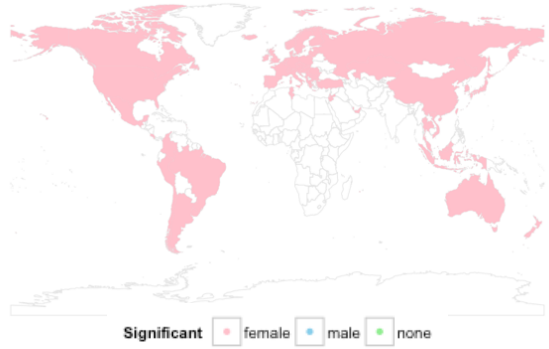
Gender & Math

United Arab Emirates
Malaysia
Thailand
Qatar
Jordan

Surprise!

Gender & Reading

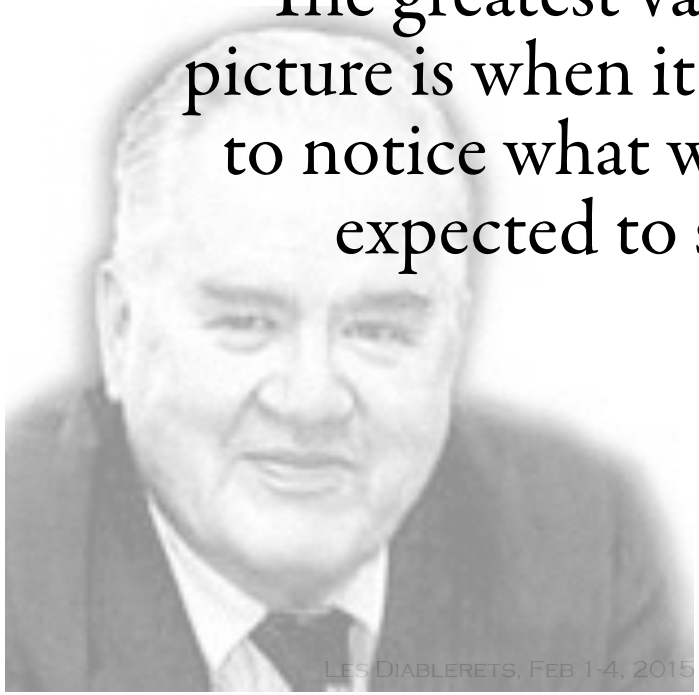




Surprised again

In reading scores, the world is PINK!
In EVERY COUNTRY tested GIRLS score significantly BETTER THAN BOYS. Why don't we talk about the gender gap in reading?

"The greatest value of a picture is when it forces us to notice what we never expected to see."

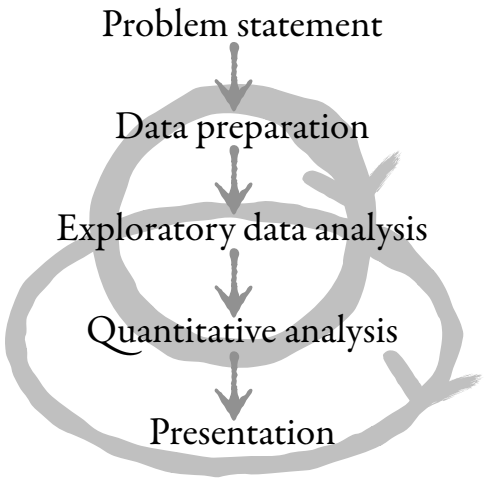


"Show the data."

Examples

- OECD PISA 2012
- CO_2 Emissions and Climate Change
- Sports: tennis

Data analysis



Exploratory data analysis

Relax the focus on the problem statement and explore broadly different aspects of the data.

Good pictures of the data provide unexpected insights, or can confirm expectations

Let the data inform = show the data

Facilitated by ~interactive~ graphics

Time to play in the sand!

EDA vs IDA

- EDA and IDA (Chatfield; Crowder & Hand), although not entirely distinct, differ in emphasis.
- Fundamental to EDA is the desire to let the data inform us, to approach the data without pre-conceived hypotheses, so that we may discover unexpected features. Of course, some of the unexpected features may be errors in the data. IDA emphasizes finding these errors by checking the quality of data prior to formal modeling.
- IDA is much more closely tied to inference than EDA: Problems with the data that violate the assumptions required for valid inference need to be discovered and fixed early.

Data snooping

- Because EDA is very graphical, it sometimes gives rise to a suspicion that patterns in the data are being detected and reported that are not really there.
- This is called data snooping.
- Validation of findings, by all means possible, is an important component of data analysis.

Data snooping

"In our experience, false discovery is the lesser danger when compared to nondiscovery. Nondiscovery is the failure to identify meaningful structure, and it may result in false or incomplete modeling. In a healthy scientific enterprise, the fear of nondiscovery should be at least as great as the fear of false discovery." (Buja's remark on discussion on Koschat & Swayne (1996))

PISA 2012 Process

- Files distributed as an external representation of an R object (`.rda` file), dictionary files=variable coding.
- Read in all files to R, browse size of files, dictionary of items, make some tables/pictures
- Make a list of questions to explore
- Read map data from `rworldmap` package, coordinate names for all countries in OECD data, and merge polygons with subset of variables

Example

```
> head(dict_student2012, 20)
   variable                                                                    description
1       CNT                                                          Country code 3-character
2  SUBNATIO Adjudicated sub-region code 7-digit code (3-digit country code + region ID + stratum ID)
3   STRATUM                          Stratum ID 7-character (cnt + region ID + original stratum ID)
4      OECD                                                                  OECD country
5        NC                                                  National Centre 6-digit Code
6  SCHOOLID                          School ID 7-digit (region ID + stratum ID + 3-digit school ID)
7   STIDSTD                                                                    Student ID
8   ST01Q01                                                          International Grade
9   ST02Q01                                                       National Study Programme
10  ST03Q01                                                             Birth - Month
11  ST03Q02                                                              Birth -Year
12  ST04Q01                                                                   Gender
13  ST05Q01                                                        Attend <ISCED 0>
14  ST06Q01                                                        Age at <ISCED 1>
15  ST07Q01                                                      Repeat - <ISCED 1>
16  ST07Q02                                                      Repeat - <ISCED 2>
17  ST07Q03                                                      Repeat - <ISCED 3>
18  ST08Q01                                                   Truancy - Late for School
19  ST09Q01                                                Truancy - Skip whole school day
20 ST115Q01                                          Truancy - Skip classes within school day
…
```

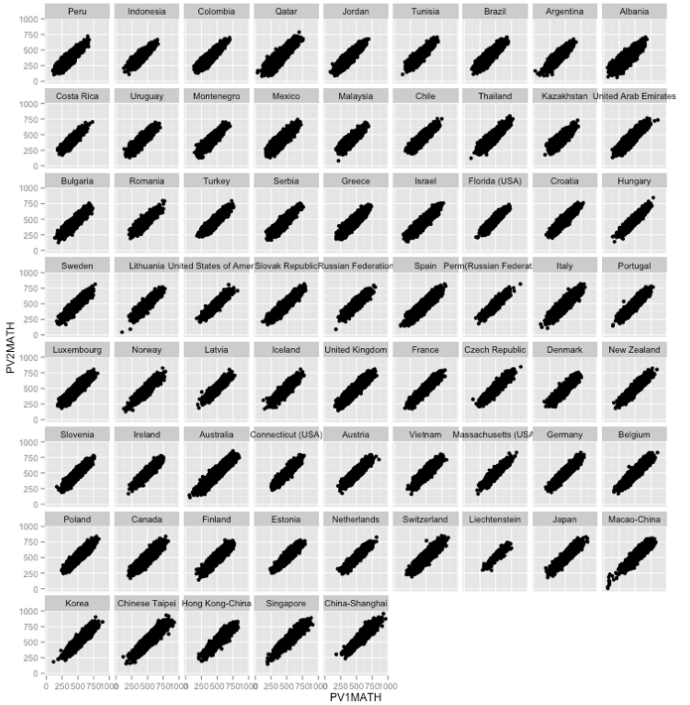

Example

```
> tail(dict_student2012, 5)
     variable                                                  description
631   W_FSTR80                  FINAL STUDENT REPLICATE BRR-FAY WEIGHT80
632   WVARSTRR                  RANDOMIZED FINAL VARIANCE STRATUM (1-80)
633   VAR_UNIT                          RANDOMLY ASSIGNED VARIANCE UNIT
634 SENWGT_STU Senate weight - sum of weight within the country is 1000
635    VER_STU                             Date of the database creation
```

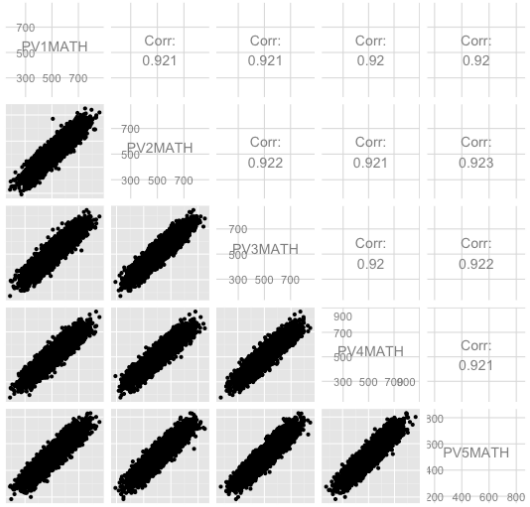
Example

```
> sort(table(student2012$CNT))
        Liechtenstein       Connecticut (USA)  Massachusetts (USA) Perm(Russian Federation)
                  293                    1697                    1723                    1761
        Florida (USA)               Iceland             New Zealand                  Latvia
                 1896                    3508                    4291                    4306
              Tunisia           Netherlands              Costa Rica                  Poland
                 4407                    4460                    4602                    4607
               France           Lithuania        Hong Kong-China          Slovak Republic
                 4613                    4618                    4670                    4678

                                          ...

  Russian Federation              Luxembourg                Bulgaria                 Uruguay
                5231                    5258                    5282                    5315
      Czech Republic               Macao-China               Singapore               Indonesia
                5327                    5335                    5546                    5622
            Portugal              Kazakhstan               Argentina                Slovenia
                5722                    5808                    5908                    5911
                Peru          Chinese Taipei                   Japan                Thailand
                6035                    6046                    6351                    6606
               Chile                  Jordan                 Denmark                 Belgium
                6856                    7038                    7481                    8597
             Finland                Colombia                   Qatar             Switzerland
                8829                    9073                   10966                   11229
United Arab Emirates          United Kingdom               Australia                  Brazil
               11500                   12659                   14481                   19204
              Canada                   Spain                   Italy                  Mexico
               21544                   25313                   31073                   33806
```

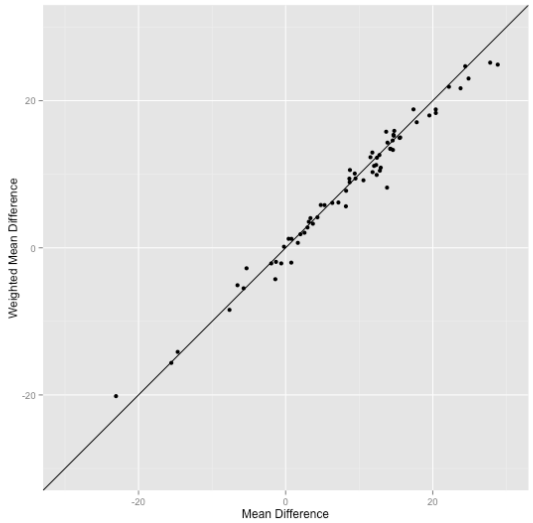

Compare plausible values



Compare plausible values for Switzerland



Do sample weights matter?



Questions

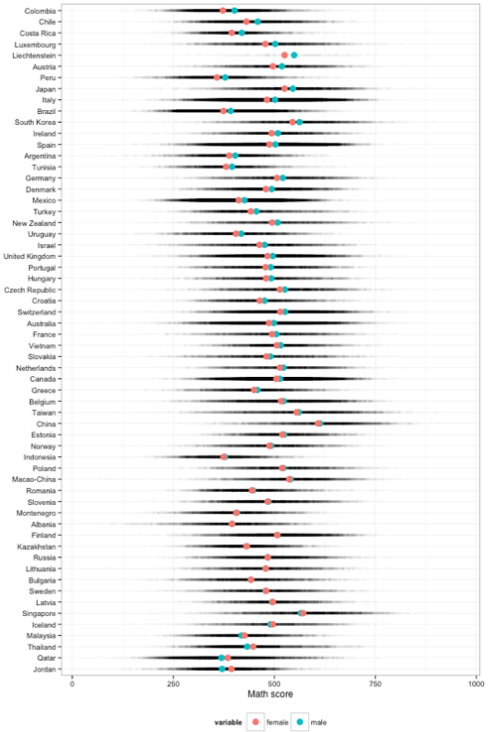
- Is the gender gap evident in the math scores?
- Do students work hard outside school hours? And does this pay off in better scores?
- Does truancy affect performance?
- Do more household possessions mean better performance?
- Do parents matter?

...

Expectations

- Gender gap: "boys are better at math"
- USA doesn't perform well compared to other countries.
- I would expect parents, time studying and socioeconomic status to be important influences on performance.

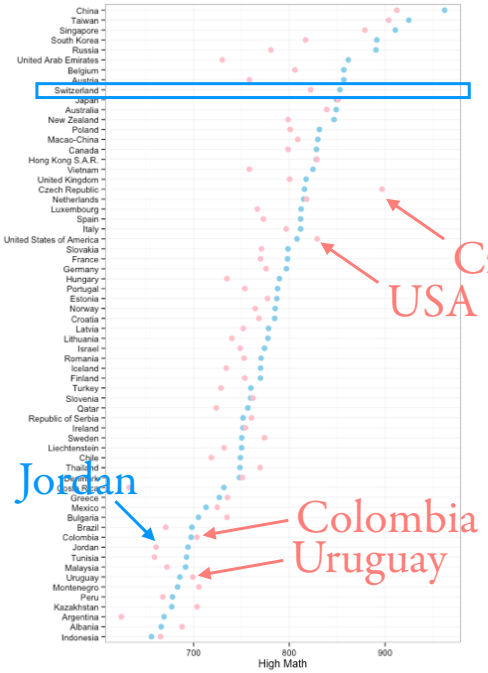
Look at the individuals, not just summary statistics



Individuals

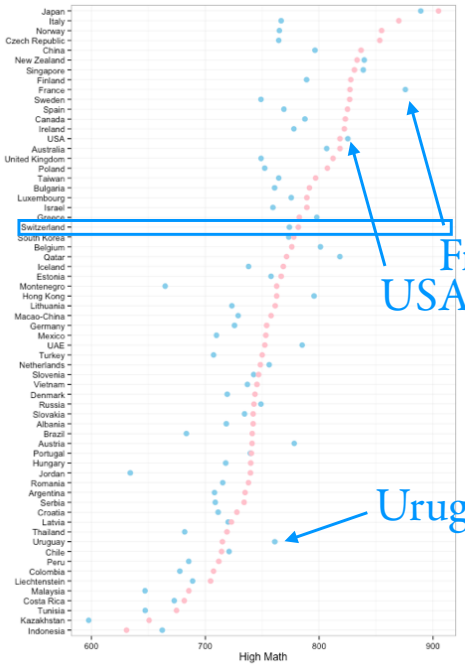
- Test scores range from 0-1000.
- Gaps for math were at most 30 points.
- For reading at most 80 points.
- *Differences are tiny.*

Individuals



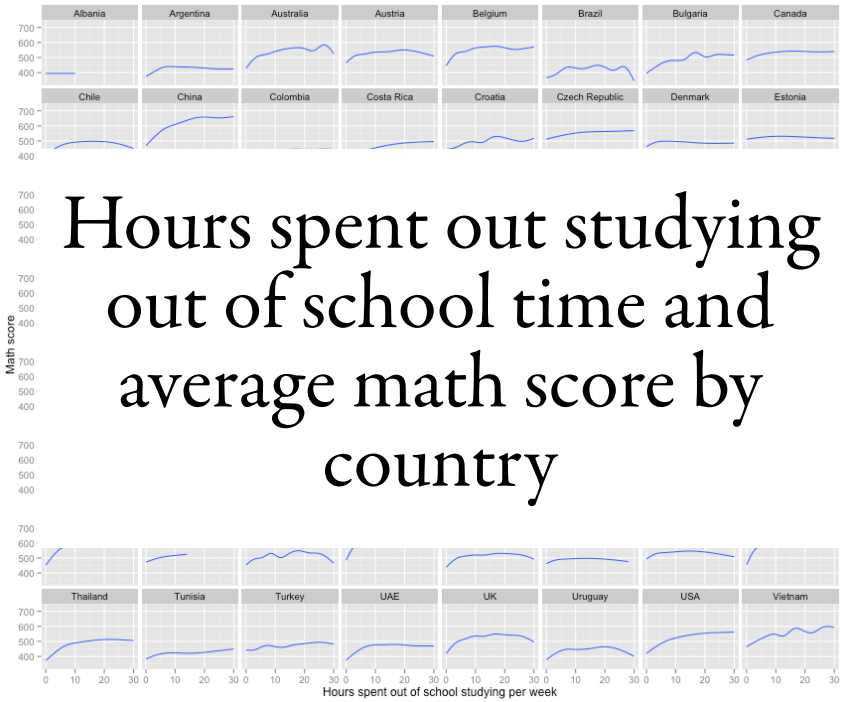
- Even countries with a math gender gap, sometimes have a girl who scored the top mark.

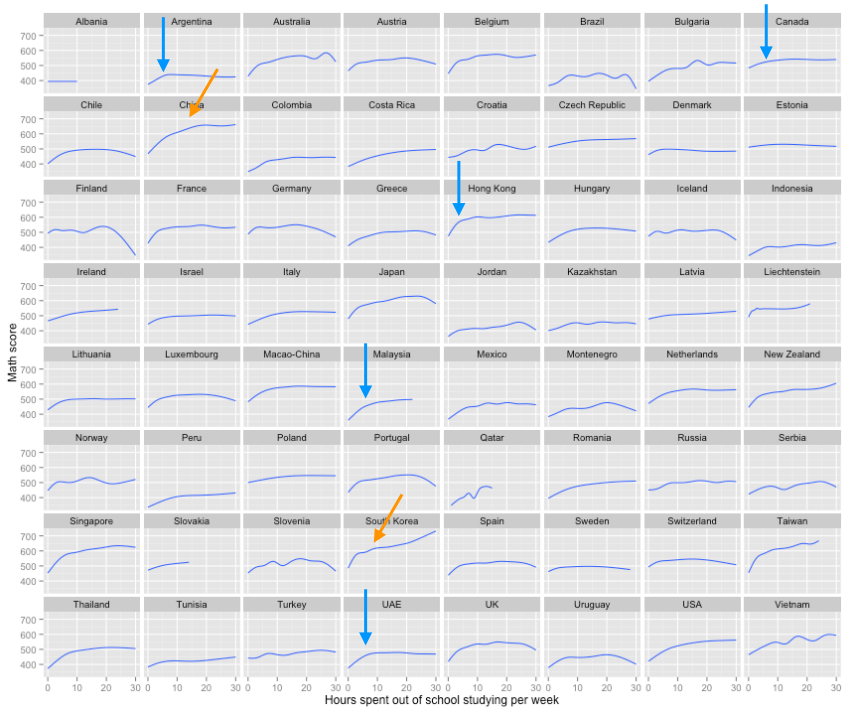
Individuals

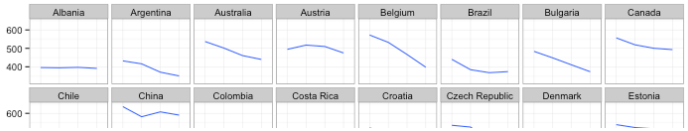


- And although there is a gender gap in reading in all countries, individually some top reading scores are obtained by boys.

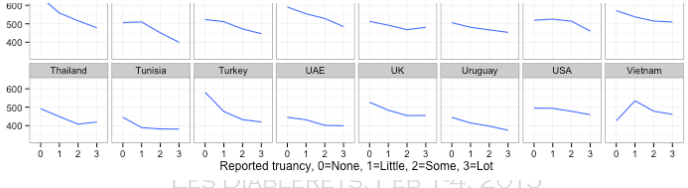
Hours spent out studying out of school time and average math score by country

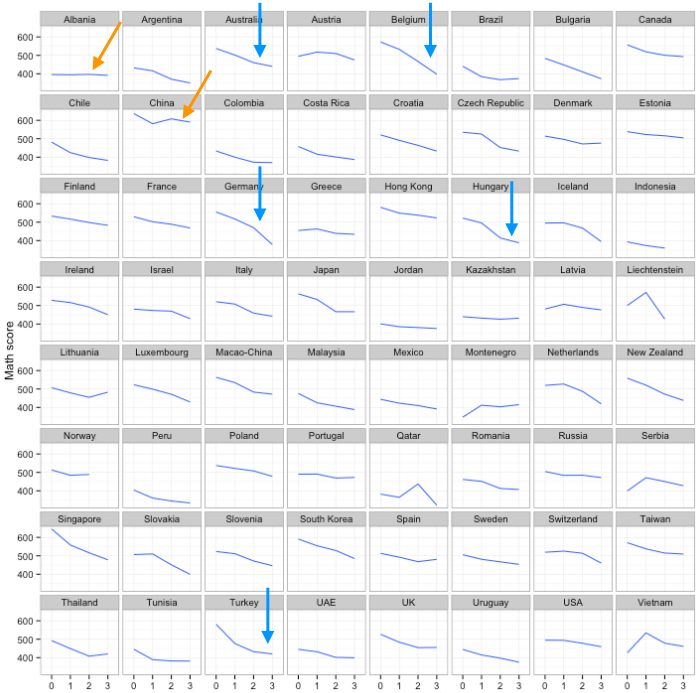


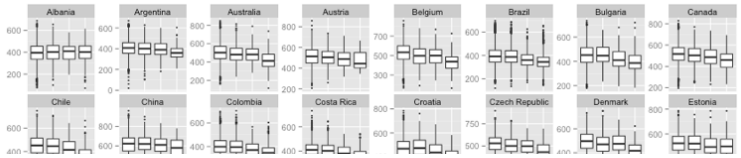




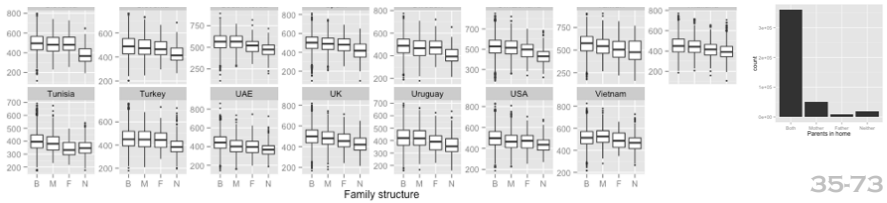
Reported truancy and average math score by country

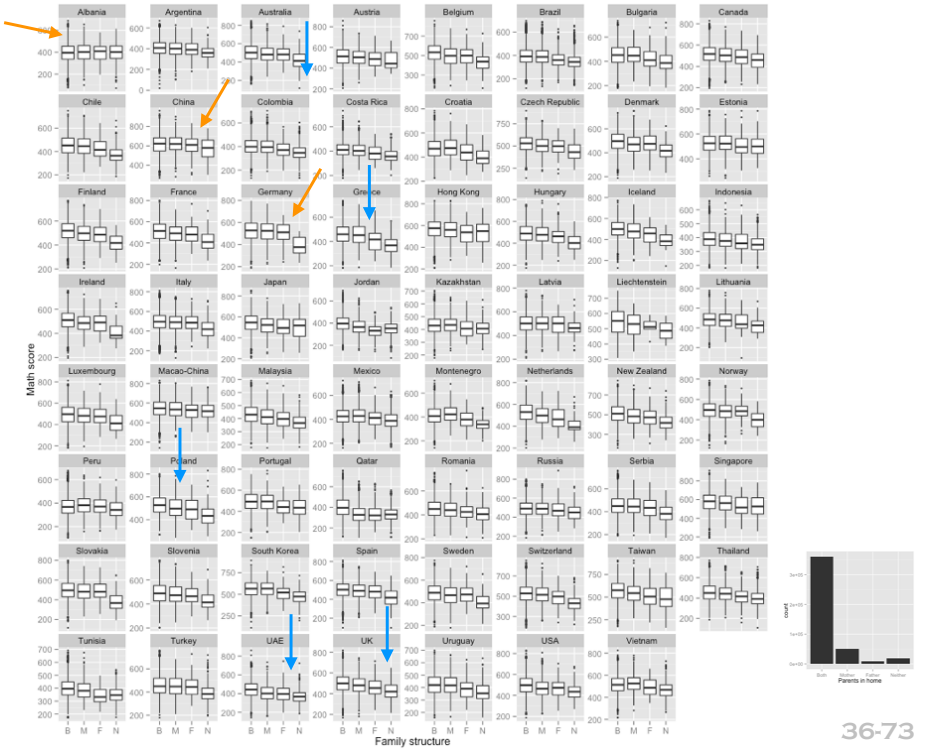


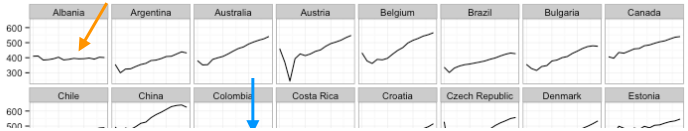




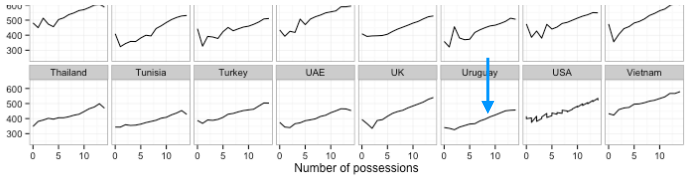
Parents in the home and average math score by country

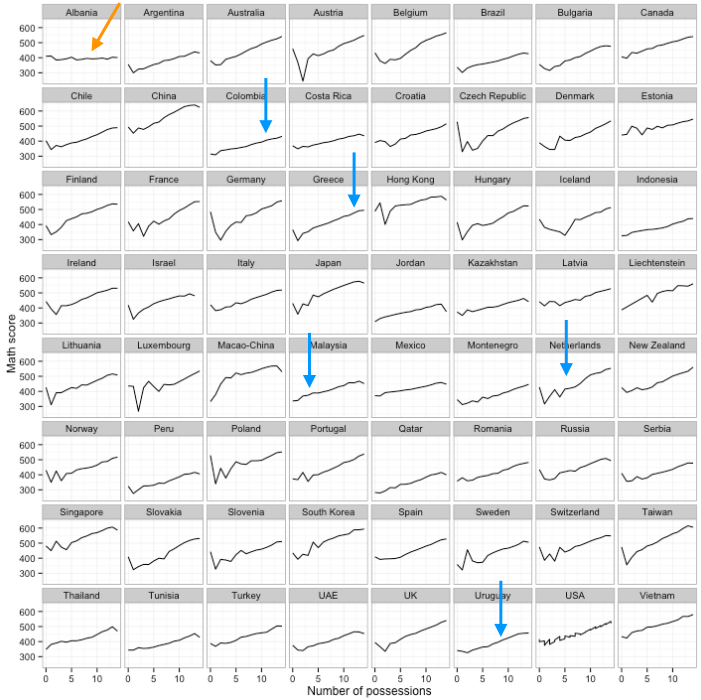


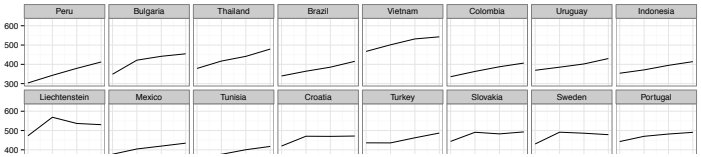




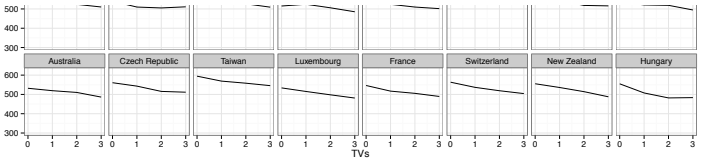
Possessions and average math score by country

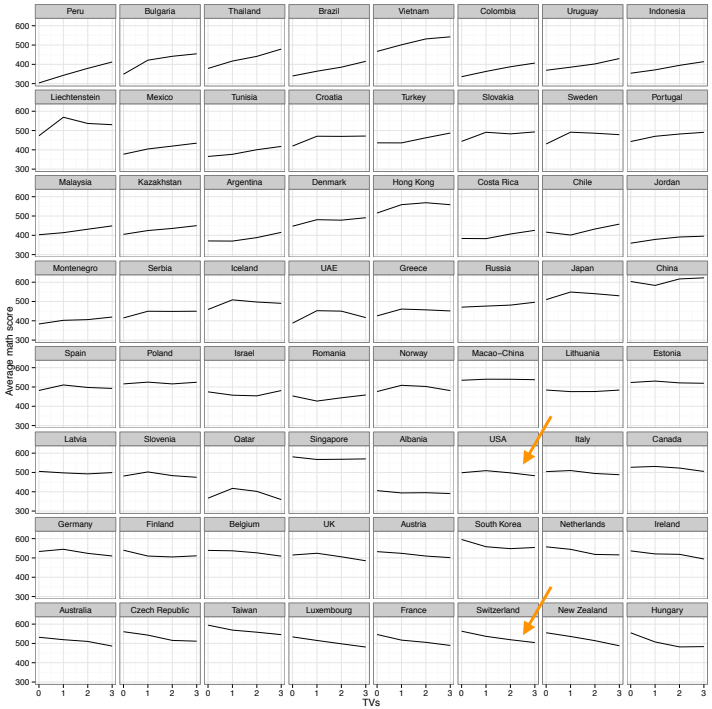




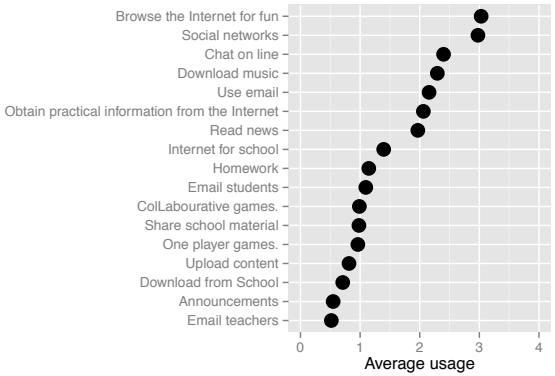


Number of TVs and average math score by country





Reported internet use by Swiss teens



"Never or hardly ever" = 0
"Once or twice a month" =1
"Once or twice a week" = 2
"Almost every day" = 3
"Every day" = 4

What we learned

- Gender gap is not universal in math.
- Gender gap is universal in reading.
- Individual differences trump everything else.
- Parents matter! Mothers more than fathers!
- Socioeconomic status matters.
- Turn the TV off, if you live in a developed country!
- Something's funny about Albania's data.

Your Turn

Take two minutes to brainstorm with your neighbors.

- Based on the data, what other things would you like to investigate?
- What calculations, tables, plots would you make to tackle these questions?

Graphics choices

- Sorting!
- Ordered dot plots
- Line plots
- Histograms
- Showing stats vs all values
- Uncertainty - barcharts of category counts

Climate change

CO2 alarm bells?

"Planet's CO_2 level reaches 400 ppm for first time in human existence."

"It's not a question of if air capture technology will be adopted; it's a question of when," said Klaus Lackner

"In the last 80 years, as CO_2 emissions have most rapidly escalated, the annual rate of climate-related deaths worldwide fell by an incredible 98%. This means the incidence of death from climate is 50 times lower than it was 80 years ago," writes Epstein.

Climate change

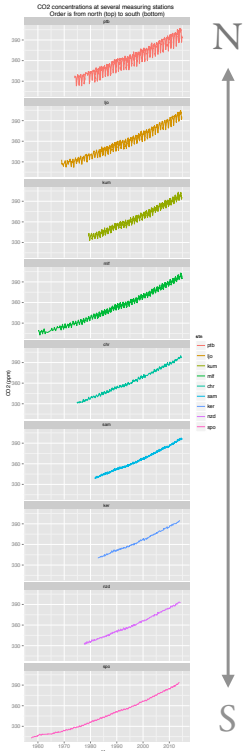
Data available at http://scrippsco2.ucsd.edu

```
> head(CO2.all)
        date   time      day  decdate n flg    co2  lat    lon stn
1 1997-01-21  13:40 35451.57 1997.056 4   0 365.82 23.3 -110.2 bcs
2 1997-02-08  15:03 35469.63 1997.106 2   0 365.57 23.3 -110.2 bcs
3 1997-02-22  15:07 35483.63 1997.144 2   0 366.28 23.3 -110.2 bcs
4 1997-03-07  14:23 35496.60 1997.180 3   0 367.85 23.3 -110.2 bcs
5 1997-03-22  14:16 35511.59 1997.221 2   0 365.28 23.3 -110.2 bcs
6 1997-04-05  13:37 35525.57 1997.259 3   0 368.96 23.3 -110.2 bcs
…
```


Climate change

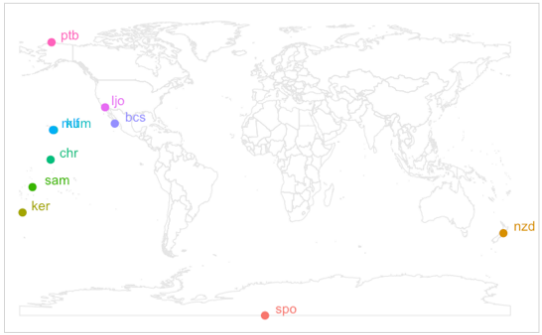
I expected:

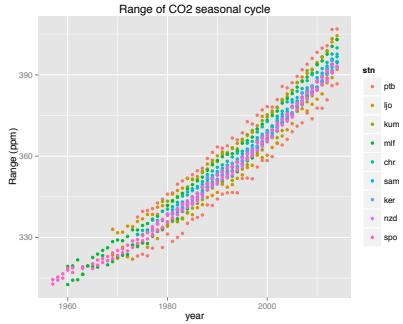
- CO2 concentrations to be flattening over time
- Raw data to look like raw data - messy

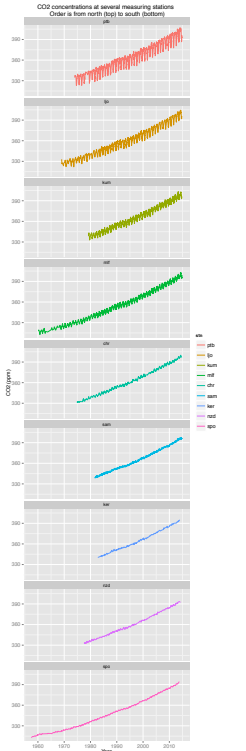


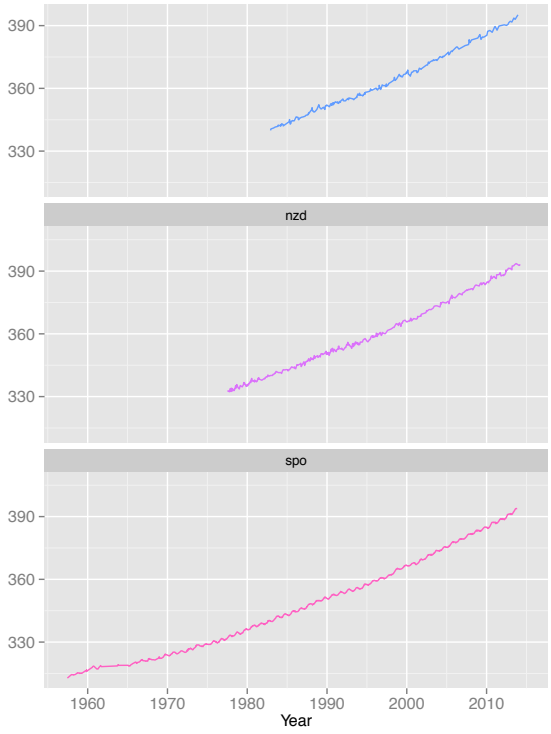
N

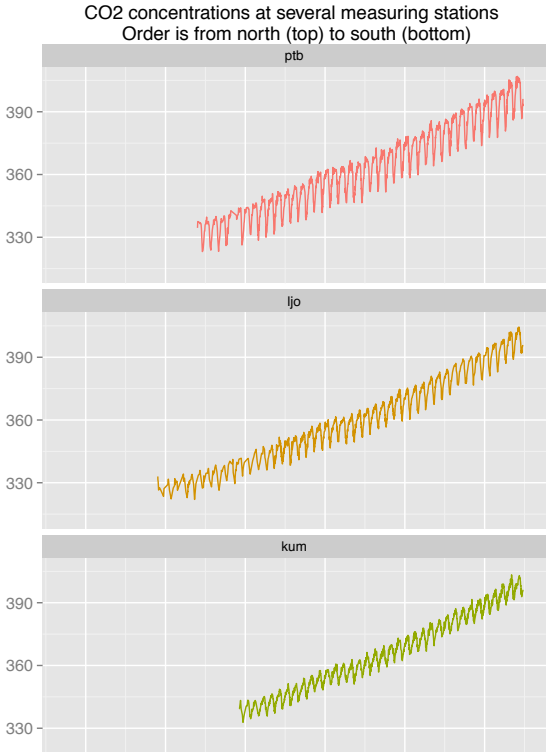
S

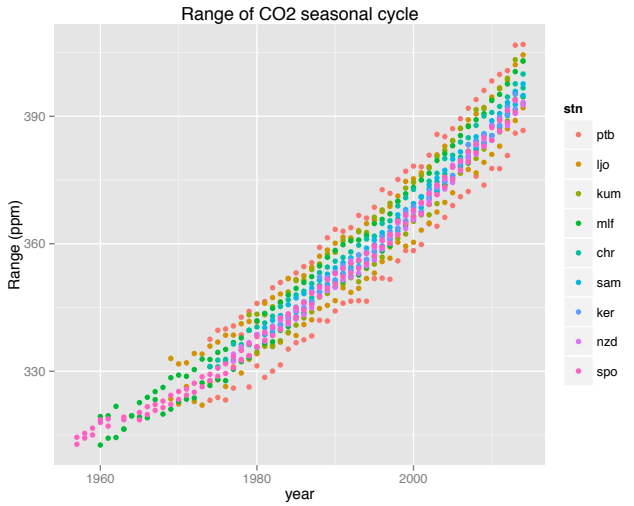




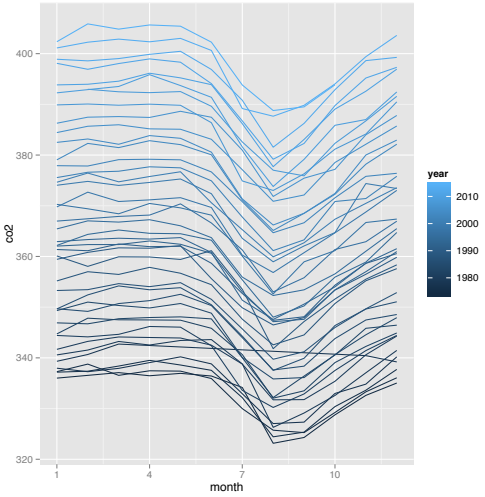






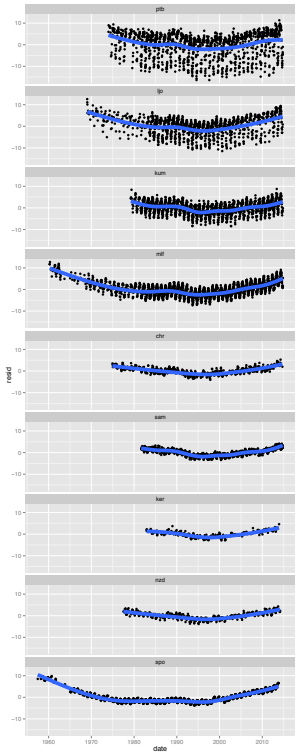


Minimum and maximum for each year and station, show that they are effectively measuring the same product

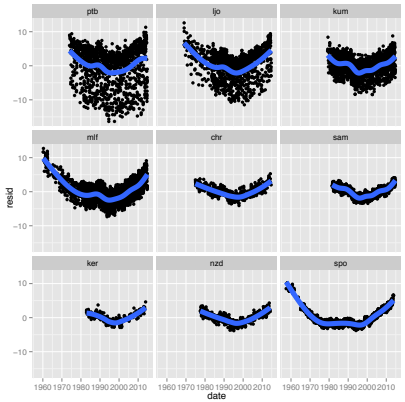


For station, ptb, most northerly station, examine monthly trend. Drop in CO_2 occurs every year in June.

Strange year is 1978, and lack measurements for summer.



Residuals from a linear model fit indicate the rate of increase is exponential.

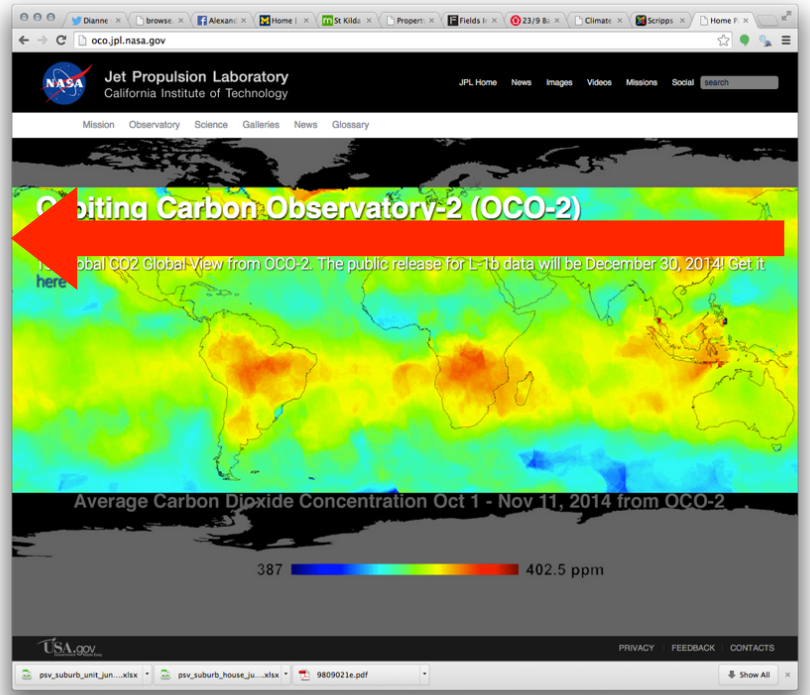


Change aspect ratio and anomalies at different sites are visible.

Climate change

Surprises:

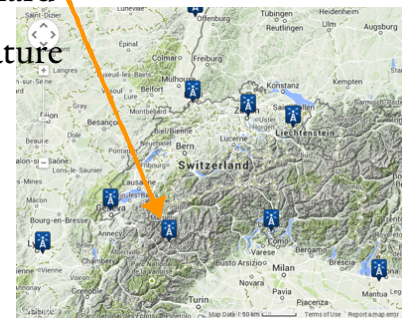
- CO2 concentrations increasing consistently.
- Northern stations show seasonality.
- Data looks very regular. Every recording station essentially producing same values, ignoring seasonality, with a few slight anomalies.



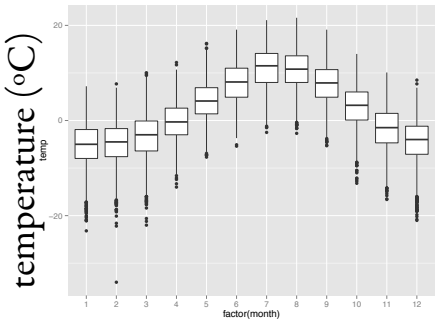
Climate change

What's happening near Les Diablerets?

- Global Historical Climatological Network data
- Station: Col du Grand St Bernard
- Minimum/maximum temperature and precipitation



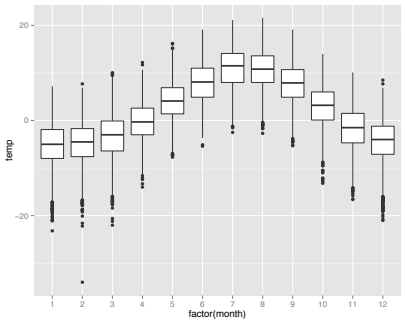
`ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/readme.txt`



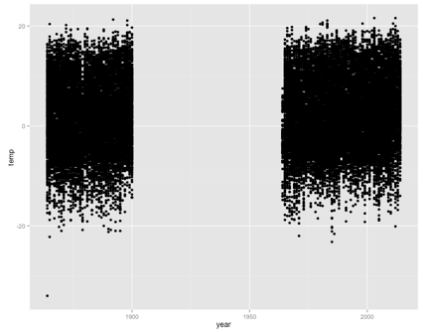
Maximum daily temperature

Seasonal trend visible from plotting temperature by month

Temperature does NOT reach freezing in SUMMER occasionally



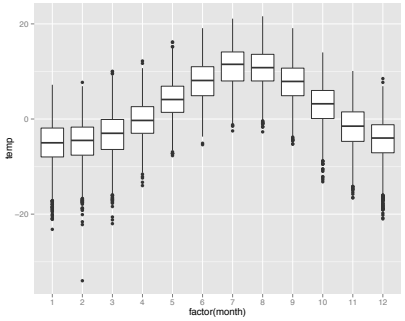
Maximum daily temperature

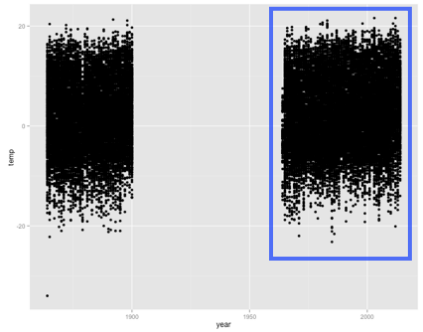


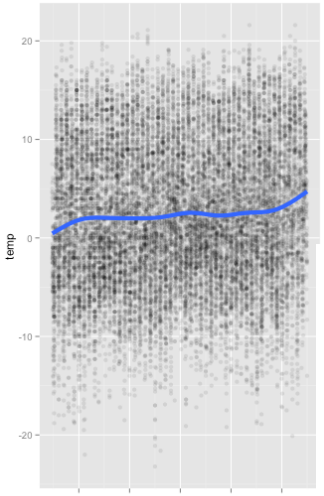
Plot of temperature by year reveals a big gap in measurements!

May need to focus on one period or the other.

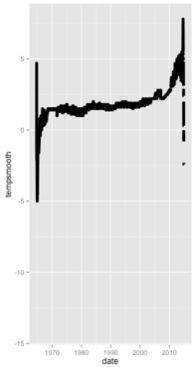
Maximum daily temperature



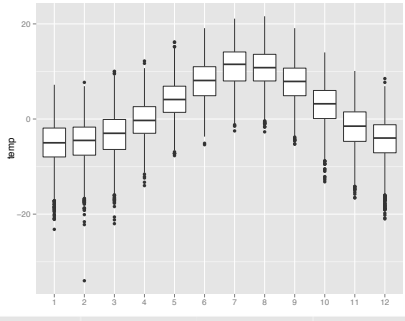


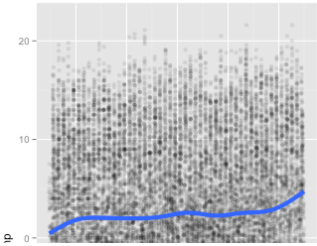


Increasing?

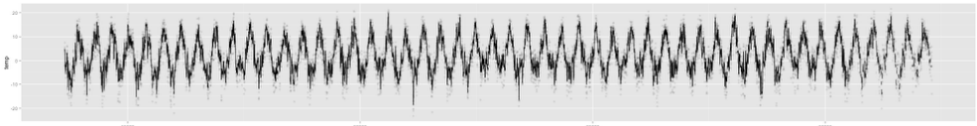


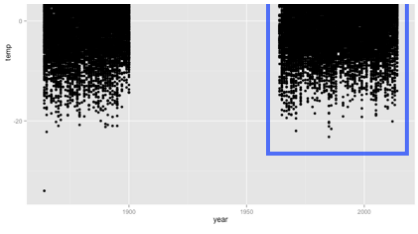
Maximum daily temperature

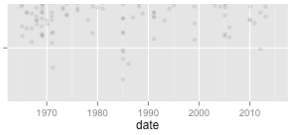


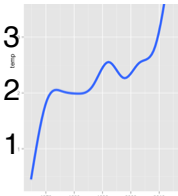


Change aspect ratio for studying season effects





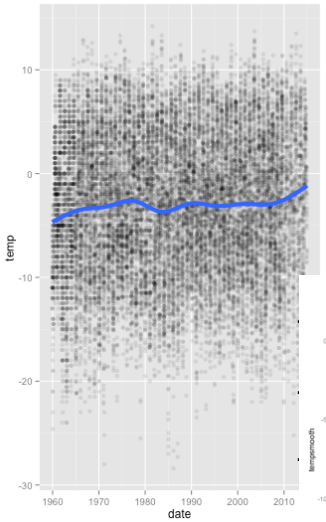


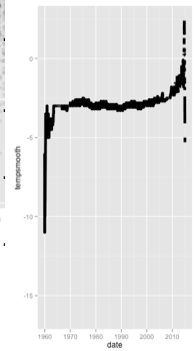


double dip winters, ...

Minimum daily temperature

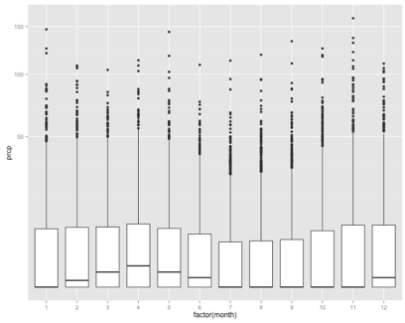
Similar pattern with minimum temperature?





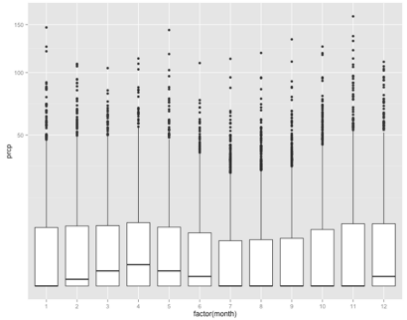
Why are there so many missing values in the last decade?

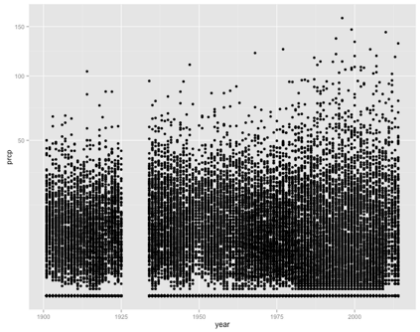
Precipitation (sqrt scale)



Small seasonal trend visible from plotting precip by month - increase Feb-Jun.

Precipitation (sqrt scale)

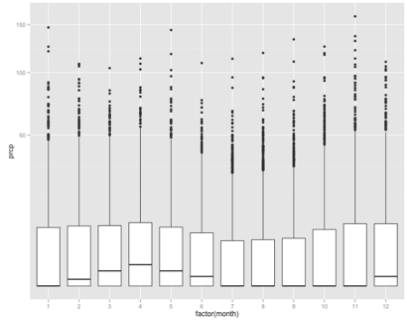


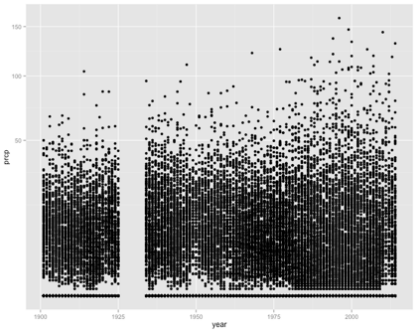


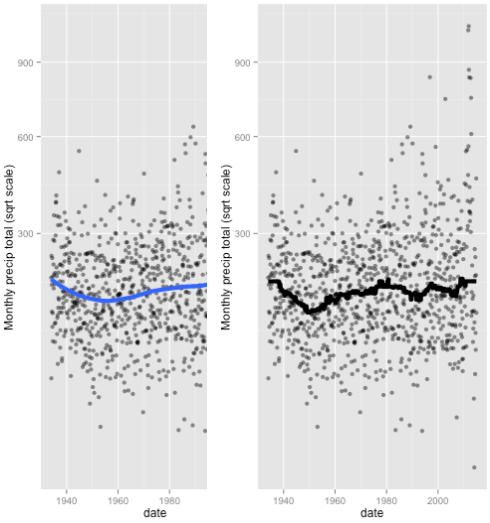
Small gap in measurement collections. Change to only look at latter measurements.

And compute monthly totals (adjusted for missing values).

Precipitation (sqrt scale)

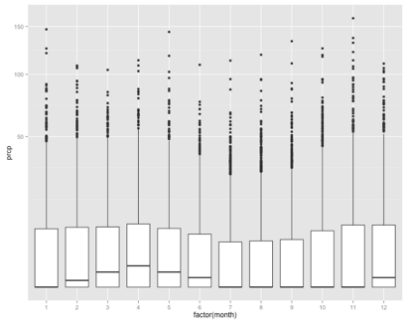


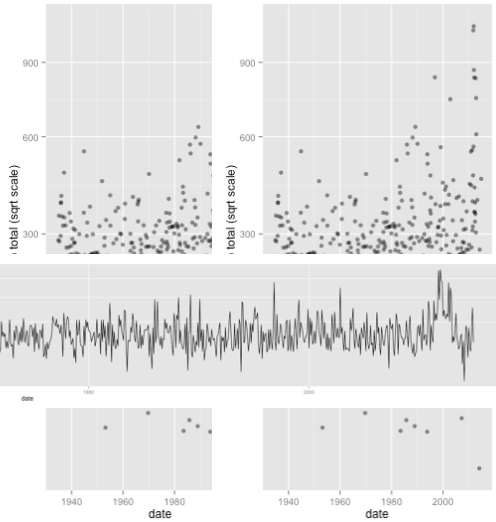




Are extremes becoming more common?

Precipitation (sqrt scale)





What happened in 2012?

Your Turn

Take two minutes to brainstorm with your neighbors.

- Based on what we have seen with min/max temperature and precip what might you do to find additional information that supports or refutes?
- What data, calculations, plots would you make?

Summary

- Pulling data to check things for yourself is so much easier today. One of the most useful skills you can attain!
- Graphics for exploratory data analysis are ephemeral. Once created, once things are learned, they evaporate, and need to be replaced with something overly produced and beautiful for general consumption.

Acknowledgements

- Code is available at:

  `https://github.com/dicook/lesdiablerets-code`

- Software used: R (http://www.R-project.org) and primarily the package ggplot2

Coming next...

- Do you like tennis?
- Data doesn't come with only two variables. How do you see in high dimensions?
- How can you quantify if what we see is "real"?