Stephan Hoyer (1), Joe Hamman (2), Fabien Maussion (3) and Benoît Bovy (4)
(1) Google Research, Mountain View, CA, USA (2) NCAR, Boulder, CO, USA (3) University of Innsbruck, Austria (4) GFZ Potsdam, Germany

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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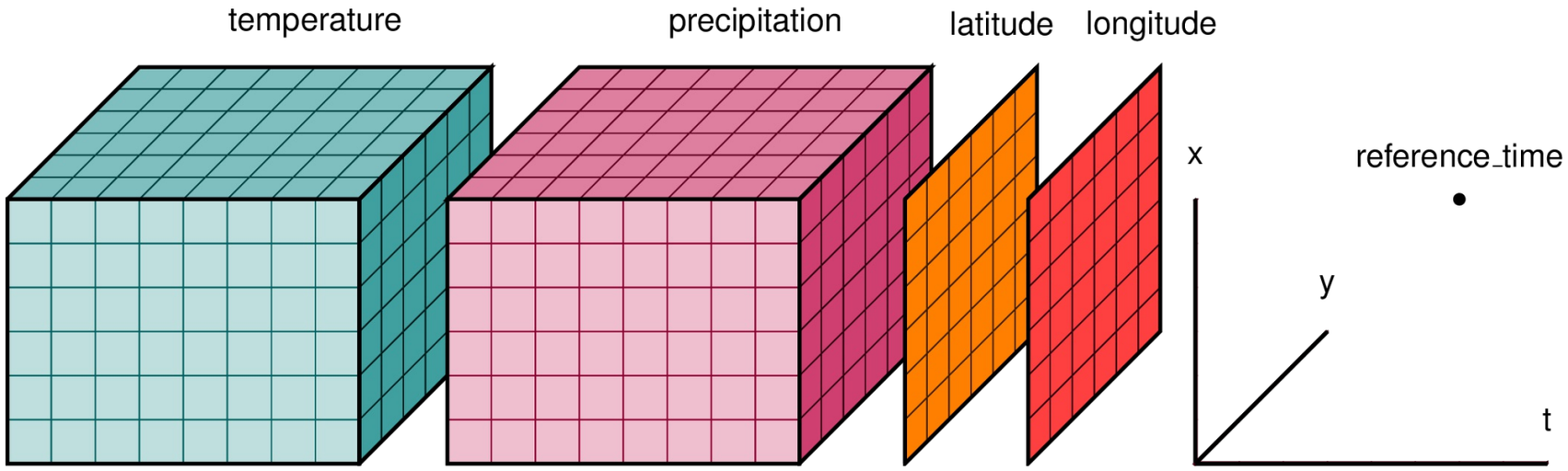
What is xarray?

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!

Stephan Hoyer (1), Joe Hamman (2), Fabien Maussion (3) and Benoît Bovy (4)
(1) Google Research, Mountain View, CA, USA (2) NCAR, Boulder, CO, USA (3) University of Innsbruck, Austria (4) GFZ Potsdam, Germany

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: v0.9.2 (02.04.2017)
- 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
```

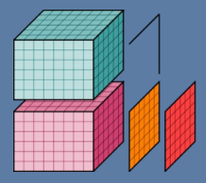
```
4
```

```
>>> 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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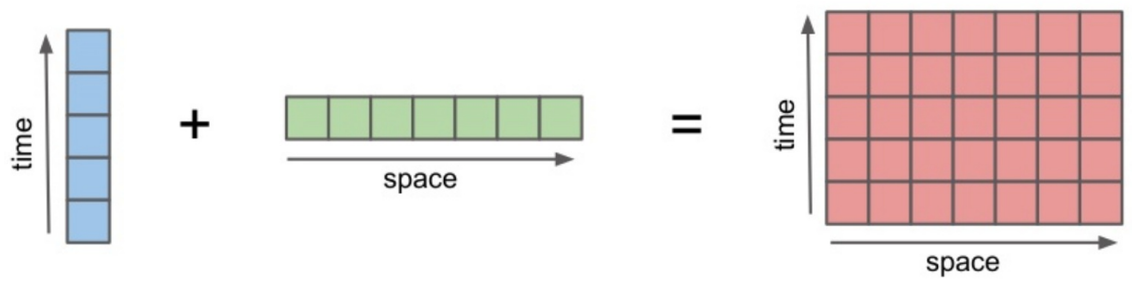
Analytics

- 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
```

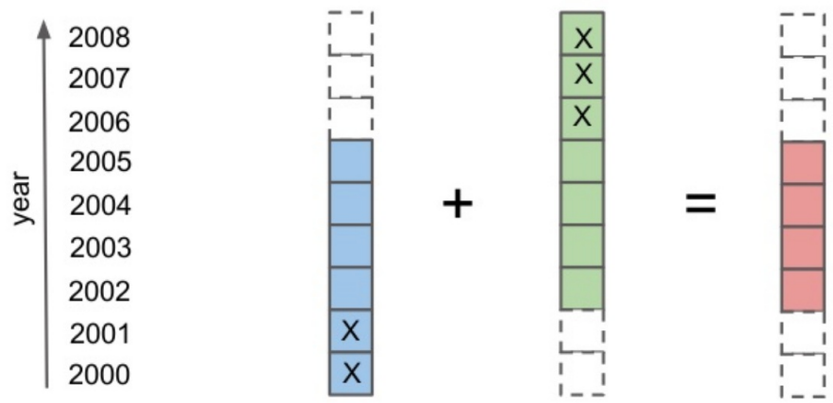


Analytics

- 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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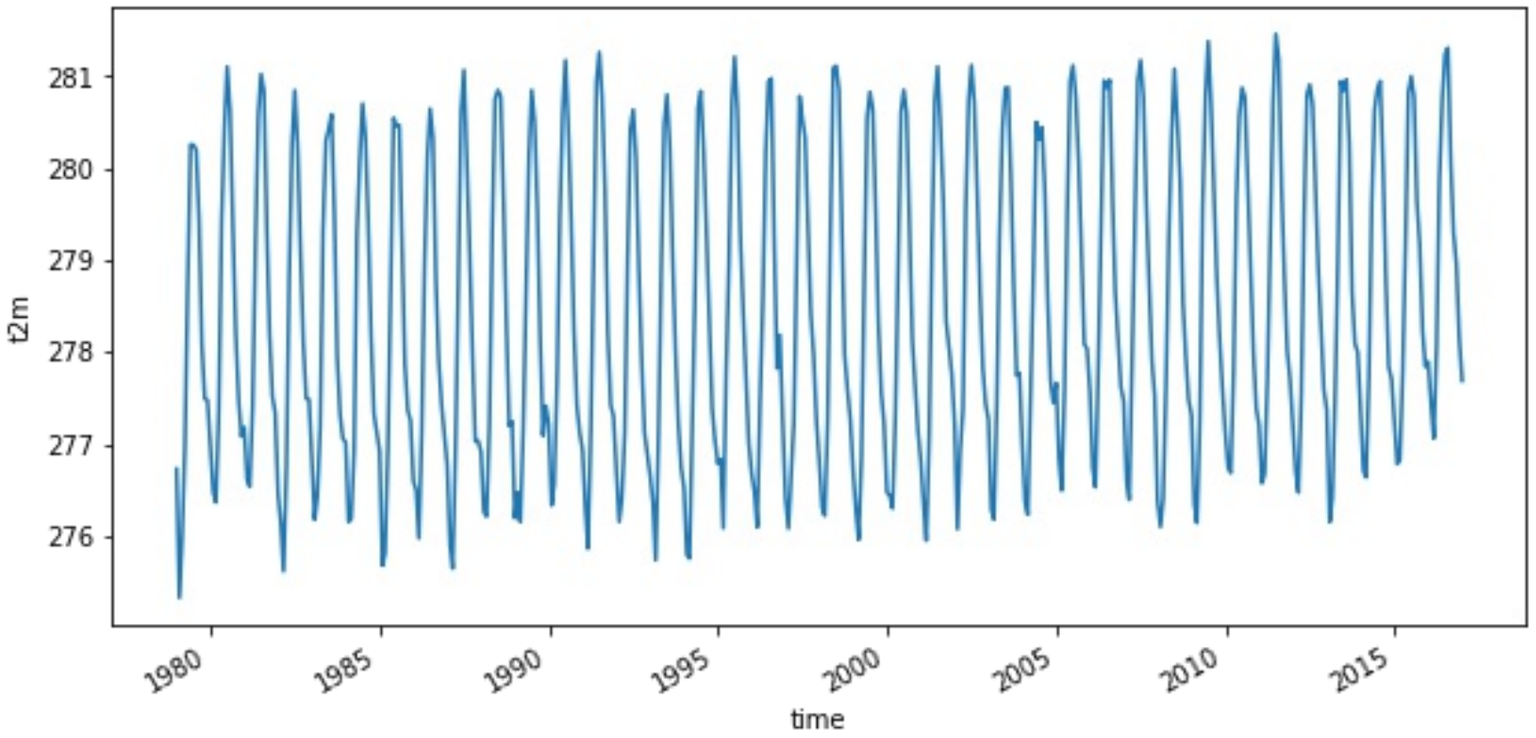
Plotting

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



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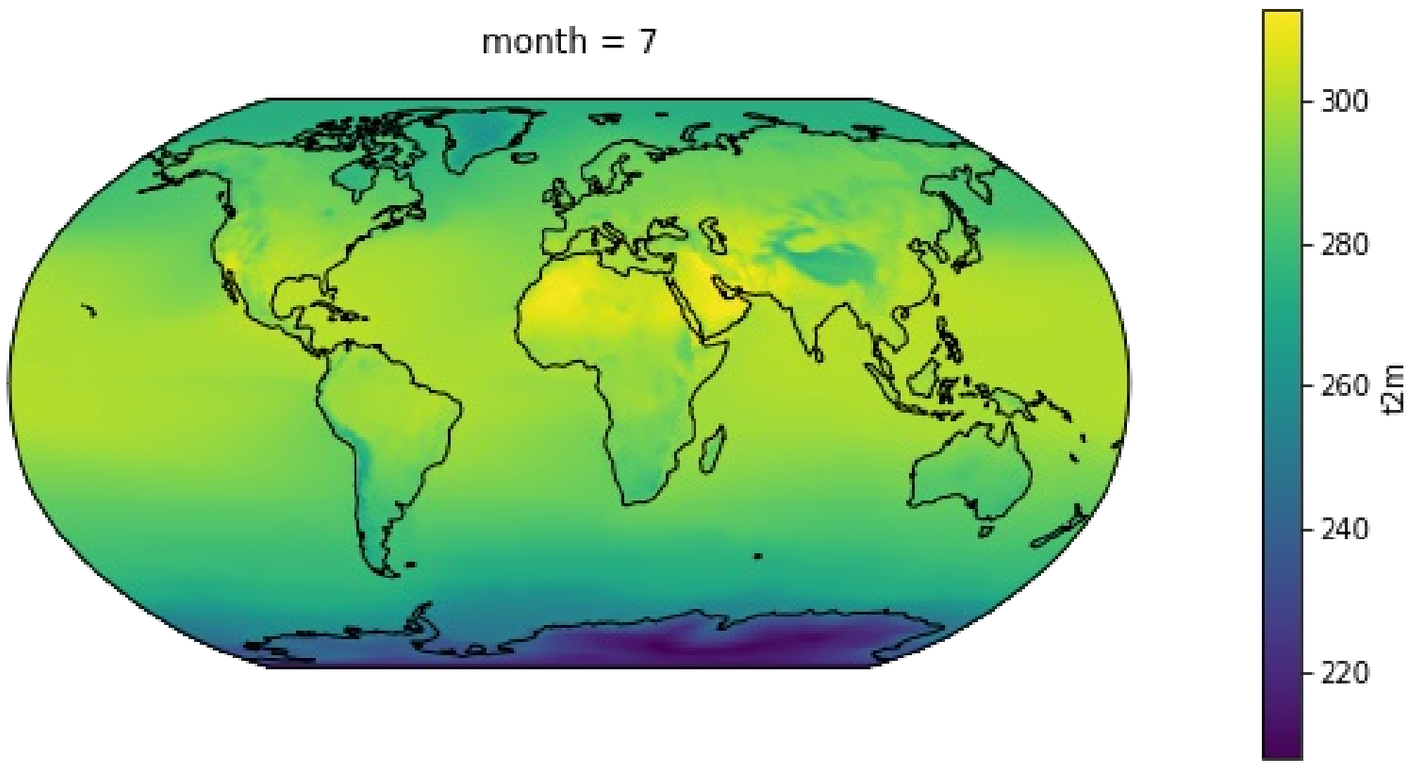
Plotting: maps

```
>>> 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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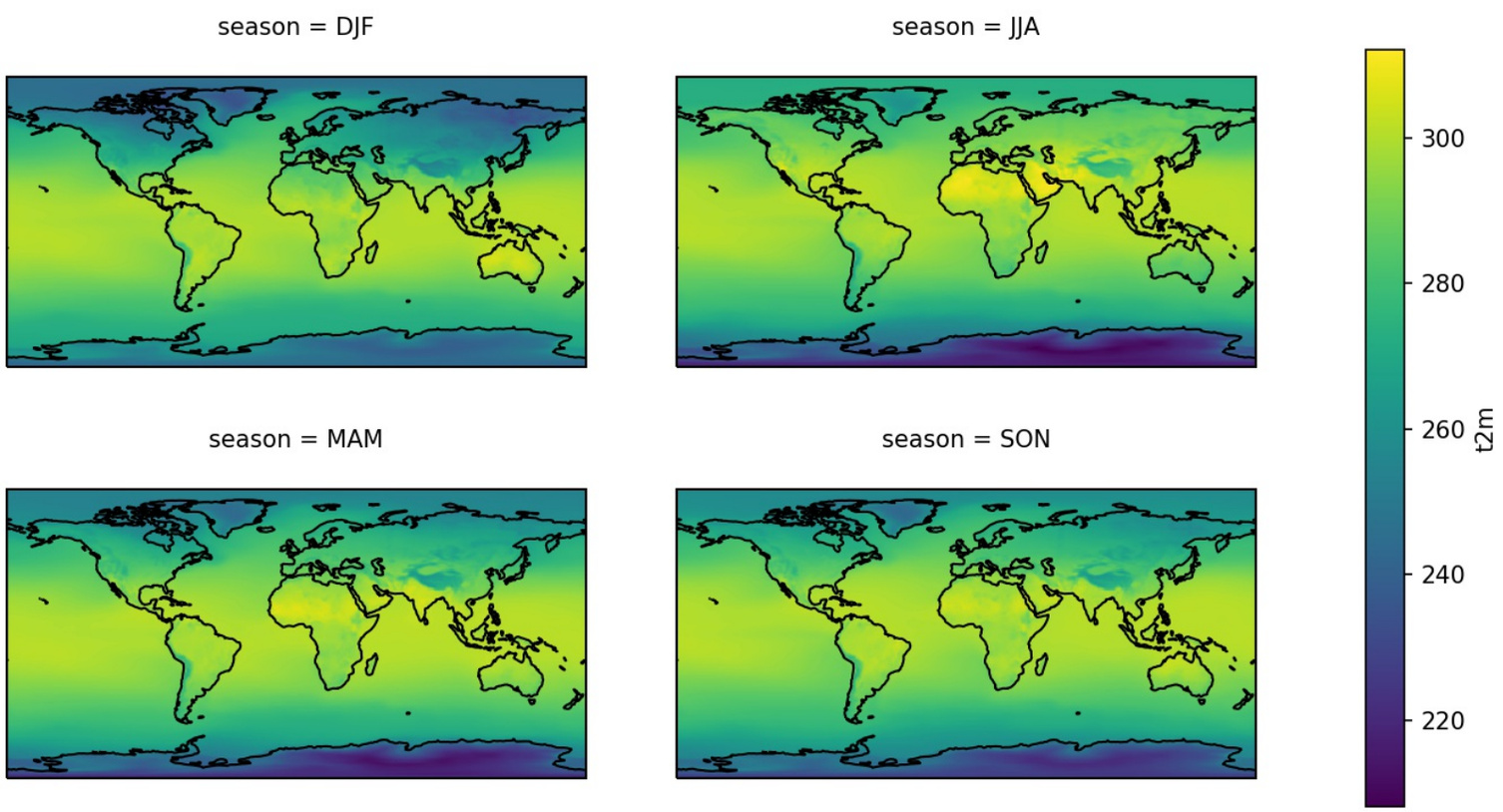
Plotting: facet plots

```
>>> 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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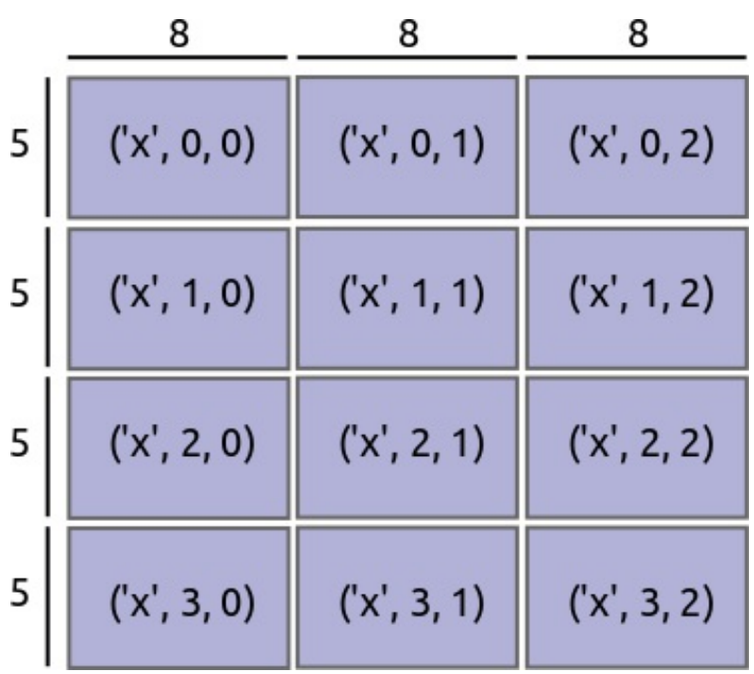
Out-of-core computing

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

```
>>> # split the array into chunks of 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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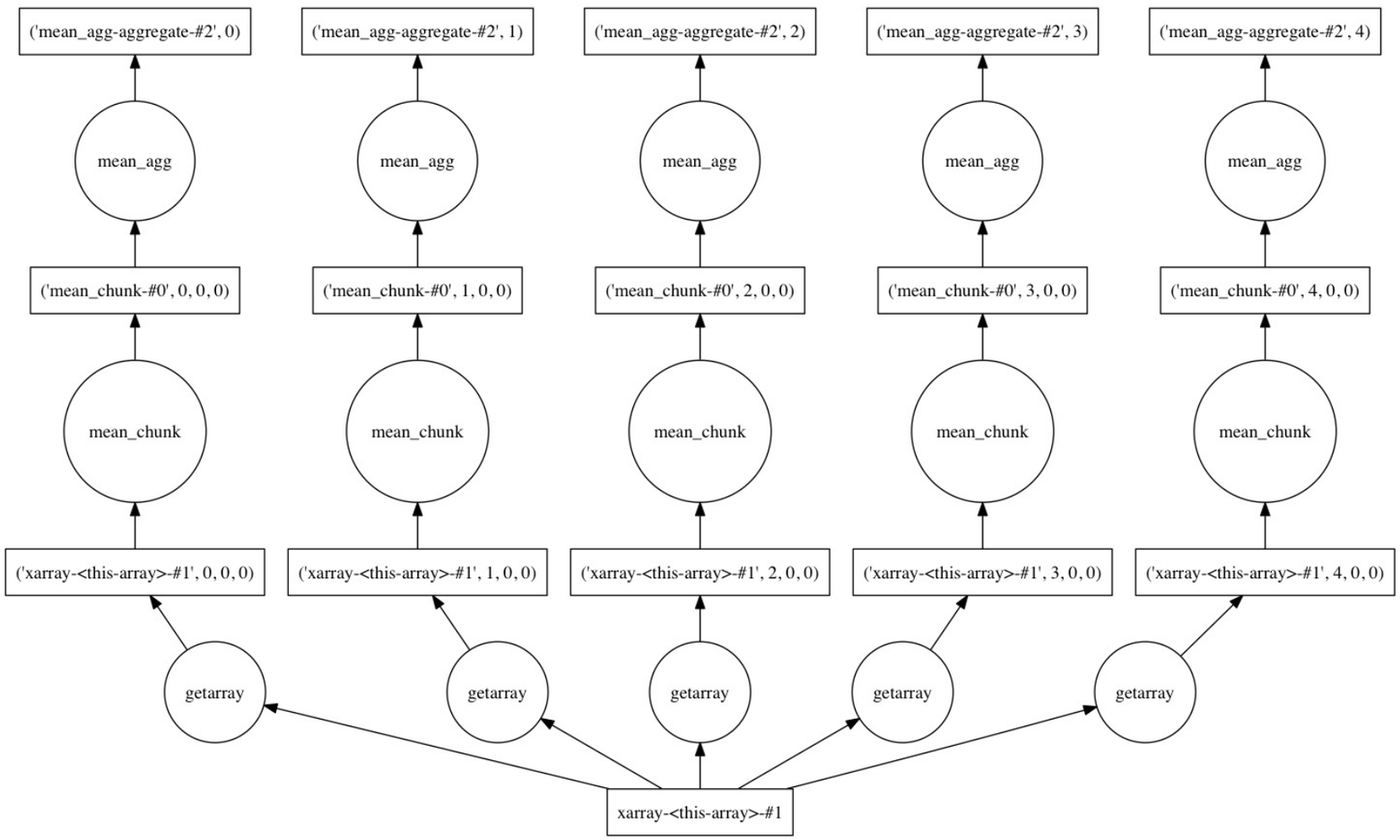
Out-of-core computing

- 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)

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