Interactive visualization of climate model data via Python or GUI with psyplot

DACH 2022

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Help

Technical Note

This presentation is a jupyter notebook presented with rise for interactive execution of the cells. You can run it interactively on mybinder in your browser:

launch binder

The link to the repo on Github: https://github.com/Chilipp/psyplot-DACH2022-presentation).

Back to first slide

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So let's import some libraries for the execution

In [1]:
```
%matplotlib widget

import psyplot.project as psy

import numpy as np
import xarray as xr
import matplotlib.pyplot as plt
import cartopy.crs as ccrs
from IPython.display import display, Video

from ipympl.backend_nbagg import Canvas
Canvas.header_visible.default_value = False

import pyvista
pyvista.rcParams['use_ipyvtk'] = True

import warnings
warnings.filterwarnings("ignore", r"\s*The on_mappable_chang
warnings.filterwarnings("ignore", r"\s*The input coordinates
warnings.filterwarnings("ignore", r"\s*shading=")
warnings.filterwarnings("ignore", r"\s*\[Warning by")
```

Outline

Main features of psyplot

How to use and extend the framework

Some more features of psyplot

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Main features of psyplot

How to use and extend the framework

Some more features of psyplot

Note:

I am not a visualization expert

The aim of this talk is not to show wonderful plots, but rather how to generate them.

You can always make them publication-ready using the rich features of matplotlib.

Main features of psyplot

Using psyplot from Python

In [2]:
```
ds = psy.open_dataset("data/icon_grid_demo.nc")
ds
```

Out[2]:
```
<xarray.Dataset>
Dimensions:    (time: 5, ncells: 5120, vertices: 3, edge:
480, no: 4, lev: 4)
Coordinates:
  * time       (time) datetime64[ns] 1979-01-31T18:00:00
... 1979-05-31T18:00:00
    clon       (ncells) float64 ...
    clon_bnds  (ncells, vertices) float64 ...
    clat       (ncells) float64 ...
    clat_bnds  (ncells, vertices) float64 ...
    elon       (edge) float32 ...
    elon_bnds  (edge, no) float32 ...
    elat       (edge) float32 ...
    elat_bnds  (edge, no) float32 ...
  * lev        (lev) float64 1e+05 8.5e+04 5e+04 2e+04
Dimensions without coordinates: ncells, vertices, edge, no
Data variables:
    t2m        (time, lev, ncells) float32 ...
    u          (time, lev, ncells) float32 ...
    v          (time, lev, ncells) float32 ...
    t2m_edge   (time, lev, edge) float32 ...
Attributes:
    CDI:                  Climate Data Interface version
1.9.1 (http://mpimet...
    Conventions:          CF-1.4
    history:              Thu Aug 30 21:54:23 2018: cdo de
lname,t2m_2d,u_2d,v...
    number_of_grid_used:  42
    uuidOfHGrid:          bf575ad8-daa6-11e7-a4a9-93d511f8
21b4
    title:                Temperature and Wind demo-File f
or python nc2map mo...
    CDO:                  Climate Data Operators version
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```

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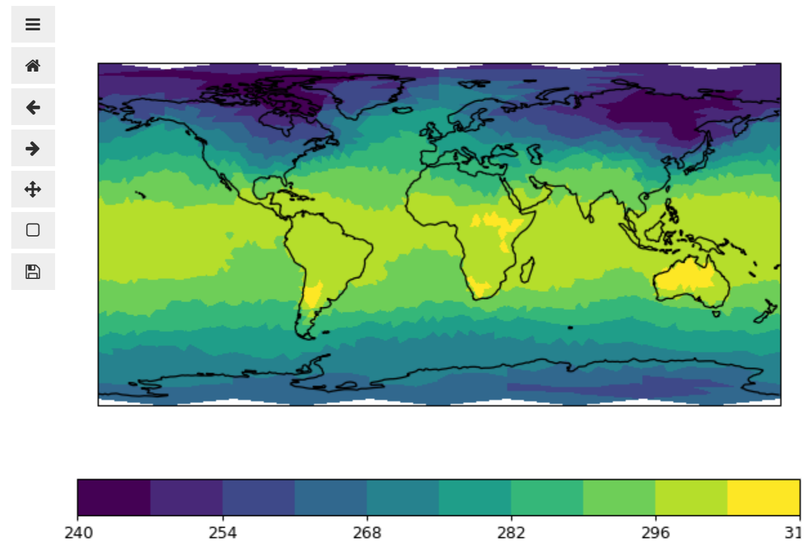
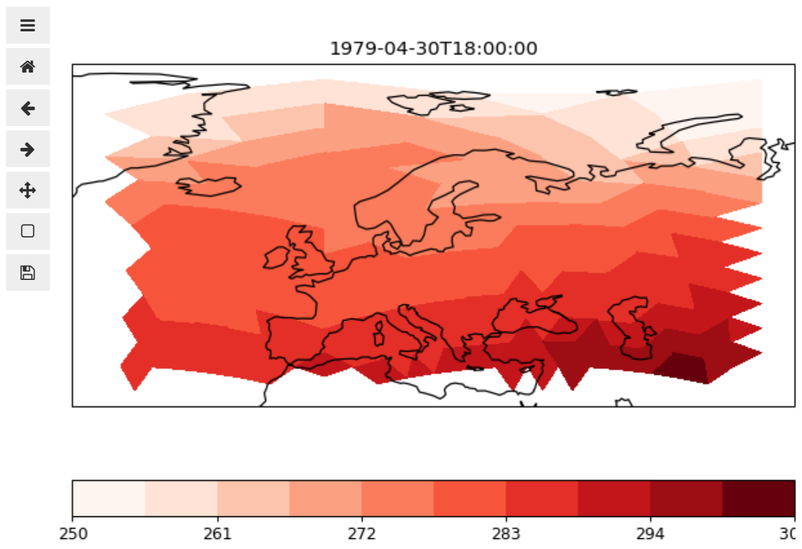
21b4
    title:                Temperature and Wind demo-File f
or python nc2map mo...
    CDO:                  Climate Data Operators version
1.9.1 (http://mpimet...
```

In [3]:
```
sp = ds.psy.plot.mapplot(
    name="t2m",
)
```



Working interactively from the command line

In [4]:
```
sp = ds.psy.plot.mapplot(
    name="t2m", cmap="Blues",
)
```



Working interactively from the command line

```
In [4]: sp = ds.psy.plot.mapplot(
            name="t2m", cmap="Blues",
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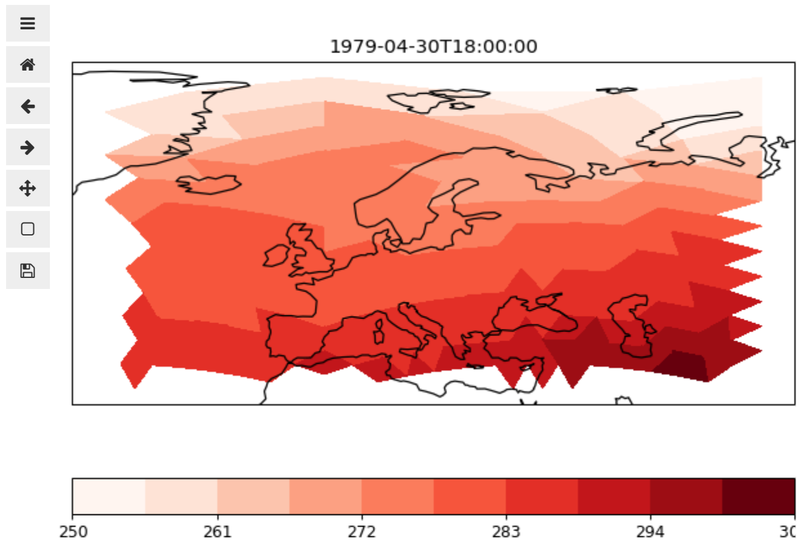
```




```
In [5]: sp.update(cmap="Reds")
```

```
In [6]: sp.update(title="%(time)s")
```

```
In [7]: sp.update(time=3)
```

```
In [8]: sp.update(lonlatbox="Europe")
```

```
In [9]: psy.close("all")
```

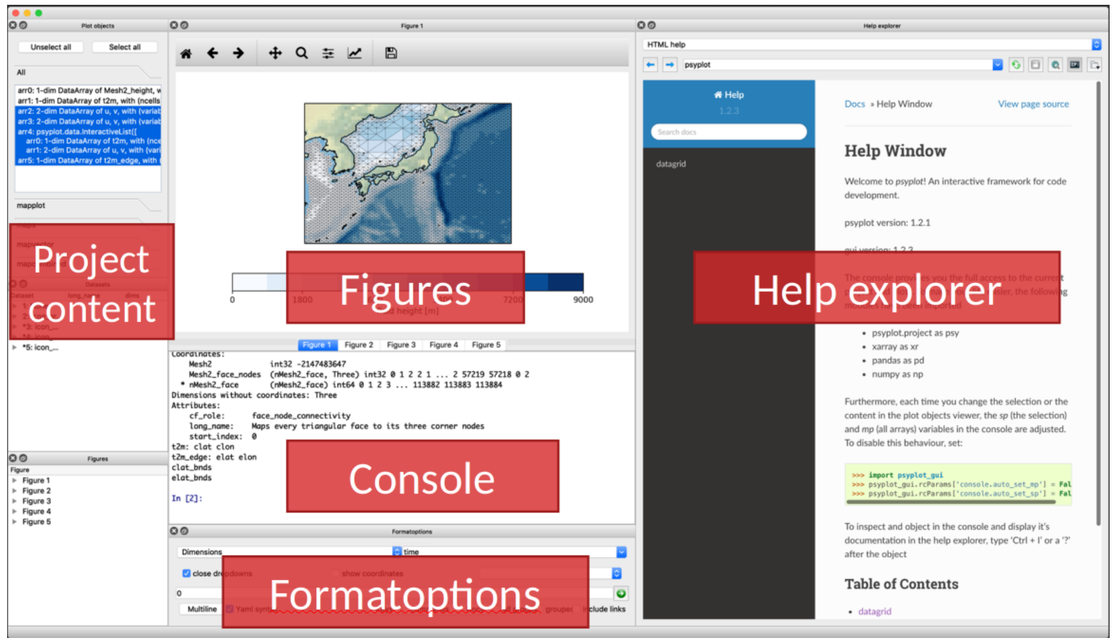
Using the GUI

psyplot comes with a flexible graphical user interface (GUI).

- On mybinder: click here.
- On mistral:
  - either via X11

    ```
    ssh -X mistral
    module load python3
    psyplot
    ```

  - or via remote desktop
- On your on own working station: Install it via `conda install -c conda-forge psy-view`

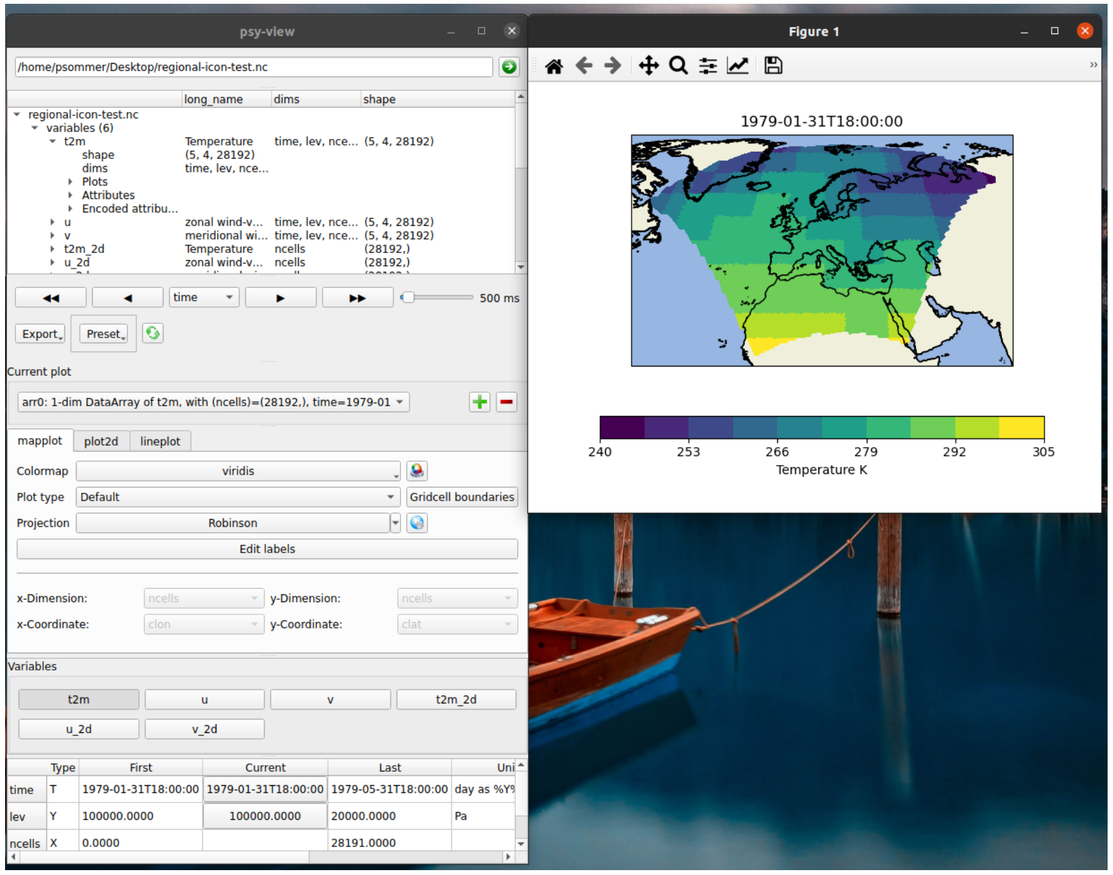


psy-view

An ncview-like interface, but with psyplot

- quick access to netcdf-variables via buttons
- switch between projections
- modify basemap
- change labels, colormaps, etc.
- display time-series when clicking on the map
- load presets for your plots
- animate through time, z, etc.

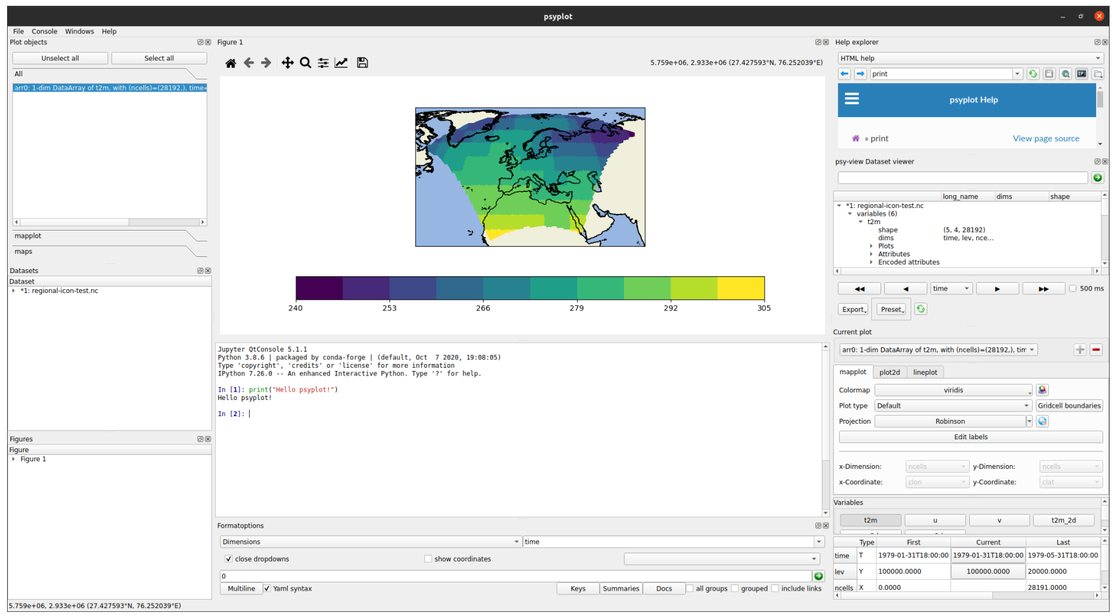
https://psyplot.github.io/psy-view



The psyplot GUI

Flexible GUI for coding and clicking

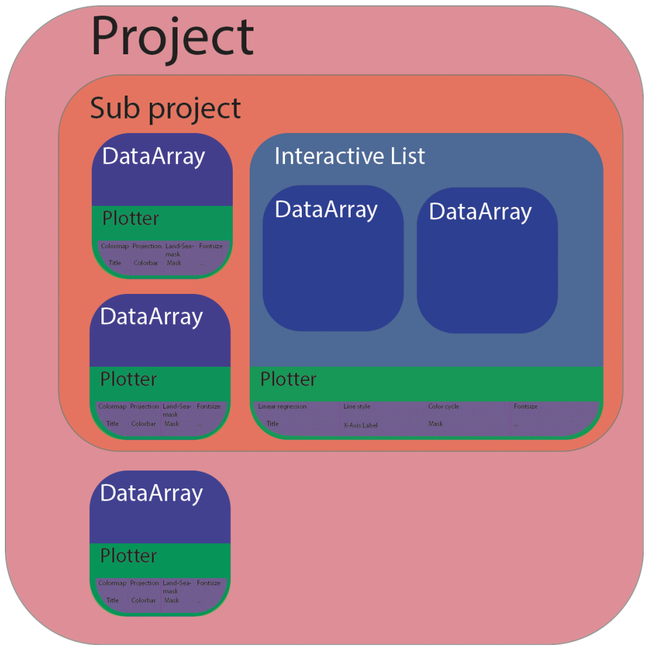
- integrated IPython console for interactive use of the command line
- connected help window that renders help and python object documentation
- integrated psy-view window
- shortcut widgets for individual formatoptions



https://psyplot.github.io/psyplot-gui

An introduction into the psyplot framework

The psyplot data model



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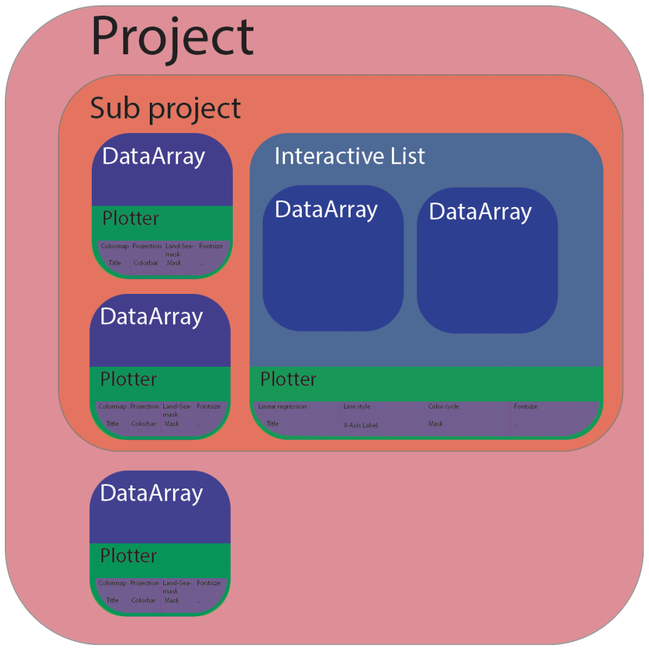

- `Formatoption`: The smallest possible unit. Each formatoption controls one aspect of the plot (cmap, lonlatbox, etc.)
- `Plotter`: A set of formatoptions that visualizes data

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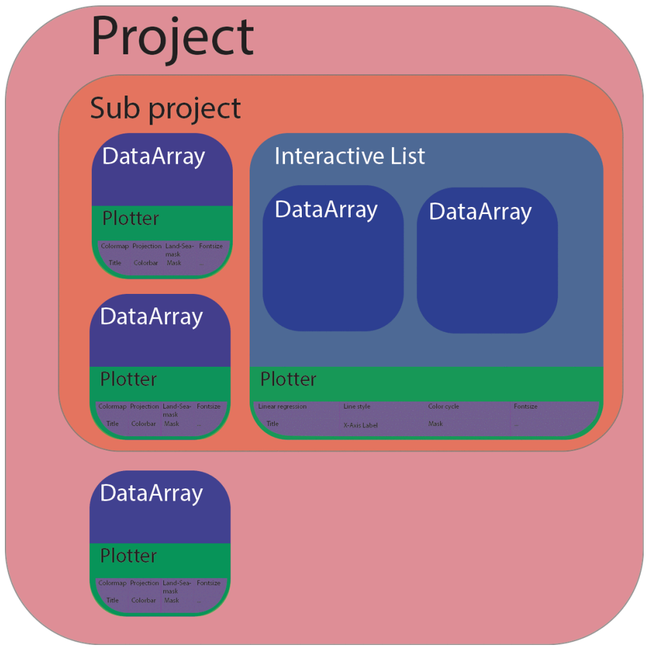

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- `DataArray`: Standard `xarray`
- `InteractiveList`: A collection of `DataArray`s that are visualized by one plotter (e.g. a collection of lines)

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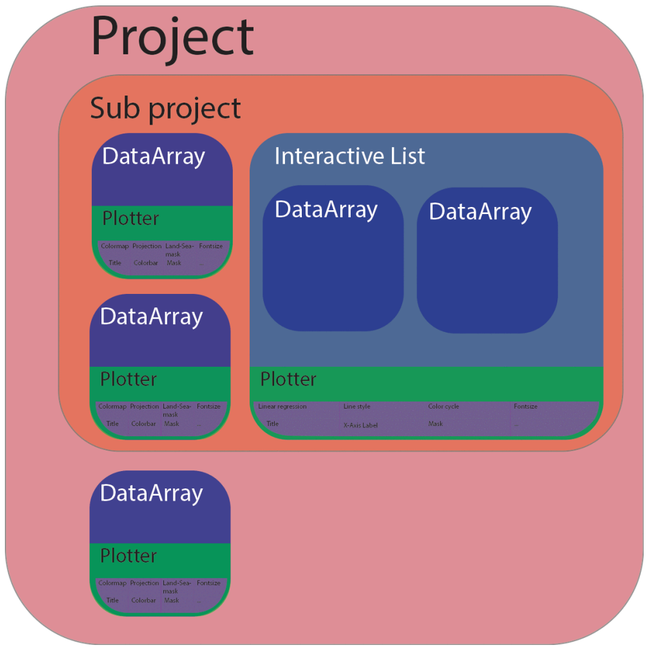

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- `Plotter`: A set of formatoptions that visualizes data

- `DataArray`: Standard `xarray`
- `InteractiveList`: A collection of `DataArray`s that are visualized by one plotter (e.g. a collection of lines)

- `Project`: A set of data objects, each visualized by one plotter
- `Sub project`: A subset of a larger `Project`

Low-level interface

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import the necessary objects from the framework

In [10]:
```
from psyplot.plotter import Formatoption, Plotter
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define a formatoption

In [11]:
```
class MyFormatoption(Formatoption):

    #: the default value for the formatoption
    default = 'my text'

    def initialize_plot(self, value):
        # method initialize the plot in the very beginning
        self.text = self.ax.text(0.5, 0.5, value, fontsize="xx-large")

    def update(self, value):
        # method to update the plot
        self.text.set_text(value)
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```

assign the formatoption to a plotter

In [12]:
```
class MyPlotter(Plotter):
    my_fmt = MyFormatoption('my_fmt')
```

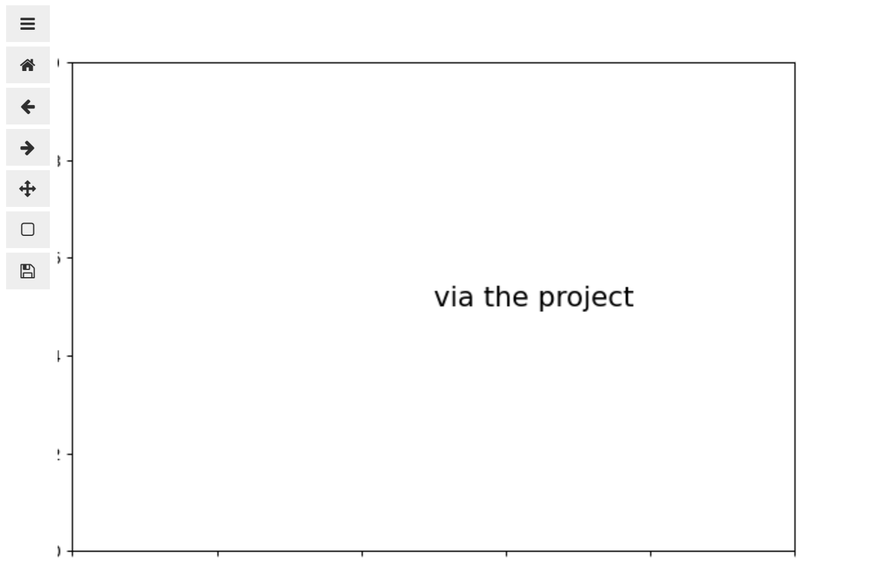
Low-level interface

In [13]:
```
# make the plot

ds = psy.open_dataset('data/demo.nc')

data = ds.psy.t2m

plotter = MyPlotter(data)
```



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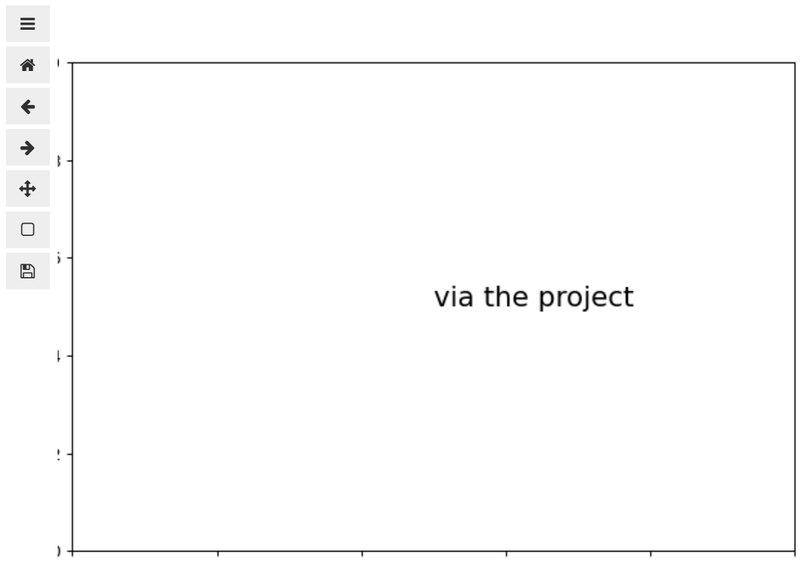

In [14]:
```
# turn it into a project

from psyplot.project import Project
project = Project([data])

project
```

Out[14]:
```
1 Main psyplot.project.Project([    arr0: 4-dim DataArray
of t2m, with (time, lev, lat, lon)=(5, 4, 96, 192), ])
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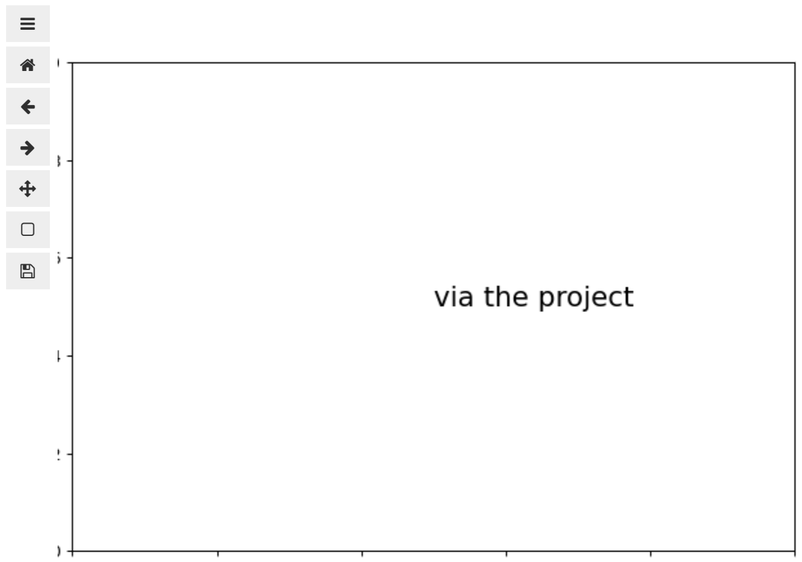

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In [15]:
```
# update the plot

data.psy.update(my_fmt="via the data accessor")
```

In [16]:
```
plotter.update(my_fmt="via the plotter")
```

In [17]:
```
project.update(my_fmt="via the project")
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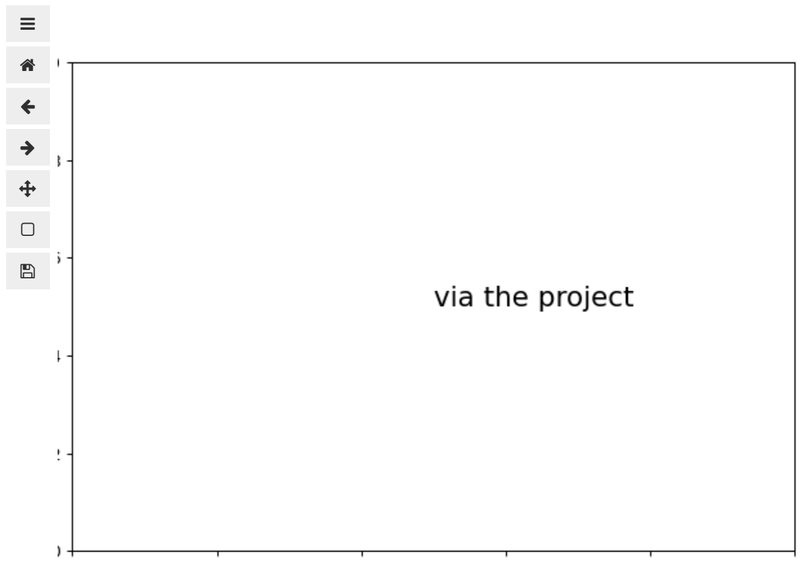

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In [18]:
```
# finally, you should always close the project
project.close(True, True, True)
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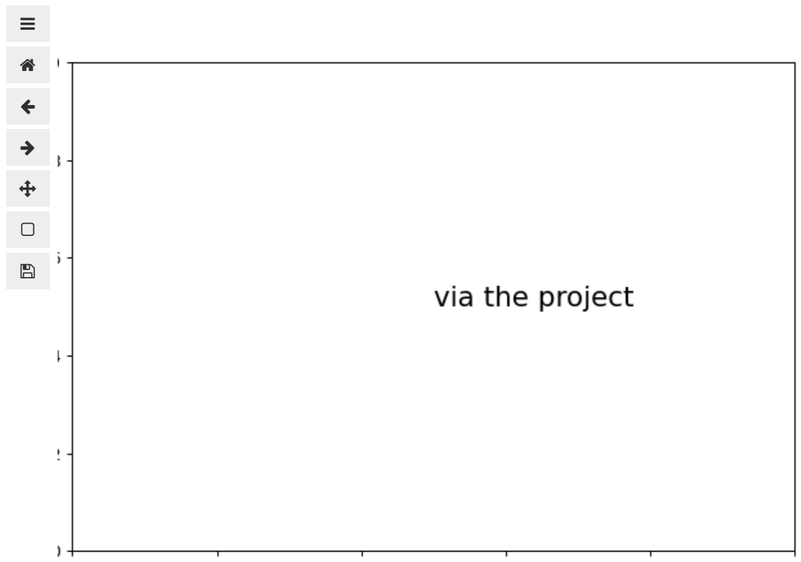

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Tutorial notebook:
https://psyplot.github.io/examples/general/example_exte

High-level interface

You can register plotters such that they become available via `psyplot.project.plot.<something>`, or `xarray.Dataset.psy.plot.<something>`.

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In [19]:
```
psy.register_plotter('my_plotter', MyPlotter.__module__,
                     'MyPlotter', MyPlotter)
```

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In [19]:
```
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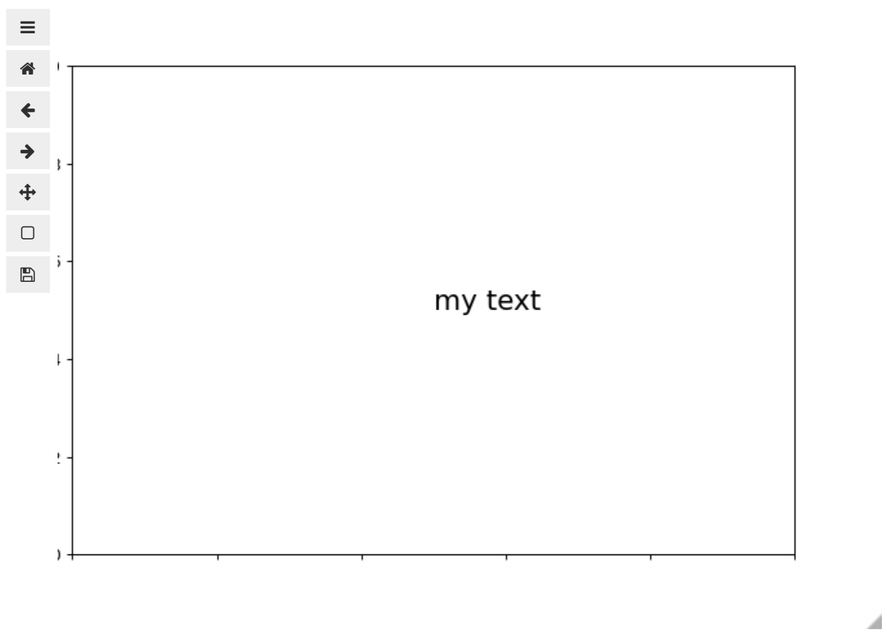
                     'MyPlotter', MyPlotter)
```

In [20]:
```
psy.plot.my_plotter('data/demo.nc', name='t2m')
```



Out[20]:
```
psyplot.project.Project([    arr2: 4-dim DataArray of t2m,
with (time, lev, lat, lon)=(5, 4, 96, 192), ])
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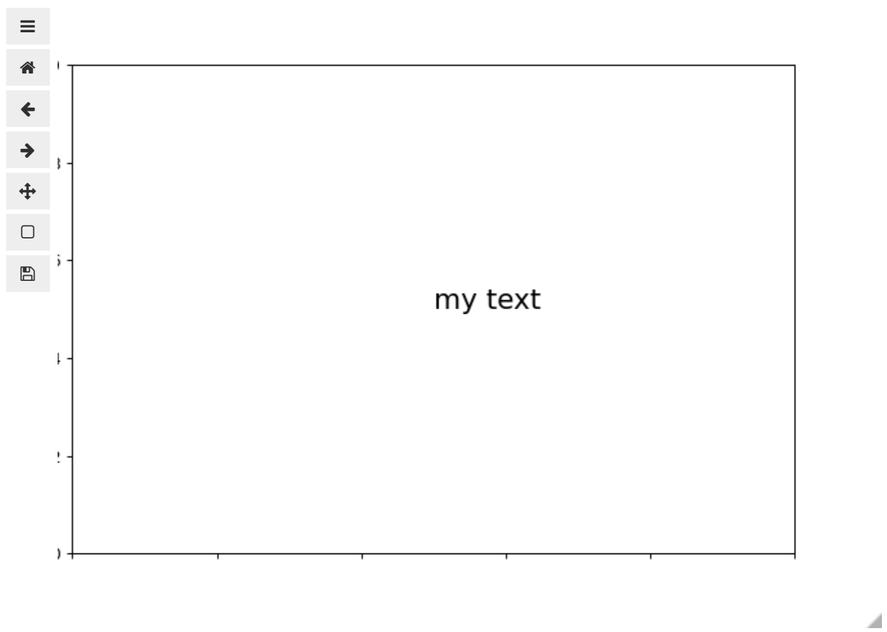

Out[20]:
```
psyplot.project.Project([    arr2: 4-dim DataArray of t2m,
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```
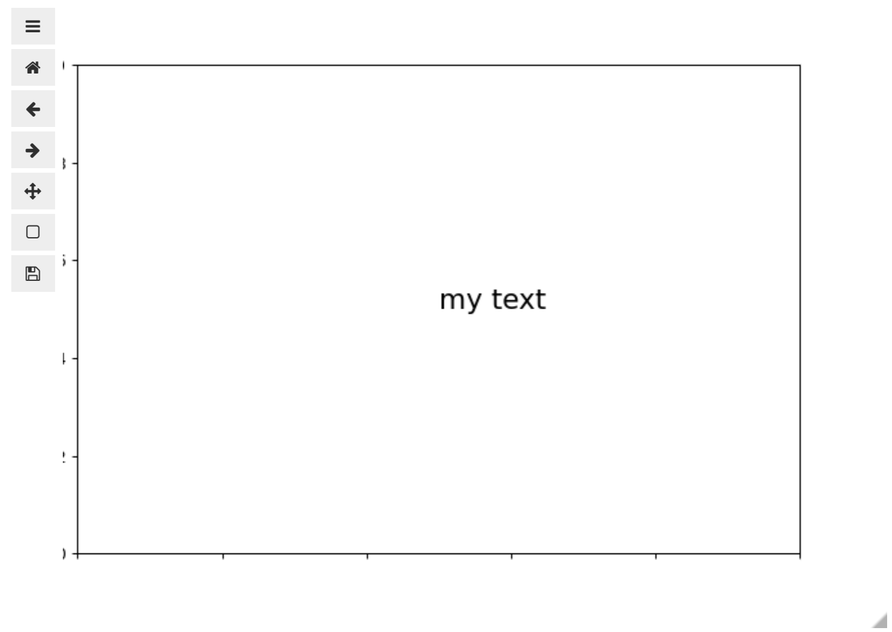

In [21]:
```
ds.psy.plot.my_plotter(name="t2m")
```



Out[21]:
```
psyplot.project.Project([    arr3: 4-dim DataArray of t2m,
with (time, lev, lat, lon)=(5, 4, 96, 192), ])
```

Plugins for visualization

psyplot is the core that defines the framework (Plotter, Formatoption, Project, CFDecoder), the plot methods are implemented by plugins:

- `psy-simple`: for standard 1D and 2D plot
    - e.g. lineplot, plot2d, vector, barplot
- `psy-maps`: for georeferenced plots (i.e. maps)
    - e.g. mapplot, mapvector, etc.
- `psy-reg`: for regression analysis
    - linreg, densityreg

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```
In [22]: psy.plot.show_plot_methods()
```

```
barplot
    Make a bar plot of one-dimensional data
combined
    Plot a 2D scalar field with an overlying vector field
density
    Make a density plot of point data
fldmean
    Calculate and plot the mean over x- and y-dimensions
horizontal_mapcombinedtransect
    Open and plot data via :class:`psy_transect.maps.Horiz
ontalTransectCombinedPlotter` plotters
horizontal_maptransect
    Open and plot data via :class:`psy_transect.maps.Horiz
ontalTransectFieldPlotter` plotters
horizontal_mapvectortransect
    Open and plot data via :class:`psy_transect.maps.Horiz
ontalTransectVectorPlotter` plotters
lineplot
    Make a line plot of one-dimensional data
mapcombined
    Plot a 2D scalar field with an overlying vector field
on a map
mapplot
    Plot a 2D scalar field on a map
mapvector
    Plot a 2D vector field on a map
my_plotter
    Open and plot data via :class:`__main__.MyPlotter` plo
tters
plot2d
    Make a simple plot of a 2D scalar field
vector
    Make a simple plot of a 2D vector field
vertical_maptransect
    Open and plot data via :class:`psy_transect.plotters.V
erticalMapTransectPlotter` plotters
vertical_transect
    Open and plot data via :class:`psy_transect.plotters.V
erticalTransectPlotter` plotters
violinplot
    Make a violin plot of your data
```

They already have a lot of formatoptions available

In [23]:
```
psy.plot.mapplot.keys(grouped=True)
```

```
******************
Axes formatoptions
******************
+------------+------------+------------+
| background | tight      | transpose  |
+------------+------------+------------+

*************************
Color coding formatoptions
*************************
+-------------+-------------+-------------+-------------+
| bounds      | cbar        | cbarspacing | cmap        |
+-------------+-------------+-------------+-------------+
| ctickprops  | cticksize   | ctickweight | extend      |
+-------------+-------------+-------------+-------------+
| levels      | miss_color  |             |             |
+-------------+-------------+-------------+-------------+

*******************
Label formatoptions
*******************
+----------------+----------------+----------------+----------------+
| clabel         | clabelprops    | clabelsize     | clabelweight   |
+----------------+----------------+----------------+----------------+
| figtitle       | figtitleprops  | figtitlesize   | figtitleweight |
+----------------+----------------+----------------+----------------+
| text           | title          | titleprops     | titlesize      |
+----------------+----------------+----------------+----------------+
| titleweight    |                |                |                |
+----------------+----------------+----------------+----------------+

**************************
Miscallaneous formatoptions
**************************
+----------------+----------------+----------------+----------------+
| clat           | clip           | clon           | datagrid       |
+----------------+----------------+----------------+----------------+
| grid_color     | grid_labels    | grid_labelsize | grid_settings  |
+----------------+----------------+----------------+----------------+
| interp_bounds  | lonlatbox      | lsm            | map_extent     |
+----------------+----------------+----------------+----------------+
| mask_datagrid  | projection     | stock_img      | transform      |
+----------------+----------------+----------------+----------------+
| xgrid          | ygrid          |                |                |
+----------------+----------------+----------------+----------------+

***********************
Axis tick formatoptions
***********************
```

Make your own data plotter

In [24]:
```python
import numpy as np
from psy_simple.plotters import CMap, Bounds
from psy_maps.plotters import Transform, MapPlot2D

from psyplot.plotter import Plotter

class MySimpleMapplot(Plotter):

    # Specify the defaults
    rc = {
        "cmap": "Reds",
        "norm": None,
        "transform": "cf",
        "plot": "poly",
    }

    def convert_coordinate(self, coord, *variables):
        if coord.attrs.get("units", "").startswith("radian") or any(
            var.attrs.get('units', '').startswith('radian')
            for var in variables
        ):
            coord = coord.copy(data=coord * 180. / np.pi)
            coord.attrs["units"] = "degrees"
        return coord

    # Specify the formatoptions
    cmap = CMap("cmap", bounds="norm")
    norm = Bounds("norm")
    transform = Transform("transform")

    plot = MapPlot2D("plot", bounds="norm")


def plot(data, ax, **formatoptions):
    return MySimpleMapplot(
        data, ax=ax, **formatoptions
    )
```

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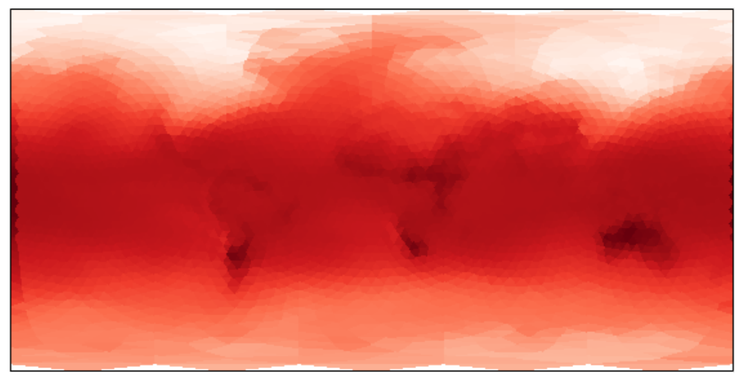
def plot(data, ax, **formatoptions):
    return MySimpleMapplot(
        data, ax=ax, **formatoptions
    )
```

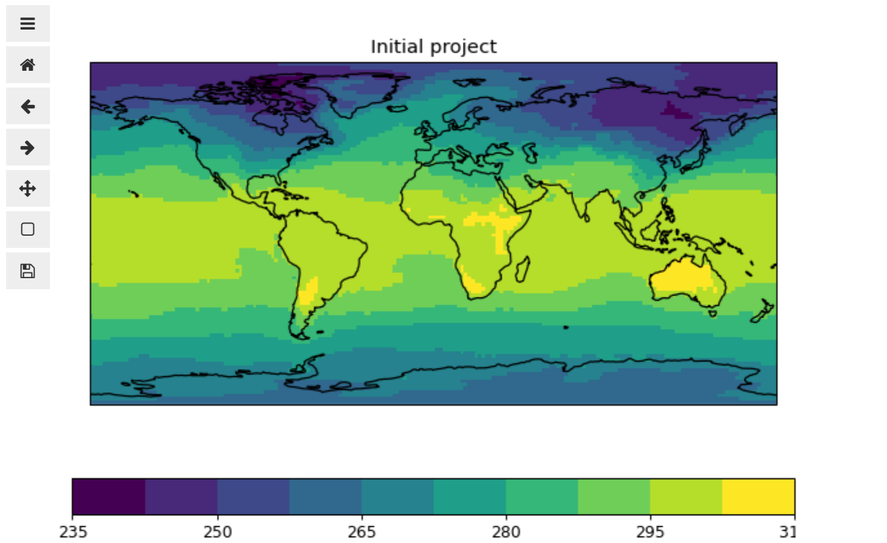
In [25]:
```python
fig, ax = plt.subplots(subplot_kw=dict(
    projection=ccrs.PlateCarree())
)
ax.set_global()

ds = psy.open_dataset("data/icon.nc")

plot(ds.psy.t2m, ax=ax);
```



Other features of psyplot

Save and load projects

In [26]:
```
initial = psy.plot.mapplot('data/demo.nc', name='t2m', title
initial.save_project('my-project.pkl')
```



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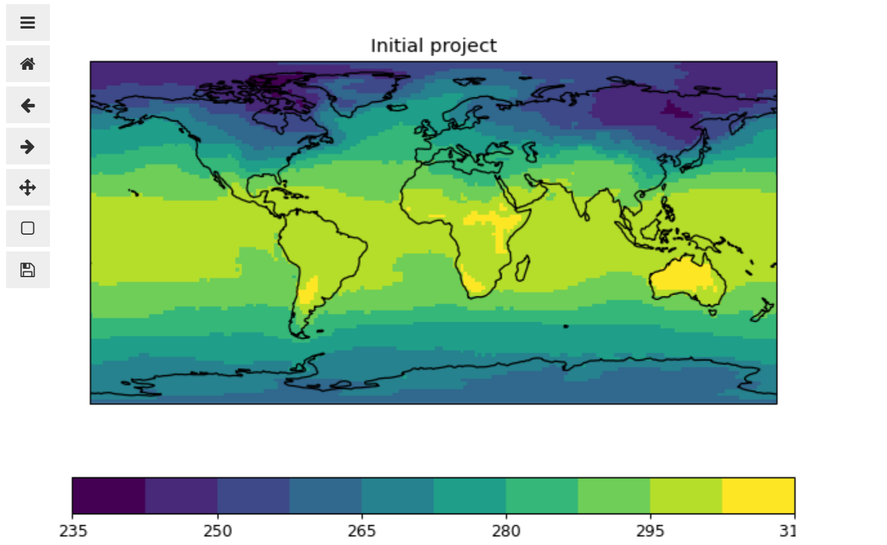
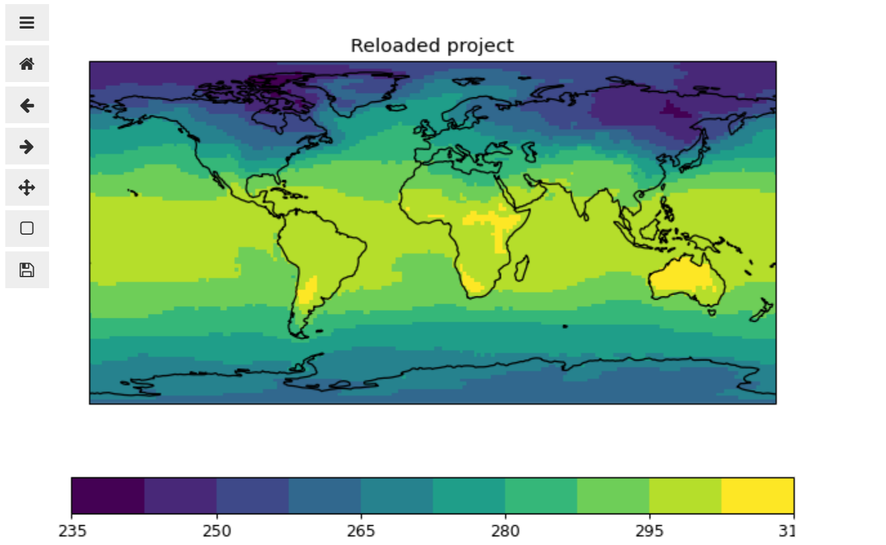


In [27]:
```
reloaded = psy.Project.load_project('my-project.pkl')
reloaded.update(title='Reloaded project')
```



Export plots

In [28]:
```
plt.ioff()

with psy.plot.mapplot('data/demo.nc', name='t2m', time=[0, 1, 2], title='%(time)s') as sp:
    sp.export('data/step-%i.png')

plt.ion()

!ls data/step-?.png
```

```
data/step-1.png  data/step-2.png  data/step-3.png
```

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```

```
data/step-1.png  data/step-2.png  data/step-3.png
```

In [29]:
```
from IPython.display import display, HTML, Image
s = '<table><tr><td><img src="data/step-1.png"></td><td><img src="data/step-2.png"></td><td><img src="data/step-3.png"></td></tr></tab
display(HTML(s))
```

Generate plots from the command line

In [30]:
```
!echo 'projection: robin' > fmt.yml
!psyplot data/demo.nc -n t2m -pm mapplot -fmt fmt.yml -o data/output.png
```

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!psyplot data/demo.nc -n t2m -pm mapplot -fmt fmt.yml -o data/output.png
```
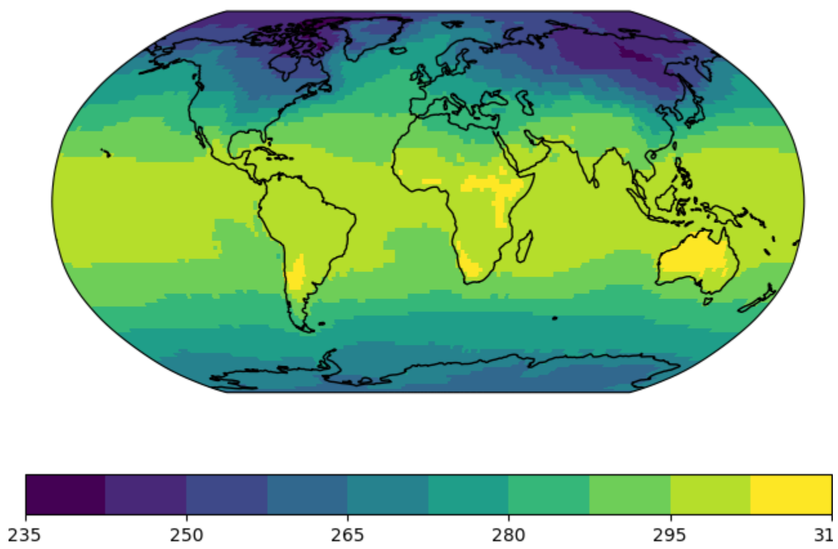
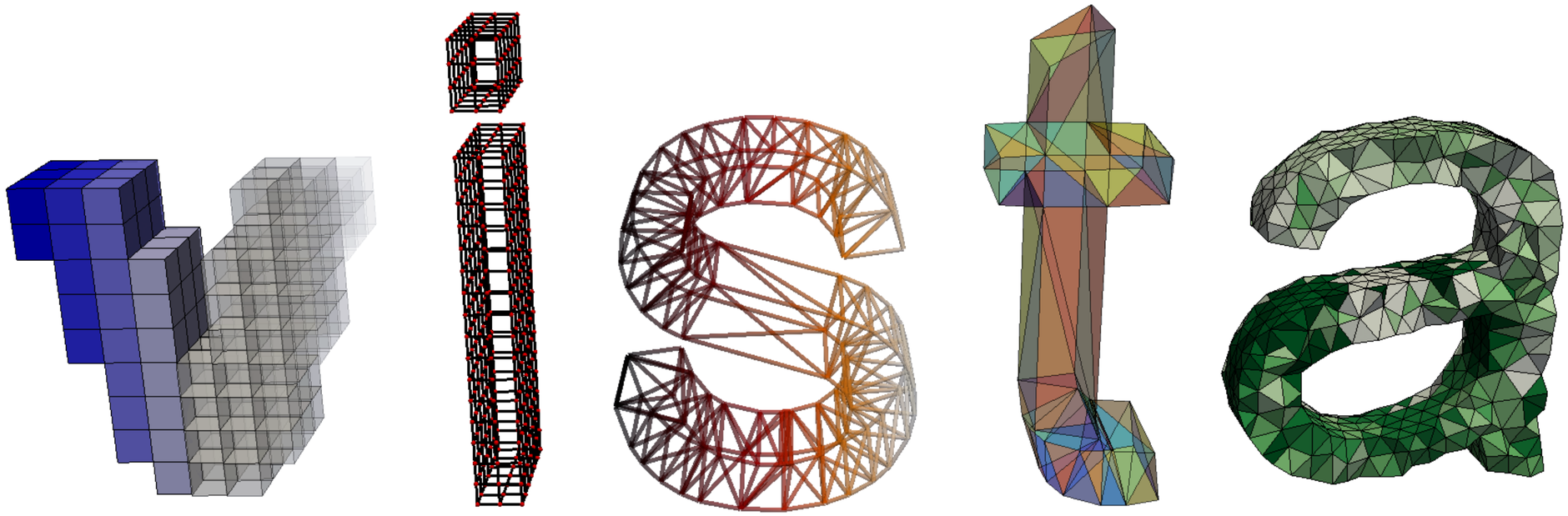

In [31]:
```
display(Image('data/output.png'))
```



Outlook

3D visualization (not matplotlib, VTK)



pyvista: VTK and matplotlib

In [32]:
```
import psy_vtk.plotters as pvtk

ds = psy.open_dataset('data/rectilinear.nc')

globe_plot = pvtk.GlobePlotter(ds.psy.t2m)
disp = globe_plot.ax.show()
```

pyvista combines the power and efficiency of the (pretty difficult) VTK python bindings with a well-documented interface and matplotlib-like functionalities.

And it can even work with psyplot pretty much out of the box!

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And it can even work with psyplot pretty much out of the box!

In [33]:
```
globe_plot.update(cmap='Reds')
```

In [34]:
```
globe_plot.update(datagrid=True)
```

Immediate support of all grids

In [35]:
```
ds = psy.open_dataset('data/rectilinear.nc')

globe_plot = pvtk.GlobePlotter(ds.psy.t2m)
globe_plot.ax.show();
```

In [36]:
```
ds = psy.open_dataset('data/curvilinear.nc')

globe_plot = pvtk.GlobePlotter(ds.psy.t2m)
globe_plot.ax.show();
```

Visualizing big data

For 4.4 million cells:

psy-vtk needs a couple of seconds to visualize it and it works fluently.

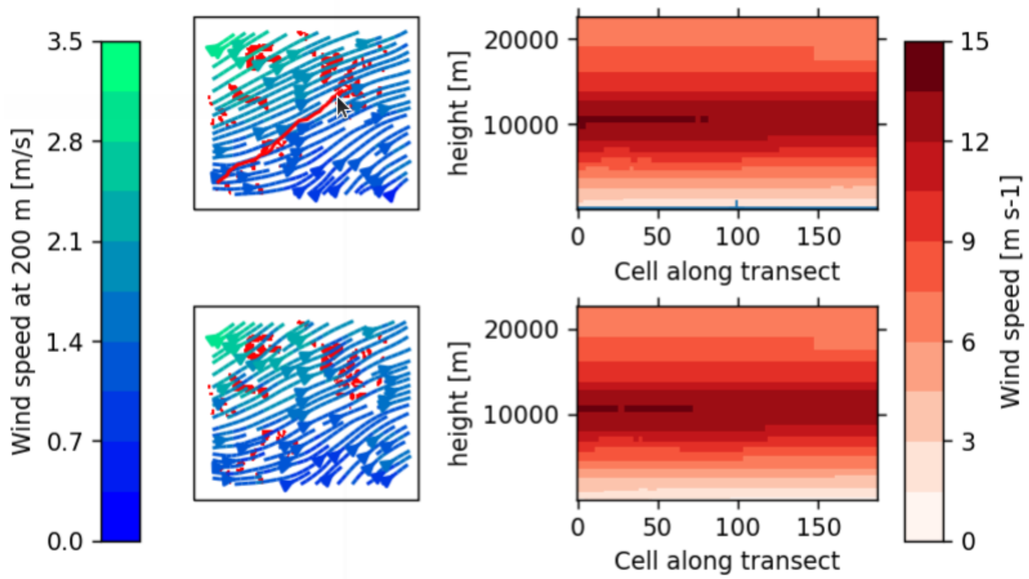
```
In [37]: Video("data/screencast.mp4", embed=True, html_attributes="au
```

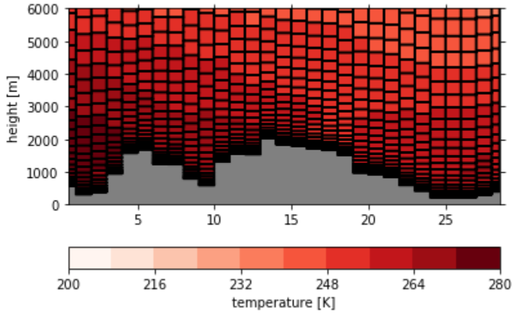
Out[37]:

Transects

psy-transect

- interpolate rastered (or unstructured) data on to a path.
- display vertical profiles (with respect to orography, if available)
- supports vector (wind) or scalar fields (temperature)
- made for interactive usage





Summary

The framework

- the psyplot core for the data model, and plugins for various visualizations
- designed to be flexible and sustainable
- equipped via flexible graphical user interface

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The data model

- based on a netCDF-like infrastructure and interpretes CF- and UGRID conventions
- support for multiple grids: rectilinear, circumpolar and unstructured

Scriptability

- close to the data with a minimum of visualization overhead (compared to Paraview or something else)
- can easily be enhanced by other powerful libraries, such as scipy, scikit-learn, etc.