
Applied Geodata Science I

# Session 3

**Prof. Dr. Benjamin Stocker**

Spring semester 2023

GECO

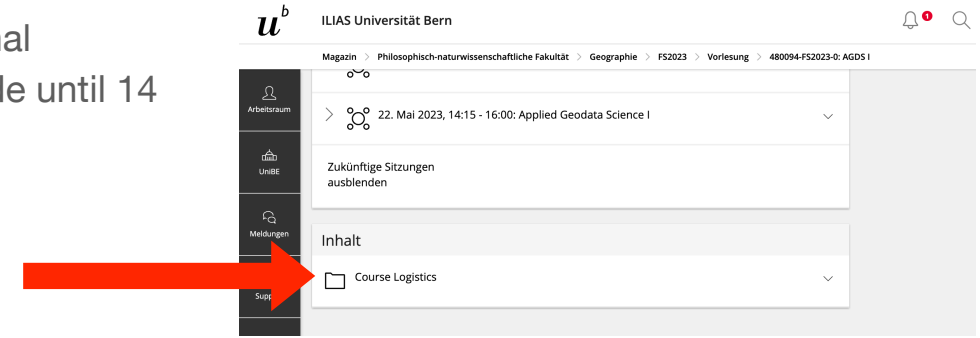
UNIVERSITÄT BERN

# Updated info on course logistics

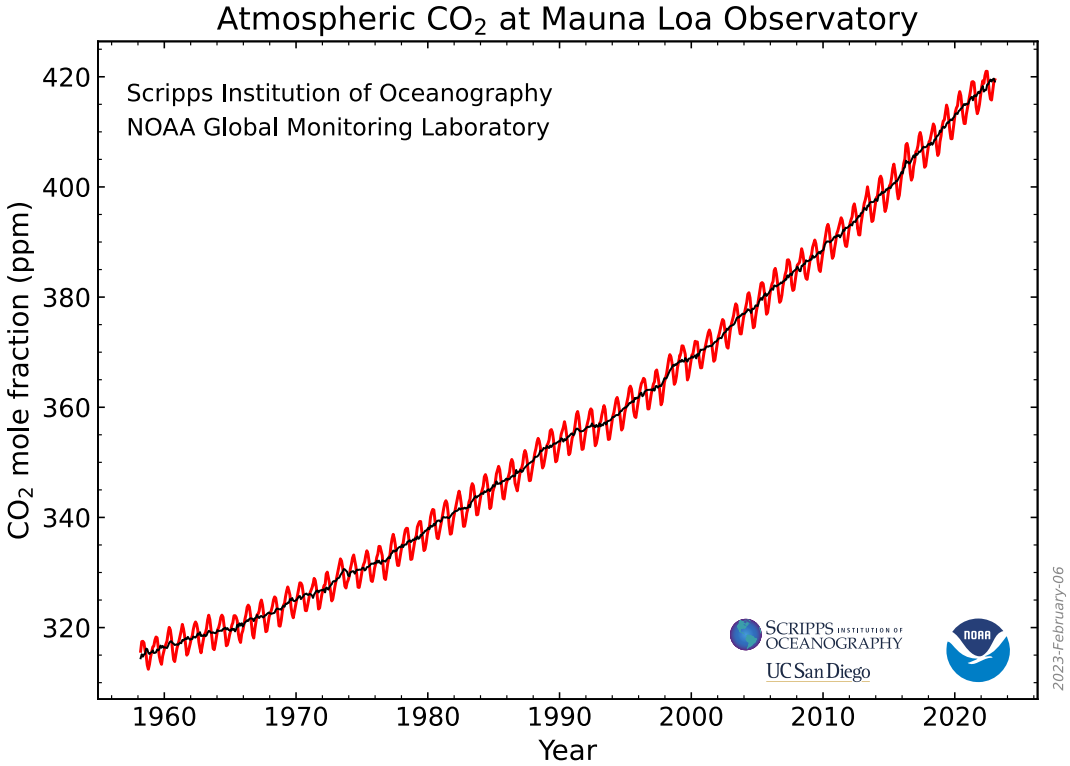
- On ILIAS
- AGDS I is required for the Proseminar in Applied Geodata Science, held in the autumn semester after AGDS I.
- The course is not formally “creditable” (German: anrechenbar) towards the Master studies in Geography. Requests for crediting can be made and will be handled on an individual basis.
- Master students in Climate Sciences can credit AGDS I as Elective Module.
- Definite course registrations have to be made until 15.03.2023.
- Registrations for the exam (in the form of the Final Report, see separate document) have to be made until 14 days before the last session (22.05.2023).

# Updated info on course logistics

- On ILIAS
- AGDS I is required for the Proseminar in Applied Geodata Science, held in the autumn semester after AGDS I.
- The course is not formally “creditable” (German: anrechenbar) towards the Master studies in Geography. Requests for crediting can be made and will be handled on an individual basis.
- Master students in Climate Sciences can credit AGDS I as Elective Module.
- Definite course registrations have to be made until 15.03.2023.
- Registrations for the exam (in the form of the Final Report, see separate document) have to be made until 14 days before the last session (22.05.2023).

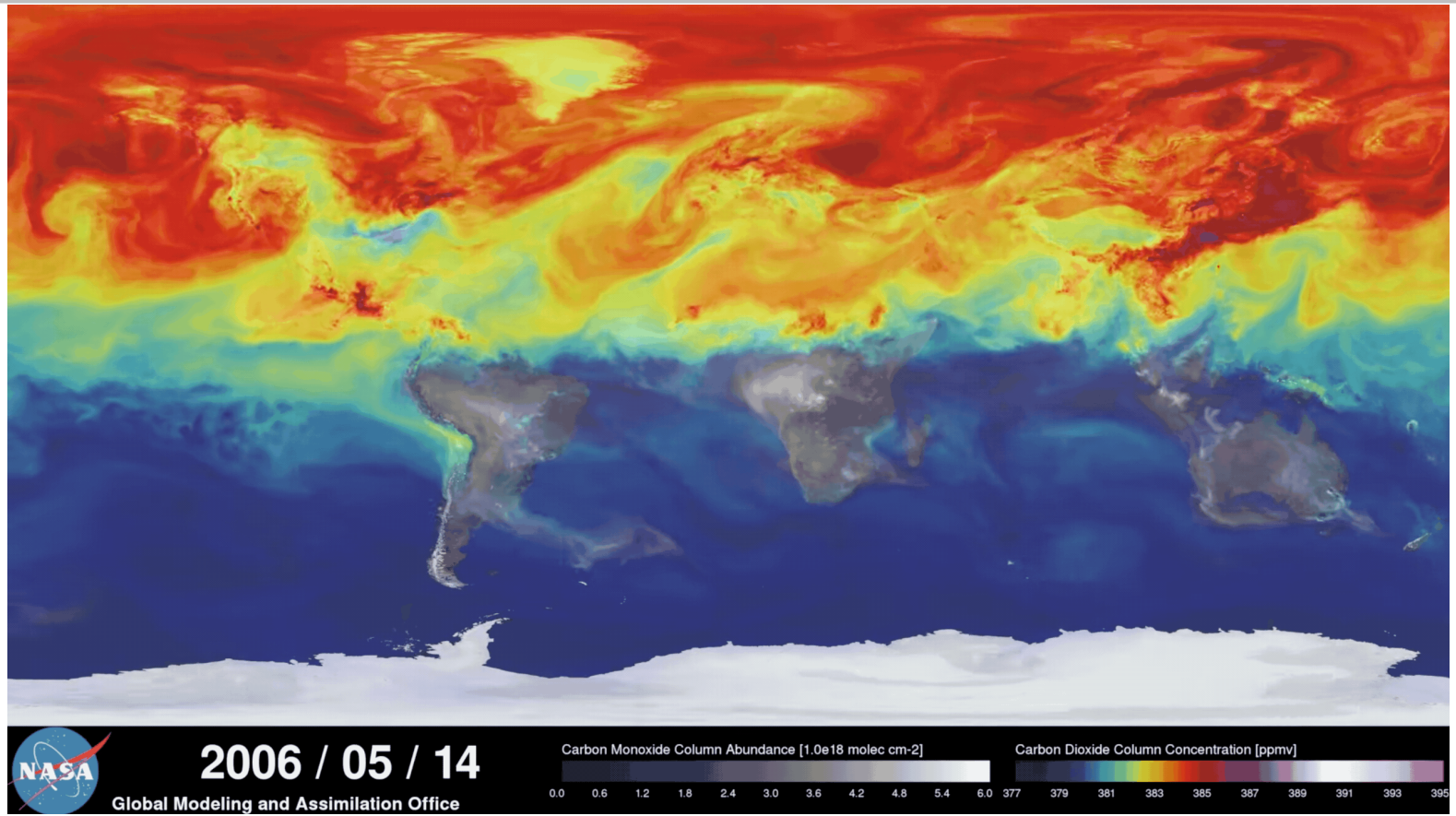


# Atmospheric CO2 concentration



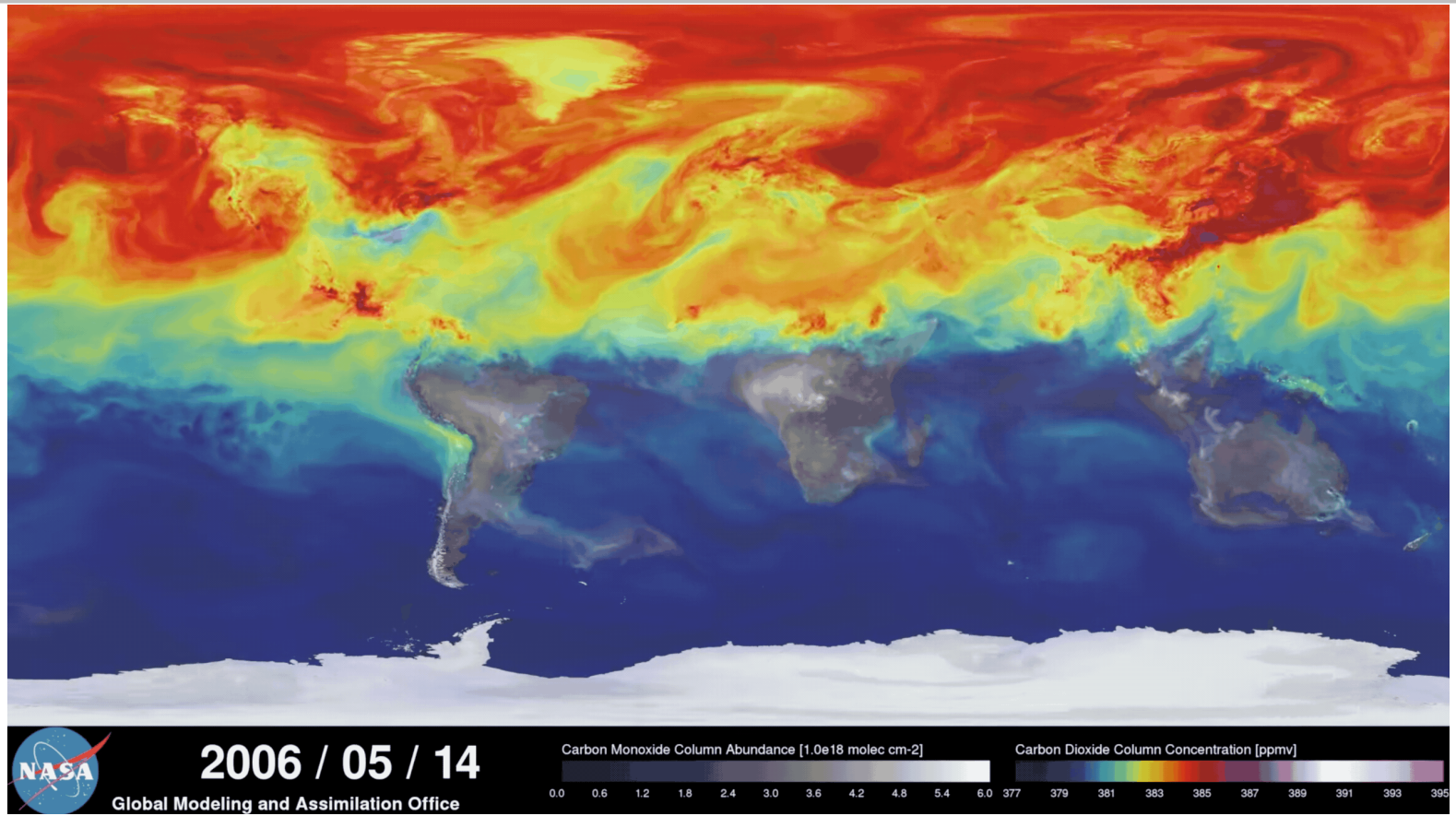

https://gml.noaa.gov/ccgg/trends/

# Atmospheric CO2 concentration



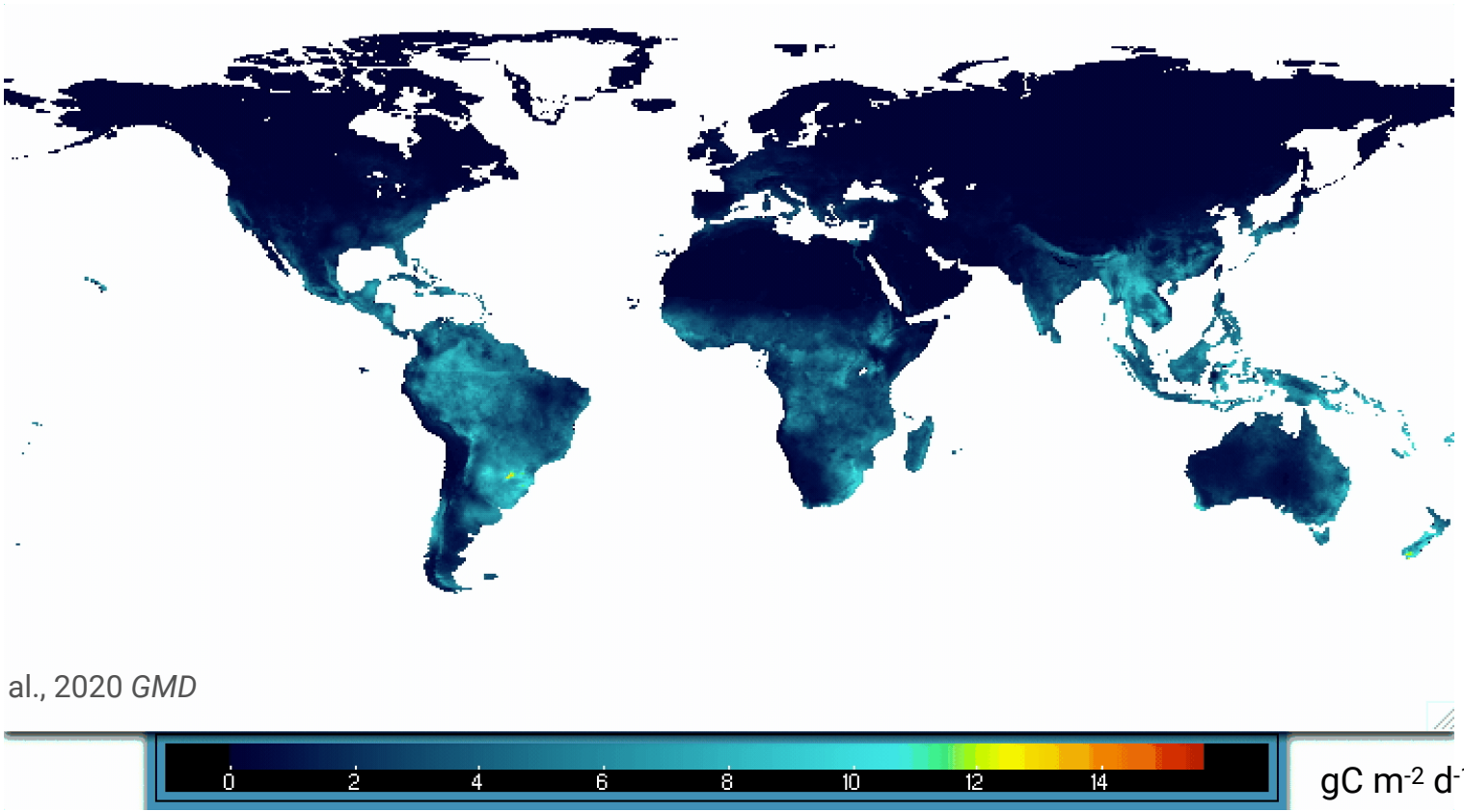

*Source:* NASA (https://www.youtube.com/watch?v=x1SgmFa0r04)

# Atmospheric CO2 concentration



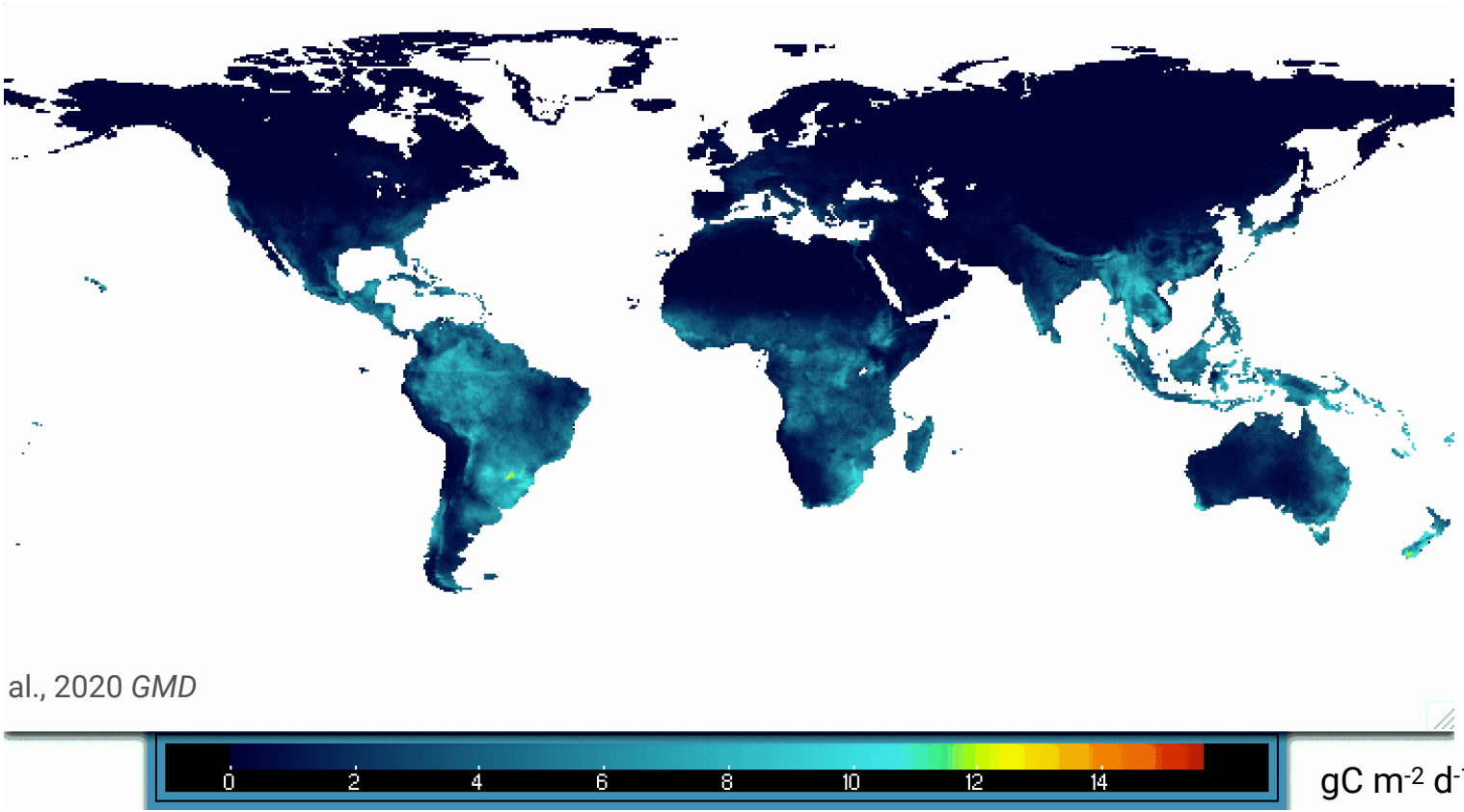

*Source:* NASA (https://www.youtube.com/watch?v=x1SgmFa0r04)

# Seasonality in gross primary production




Stocker et al., 2020 *GMD*

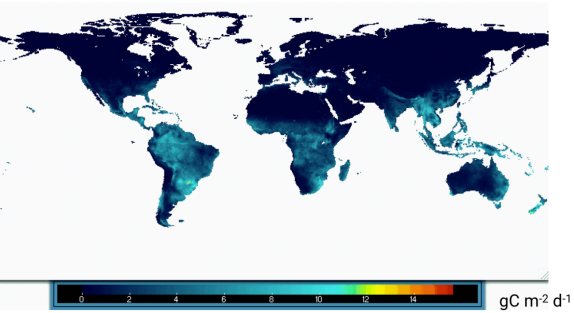
# Seasonality in gross primary production




Stocker et al., 2020 *GMD*

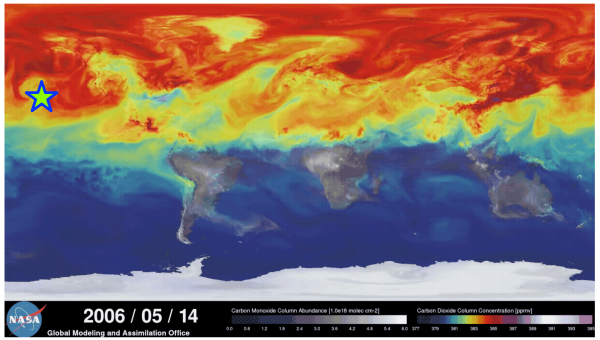
# Breathing of the Earth

Photosynthetic $CO_2$ assimilation

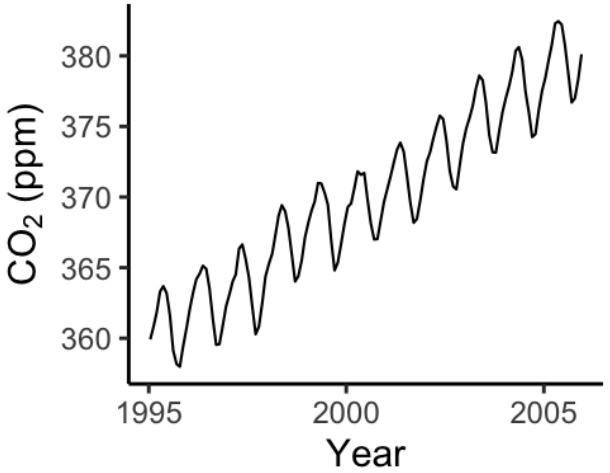



Stocker et al., 2020 *GMD*

Atmospheric $CO_2$ concentration



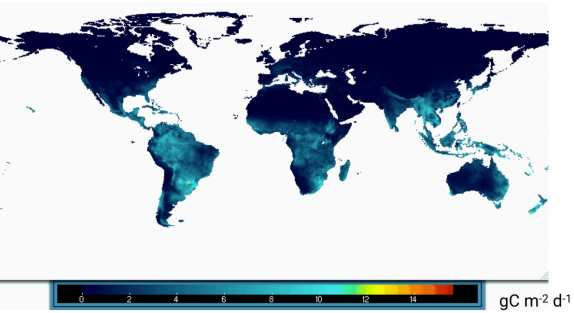

$CO_2$ concentration at Mauna Loa




Keeling et al., 1976 *Tellus*
Thoning et al., 1989 *JGR*

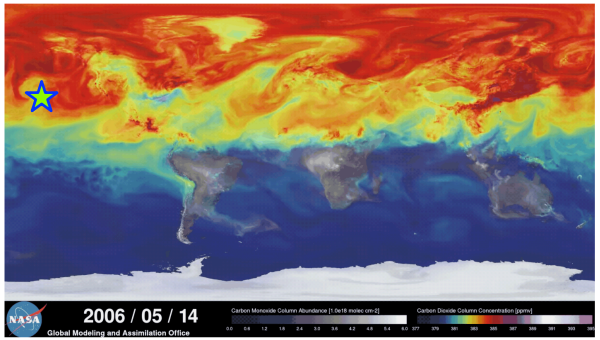
# Breathing of the Earth

Photosynthetic $CO_2$ assimilation

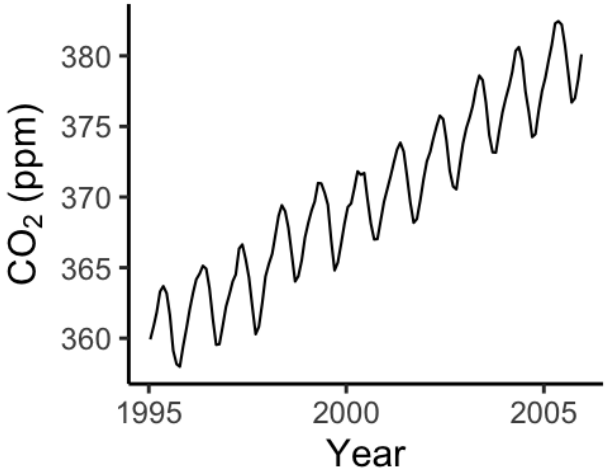



Stocker et al., 2020 *GMD*

Atmospheric $CO_2$ concentration



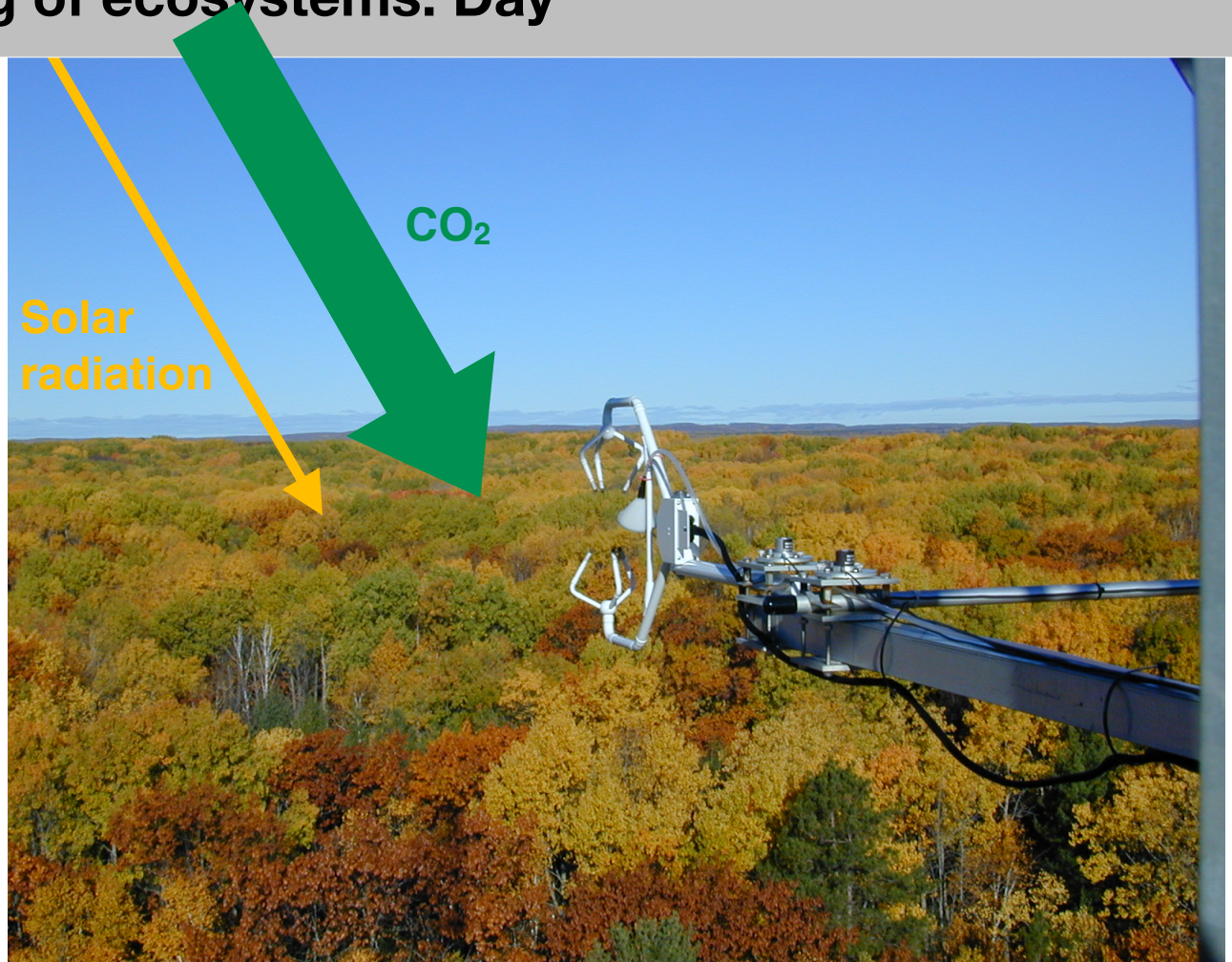

$CO_2$ concentration at Mauna Loa




Keeling et al., 1976 *Tellus*
Thoning et al., 1989 *JGR*

# Breathing of ecosystems: Day

# Breathing of ecosystems: Day



# Breathing of ecosystems: Night


https://andrewsforest.oregonstate.edu/research/programs

# Land-atmosphere gas exchange through eddies

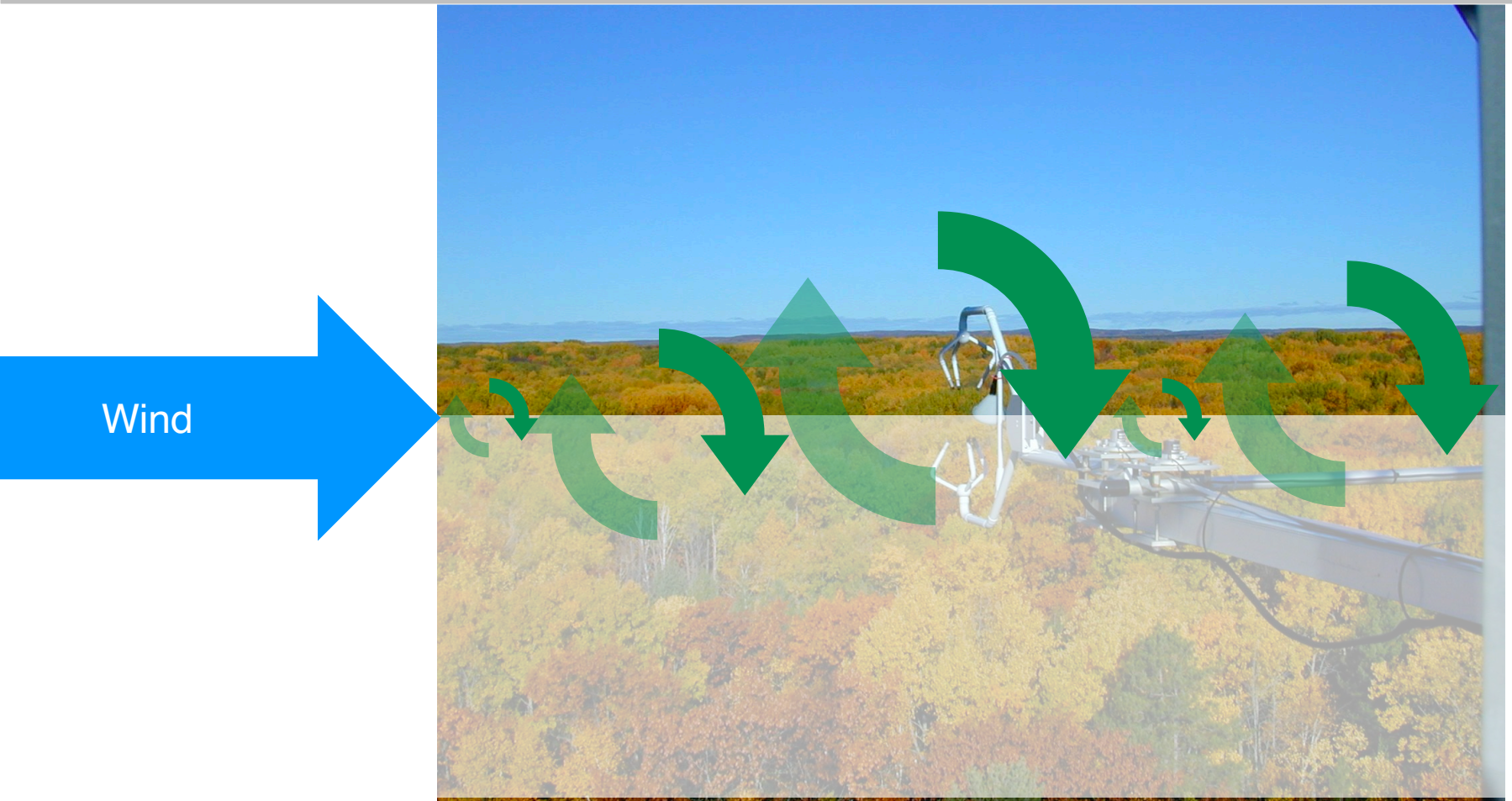
# Land-atmosphere gas exchange through eddies

Wind

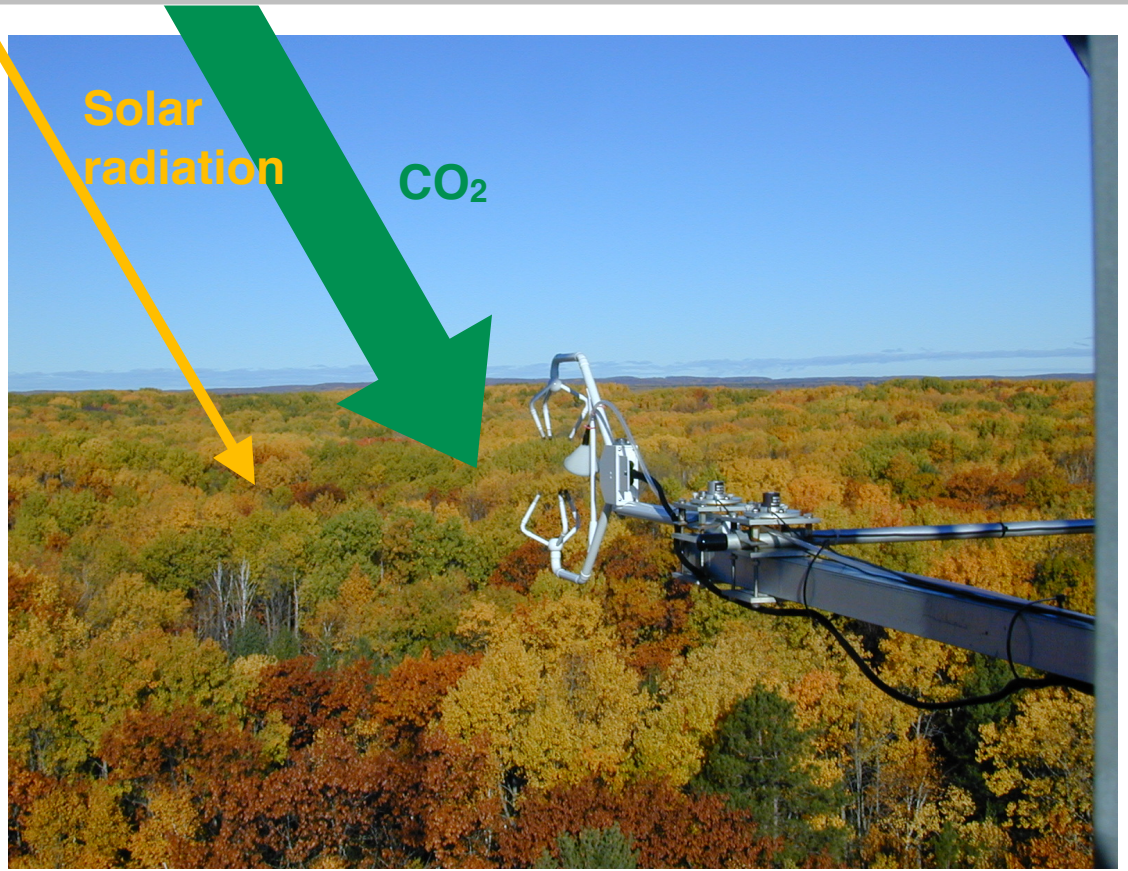
# Land-atmosphere gas exchange through eddies

# Land-atmosphere gas exchange through eddies

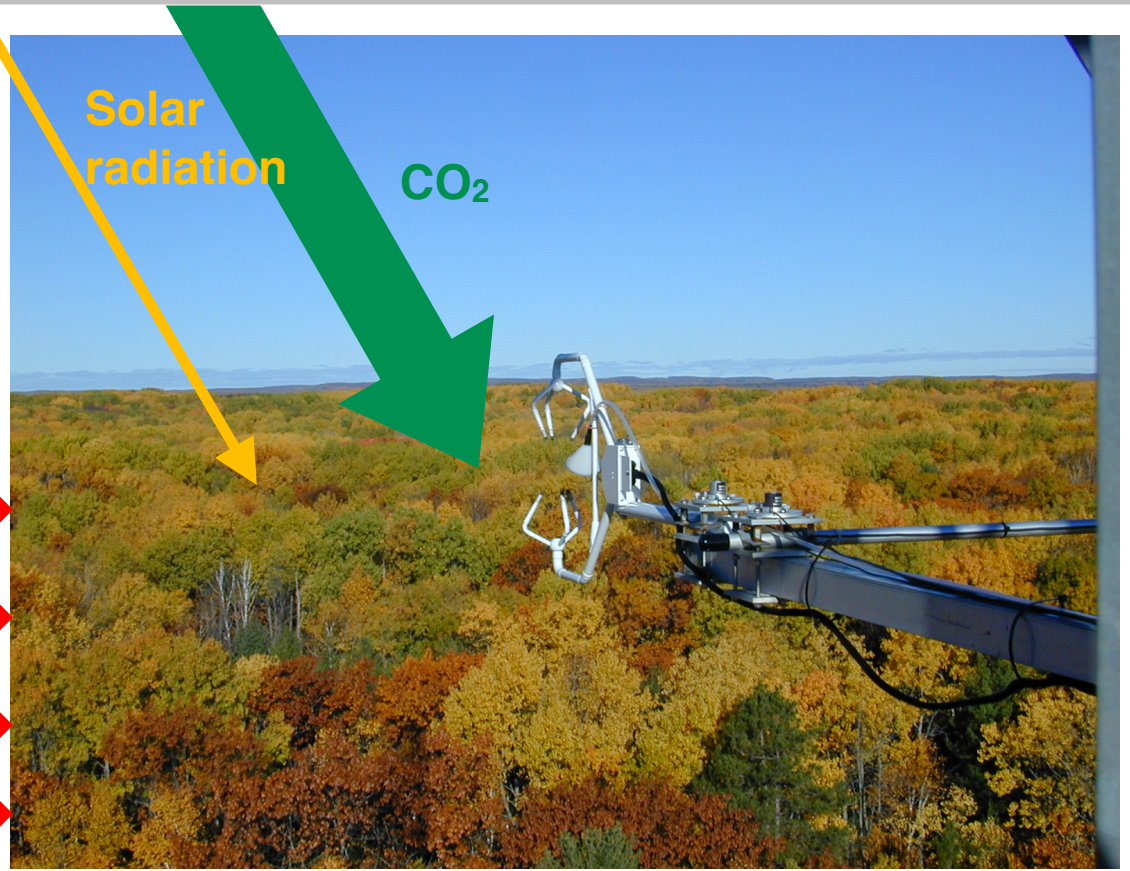
# Eddies and $CO_2$ transport



# Breathing of ecosystems



# Breathing of ecosystems



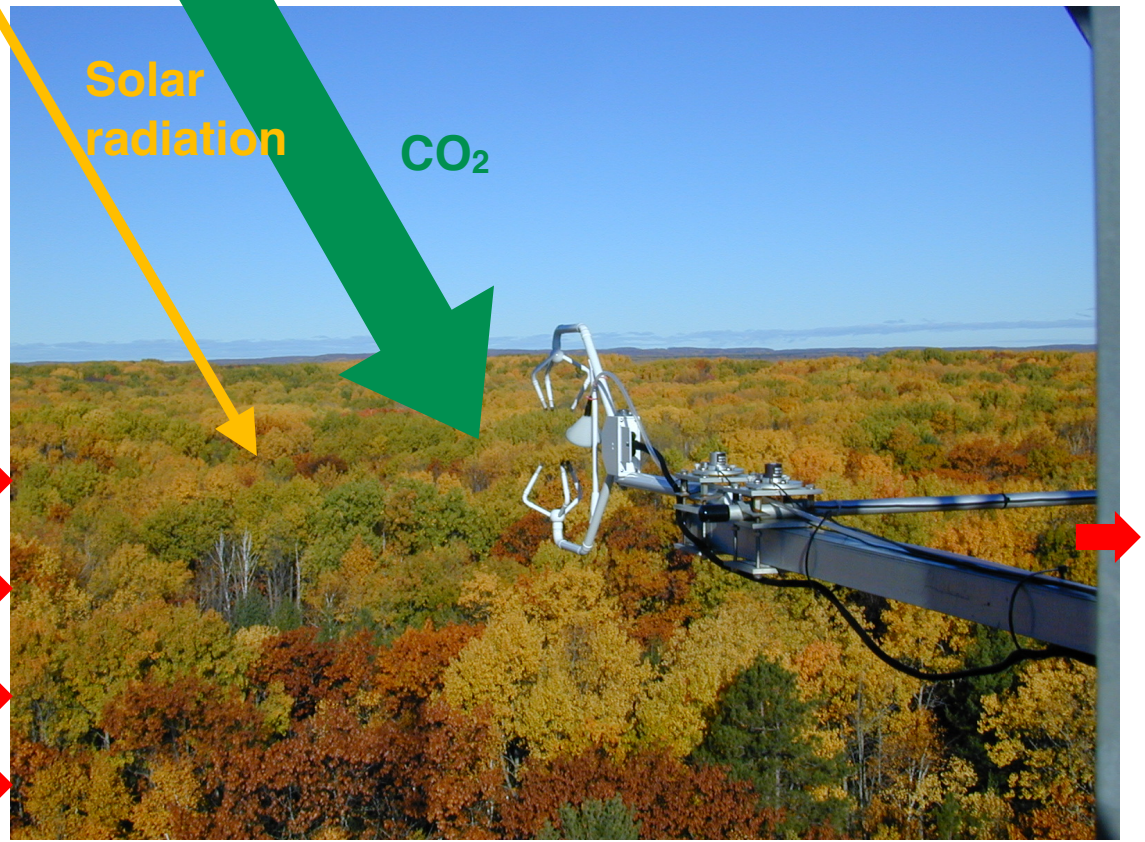

Temperature

Atmospheric humidity

Soil moisture

Leaf area

# Breathing of ecosystems




Temperature

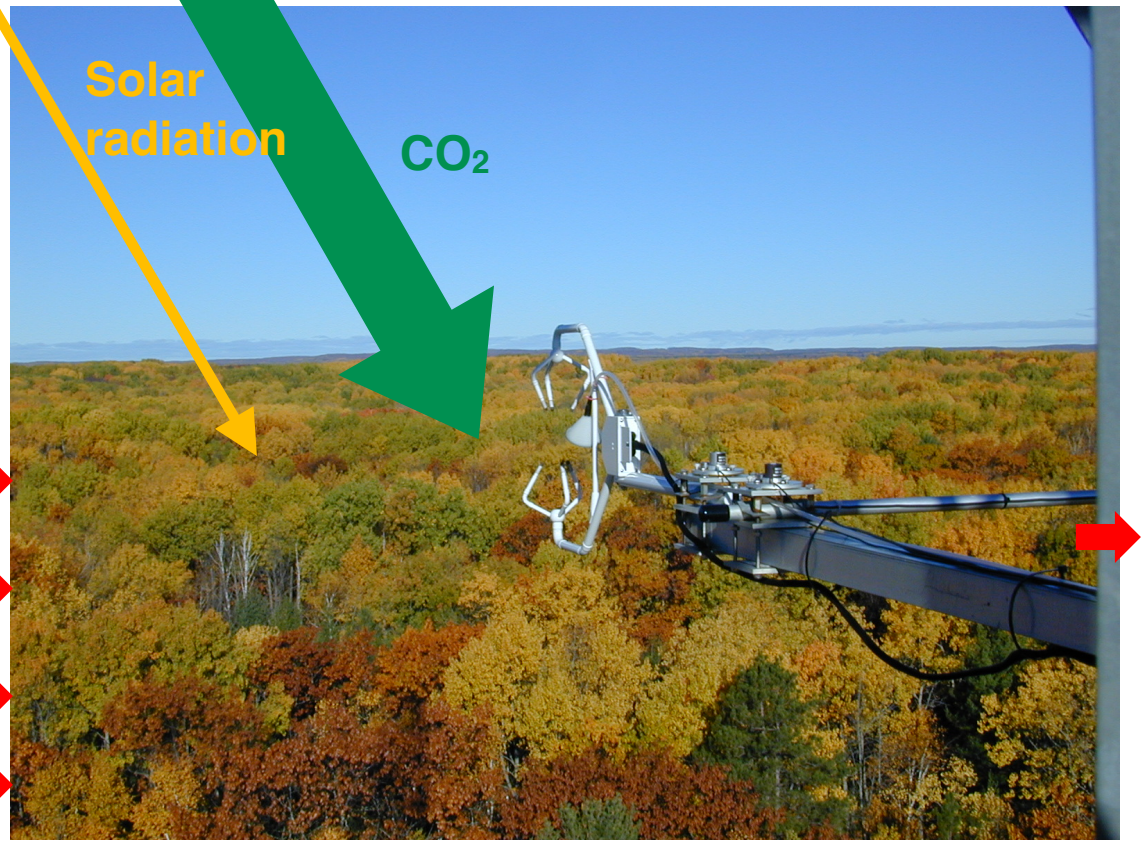
Atmospheric humidity

Soil moisture

Leaf area

Net $CO_2$ uptake

# Breathing of ecosystems




Temperature

Atmospheric humidity

Soil moisture

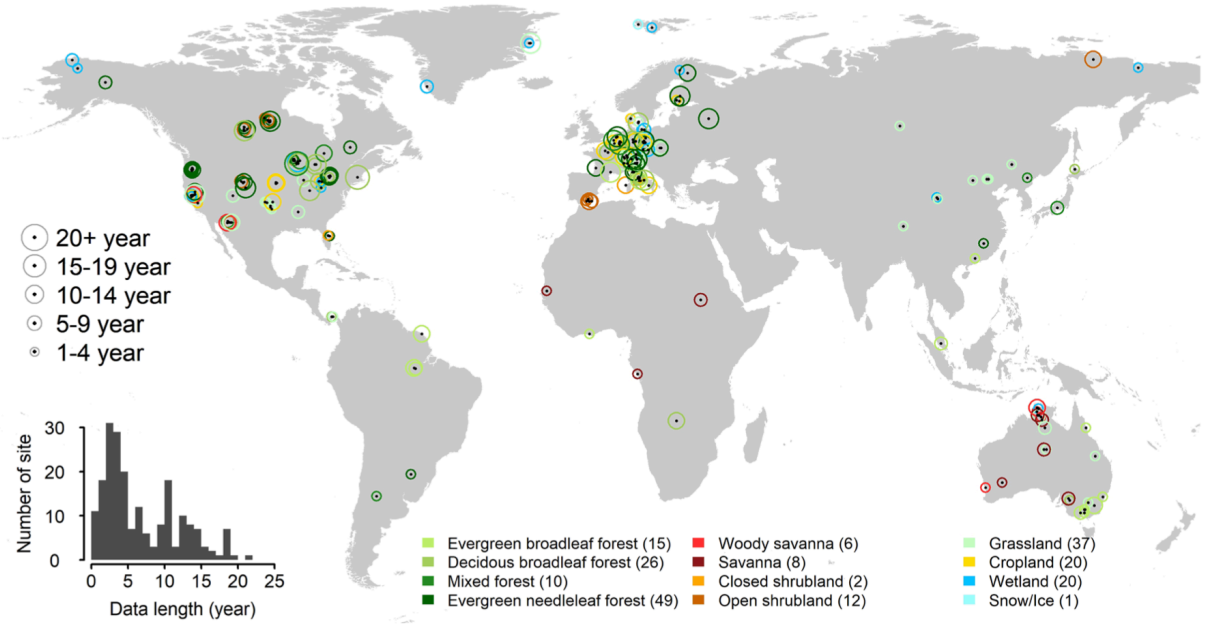
Leaf area

Ecosystem respiration

Net $CO_2$ uptake

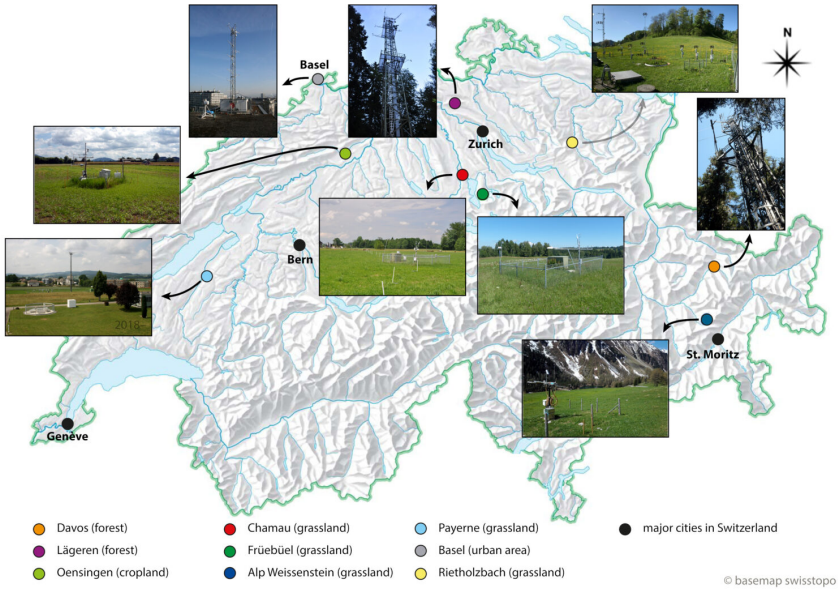
Gross primary production

# The FLUXNET network




Pastorello et al., 2020 *Sci. Dat.*

# SwissFluxNet



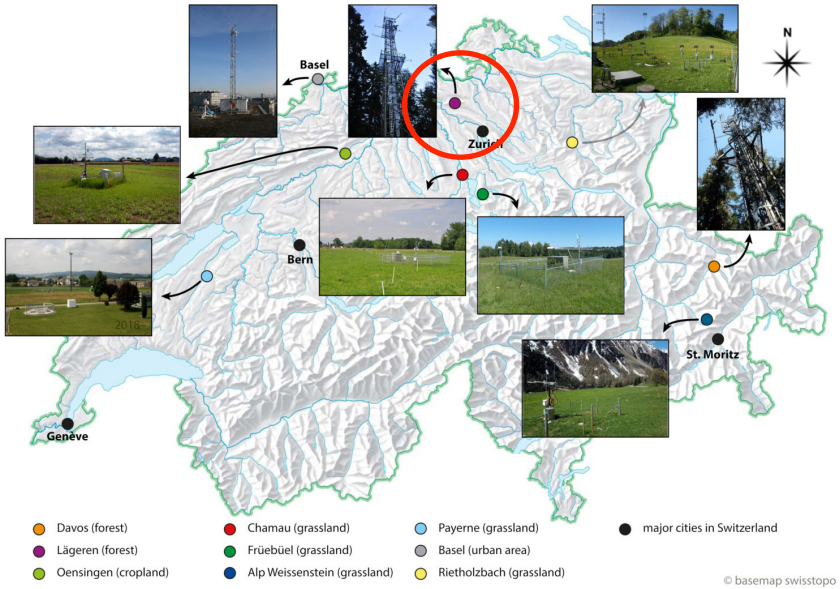

https://www.swissfluxnet.ethz.ch/

# SwissFluxNet

Image Markus Staudinger

## Lägern

CH-Lae



# SwissFluxNet

Image Markus Staudinger

## Lägern
CH-Lae

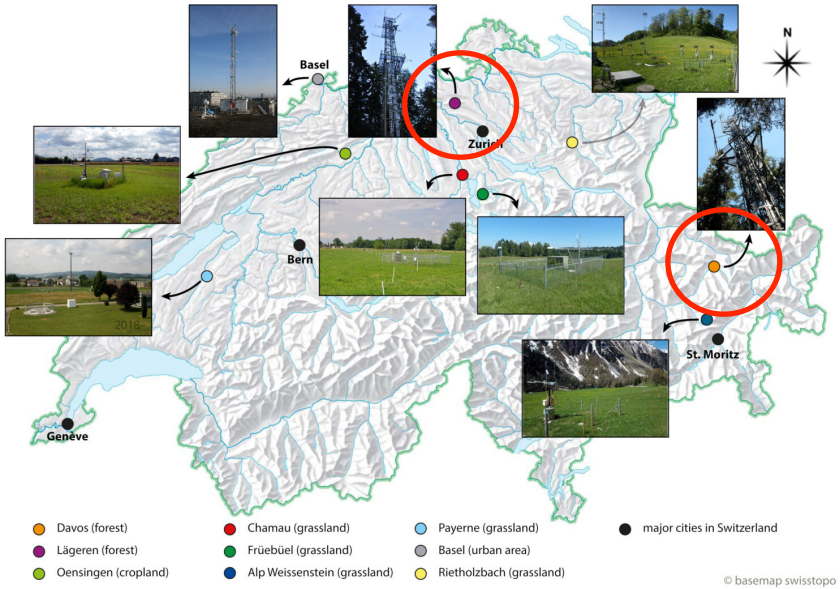



Image Lukas Hörtnagl

## Davos
CH-Dav

https://www.swissfluxnet.ethz.ch/

# Variables in a FLUXNET-standard dataset

www.nature.com/scientificdata

SCIENTIFIC DATA

Check for updates

OPEN

DATA DESCRIPTOR

## The FLUXNET2015 dataset and the ONEFlux processing pipeline for eddy covariance data

Gilberto Pastorello *et al.*#

# Variables in a FLUXNET-standard dataset

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

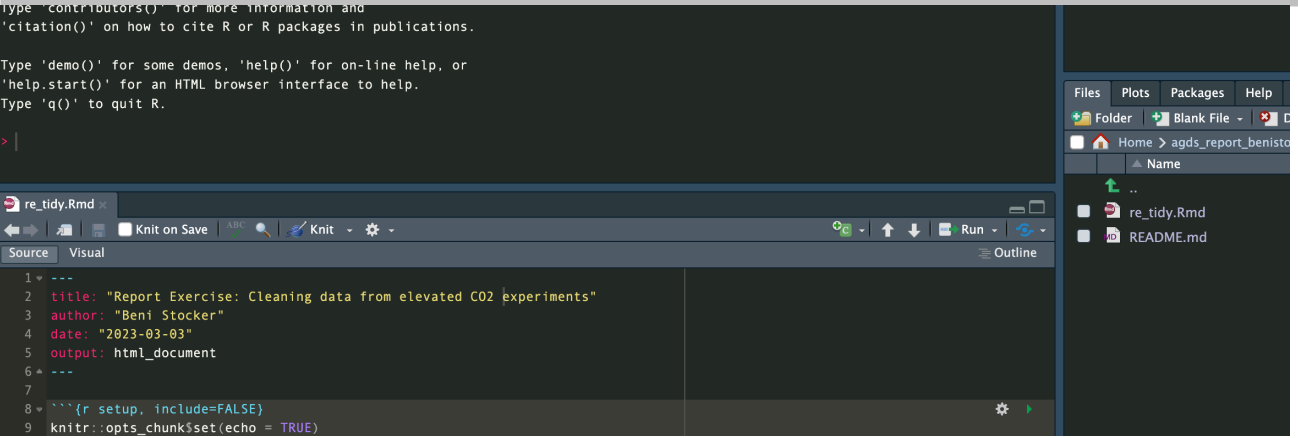
DATA DESCRIPTOR

## The FLUXNET2015 dataset and the ONEFlux processing pipeline for eddy covariance data

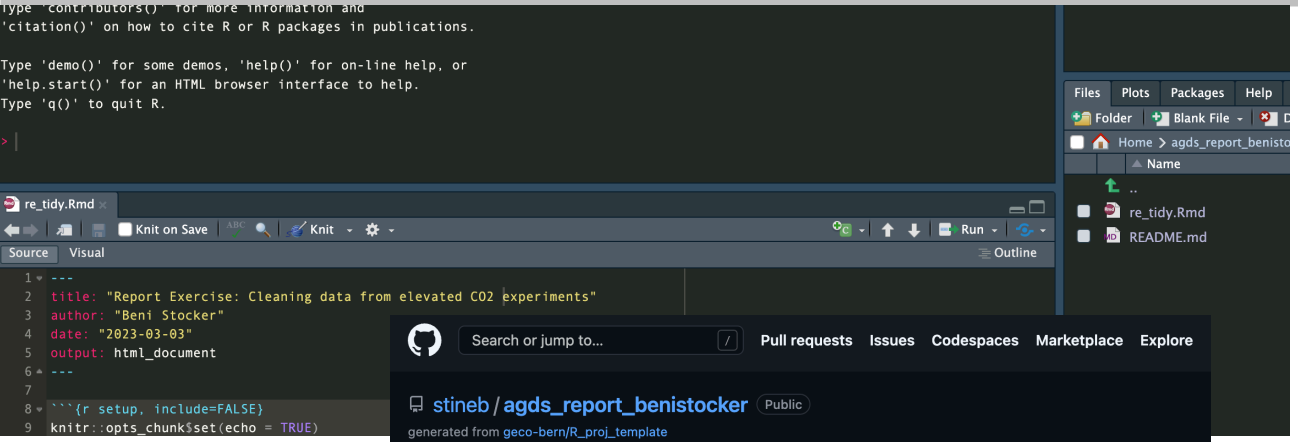
Gilberto Pastorello *et al.*#

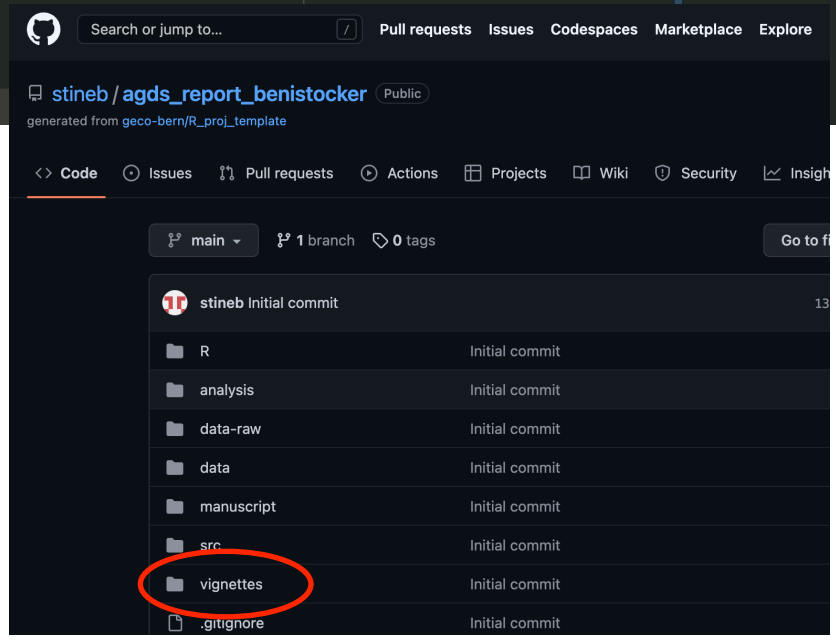
- `TIMESTAMP_START` : Hour and day of the start of the measurement period for which the respective row's data are representative. Provided in a format of "YYYYMMDDhhmm".
- `TIMESTAMP_END` : Hour and day of the end of the measurement period for which the respective row's data are representative. Provided in a format of "YYYYMMDDhhmm".
- `TA_*` (°C): Air temperature.
- `SW_IN_*` (W $m^{-2}$): Shortwave incoming radiation
- `LW_IN_*` (W $m^{-2}$): Longwave incoming radiation
- `VPD_*` (hPa): Vapor pressure deficit (the difference between actual and saturation water vapor pressure)
- `PA_*` (kPa): Atmospheric pressure
- `P_*` (mm): Precipitation
- `WS_*` (m $^{-1}$): Wind speed
- `SWC_*` (%): Volumetric soil water content
- `GPP_*` ($\mu$mol $CO_2$ $m^{-2}$ $s^{-1}$): Gross primary production (the ecosystem-level gross $CO_2$ uptake flux driven by photosynthesis)
- `*_QC` : Quality control information for the variable `*` . Important for us: `NEE_*_QC` is the quality control information for the net ecosystem $CO_2$ exchange flux ( `NEE_*` ) and for GPP derived from the corresponding NEE estimate ( `GPP_*` ). 0 = measured, 1 = good quality gap-filled, 2 = medium, 3 = poor.

# Report Exercise

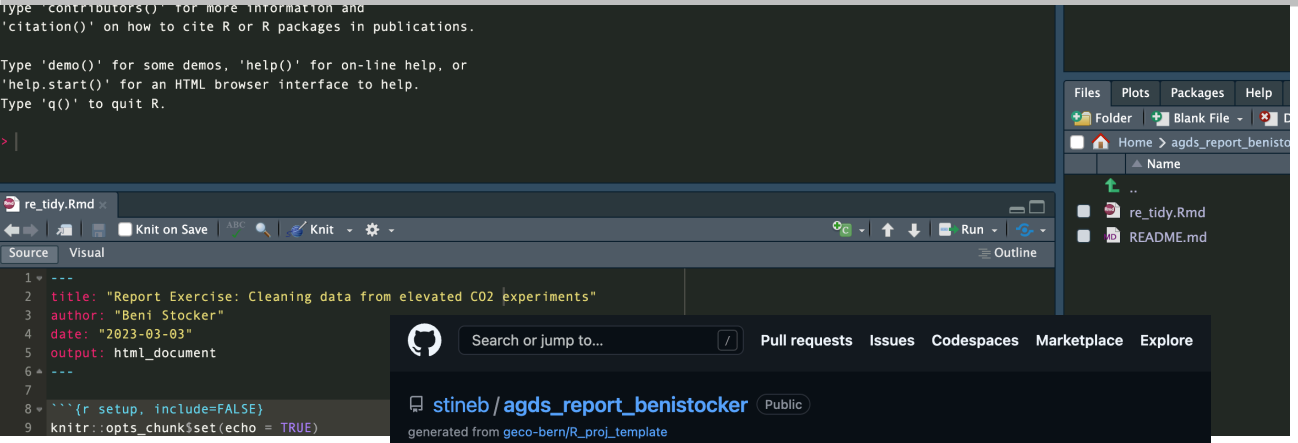


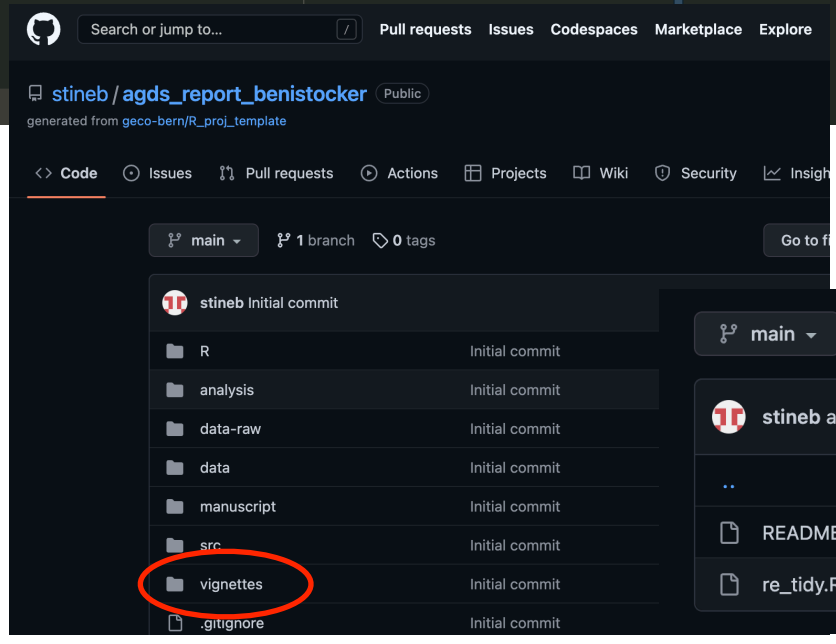
# Report Exercise



# Report Exercise

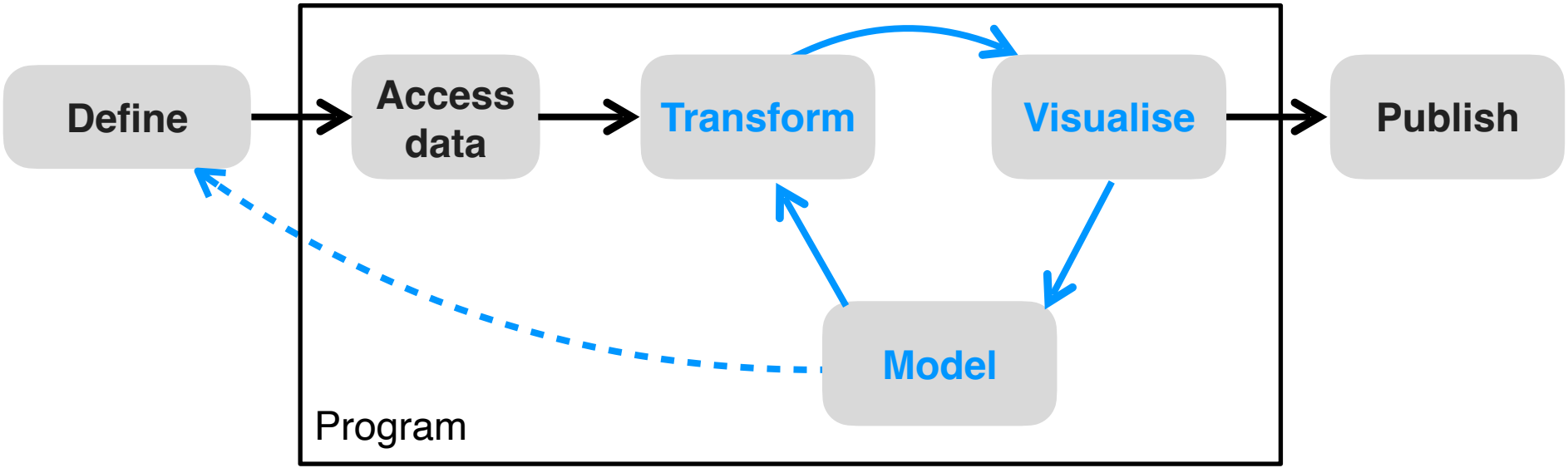


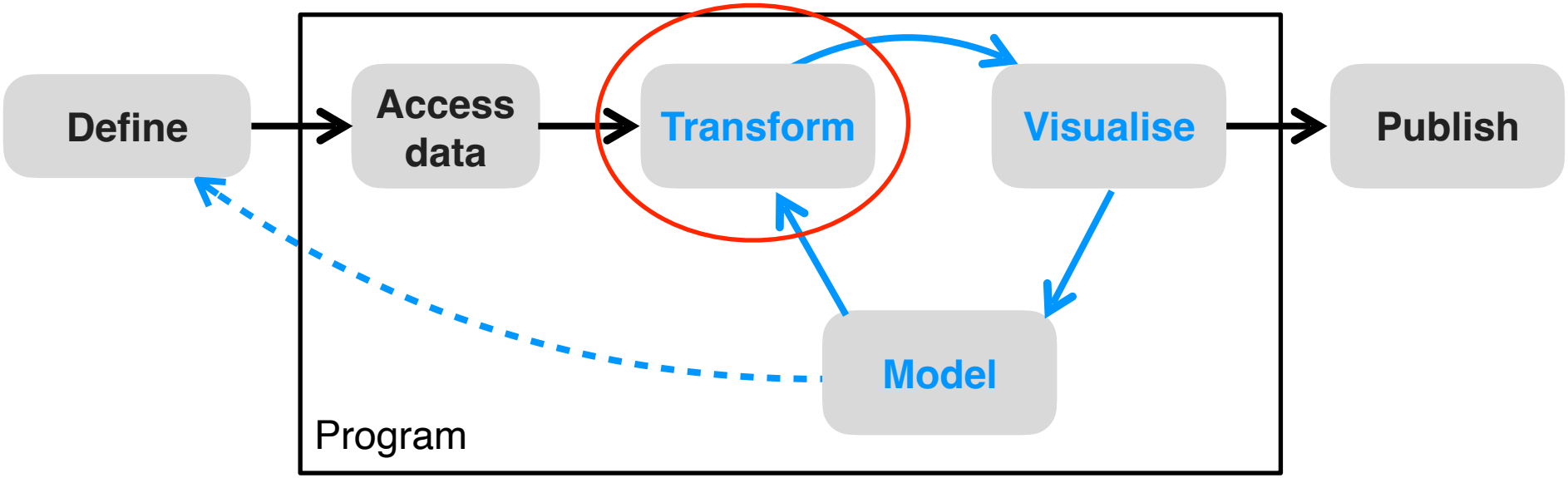
# Report Exercise: Criteria

File on ILIAS

# The data science workflow



# The data science workflow



# Overview

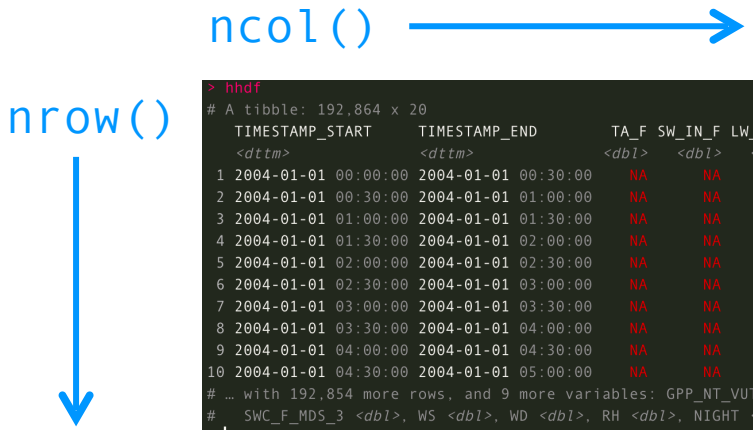
**Chapters 1 and 2**

- Getting ready with R
- Data frames

# Overview

**Chapters 1 and 2**

- Getting ready with R
- Data frames




```
> hhdf
# A tibble: 192,864 x 20
   TIMESTAMP_START     TIMESTAMP_END       TA_F SW_IN_F LW_IN_F VPD_F  PA_F   P_F  WS_F CO2_F_MDS PPFD_IN
   <dttm>              <dttm>             <dbl>   <dbl>   <dbl> <dbl> <dbl> <dbl> <dbl>      <dbl>   <dbl>
 1 2004-01-01 00:00:00 2004-01-01 00:30:00    NA      NA    304.    NA  93.3 0.014    NA         NA      NA
 2 2004-01-01 00:30:00 2004-01-01 01:00:00    NA      NA    304.    NA  93.3 0.014    NA         NA      NA
 3 2004-01-01 01:00:00 2004-01-01 01:30:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 4 2004-01-01 01:30:00 2004-01-01 02:00:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 5 2004-01-01 02:00:00 2004-01-01 02:30:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 6 2004-01-01 02:30:00 2004-01-01 03:00:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 7 2004-01-01 03:00:00 2004-01-01 03:30:00    NA      NA    281.    NA  93.2 0        NA         NA      NA
 8 2004-01-01 03:30:00 2004-01-01 04:00:00    NA      NA    281.    NA  93.2 0        NA         NA      NA
 9 2004-01-01 04:00:00 2004-01-01 04:30:00    NA      NA    264.    NA  93.2 0        NA         NA      NA
10 2004-01-01 04:30:00 2004-01-01 05:00:00    NA      NA    264.    NA  93.2 0        NA         NA      NA
# … with 192,854 more rows, and 9 more variables: GPP_NT_VUT_REF <dbl>, SWC_F_MDS_1 <dbl>, SWC_F_MDS_2 <dbl>,
#   SWC_F_MDS_3 <dbl>, WS <dbl>, WD <dbl>, RH <dbl>, NIGHT <dbl>, NEE_VUT_REF_QC <dbl>
```

# Overview

## Chapters 1 and 2

- Getting ready with R
- Data frames

ncol() →

nrow() ↓

```
> hhdf
# A tibble: 192,864 x 20
   TIMESTAMP_START     TIMESTAMP_END       TA_F SW_IN_F LW_IN_F VPD_F  PA_F   P_F  WS_F CO2_F_MDS PPFD_IN
   <dttm>              <dttm>             <dbl>   <dbl>   <dbl> <dbl> <dbl> <dbl> <dbl>      <dbl>   <dbl>
 1 2004-01-01 00:00:00 2004-01-01 00:30:00    NA      NA    304.    NA  93.3 0.014    NA         NA      NA
 2 2004-01-01 00:30:00 2004-01-01 01:00:00    NA      NA    304.    NA  93.3 0.014    NA         NA      NA
 3 2004-01-01 01:00:00 2004-01-01 01:30:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 4 2004-01-01 01:30:00 2004-01-01 02:00:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 5 2004-01-01 02:00:00 2004-01-01 02:30:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 6 2004-01-01 02:30:00 2004-01-01 03:00:00    NA      NA    281.    NA  93.3 0        NA         NA      NA
 7 2004-01-01 03:00:00 2004-01-01 03:30:00    NA      NA    281.    NA  93.2 0        NA         NA      NA
 8 2004-01-01 03:30:00 2004-01-01 04:00:00    NA      NA    281.    NA  93.2 0        NA         NA      NA
 9 2004-01-01 04:00:00 2004-01-01 04:30:00    NA      NA    264.    NA  93.2 0        NA         NA      NA
10 2004-01-01 04:30:00 2004-01-01 05:00:00    NA      NA    264.    NA  93.2 0        NA         NA      NA
# … with 192,854 more rows, and 9 more variables: GPP_NT_VUT_REF <dbl>, SWC_F_MDS_1 <dbl>, SWC_F_MDS_2 <dbl>,
#   SWC_F_MDS_3 <dbl>, WS <dbl>, WD <dbl>, RH <dbl>, NIGHT <dbl>, NEE_VUT_REF_QC <dbl>
```

## Chapter 3

- Understand data and its “dimensions” and “variations”
- Data transformation
- Entering the R *tidyverse*

```
co2_concentration_monthly |>
  pivot_longer(cols = 2:13, names_to = "month", values_to = "co2")
```

```
## # A tibble: 36 × 3
##     year month   co2
##    <int> <chr> <dbl>
##  1  1959 Jan    315.
##  2  1959 Feb    316.
##  3  1959 Mar    316.
```

# Variations and dimensions

- **Variation**: How data points vary between observations.
- **Dimension**: Factors that vary along with observations.

# Variations and dimensions

- **Variation**: How data points vary between observations.
- **Dimension**: Factors that vary along with observations.

**Example:**

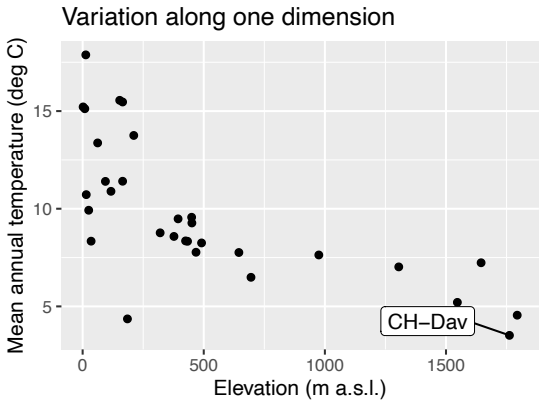
- **Variation along 1 dimension**:
  - Mean annual temperature along an elevational gradient.

# Variations and dimensions

- **Variation**: How data points vary between observations.
- **Dimension**: Factors that vary along with observations.

**Example:**

- **Variation along 1 dimension**:
  - Mean annual temperature along an elevational gradient.

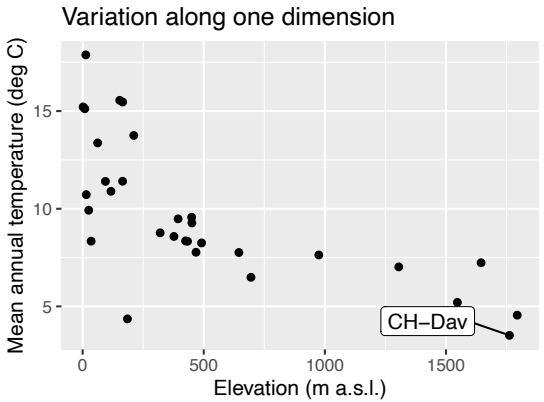


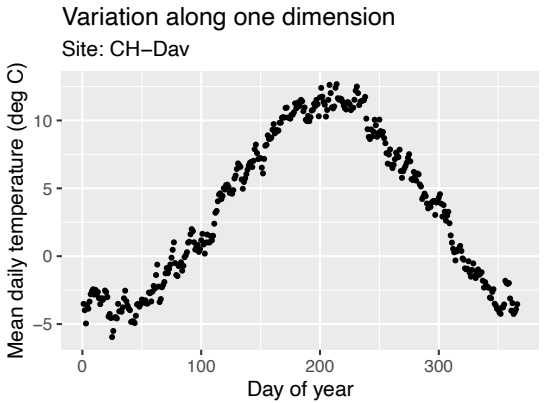
# Variations and dimensions

- **Variation**: How data points vary between observations.
- **Dimension**: Factors that vary along with observations.

**Example:**

- **Variation along 1 dimension**:
  - Mean annual temperature along an elevational gradient.
  - Temperature mean seasonality (of one site)



# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis

| | | | | | g C $m^{-2}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | mean ambient $CO_2$ | mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
| **Experiment** | Citation | Depth | Sample date | ime (years | | | | |
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis


| | | | | | g C m$^{-2}$ | | | |
|---|---|---|---|---|---|---|---|---|
| Experiment | Citation | Depth | Sample date | ime (years | mean ambient $CO_2$ | mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis

Variable →

Experiment ↓

| Experiment | Citation | Depth | Sample date | Time (years | g C m$^{-2}$ mean ambient $CO_2$ | g C m$^{-2}$ mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis

Variable

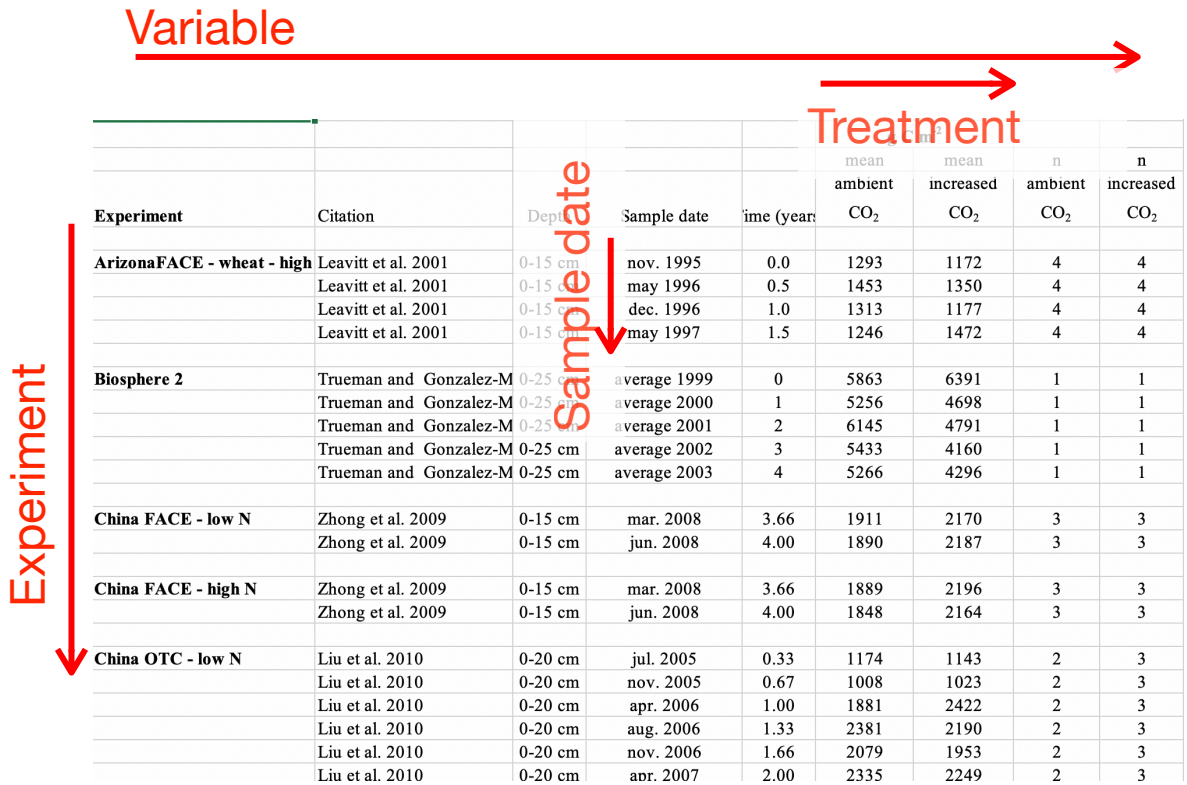
Experiment

Sample date

| Experiment | Citation | Depth | Sample date | Time (years) | g C m$^{-2}$ mean ambient $CO_2$ | g C m$^{-2}$ mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

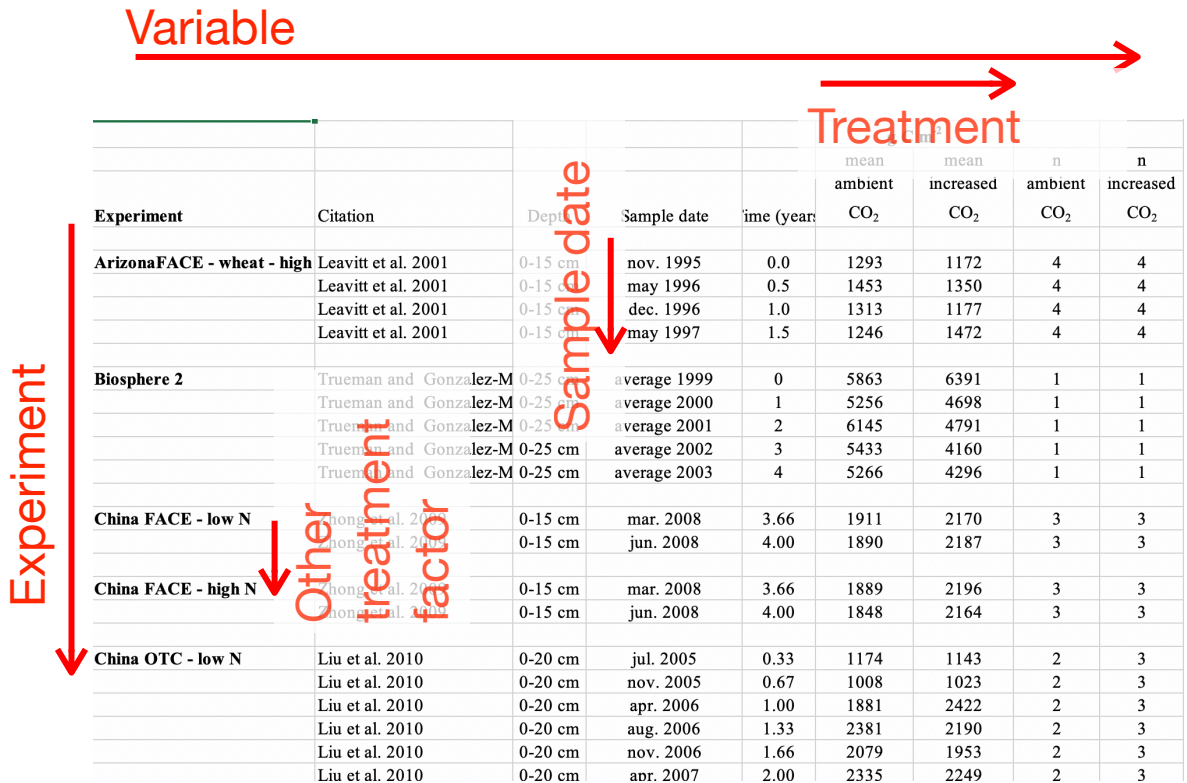
- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis




| Experiment | Citation | Depth | Sample date | Time (years | mean ambient $CO_2$ | mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2009 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2009 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis



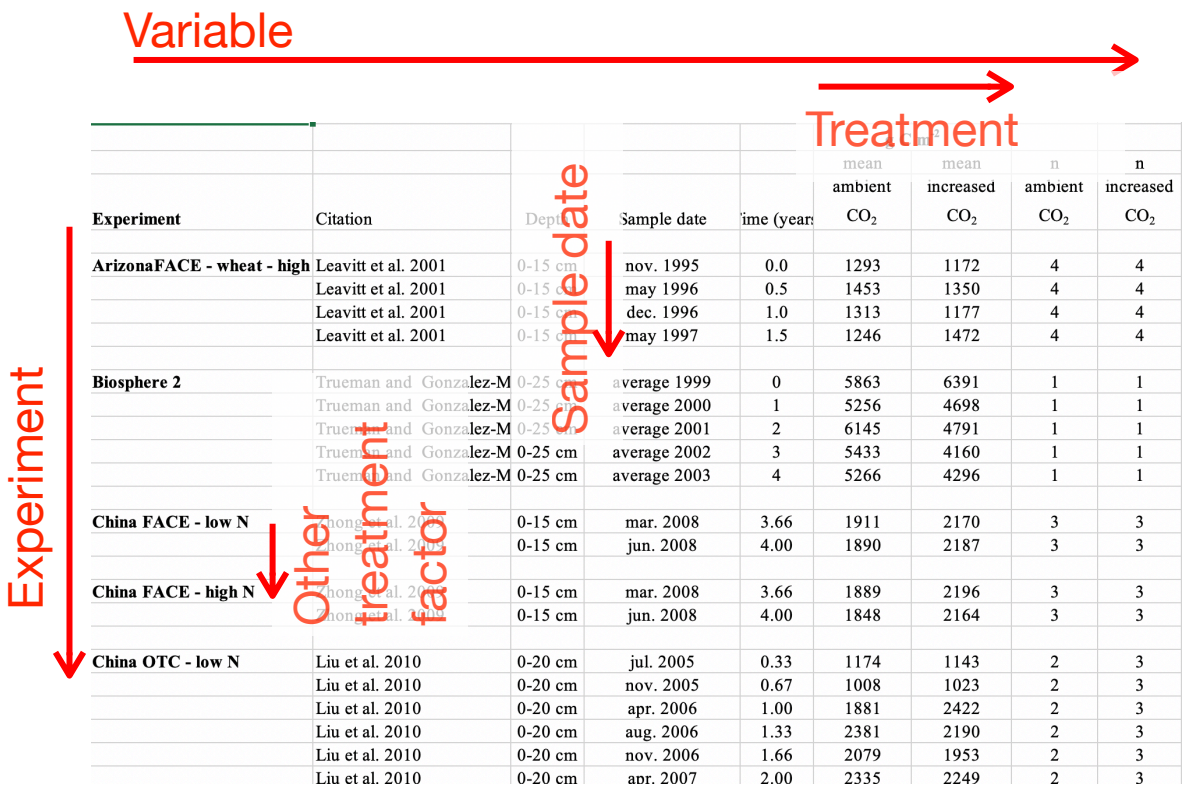

| Experiment | Citation | Depth | Sample date | Time (years) | mean ambient $CO_2$ | mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2010 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2010 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2010 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2010 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Variations and dimensions

- **Variation along >1 dimensions**:
  - Mean seasonality along an elevation gradient.
  - Data for experiments meta-analysis

➔ **Data organisation?**

➔ **Data visualisation? (Chapter 4)**




| Experiment | Citation | Depth | Sample date | Time (years) | mean ambient $CO_2$ | mean increased $CO_2$ | n ambient $CO_2$ | n increased $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| **ArizonaFACE - wheat - high** | Leavitt et al. 2001 | 0-15 cm | nov. 1995 | 0.0 | 1293 | 1172 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1996 | 0.5 | 1453 | 1350 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | dec. 1996 | 1.0 | 1313 | 1177 | 4 | 4 |
| | Leavitt et al. 2001 | 0-15 cm | may 1997 | 1.5 | 1246 | 1472 | 4 | 4 |
| **Biosphere 2** | Trueman and Gonzalez-M | 0-25 cm | average 1999 | 0 | 5863 | 6391 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2000 | 1 | 5256 | 4698 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2001 | 2 | 6145 | 4791 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2002 | 3 | 5433 | 4160 | 1 | 1 |
| | Trueman and Gonzalez-M | 0-25 cm | average 2003 | 4 | 5266 | 4296 | 1 | 1 |
| **China FACE - low N** | Zhong et al. 2017 | 0-15 cm | mar. 2008 | 3.66 | 1911 | 2170 | 3 | 3 |
| | Zhong et al. 2017 | 0-15 cm | jun. 2008 | 4.00 | 1890 | 2187 | 3 | 3 |
| **China FACE - high N** | Zhong et al. 2017 | 0-15 cm | mar. 2008 | 3.66 | 1889 | 2196 | 3 | 3 |
| | Zhong et al. 2017 | 0-15 cm | jun. 2008 | 4.00 | 1848 | 2164 | 3 | 3 |
| **China OTC - low N** | Liu et al. 2010 | 0-20 cm | jul. 2005 | 0.33 | 1174 | 1143 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2005 | 0.67 | 1008 | 1023 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2006 | 1.00 | 1881 | 2422 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | aug. 2006 | 1.33 | 2381 | 2190 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | nov. 2006 | 1.66 | 2079 | 1953 | 2 | 3 |
| | Liu et al. 2010 | 0-20 cm | apr. 2007 | 2.00 | 2335 | 2249 | 2 | 3 |

# Tidy data

## Tidy?

# Tidy data

## Tidy?

```
## # A tibble: 3 × 13
##    year   Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep   Oct   Nov   Dec
##   <int> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1  1959  315.  316.  316.  318.  318.  318   316.  315.  314.  313.  315.  315.
## 2  1960  316.  317.  317.  319.  320.  319.  318.  316.  314   314.  315.  316.
## 3  1961  317.  318.  318.  319.  320.  320.  318.  317.  315.  315.  316.  317.
```

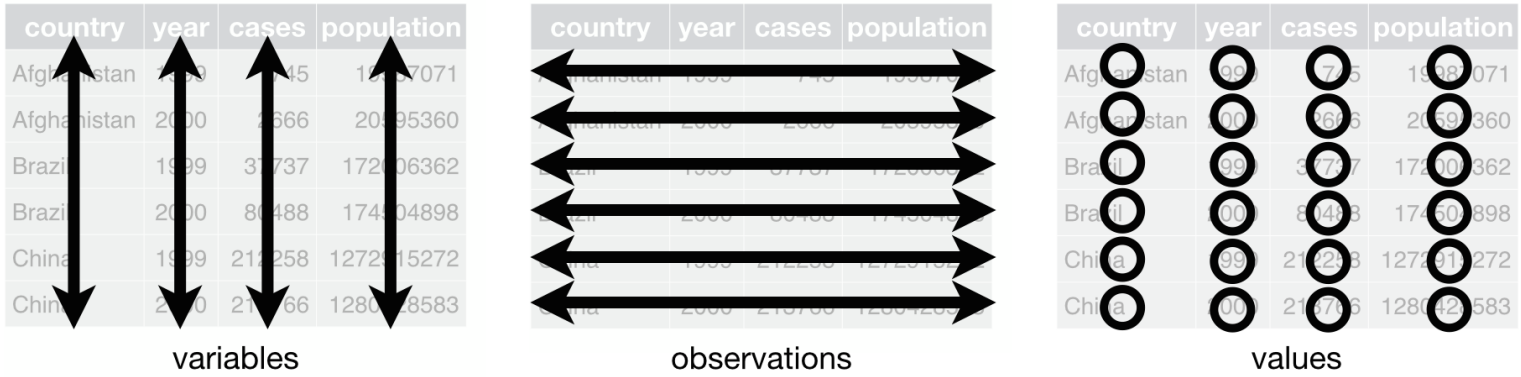
# Tidy data

## Tidy?

```
## # A tibble: 3 × 13
##    year   Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep   Oct   Nov   Dec
##   <int> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1  1959  315.  316.  316.  318.  318.  318   316.  315.  314.  313.  315.  315.
## 2  1960  316.  317.  317.  319.  320.  319.  318.  316.  314   314.  315.  316.
## 3  1961  317.  318.  318.  319.  320.  320.  318.  317.  315.  315.  316.  317.
```

```
## # A tibble: 36 × 3
##     year month   co2
##    <int> <chr> <dbl>
##  1  1959 Jan    315.
##  2  1959 Feb    316.
##  3  1959 Mar    316.
##  4  1959 Apr    318.
##  5  1959 May    318.
##  6  1959 Jun    318
##  7  1959 Jul    316.
##  8  1959 Aug    315.
##  9  1959 Sep    314.
## 10  1959 Oct    313.
## # … with 26 more rows
```

# Tidy data




Wickham & Grolemund, 2017