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  `https://github.com/julianmak/academic-notes`

  The repository principally contains the compiled products rather than the source for size reasons.
- Associated Python code (as Jupyter notebooks mostly) will be held on the same repository. The source data however might be big, so I am going to be naughty and possibly just refer you to where you might get the data if that is the case (e.g. JRA-55 data). I know I should make properly reproducible binders etc., but I didn't...
- I do not claim the compiled products and/or code are completely mistake free (e.g. I know I don't write Pythonic code). Use the material however you like, but use it at your own risk.
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OCES 3301 :

basic Data Analysis in ocean sciences

Session 9: fun with maps

Outline

(Just overview here; for actual content see Jupyter notebooks)

- multi-dimensional arrays

  → documenting data varying in **space** (and in **time**)

  → basics of plotting (contours, animations) and statistics
- GEBCO and WOA13 data

  → NetCDF and `xarray`, basic functionalities

  → vertical profiles, meridional sections

  → masking, basic statistics, Hovmöller plots

Recap: data so far

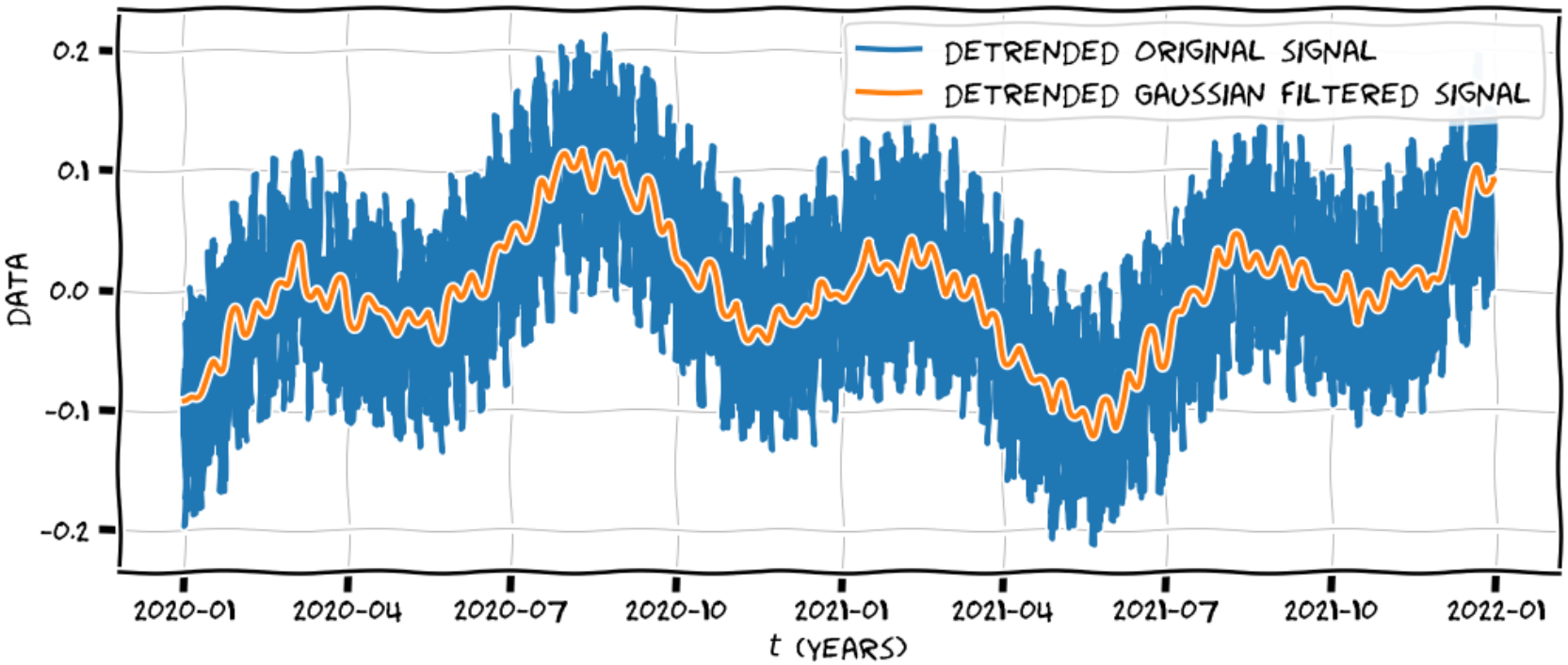


Figure: A detrended signal, as a 1d array varying in time.

Recap: data so far

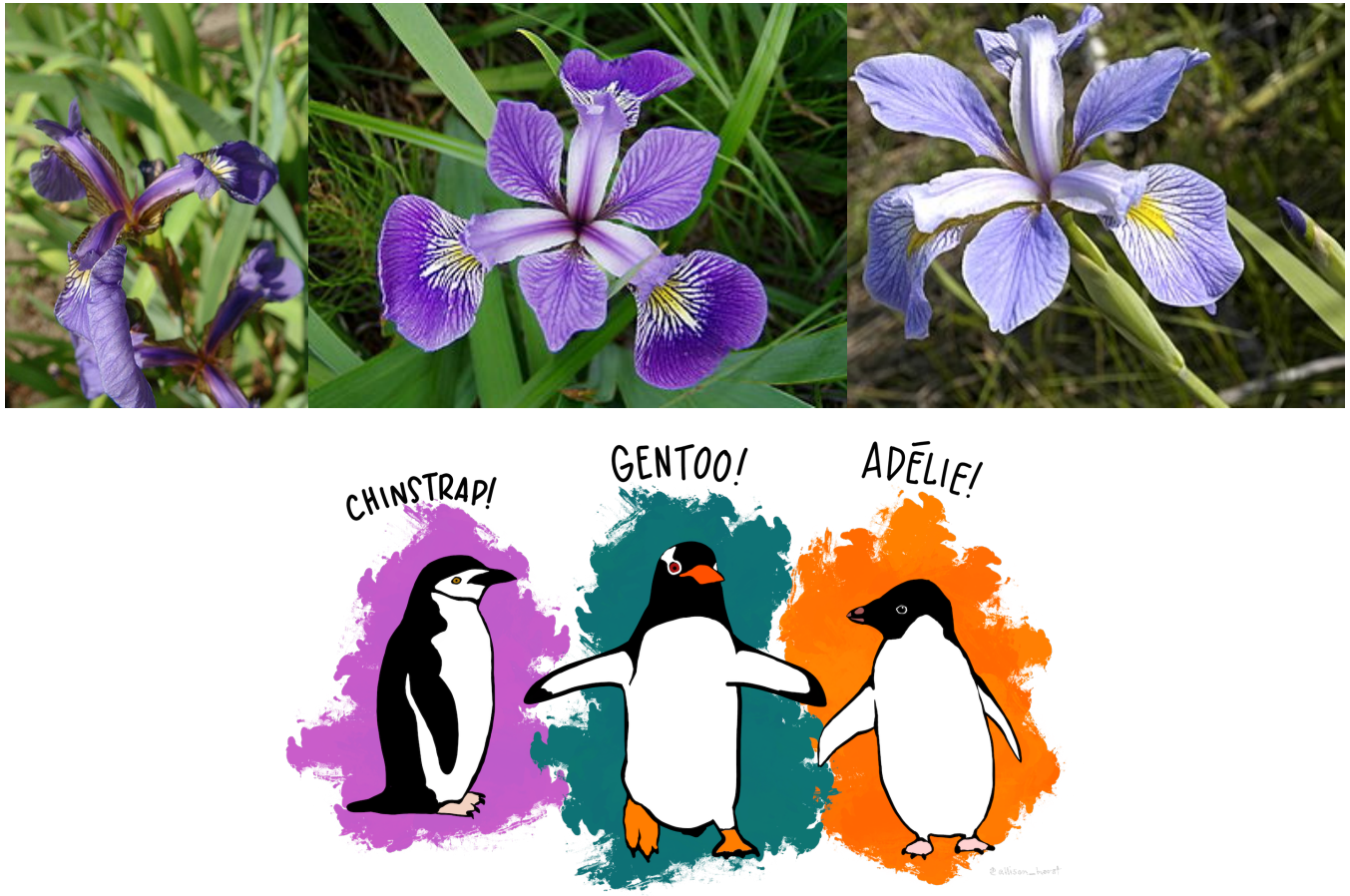


Figure: Analysis of data as 1d arrays against each other, but stored as multi-dimensional arrays.

Basic 2d array

Consider the function

$$f(x, y) = \sin(x)\cos(y)$$

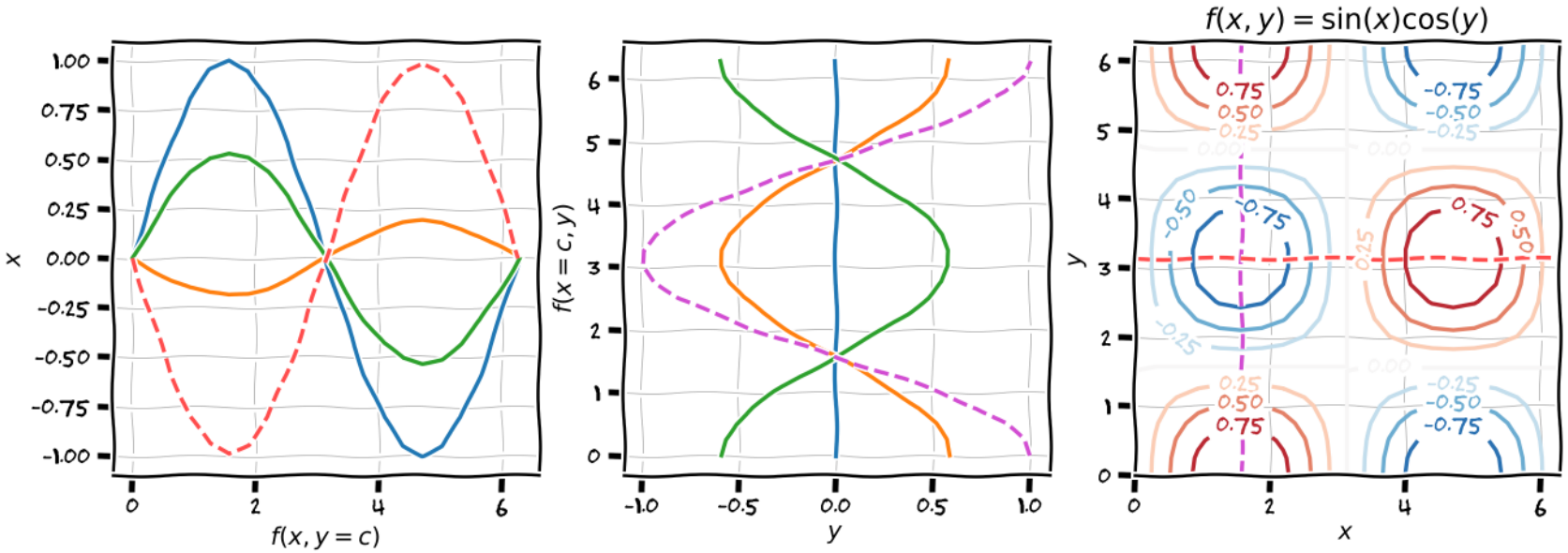


Figure: $f(x, y) = \sin(x)\cos(y)$ as lines at fixed y, fixed x, and contours in the (x, y).

- varying as sines in x and cosines in y
- circular 'blobs' in top-down view

Basic 2d array

$$f(x, y) = \sin(x)\cos(y)$$

Take

$$x = \begin{pmatrix} x_0 \\ x_1 \\ \vdots \\ x_{N_x} \end{pmatrix}, \qquad y = \begin{pmatrix} y_0 \\ y_1 \\ \vdots \\ y_{N_y} \end{pmatrix}$$

and store as (see notebook to see how this would be generated)

$$f(x, y) = \begin{pmatrix} f(x_0, y_0) & f(x_1, y_0) & \cdots & f(x_{N_x}, y_0) \\ f(x_0, y_1) & f(x_1, y_1) & \cdots & f(x_{N_x}, y_1) \\ \vdots & \vdots & \ddots & \vdots \\ f(x_0, y_{N_y}) & f(x_1, y_{N_y}) & \cdots & f(x_{N_x}, y_{N_y}) \end{pmatrix}.$$

- Python plotting 'prefers' storage of arrays in 'descending' dimensions `f[t,z,y,x]` etc.

Basic 2d array

$$f(x, y) = \sin(x)\cos(y)$$

- view the contour (or filled contour) plots as 'top-down' views of 3d plot

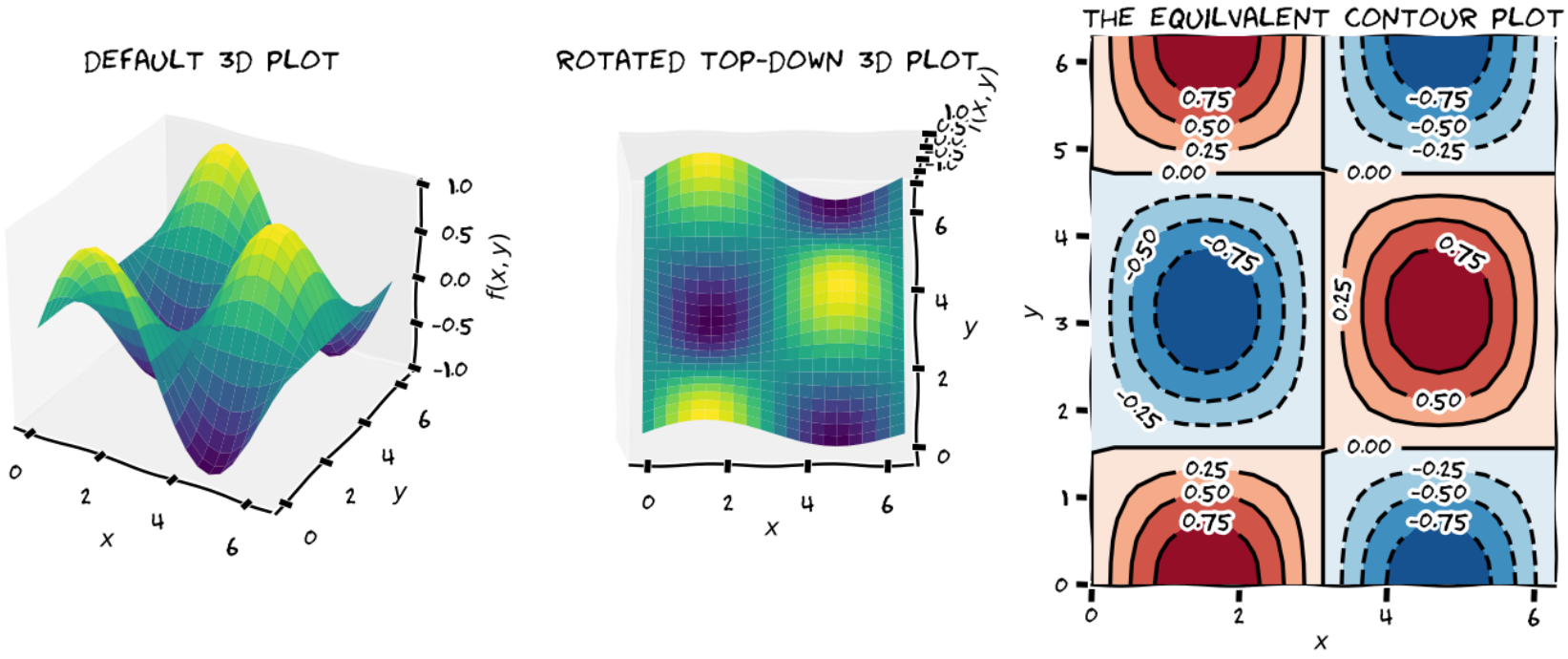


Figure: $f(x, y) = \sin(x)\cos(y)$ as 3d plots.

e.g. equation of state

- oceanography relevant 2d example: equation of state (EOS)

  $\rightarrow \rho = \rho(T, S, \cdots)$

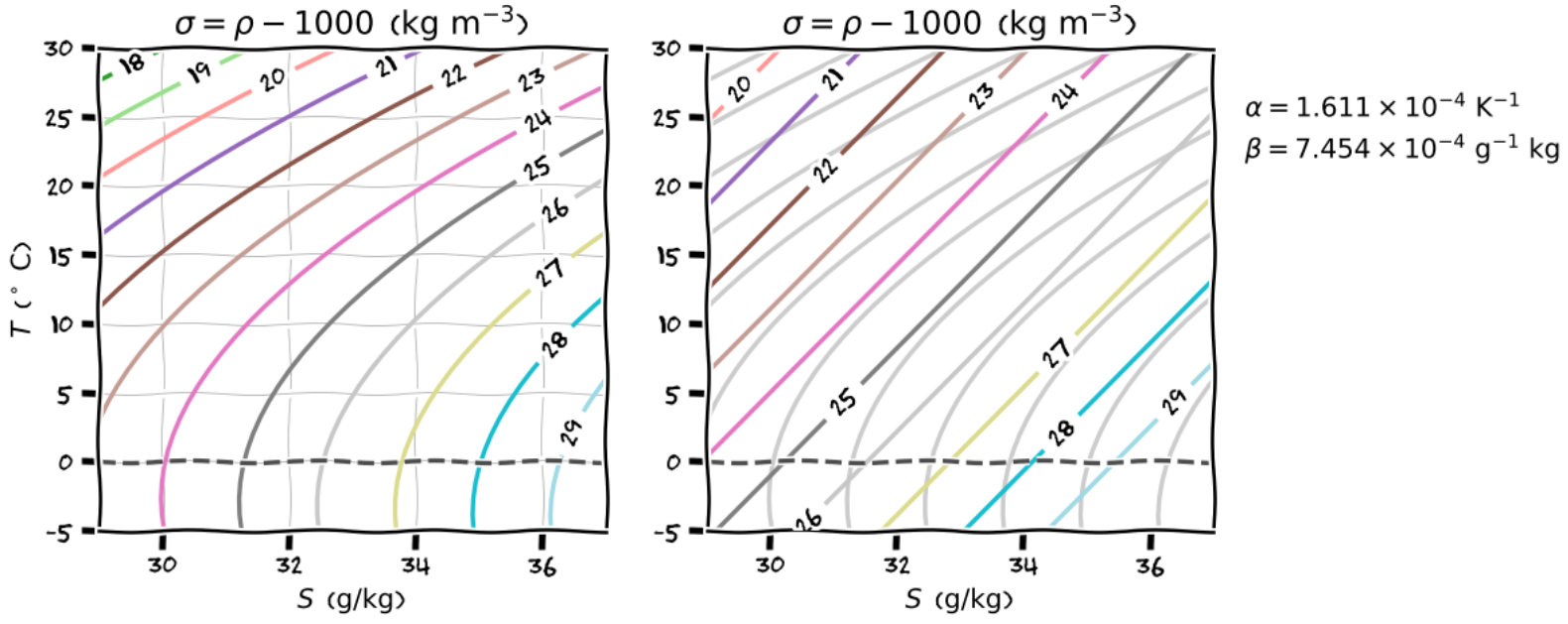


Figure: $\rho = \rho(T, S, \cdots)$ over choices of T and S, for the nonlinear TEOS-10 and linear EOS for some choice of α and β.

Animations

- really just pictures transitioning quickly

  $\rightarrow$ think flipbooks

  $\rightarrow$ a few still images as frames

  $\rightarrow$ transitioning with a frame rate (fps = frames per second)

(Humans perceive anything larger than about 16 fps as ‘smooth’, loosely speaking)

cursed beast most foul

(2 + 1)d array

$$f(x, y) = \sin(x)\cos(y)\sin(t)$$

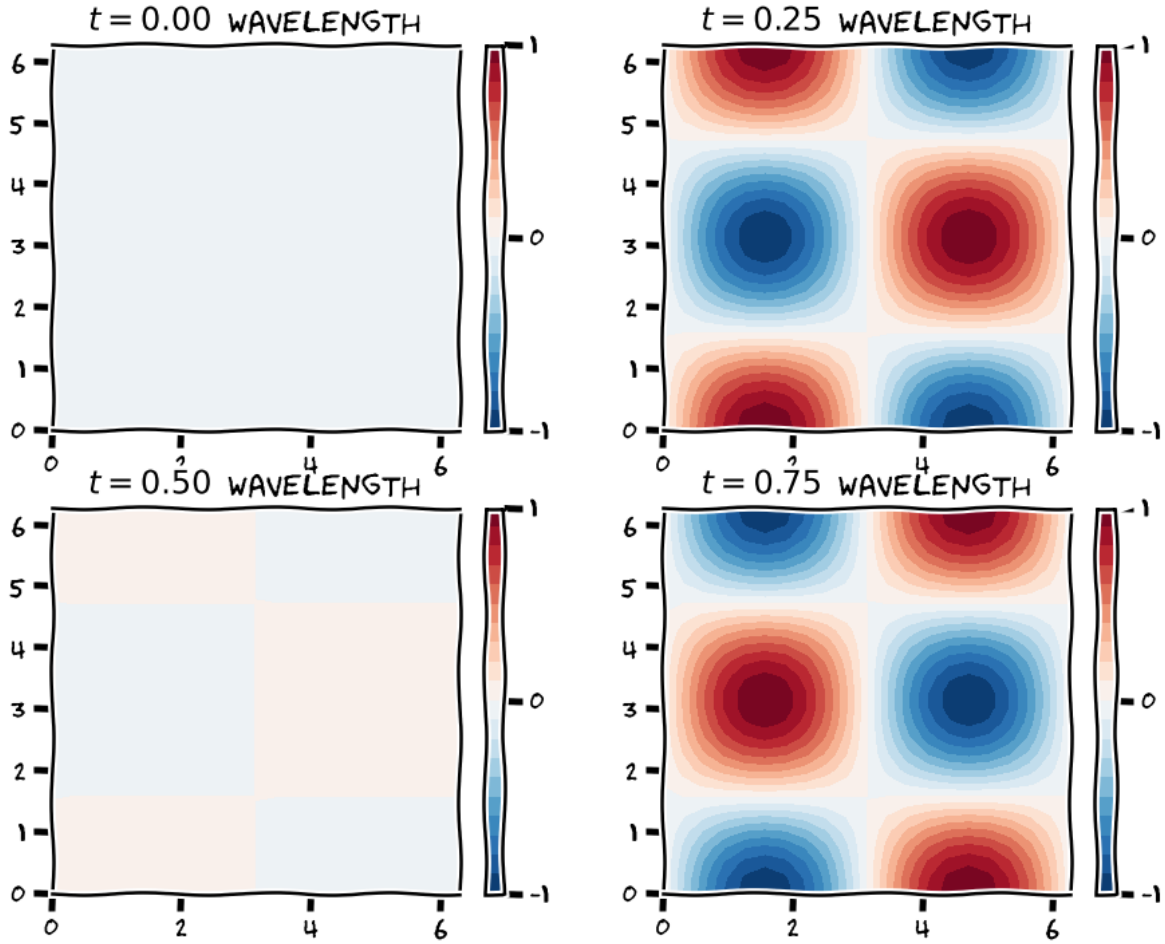


Figure: $f(x, y, t) = \sin(x)\cos(y)\sin(t)$ at some fixed times.

(2 + 1)d array

$$f(x, y) = \sin(x) \cos(y) \sin(t)$$

- data stored as `f[t_k, y_j, x_i]`
- see code for how you might animate the above in Python/Jupyter

(I tend to output all frames in Python but assemble into animation externally)

wibbly wobbly timey wimey

(2 + 1)d array: statistics

$$f(x, y) = \sin(x)\cos(y)\sin(t)$$

- can compute averages, stds, rolling-averages etc.
  → over t (time average)
  → over space (spatial average)
  → over the longitude or x (zonal average)

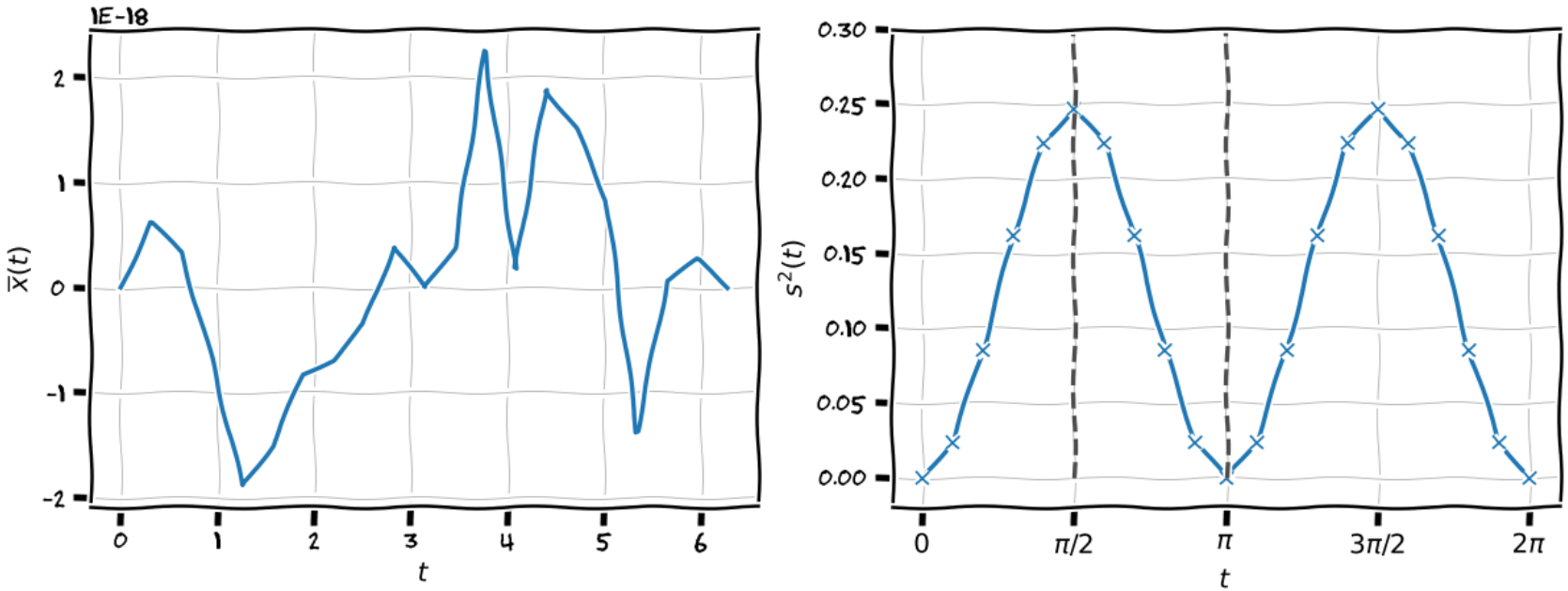


Figure: Spatial average and variance of $f(x, y, t) = \sin(x)\cos(y)\sin(t)$ as a function of time.

GEBCO and WOA13 data

More 'realistic' examples:

- GEBCO (The General Bathymetric Chart of the Oceans)

  → topography (above sea level) and bathymetry (below sea level) I will probably use them interchangeably

  → various spatial resolutions, time independent

  → $\text{elev}(\text{lat}, \text{lon})$

- WOA13 (World Ocean Atlas 2013)

  → various quantities, going to deal with T and S here

  → climatologies, monthly ('average' monthly condition)

  → 1° spatial resolution (but will find denser interpolated versions)

  → $f(\text{month}, \text{depth}, \text{lat}, \text{lon})$

GEBCO and WOA13 data

Geophysical data normally comes as NetCDF (Network Common Data Form)

- with extension `*.nc` or sometimes `*.nc4`

  → self-describing, normally includes co-ordinates files, masks (see later), attributes etc.

  → need a library to read it

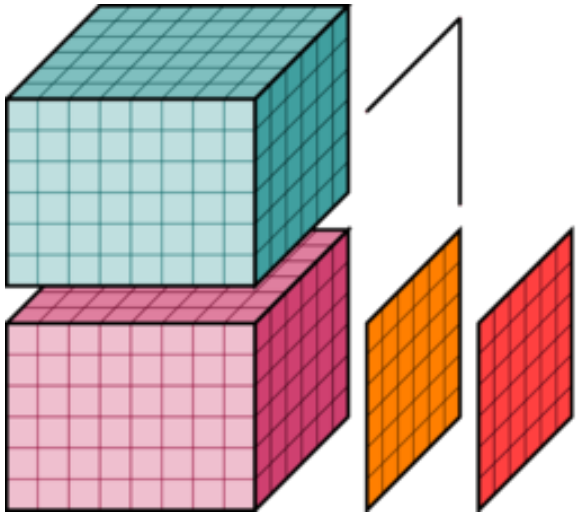
NetCDF and CF: The Basics

GEBCO and WOA13 data

- going to use `xarray` to read NetCDF files

  → could think of it as a convenient front end for the Python NetCDF library

  → actually much more powerful than that (see notebook)



xarray

GEBCO and WOA13 data

- xarray returns a data frame **`df`**

  → cf. Pandas data frame

  → see co-ordinate variables, data variables, attributes etc.

```
<xarray.Dataset>
Dimensions:  (lat: 451, lon: 901)
Coordinates:
  * lat      (lat) float64 -90.0 -89.6 -89.2 -88.8 -88.4 ... 88.8 89.2 89.6 90.0
  * lon      (lon) float64 -180.0 -179.6 -179.2 -178.8 ... 179.2 179.6 180.0
Data variables:
    elev     (lat, lon) float32 ...
Attributes:
    Conventions:  CF-1.6
    title:        The GEBCO One Minute Grid - a continuous terrain model for ...
    institution:  On behalf of the General Bathymetric Chart of the Oceans (G...
    source:       The grid is largely based on the bathymetric contours conta...
    history:      This is version 2.0 of the data set, released in November 2008
    references:   Information on the data set is available from the internet:...
    comment:      The data in the GEBCO One Minute Grid should not be used fo...
    node_offset:  0
```

Figure: Sample output from GEBCO read via xarray.

GEBCO and WOA13 data: surface plots

- xarray objects have imbued functions

  → `df["elev"].plot()` below with GEBCO data

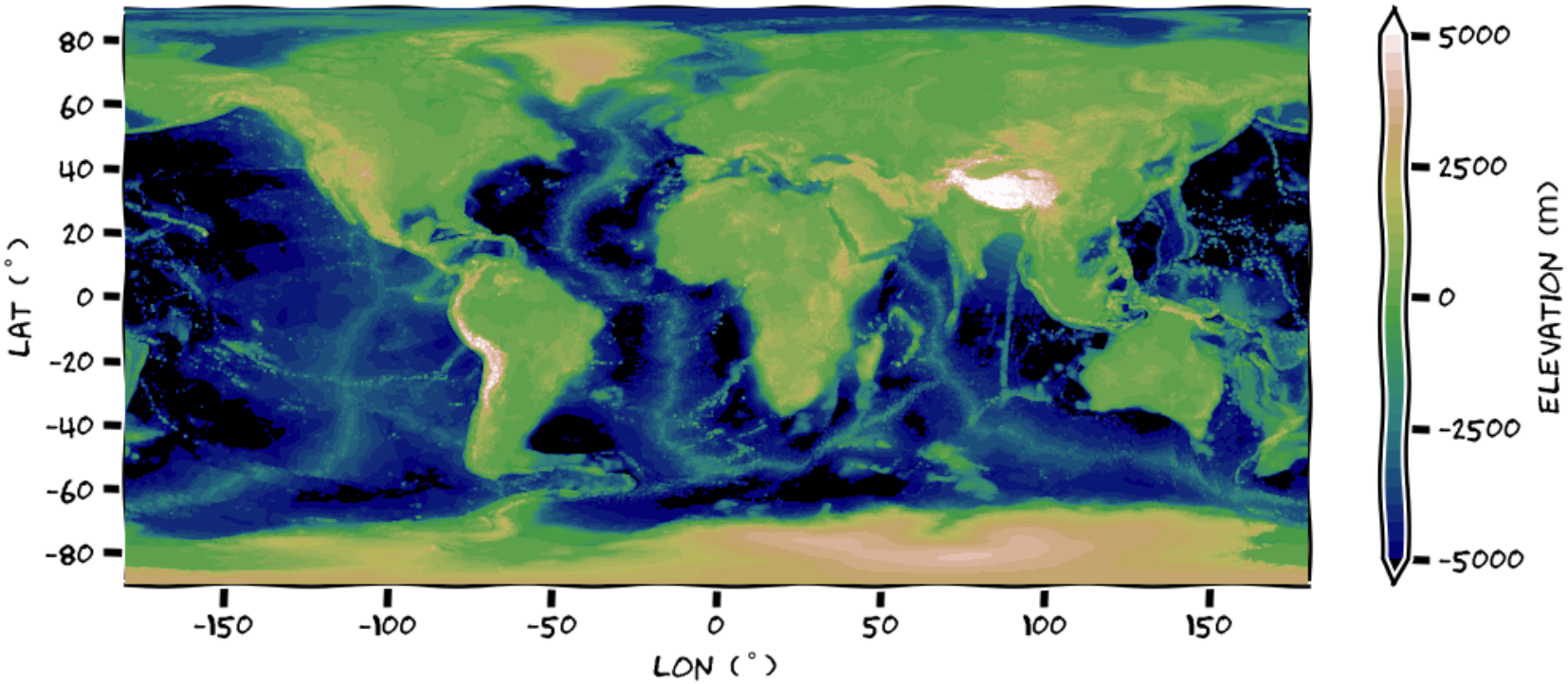


Figure: Sample output from GEBCO read via xarray.

GEBCO and WOA13 data: vertical profile

- xarray objects have imbued functions
  → `df["votemper"].sel().plot()` to pick out lon/lat/time locations rather than specifying the index explicitly, and doing plot

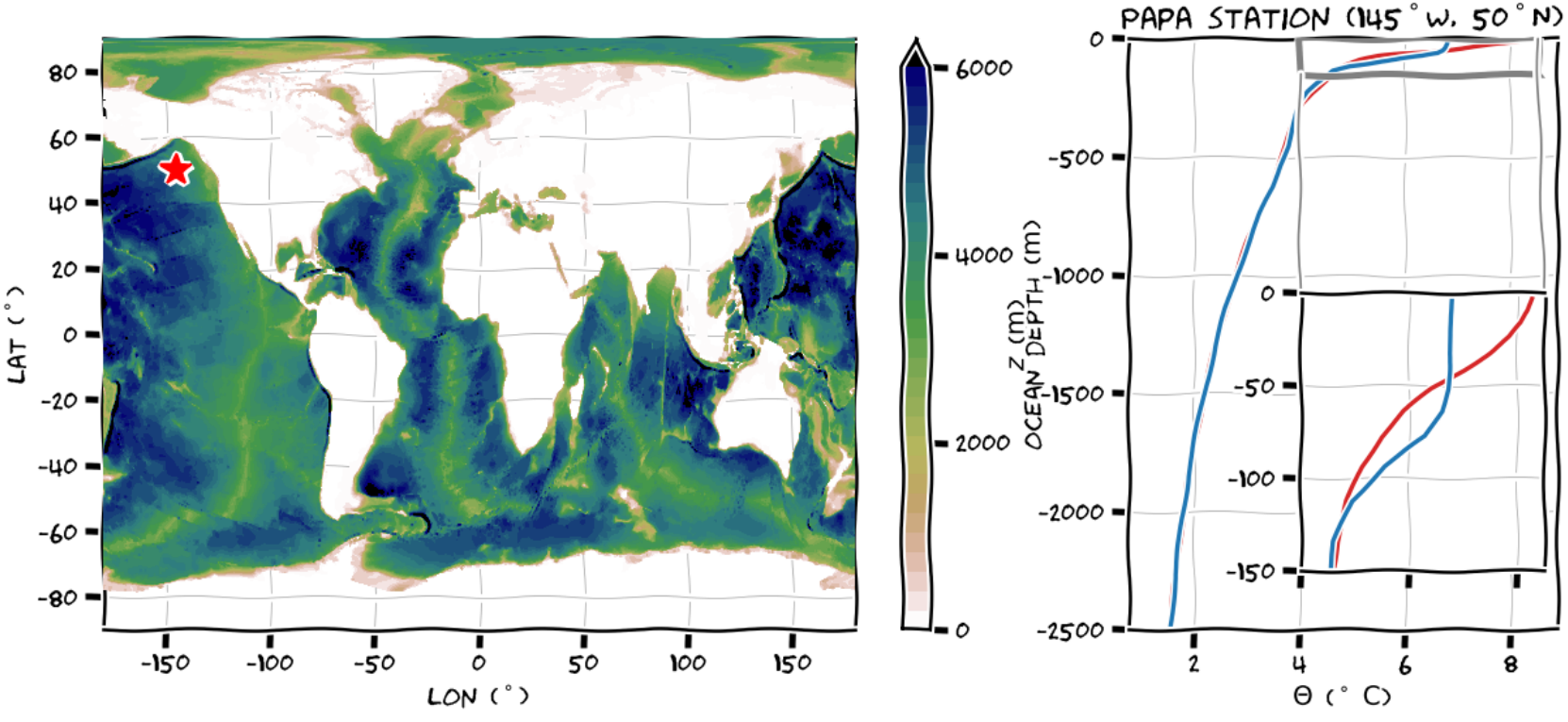


Figure: Vertical profile of WOA13 (conservative) temperature at summer and winter months at PAPA station.

GEBCO and WOA13 data: meridional section

- as previous, but for meridional section
  → fixed latitude, function of lon and depth
  → `.sel(lat=SOMETHING, method="nearest")`

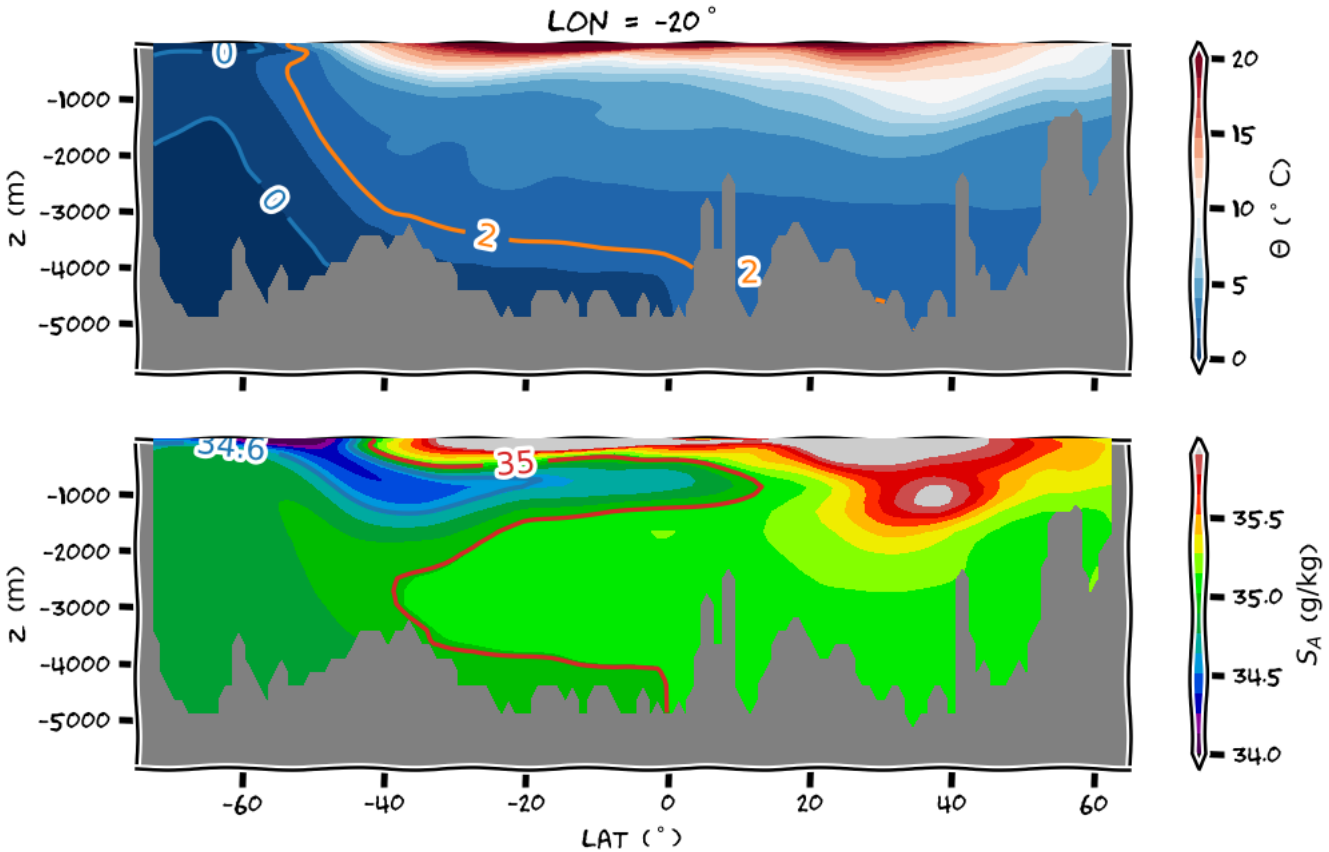


Figure: Meridional profile of time-averaged WOA13 (conservative) temperature and (absolute) salinity. Masking of based on GEBCO data.

GEBCO and WOA13 data: masking

- WOA13 data here is not masked

  → e.g. $f(\text{month}, \text{depth}, \text{lat}, \text{lon})$ contains co-ordinates at land points

  → wanted to exclude those points when doing calculations (e.g. averages)

- create a mask separately here from GEBCO data

  → boolean arrays of `True/False` or integer arrays of `1/0` to correspond to ocean/land points

  → using some conditional, e.g. `if df["elev"] < 0 then 1 else 0`

GEBCO and WOA13 data: masking

- mask is (`df["elev"] < 0`) AND (lon and lat within some region)
  $\rightarrow$ 1 if true, 0 otherwise
- construct $T \times$ mask
  $\rightarrow$ I actually used NaNs instead of 0

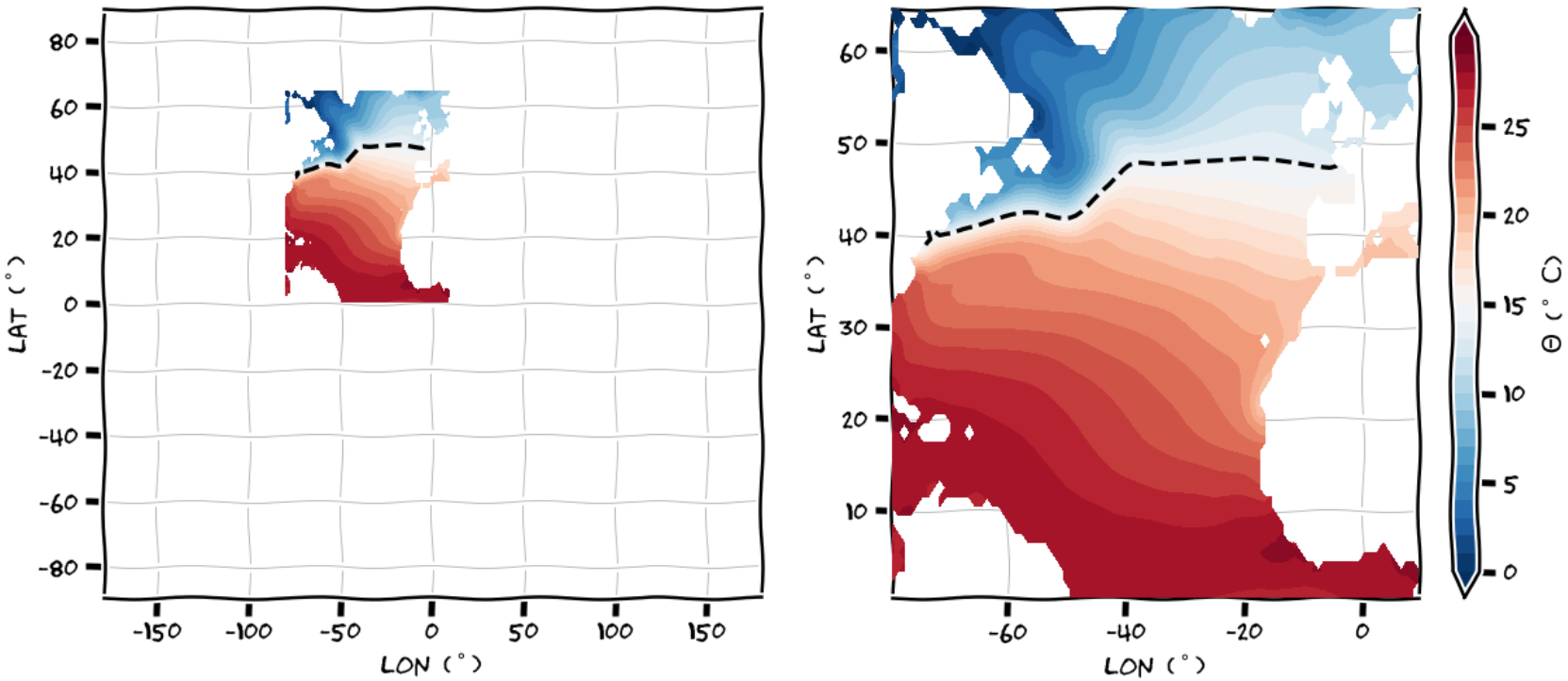


Figure: Mask created GEBCO data based on land, and within a certain region in the Atlantic. Plotting the surface WOA13 temperature on top of that.

GEBCO and WOA13 data: masking and stats

NaNs instead of zeroes might be preferably because

- plotting commands normally ignore NaNs (see above)

  $\rightarrow$ e.g. if zeroes, then contours of '0' will probably dominate

- there are routines to ignore NaNs in calculations (e.g. `np.nanmean`)

  $\rightarrow$ e.g.

$$\begin{aligned} \text{nanmean}\{1,2,3,\text{NaN}\} &= \frac{1+2+3}{3} &&= 2 \\ \text{mean}\{1,2,3,0\} &= \frac{1+2+3+0}{4} &&= 1.5 \\ \text{mean}\{1,2,3,\text{NaN}\} &= \frac{1+2+3+\text{NaN}}{4} &&= ??? \end{aligned}$$

GEBCO and WOA13 data: masking and stats

Domain average (really just nanmean twice here) and zonal average (really just nanmean over longitude)

$$\langle \Theta \rangle = \frac{1}{A} \iint \Theta \, \mathrm{d}\boldsymbol{A} = \frac{1}{A} \iint \Theta \, \mathrm{d}x \, \mathrm{d}y \qquad \overline{\Theta} = \frac{1}{L_x} \int \Theta \, \mathrm{d}x.$$

- $\langle \Theta \rangle$ is a function of t only, while $\overline{\Theta}$ is a function of t and y

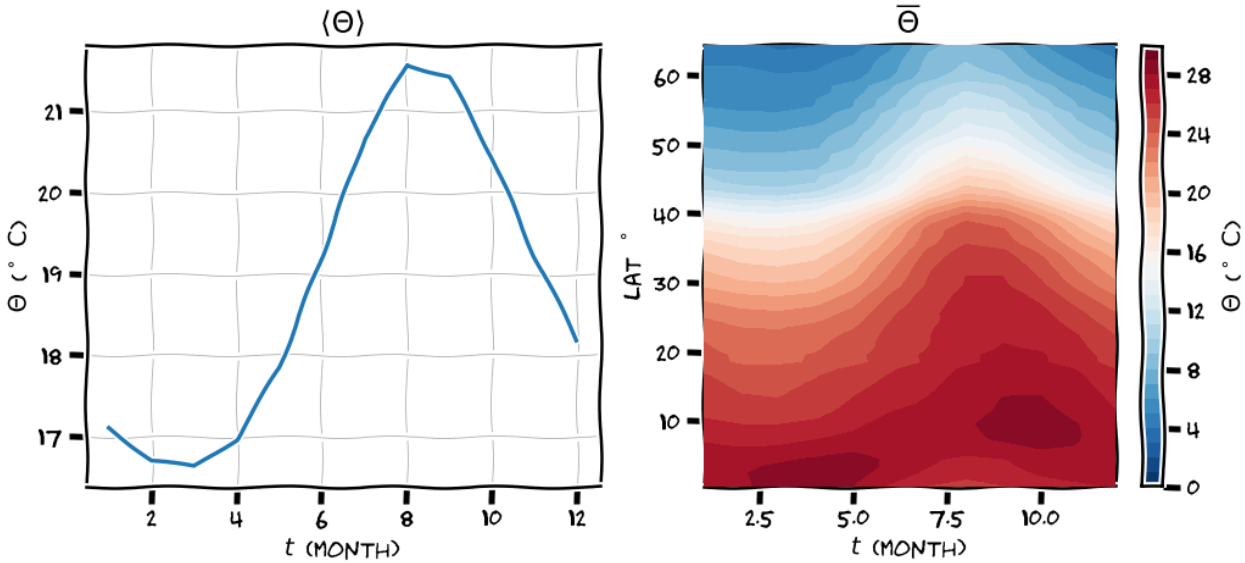


Figure: Domain and zonal average of WOA13 surface temperature over the Atlantic, as a time-series and a Hovmöller diagram.

Jupyter notebook

go to 09 Jupyter notebook to get some code practise

- try analyses on some sample data from a numerical simulation also

  → surface current speed from NEMO ORCA0083-N01

  → 1 year, every 5 days, nominally 1/12° horizontal resolution

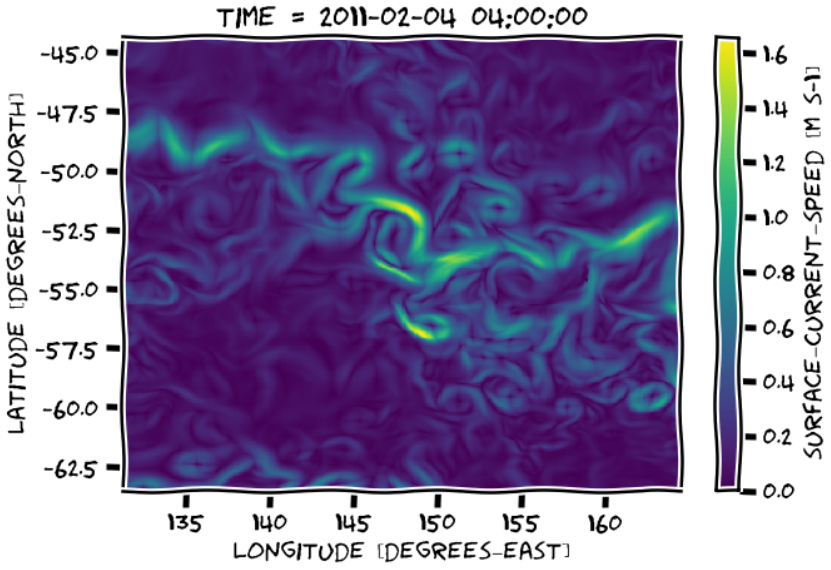


Figure: Surface current speed from NEMO ORCA0083-N01 somewhere in the Southern Ocean (ask me for more data if you want).