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What is xarray?

For Python / Numpy users

- xarray handles N-dimensional arrays with labels (dimension names & coordinates) and metadata.

For Python / Pandas users

- xarray is a powerful, pandas-like toolkit for analytics on multi-dimensional arrays.

For scientists familar with the netCDF format

- xarray implements the netCDF data model with a high level Python API.

For scientists working with big datasets

- xarray (with dask) supports efficient, out-of-core computing for datasets that don't fit in memory.

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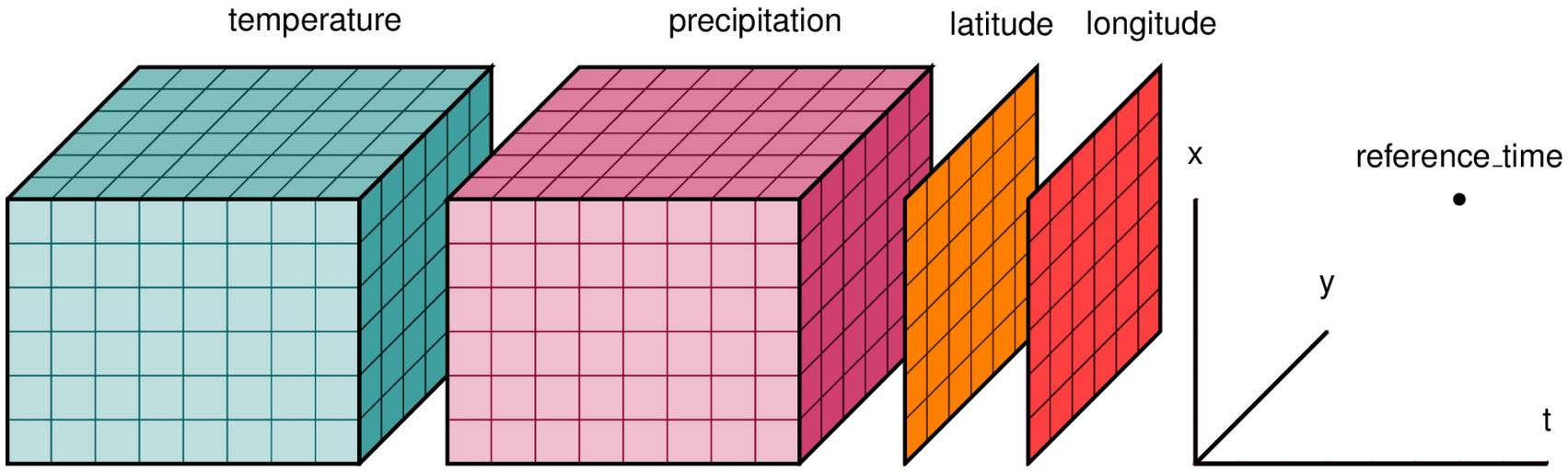
What is xarray?

If you are dealing with data that...

- is multi-dimensional ;
- is labelled ;
- has (lots of) metadata ;
- is sometimes (very) large ;



...then you may find xarray very useful!

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xarray

- Open source
- Very good integration with other Python libraries for scientific computing (SciPy / PyData Stack)
- Extensible
- Documentation: http://xarray.pydata.org
- Repository: https://github.com/pydata/xarray
- 60 contributors (still growing)
- Latest release: v0.9.5 (17.04.2017)
- Umbrellas (no funding): Python for Data & NumFOCUS

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numpy.array

```
>>> import numpy as np
>>> a = np.array([[1, 3, 9], [2, 8, 4]])
>>> a
```

```
array([[1, 3, 9],
       [2, 8, 4]])
```

```
>>> a[1, 2]   # get the value at 2nd row and 3rd column
```

```
4
```

```
>>> a.mean(axis=0)   # compute the mean column-wise
```

```
array([1.5,  5.5,  6.5])
```

Not well supported by numpy:

- array dimensions and indexes often have a meaning, e.g., latitude / longitude and their coordinates.

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xarray.DataArray

```
>>> import xarray as xr
>>> da = xr.DataArray(a, dims=['latitude', 'longitude'],
                      coords={'longitude': [11, 12, 13], 'latitude': [1, 2]})
>>> da
```

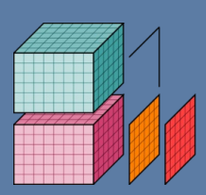
```
<xarray.DataArray (latitude: 2, longitude: 3)>
array([[1, 3, 9],
       [2, 8, 4]])
Coordinates:
  * longitude    (longitude) int64 11 12 13
  * latitude     (latitude) int64 1 2
```

```
>>> da.sel(longitude=13, latitude=2)   # easier to work with coordinate values!
```

```
<xarray.DataArray ()>
array(4)
Coordinates:
    longitude    int64 13
    latitude     int64 2
```

```
>>> da.mean(dim='latitude')    # easier to remember dimension names!
```

```
<xarray.DataArray (longitude: 3)>
array([ 1.5,  5.5,  6.5])
Coordinates:
  * longitude    (longitude) int64 11 12 13
```



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xarray.Dataset

A collection of `xarray.DataArray`, a netCDF file...

```
>>> ds = xr.open_dataset('ERA-Interim-MonthlyAvg-TUVP.nc')
>>> ds
```

```
<xarray.Dataset>
Dimensions:    (latitude: 241, longitude: 480, time: 457)
Coordinates:
  * longitude  (longitude) float32 0.0 0.75 1.5 2.25 3.0 3.75 4.5 5.25 6.0 ...
  * latitude   (latitude) float32 90.0 89.25 88.5 87.75 87.0 86.25 85.5 ...
  * time       (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
Data variables:
    sp         (time, latitude, longitude) float64 1.028e+05 1.028e+05 ...
    u10        (time, latitude, longitude) float64 -1.857 -1.854 -1.851 ...
    v10        (time, latitude, longitude) float64 -0.3266 -0.3056 -0.285 ...
    t2m        (time, latitude, longitude) float64 242.7 242.7 242.7 242.7 ...
Attributes:
    Conventions:  CF-1.6
    history:      2017-04-19 16:02:16 GMT by grib_to_netcdf-2.1.0: grib_to_ne...
```

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Analytics

- Advanced selection

```
>>> # nearest neighbor lookup: no need to provide exact coordinate values
>>> ds.sel(latitude=47.2876, longitude=11.3788, method='nearest')
```

```
<xarray.Dataset>
Dimensions:    (time: 457)
Coordinates:
    longitude  float32 11.25
    latitude   float32 47.25
  * time       (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
Data variables:
    sp         (time) float64 8.419e+04 8.41e+04 8.422e+04 8.441e+04 ...
    u10        (time) float64 0.8787 0.1095 0.7023 0.3623 0.3087 0.2992 ...
    v10        (time) float64 0.6971 0.5583 1.079 -0.04204 0.6298 -0.2448 ...
    t2m        (time) float64 265.4 270.6 273.2 273.7 280.6 284.4 284.9 ...
Attributes:
    Conventions:  CF-1.6
    history:      2017-04-19 16:02:16 GMT by grib_to_netcdf-2.1.0: grib_to_ne...
```

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Analytics

- Aggregation

```
>>> global_avg = ds.mean(dim=['latitude', 'longitude'])
>>> global_avg
```

```
<xarray.Dataset>
Dimensions:  (time: 457)
Coordinates:
  * time     (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
Data variables:
    sp       (time) float64 9.673e+04 9.667e+04 9.668e+04 9.67e+04 9.663e+04 ...
    u10      (time) float64 -0.1069 0.02902 -0.1717 -0.1011 0.001793 0.09216 ...
    v10      (time) float64 -0.2489 -0.0867 -0.1123 0.0739 0.1937 0.4532 ...
    t2m      (time) float64 276.7 275.3 276.0 277.0 278.7 280.3 280.3 280.2 ...
```

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Analytics

- Groupby (split-apply-combine)

```
>>> month_avg = ds.groupby('time.month').mean(dim='time')
>>> month_avg
```

```
<xarray.Dataset>
Dimensions:    (latitude: 241, longitude: 480, month: 12)
Coordinates:
  * longitude  (longitude) float32 0.0 0.75 1.5 2.25 3.0 3.75 4.5 5.25 6.0 ...
  * latitude   (latitude) float32 90.0 89.25 88.5 87.75 87.0 86.25 85.5 ...
  * month      (month) int64 1 2 3 4 5 6 7 8 9 10 11 12
Data variables:
    sp         (month, latitude, longitude) float64 1.014e+05 1.014e+05 ...
    u10        (month, latitude, longitude) float64 -1.982 -1.987 -1.992 ...
    v10        (month, latitude, longitude) float64 -0.7036 -0.678 -0.6526 ...
    t2m        (month, latitude, longitude) float64 246.1 246.1 246.1 246.1 ...
```

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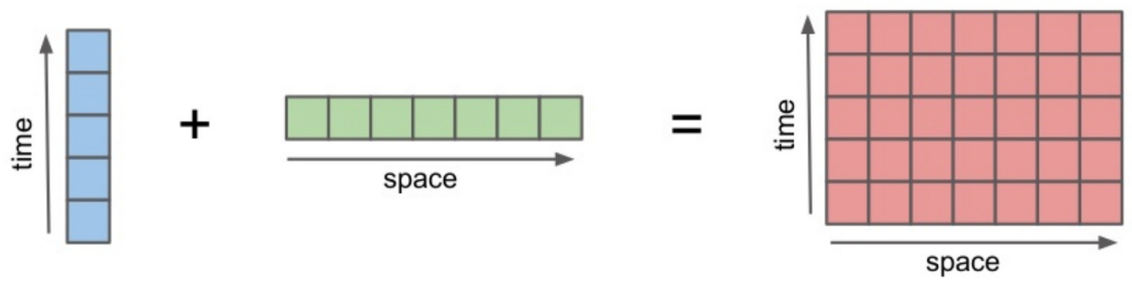
Analytics

- Arithmetic (broadcasting)

```
>>> time = xr.DataArray([0, 2, 4], dims='time',
...                     coords={'time': np.arange(3)})
>>> space = xr.DataArray([0, 1, 2, 3], dims='space',
...                      coords={'space': np.arange(4)})
>>> time + space
```

```
<xarray.DataArray (time: 3, space: 4)>
array([[0, 1, 2, 3],
       [2, 3, 4, 5],
       [4, 5, 6, 7]])
Coordinates:
  * time         (time) int64 0 1 2
  * space        (space) int64 0 1 2 3
```



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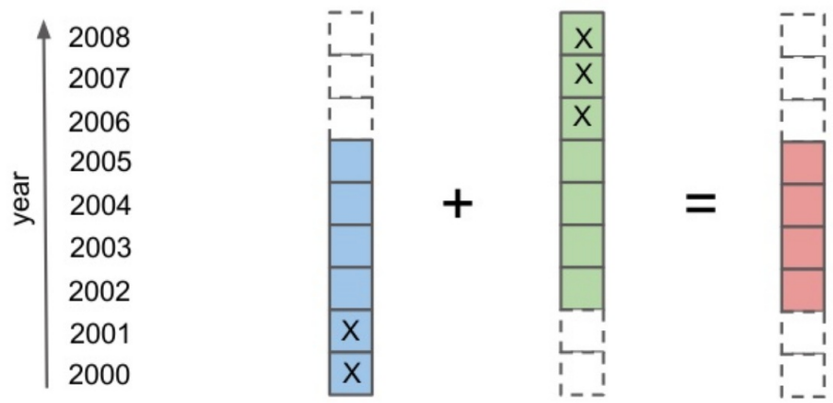
Analytics

- Arithmetic (alignment)

```
>>> a = xr.DataArray([2, 3, 4, 1, 0, 5], dims='year',
...                  coords={'year': [2000, 2001, 2002, 2003, 2004, 2005]})
>>> b = xr.DataArray([3, 4, 2, 3, 1, 0, 3], dims='year',
...                  coords={'year': [2002, 2003, 2004, 2005, 2006, 2007, 2008]})
>>> a + b
```

```
<xarray.DataArray (year: 4)>
array([7, 5, 2, 8])
Coordinates:
  * year     (year) int64 2002 2003 2004 2005
```



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Analytics

- More advanced example using both numpy.array and xarray objects

```
>>> # weighted average on a spherical Earth
>>> weight = np.cos(np.deg2rad(ds.latitude))
>>> weight = weight / weight.sum()
>>> zonal_avg = ds.mean(dim='longitude')
>>> global_avg = (zonal_avg * weight).sum(dim='latitude')
```

```
<xarray.Dataset>
Dimensions:  (time: 457)
Coordinates:
  * time     (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
Data variables:
    sp       (time) float64 9.852e+04 9.853e+04 9.853e+04 9.853e+04 ...
    u10      (time) float64 -0.2679 -0.3043 -0.3953 -0.3146 -0.2558 -0.1829 ...
    v10      (time) float64 -0.3623 -0.2423 -0.1939 -0.007289 0.2645 0.5457 ...
    t2m      (time) float64 285.5 285.4 286.3 287.2 288.2 289.0 289.1 289.1 ...
```

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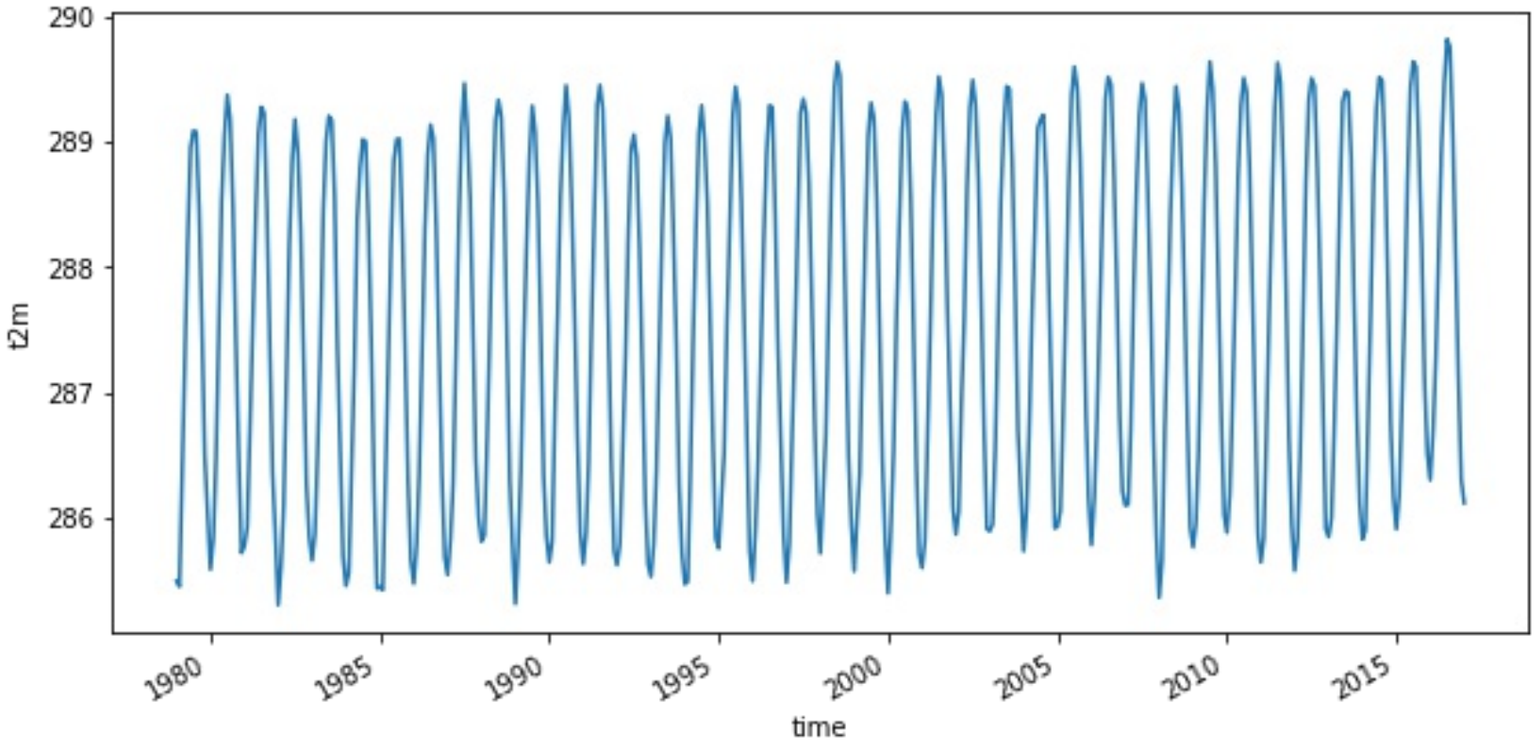
Plotting

```
>>> # plot type, axis labels and colormap inferred from data / labels
>>> global_avg.t2m.plot(figsize=(10, 5))
```



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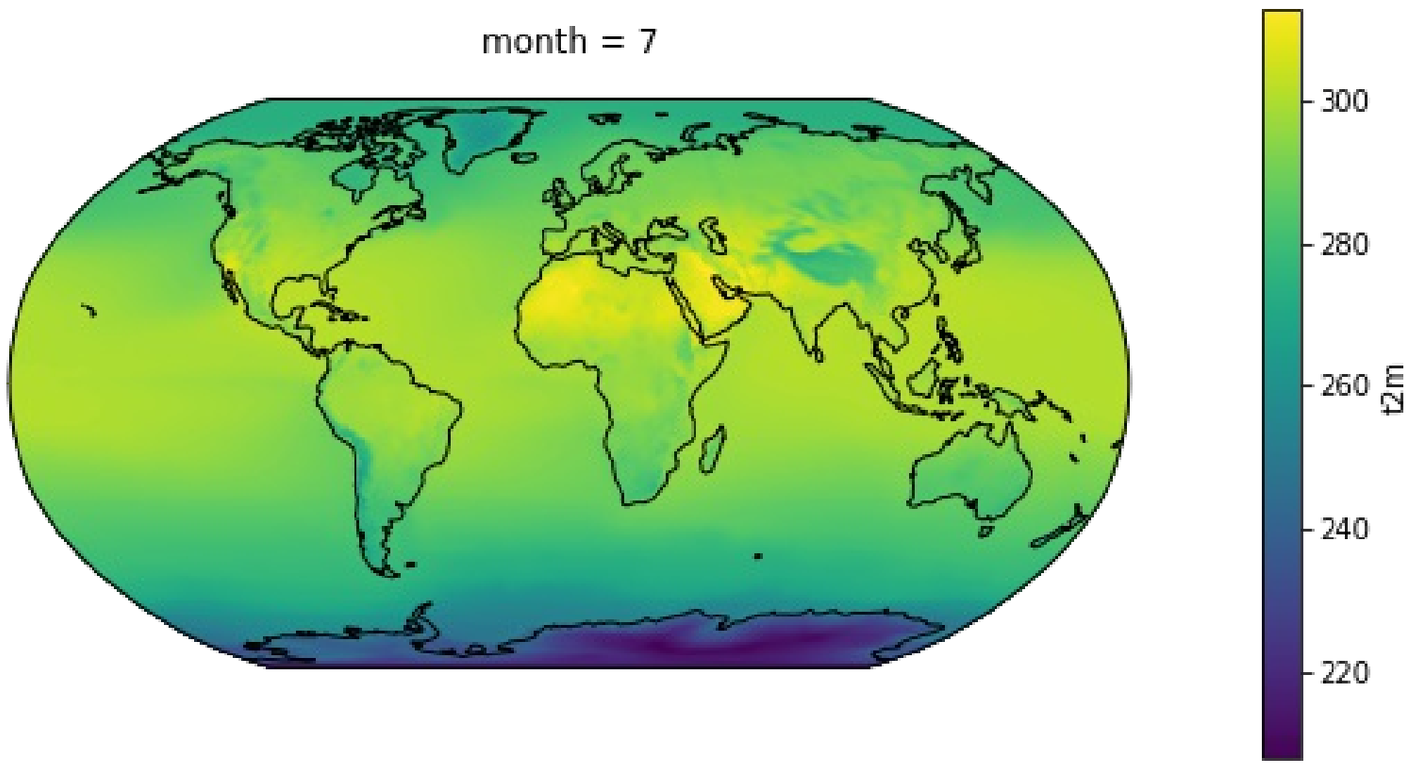
Plotting: maps

```
>>> import matplotlib.pyplot as plt
>>> import cartopy.crs as ccrs
>>> ax = plt.axes(projection=ccrs.Robinson())
>>> month_avg.t2m.sel(month=7).plot(ax=ax, transform=ccrs.PlateCarree());
>>> ax.coastlines();
```



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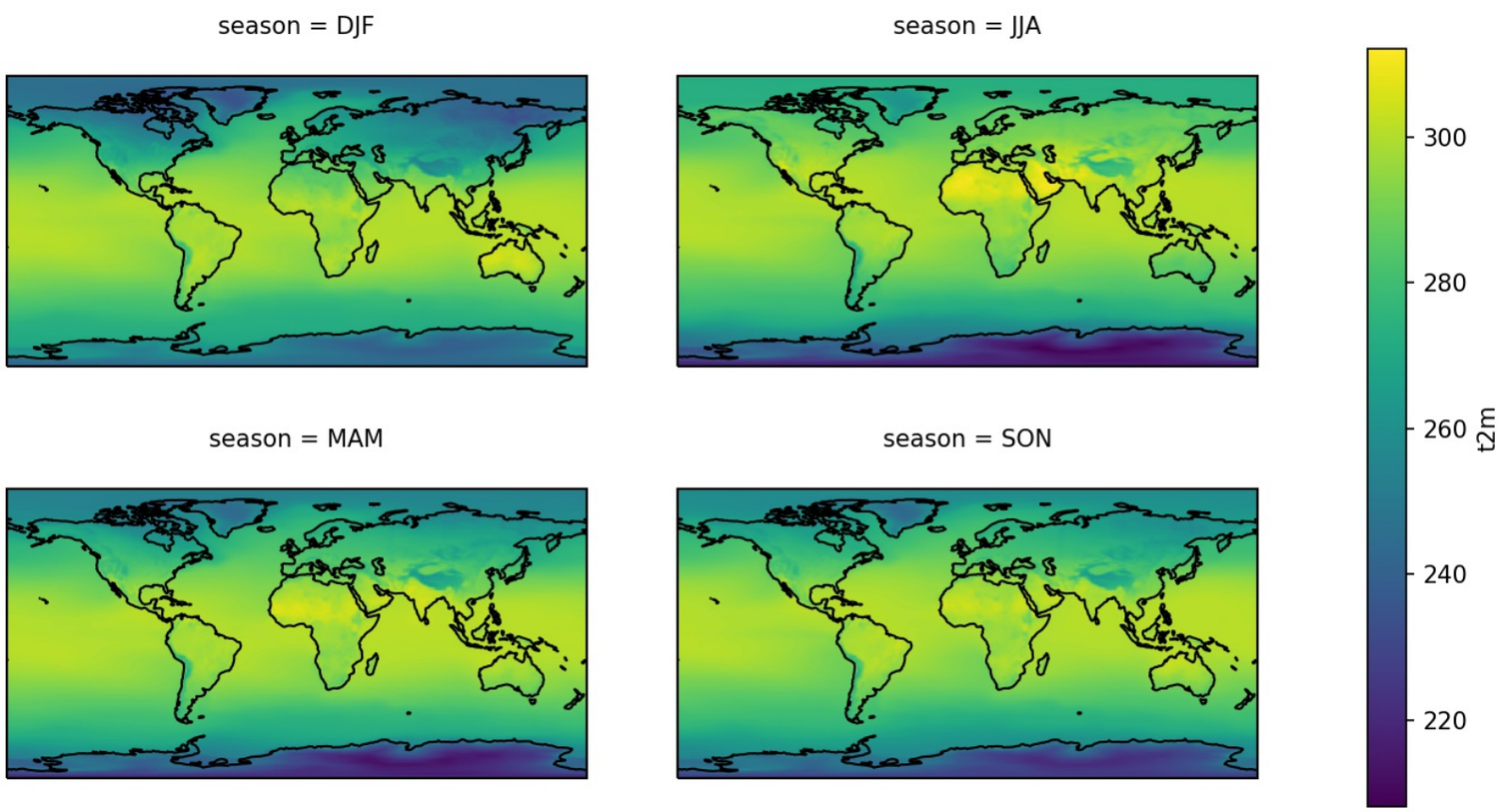
Plotting: facet plots

```
>>> season_avg = ds.groupby('time.season').mean(dim='time')
>>> p = season_avg.t2m.plot(x='longitude', y='latitude', col='season',
...                         col_wrap=2, transform=ccrs.PlateCarree(),
...                         subplot_kws={'projection': ccrs.PlateCarree()})
>>> for ax in p.axes.flat:
...     ax.coastlines()
```



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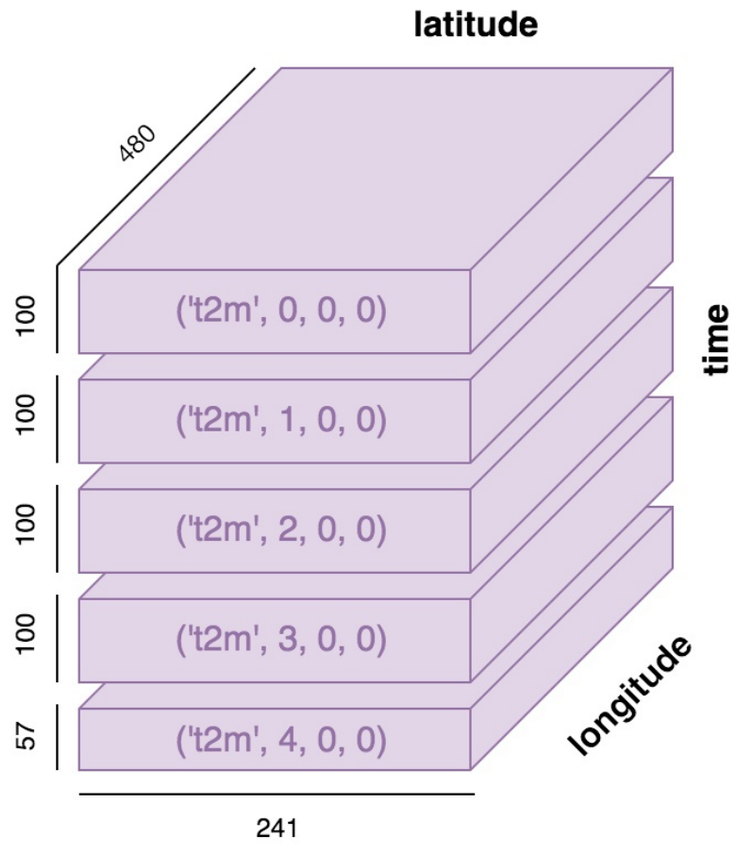
Out-of-core computing

- dask arrays: divide large arrays in smaller pieces ("chunks") fitting in memory

```
>>> # split the array into chunks of max. 100 elements on the time dimension
>>> t2m_dask = ds.t2m.chunk({'time': 100})
>>> t2m_dask.data       # returns a dask.array instead of a numpy.array
```

```
dask.array<xarray-<this-array>, shape=(457, 241, 480), chunksize=(100, 241, 480)>
```



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Out-of-core computing

- Lazy computation (deferred until requested)

```
>>> out = t2m_dask.mean(['latitude', 'longitude'])
>>> out                 # no value computed yet (still a dask.array)
```

```
<xarray.DataArray 't2m' (time: 457)>
dask.array<mean_agg-aggregate, shape=(457,), dtype=float64, chunksize=(100,)>
Coordinates:
  * time     (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
```

```
>>> out.compute()     # force triggering the computation (returns a numpy.array)
```

```
<xarray.DataArray 't2m' (time: 457)>
array([ 276.727663,  275.325389,  275.960077, ...,  278.9487  ,  278.153185,
        277.688196])
Coordinates:
  * time     (time) datetime64[ns] 1979-01-01 1979-02-01 1979-03-01 ...
```

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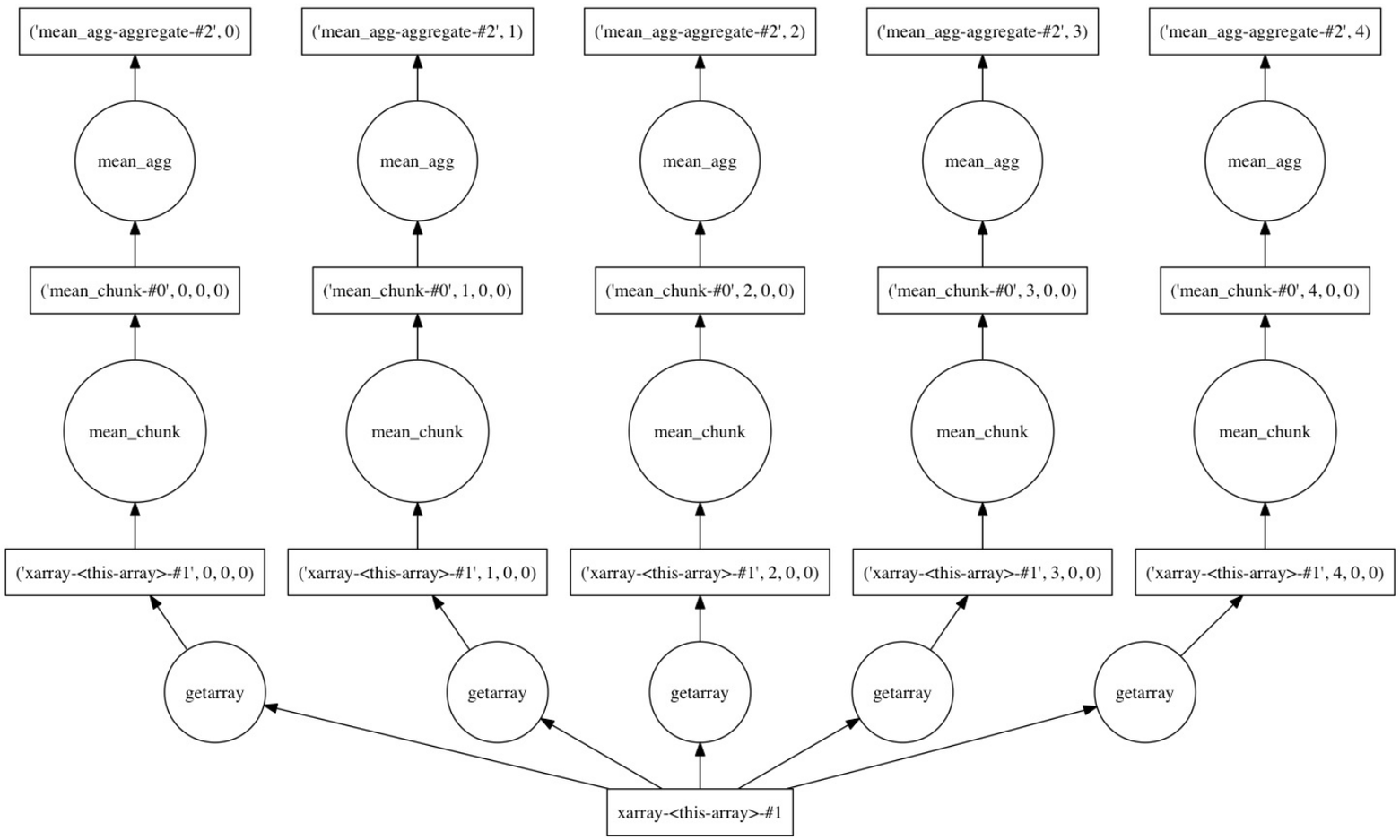
Out-of-core computing

- Computation graph (leverage multi-core processors)

```
>>> out.data.visualize()    # show a graph of the deferred computations
...                         # (requires graphviz)
```



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More features...

- Concatenate, merge & combine datasets
- Open multiple files into a single `xarray.Dataset`
- I/O backends: netCDF3/4, GRIB, HDF4... (external dependencies)
- OPeNDAP support
- Import/export from/to `pandas.DataFrame` or `pandas.Series`
- Multi-index coordinates support (stack / unstack)
- Easily extend xarray with domain specific functionality, e.g., signal processing, image processing, GCM output analytics, GIS processing...

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