

Tidy Time Series & Forecasting in R

1. Introduction to tsibbles

robjhyndman.com/workshop2020



Outline

- 1 Time series data and tsibbles
- 2 Example: Australian prison population
- 3 Example: Australian pharmaceutical sales
- 4 Lab Session 1
- 5 Time plots
- 6 Lab Session 2

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- 1 Time series data and tsibbles
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Time series data

- Four-yearly Olympic winning times
- Annual Google profits
- Quarterly Australian beer production
- Monthly rainfall
- Weekly retail sales
- Daily IBM stock prices
- Hourly electricity demand
- 5-minute freeway traffic counts
- Time-stamped stock transaction data

Class packages

```
# Data manipulation and plotting functions
library(tidyverse)
# Time series manipulation
library(tsibble)
# Forecasting functions
library(fable)
# Time series graphics and statistics
library(feasts)
# Tidy time series data
library(tsibbldata)
```

Class packages

```
# Data manipulation and plotting functions  
library(tidyverse)  
# Time series manipulation  
library(tsibble)  
# Forecasting functions  
library(fable)  
# Time series graphics and statistics  
library(feasts)  
# Tidy time series data  
library(tsibbledata)
```

```
# All of the above and more  
library(fpp3)
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
## # Key:      Country [263]
## #     Year Country          GDP Imports Exports Population
## #   <dbl> <fct>        <dbl>    <dbl>    <dbl>       <dbl>
## 1 1960 Afghanistan 537777811.    7.02     4.13 8996351
## 2 1961 Afghanistan 548888896.    8.10     4.45 9166764
## 3 1962 Afghanistan 546666678.    9.35     4.88 9345868
## 4 1963 Afghanistan 751111191.   16.9     9.17 9533954
## 5 1964 Afghanistan 800000044.   18.1     8.89 9731361
## 6 1965 Afghanistan 1006666638.   21.4    11.3 9938414
## 7 1966 Afghanistan 1399999967.   18.6     8.57 10152331
## 8 1967 Afghanistan 1673333418.   14.2     6.77 10372630
## 9 1968 Afghanistan 1373333367.   15.2     8.90 10604346
## 10 1969 Afghanistan 1408888922.   15.0    10.1 10854428
## # ... with 15,140 more rows
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
## # Key:      Country [263]
## #       Year Country          GDP Imports Exports Population
## #   Index <fct>     <dbl>    <dbl>    <dbl>    <dbl>
## 1 1960 Afghanistan 537777811.    7.02     4.13 8996351
## 2 1961 Afghanistan 548888896.    8.10     4.45 9166764
## 3 1962 Afghanistan 546666678.    9.35     4.88 9345868
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## 9 1968 Afghanistan 1373333367.   15.2     8.90 10604346
## 10 1969 Afghanistan 1408888922.   15.0    10.1 10854428
## # ... with 15,140 more rows
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
## # Key:      Country [263]
## #   Year  Country          GDP Imports Exports Population
## #   Index  Key        <dbl>    <dbl>    <dbl>     <dbl>
## 1 1960 Afghanistan 537777811.    7.02     4.13 8996351
## 2 1961 Afghanistan 548888896.    8.10     4.45 9166764
## 3 1962 Afghanistan 546666678.    9.35     4.88 9345868
## 4 1963 Afghanistan 751111191.   16.9     9.17 9533954
## 5 1964 Afghanistan 800000044.   18.1     8.89 9731361
## 6 1965 Afghanistan 1006666638.   21.4    11.3 9938414
## 7 1966 Afghanistan 1399999967.   18.6     8.57 10152331
## 8 1967 Afghanistan 1673333418.   14.2     6.77 10372630
## 9 1968 Afghanistan 1373333367.   15.2     8.90 10604346
## 10 1969 Afghanistan 1408888922.   15.0    10.1 10854428
## # ... with 15,140 more rows
```

tsibble objects

```
global_economy
```

## # A tsibble: 15,150 x 6 [1Y]						
## # Key: Country [263]						
##	Year	Country	GDP	Imports	Exports	Population
			Measured variables			
## 1	1960	Afghanistan	537777811.	7.02	4.13	8996351
## 2	1961	Afghanistan	548888896.	8.10	4.45	9166764
## 3	1962	Afghanistan	546666678.	9.35	4.88	9345868
## 4	1963	Afghanistan	751111191.	16.9	9.17	9533954
## 5	1964	Afghanistan	800000044.	18.1	8.89	9731361
## 6	1965	Afghanistan	1006666638.	21.4	11.3	9938414
## 7	1966	Afghanistan	1399999967.	18.6	8.57	10152331
## 8	1967	Afghanistan	1673333418.	14.2	6.77	10372630
## 9	1968	Afghanistan	1373333367.	15.2	8.90	10604346
## 10	1969	Afghanistan	1408888922.	15.0	10.1	10854428
## # ... with 15,140 more rows						

tsibble objects

tourism

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose  Trips
##       <qtr> <chr>    <chr> <chr>    <dbl>
## 1 1998   Q1 Adelaide SA Business  135.
## 2 1998   Q2 Adelaide SA Business  110.
## 3 1998   Q3 Adelaide SA Business  166.
## 4 1998   Q4 Adelaide SA Business  127.
## 5 1999   Q1 Adelaide SA Business  137.
## 6 1999   Q2 Adelaide SA Business  200.
## 7 1999   Q3 Adelaide SA Business  169.
## 8 1999   Q4 Adelaide SA Business  134.
## 9 2000   Q1 Adelaide SA Business  154.
## 10 2000  Q2 Adelaide SA Business  169.
## # ... with 24,310 more rows
```

tsibble objects

tourism

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose  Trips
##   Index    <chr>   <chr>  <chr>   <dbl>
## 1 1998   Q1 Adelaide SA  Business  135.
## 2 1998   Q2 Adelaide SA  Business  110.
## 3 1998   Q3 Adelaide SA  Business  166.
## 4 1998   Q4 Adelaide SA  Business  127.
## 5 1999   Q1 Adelaide SA  Business  137.
## 6 1999   Q2 Adelaide SA  Business  200.
## 7 1999   Q3 Adelaide SA  Business  169.
## 8 1999   Q4 Adelaide SA  Business  134.
## 9 2000   Q1 Adelaide SA  Business  154.
## 10 2000  Q2 Adelaide SA  Business  169.
## # ... with 24,310 more rows
```

tsibble objects

tourism

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose Trips
##   Index     Keys          <dbl>
## 1 1998 Q1 Adelaide SA Business 135.
## 2 1998 Q2 Adelaide SA Business 110.
## 3 1998 Q3 Adelaide SA Business 166.
## 4 1998 Q4 Adelaide SA Business 127.
## 5 1999 Q1 Adelaide SA Business 137.
## 6 1999 Q2 Adelaide SA Business 200.
## 7 1999 Q3 Adelaide SA Business 169.
## 8 1999 Q4 Adelaide SA Business 134.
## 9 2000 Q1 Adelaide SA Business 154.
## 10 2000 Q2 Adelaide SA Business 169.
## # ... with 24,310 more rows
```

tsibble objects

tourism

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose Trips
##   Index    Keys          Measure
## 1 1998 Q1 Adelaide SA Business 135.
## 2 1998 Q2 Adelaide SA Business 110.
## 3 1998 Q3 Adelaide SA Business 166.
## 4 1998 Q4 Adelaide SA Business 127.
## 5 1999 Q1 Adelaide SA Business 137.
## 6 1999 Q2 Adelaide SA Business 200.
## 7 1999 Q3 Adelaide SA Business 169.
## 8 1999 Q4 Adelaide SA Business 134.
## 9 2000 Q1 Adelaide SA Business 154.
## 10 2000 Q2 Adelaide SA Business 169.
## # ... with 24,310 more rows
```

tsibble objects

tourism

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose Trips
##   Index    Keys          Measure
## 1 1998 Q1 Adelaide SA Business 135.
## 2 1998 Q2 Adelaide SA Business 110.
## 3 1998 Q3 Adelaide SA Business 166.
## 4 1998 Q4 Adelaide SA Business 127.
## 5 1999 Q1 Adelaide SA Business 137.
## 6 1999 Q2 Adelaide SA Business 200.
## 7 1999 Q3 Adelaide SA Business 169.
## 8 1999 Q4 Adelaide SA Business 134.
## 9 2000 Q1 Adelaide SA Business 154.
## 10 2000 Q2 Adelaide SA Business 169.
## # ... with 24,310 more rows
```

Domestic visitor
nights in thousands
by state/region and
purpose.

tsibble objects

- A tsibble allows storage and manipulation of multiple time series in R.
- It contains:
 - ▶ An index: time information about the observation
 - ▶ Measured variable(s): numbers of interest
 - ▶ Key variable(s): optional unique identifiers for each series
- It works with tidyverse functions.

The **tsibble** index

Example

```
mydata <- tsibble(year = 2012:2016,  
                    y = c(123,39,78,52,110),  
                    index = year)  
  
mydata
```

```
## # A tsibble: 5 x 2 [1Y]  
##   year     y  
##   <int> <dbl>  
## 1 2012     123  
## 2 2013     39  
## 3 2014     78  
## 4 2015     52  
## 5 2016    110
```

The `tsibble` index

For observations more frequent than once per year, we need to use a time class function on the index.

z

```
## # A tibble: 5 x 2
##   Month     Observation
##   <chr>        <dbl>
## 1 2019      50
## 2 2019      23
## 3 2019      34
## 4 2019      30
## 5 2019      25
```

The tsibble index

For observations more frequent than once per year, we need to use a time class function on the index.

```
#> %>%  
#>   mutate(Month = yearmonth(Month)) %>%  
#>   as_tsibble(index = Month)
```

```
## # A tsibble: 5 x 2 [1M]  
##       Month Observation  
##       <mth>      <dbl>  
## 1 2019 Jan        50  
## 2 2019 Feb        23  
## 3 2019 Mar        34  
## 4 2019 Apr        30  
## 5 2019 May        25
```

The `tsibble` index

Common time index variables can be created with these functions:

Frequency	Function
Annual	<code>start:end</code>
Quarterly	<code>yearquarter()</code>
Monthly	<code>yearmonth()</code>
Weekly	<code>yearweek()</code>
Daily	<code>as_date(), ymd()</code>
Sub-daily	<code>as_datetime()</code>

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Australian prison population



Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv")
```

```
## # A tibble: 3,072 x 6
##   date      state gender legal indigenous count
##   <date>    <chr>  <chr>  <chr>    <chr>      <dbl>
## 1 2005-03-01 ACT    Female Remanded ATSI        0
## 2 2005-03-01 ACT    Female Remanded Other       2
## 3 2005-03-01 ACT    Female Sentenced ATSI        0
## 4 2005-03-01 ACT    Female Sentenced Other       0
## 5 2005-03-01 ACT    Male    Remanded ATSI        7
## 6 2005-03-01 ACT    Male    Remanded Other      58
## 7 2005-03-01 ACT    Male    Sentenced ATSI        0
## 8 2005-03-01 ACT    Male    Sentenced Other       0
## 9 2005-03-01 NSW   Female Remanded ATSI       51
## 10 2005-03-01 NSW   Female Remanded Other     131
## # ... with 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date))
```

```
## # A tibble: 3,072 x 7  
##   date      state gender legal indigenous count Quarter  
##   <date>    <chr>  <chr>  <chr>    <chr>    <dbl>  <qtr>  
## 1 2005-03-01 ACT    Female Rema~ ATSI        0  2005 Q1  
## 2 2005-03-01 ACT    Female Rema~ Other       2  2005 Q1  
## 3 2005-03-01 ACT    Female Sent~ ATSI       0  2005 Q1  
## 4 2005-03-01 ACT    Female Sent~ Other      0  2005 Q1  
## 5 2005-03-01 ACT    Male    Rema~ ATSI       7  2005 Q1  
## 6 2005-03-01 ACT    Male    Rema~ Other      58 2005 Q1  
## 7 2005-03-01 ACT    Male    Sent~ ATSI       0  2005 Q1  
## 8 2005-03-01 ACT    Male    Sent~ Other      0  2005 Q1  
## 9 2005-03-01 NSW    Female Rema~ ATSI      51 2005 Q1  
## 10 2005-03-01 NSW   Female Rema~ Other     131 2005 Q1  
## # ... with 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date)) %>%  
  select(-date)
```

```
## # A tibble: 3,072 x 6  
##   state gender legal      indigenous count Quarter  
##   <chr>  <chr>  <chr>      <chr>     <dbl>    <qtr>  
## 1 ACT    Female  Remanded  ATSI         0  2005 Q1  
## 2 ACT    Female  Remanded  Other        2  2005 Q1  
## 3 ACT    Female  Sentenced ATSI         0  2005 Q1  
## 4 ACT    Female  Sentenced Other        0  2005 Q1  
## 5 ACT    Male    Remanded  ATSI        7  2005 Q1  
## 6 ACT    Male    Remanded  Other       58  2005 Q1  
## 7 ACT    Male    Sentenced ATSI         0  2005 Q1  
## 8 ACT    Male    Sentenced Other        0  2005 Q1  
## 9 NSW    Female  Remanded  ATSI       51  2005 Q1  
## 10 NSW   Female  Remanded  Other      131  2005 Q1  
## # ... with 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date)) %>%  
  select(-date) %>%  
  as_tsibble(index=Quarter,  
             key=c(state, gender, legal, indigenous))
```

```
## # A tsibble: 3,072 x 6 [1Q]  
## # Key:      state, gender, legal, indigenous [64]  
##      state gender legal    indigenous count Quarter  
##      <chr>  <chr>  <chr>      <chr>     <dbl>   <qtr>  
## 1 ACT    Female Remanded ATSI         0 2005 Q1  
## 2 ACT    Female Remanded ATSI         1 2005 Q2  
## 3 ACT    Female Remanded ATSI         0 2005 Q3  
## 4 ACT    Female Remanded ATSI         0 2005 Q4  
## 5 ACT    Female Remanded ATSI         1 2006 Q1  
## 6 ACT    Female Remanded ATSI         1 2006 Q2  
## 7 ACT    Female Remanded ATSI         1 2006 Q3  
## 8 ACT    Female Remanded ATSI         0 2006 Q4
```

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Australian Pharmaceutical Benefits Scheme



Australian Pharmaceutical Benefits Scheme

The **Pharmaceutical Benefits Scheme** (PBS) is the Australian government drugs subsidy scheme.

Australian Pharmaceutical Benefits Scheme

The **Pharmaceutical Benefits Scheme** (PBS) is the Australian government drugs subsidy scheme.

- Many drugs bought from pharmacies are subsidised to allow more equitable access to modern drugs.
- The cost to government is determined by the number and types of drugs purchased. Currently nearly 1% of GDP.
- The total cost is budgeted based on forecasts of drug usage.
- Costs are disaggregated by drug type (ATC1 x15 / ATC2 84), concession category (x2) and patient type (x2), giving $84 \times 2 \times 2 = 336$ time series.

Working with tsibble objects

PBS

```
## # A tsibble: 65,219 x 9 [1M]
## # Key:      Concession, Type, ATC1, ATC2 [336]
##       Month Concession Type  ATC1  ATC1_desc ATC2
##       <mth>    <chr>     <chr>  <chr>     <chr>
## 1 1991 Jul Concessio~ Co-p~ A   Alimenta~ A01
## 2 1991 Aug Concessio~ Co-p~ A   Alimenta~ A01
## 3 1991 Sep Concessio~ Co-p~ A   Alimenta~ A01
## 4 1991 Oct Concessio~ Co-p~ A   Alimenta~ A01
## 5 1991 Nov Concessio~ Co-p~ A   Alimenta~ A01
## 6 1991 Dec Concessio~ Co-p~ A   Alimenta~ A01
## 7 1992 Jan Concessio~ Co-p~ A   Alimenta~ A01
## 8 1992 Feb Concessio~ Co-p~ A   Alimenta~ A01
## 9 1992 Mar Concessio~ Co-p~ A   Alimenta~ A01
## 10 1992 Apr Concessio~ Co-p~ A   Alimenta~ A01
## # ... with 65,209 more rows, and 3 more variables:
## #   ATC2_desc <chr>, Scripts <dbl>, Cost <dbl>
```

Working with `tsibble` objects

We can use the `filter()` function to select rows.

```
PBS %>%  
  filter(ATC2=="A10")
```

```
## # A tsibble: 816 x 9 [1M]  
## # Key:      Concession, Type, ATC1, ATC2 [4]  
##           Month Concession Type  ATC1  ATC1_desc ATC2  
##           <mth>   <chr>     <chr> <chr>  <chr>    <chr>  
## 1  1991 Jul Concessio~ Co-p~ A  Alimenta~ A10  
## 2  1991 Aug Concessio~ Co-p~ A  Alimenta~ A10  
## 3  1991 Sep Concessio~ Co-p~ A  Alimenta~ A10  
## 4  1991 Oct Concessio~ Co-p~ A  Alimenta~ A10  
## 5  1991 Nov Concessio~ Co-p~ A  Alimenta~ A10  
## 6  1991 Dec Concessio~ Co-p~ A  Alimenta~ A10  
## 7  1992 Jan Concessio~ Co-p~ A  Alimenta~ A10  
## 8  1992 Feb Concessio~ Co-p~ A  Alimenta~ A10  
## 9  1992 Mar Concessio~ Co-p~ A  Alimenta~ A10  
## 10 1992 Apr Concessio~ Co-p~ A  Alimenta~ A10  
## # ... with 806 more rows, and 3 more variables:
```

Working with tsibble objects

We can use the `select()` function to select columns.

```
PBS %>%
  filter(ATC2=="A10") %>%
  select(Cost)
```

Selecting index: "Month"

Error: The result is not a valid tsibble.

Do you need `as_tibble()` to work with data frame?

Working with tsibble objects

We can use the `select()` function to select columns.

```
PBS %>%
  filter(ATC2=="A10") %>%
  select(Month, Concession, Type, Cost)
```

```
## # A tsibble: 816 x 4 [1M]
## # Key:      Concession, Type [4]
##       Month Concession     Type      Cost
##       <mth> <chr>        <chr>      <dbl>
## 1 1991 Jul Concessional Co-payments 2092878
## 2 1991 Aug Concessional Co-payments 1795733
## 3 1991 Sep Concessional Co-payments 1777231
## 4 1991 Oct Concessional Co-payments 1848507
## 5 1991 Nov Concessional Co-payments 1686458
## 6 1991 Dec Concessional Co-payments 1843079
## 7 1992 Jan Concessional Co-payments 1564702
## 8 1992 Feb Concessional Co-payments 1732508
## 9 1992 Mar Concessional Co-payments 2046102
## 10 1992 Apr Concessional Co-payments 2225977
```

Working with tsibble objects

We can use the `summarise()` function to summarise over keys.

```
PBS %>%
  filter(ATC2=="A10") %>%
  select(Month, Concession, Type, Cost) %>%
  summarise(total_cost = sum(Cost))
```

```
## # A tsibble: 204 x 2 [1M]
##       Month total_cost
##       <mth>     <dbl>
## 1 1991 Jul     3526591
## 2 1991 Aug     3180891
## 3 1991 Sep     3252221
## 4 1991 Oct     3611003
## 5 1991 Nov     3565869
## 6 1991 Dec     4306371
## 7 1992 Jan     5088335
## 8 1992 Feb     2814520
## 9 1992 Mar     2985811
## 10 1992 Apr    3204780
```

Working with tsibble objects

We can use the `mutate()` function to create new variables.

```
PBS %>%
  filter(ATC2=="A10") %>%
  select(Month, Concession, Type, Cost) %>%
  summarise(total_cost = sum(Cost)) %>%
  mutate(total_cost = total_cost/1e6)
```

```
## # A tsibble: 204 x 2 [1M]
```

```
##      Month total_cost
##      <mth>     <dbl>
## 1 1991 Jul     3.53
## 2 1991 Aug     3.18
## 3 1991 Sep     3.25
## 4 1991 Oct     3.61
## 5 1991 Nov     3.57
## 6 1991 Dec     4.31
## 7 1992 Jan     5.09
## 8 1992 Feb     2.81
## 9 1992 Mar     2.89
```

Working with tsibble objects

We can use the `mutate()` function to create new variables.

```
PBS %>%
  filter(ATC2=="A10") %>%
  select(Month, Concession, Type, Cost) %>%
  summarise(total_cost = sum(Cost)) %>%
  mutate(total_cost = total_cost/1e6) -> a10
```

```
## # A tsibble: 204 x 2 [1M]
```

```
##      Month total_cost
##      <mth>     <dbl>
## 1 1991 Jul     3.53
## 2 1991 Aug     3.18
## 3 1991 Sep     3.25
## 4 1991 Oct     3.61
## 5 1991 Nov     3.57
## 6 1991 Dec     4.31
## 7 1992 Jan     5.09
## 8 1992 Feb     2.81
## 9 1992 Mar     2.89
```

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Lab Session 1

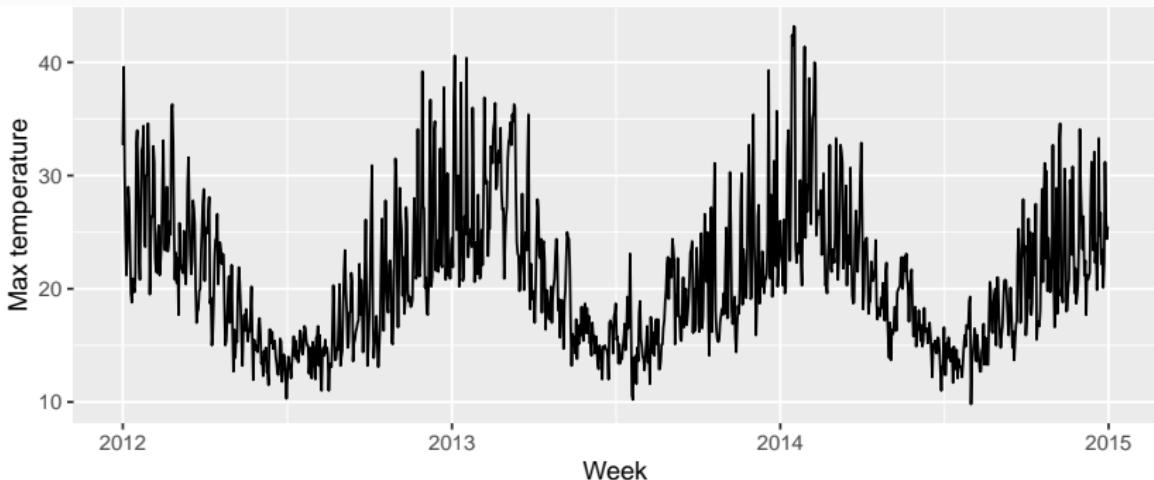
- 1 Download `tourism.xlsx` from
<http://robjhyndman.com/data/tourism.xlsx>,
and read it into R using `read_excel()` from the
`readxl` package.
- 2 Create a `tsibble` which is identical to the `tourism`
`tsibble` from the `tsibble` package.
- 3 Find what combination of Region and Purpose
had the maximum number of overnight trips on
average.
- 4 Create a new `tsibble` which combines the
Purposes and Regions, and just has total trips by
State.

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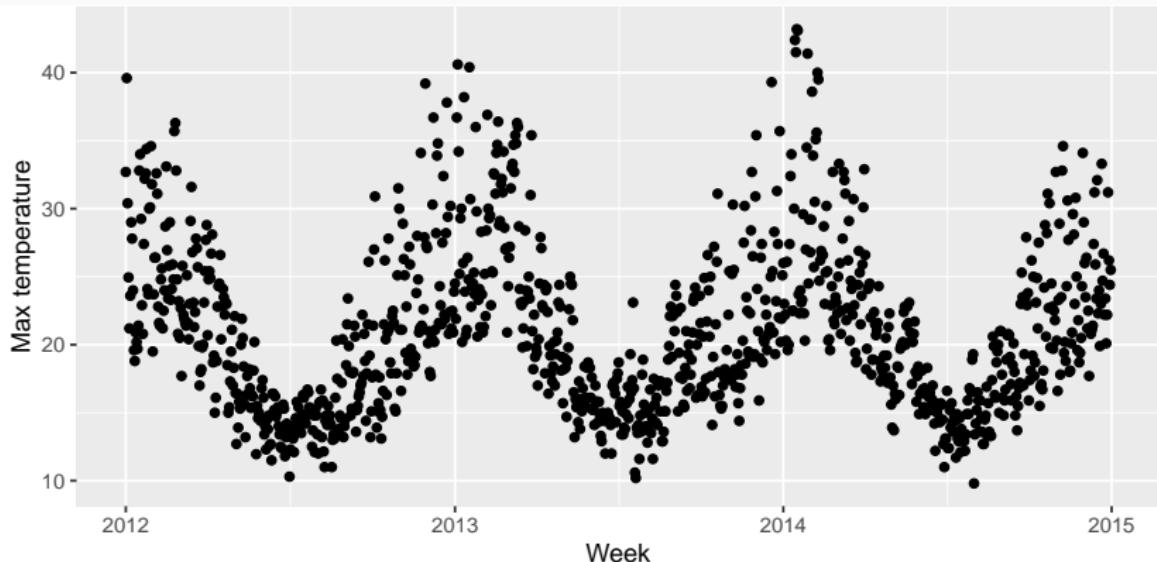
Are line plots best?

```
maxtemp <- vic_elec %>%  
  index_by(Day = date(Time)) %>%  
  summarise(Temperature = max(Temperature))  
maxtemp %>%  
  autoplot(Temperature) +  
  xlab("Week") + ylab("Max temperature")
```



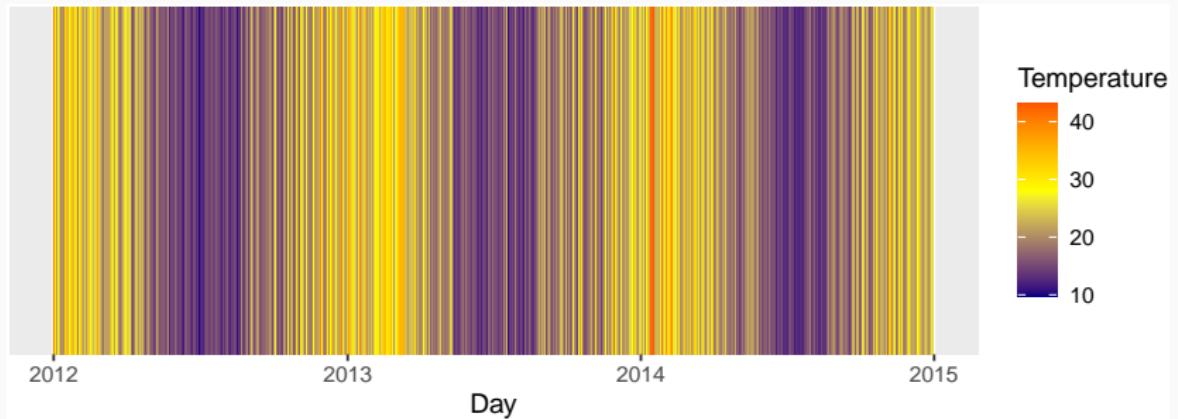
Are line plots best?

```
maxtemp %>%
  ggplot(aes(x = Day, y = Temperature)) +
  geom_point() +
  xlab("Week") + ylab("Max temperature")
```

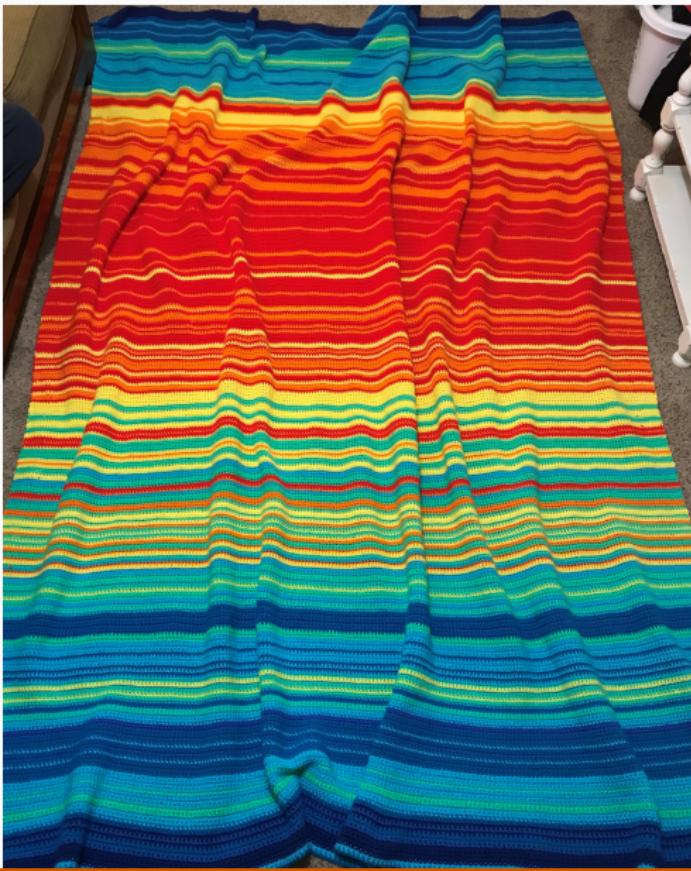


Are line plots best?

```
maxtemp %>%
  ggplot(aes(x = Day, y = 1)) +
  geom_tile(aes(fill = Temperature)) +
  scale_fill_gradient2(low = "navy", mid = "yellow",
                        high = "red", midpoint=28) +
  ylab("") + scale_y_discrete(expand=c(0,0))
```



Are line plots best?



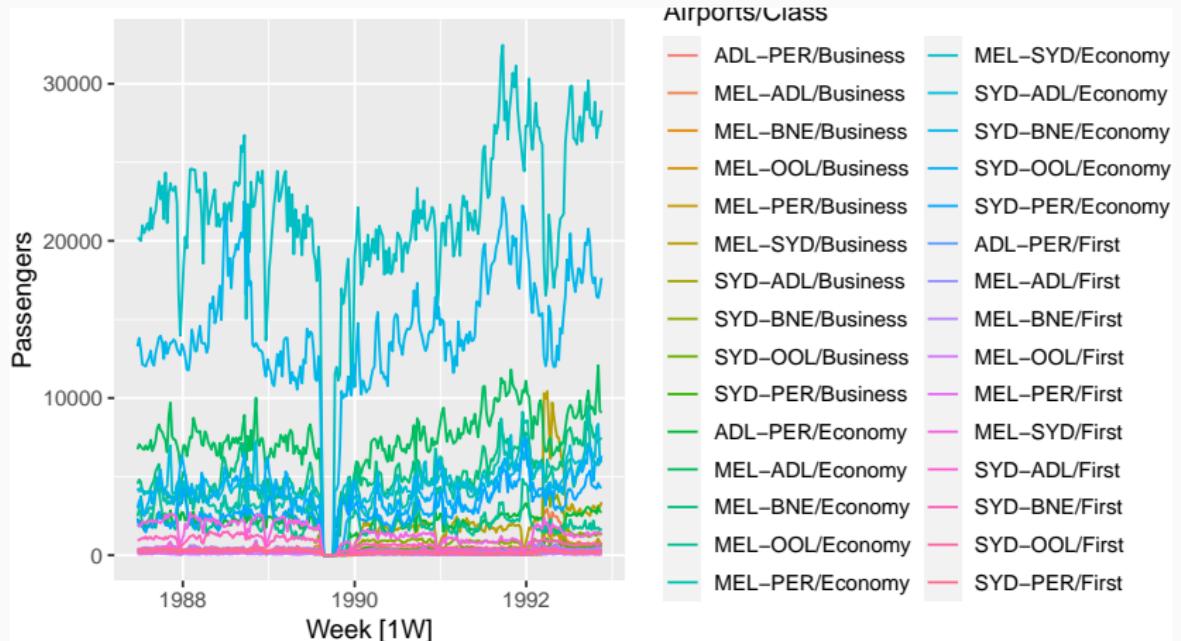
Ansett airlines



Ansett airlines

ansett %>%

autoplott(Passengers)

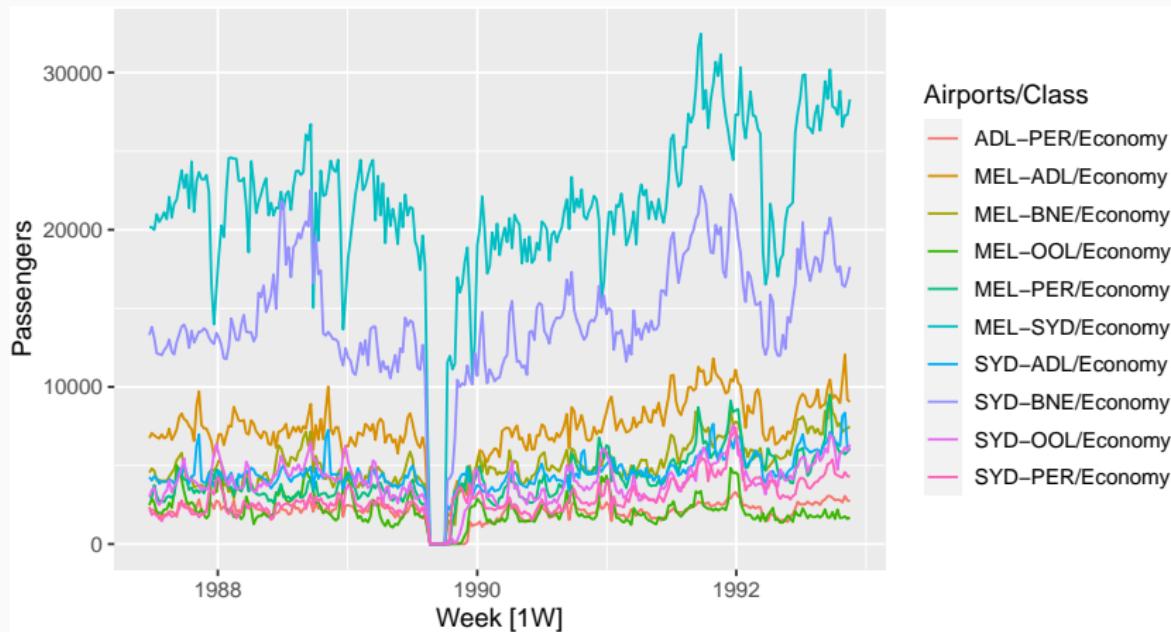


Ansett airlines

```
ansett %>%
```

```
  filter(Class=="Economy") %>%
```

```
  autoplot(Passengers)
```

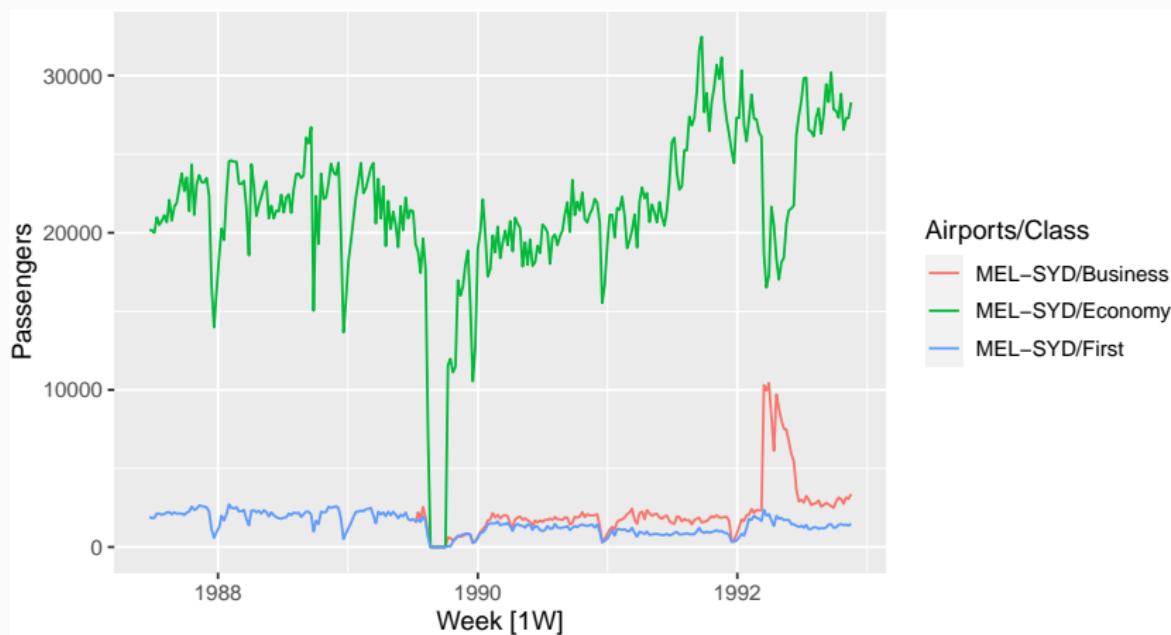


Ansett airlines

```
ansett %>%
```

```
  filter(Airports=="MEL-SYD") %>%
```

```
  autoplot(Passengers)
```

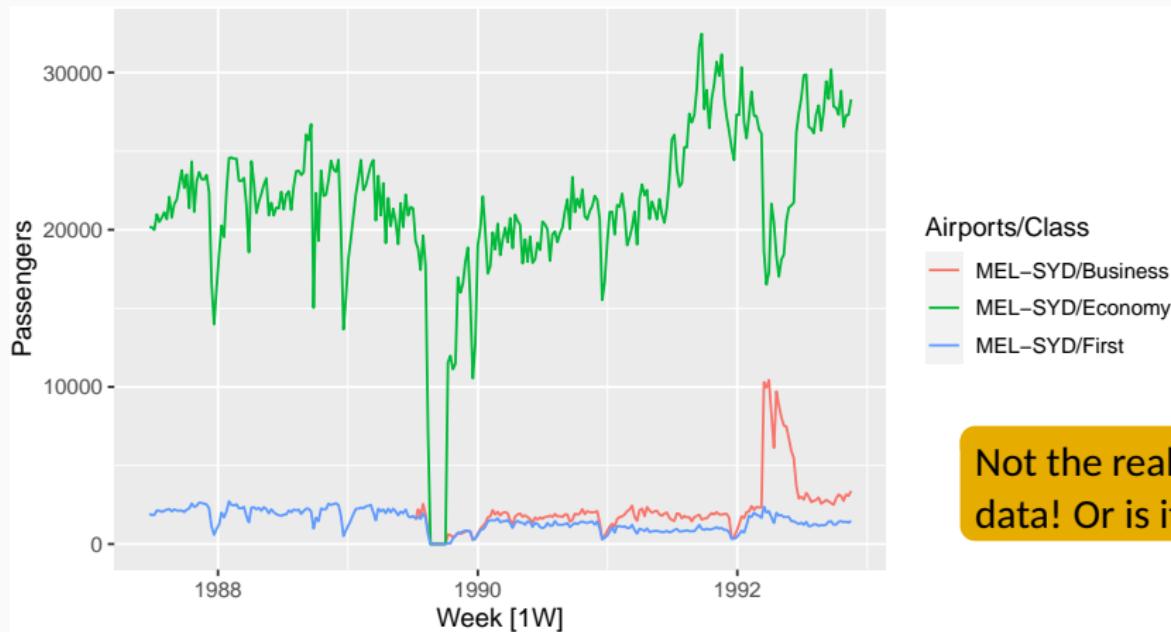


Ansett airlines

```
ansett %>%
```

```
  filter(Airports=="MEL-SYD") %>%
```

```
  autoplot(Passengers)
```



Outline

- 1 Time series data and tsibbles
- 2 Example: Australian prison population
- 3 Example: Australian pharmaceutical sales
- 4 Lab Session 1
- 5 Time plots
- 6 Lab Session 2

Lab Session 2

- Create time plots of the following four time series: Bricks from aus_production, Lynx from pelt, Close from gafa_stock, Demand from vic_elec.
- Use `help()` to find out about the data in each series.
- For the last plot, modify the axis labels and title.