xarray

Working with netCDF files (N-dimensional arrays)

ESS 116 | Fall 2024

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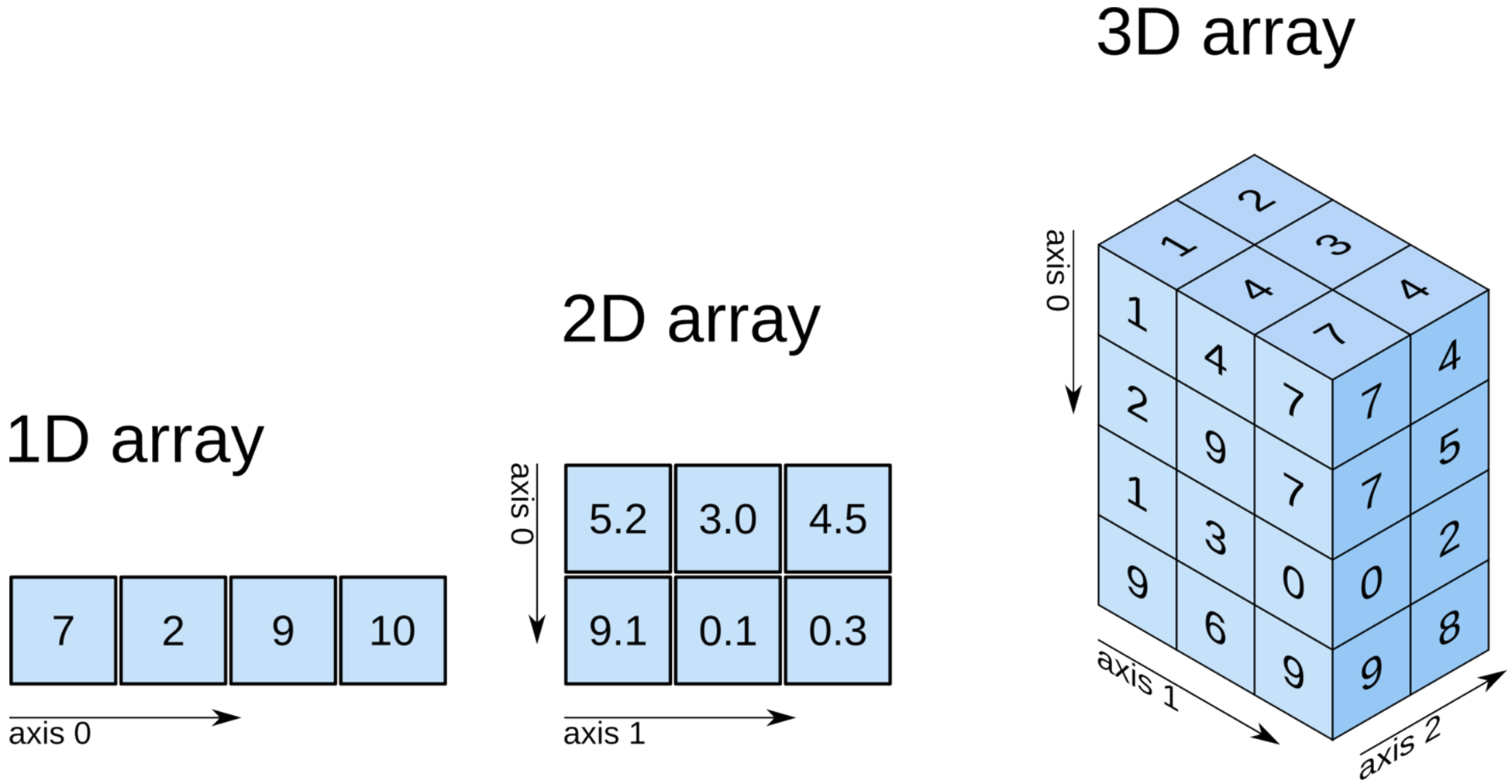
(Modified from Ethan Campbell and Katy Christensen's materials for UW's Ocean 215)

What we'll cover in this lesson

1. **`xarray`: `DataArray` and `Dataset` objects; netCDF files**
2. `xarray`: working with higher-dimensional data

Array values are identified by their coordinates along axes

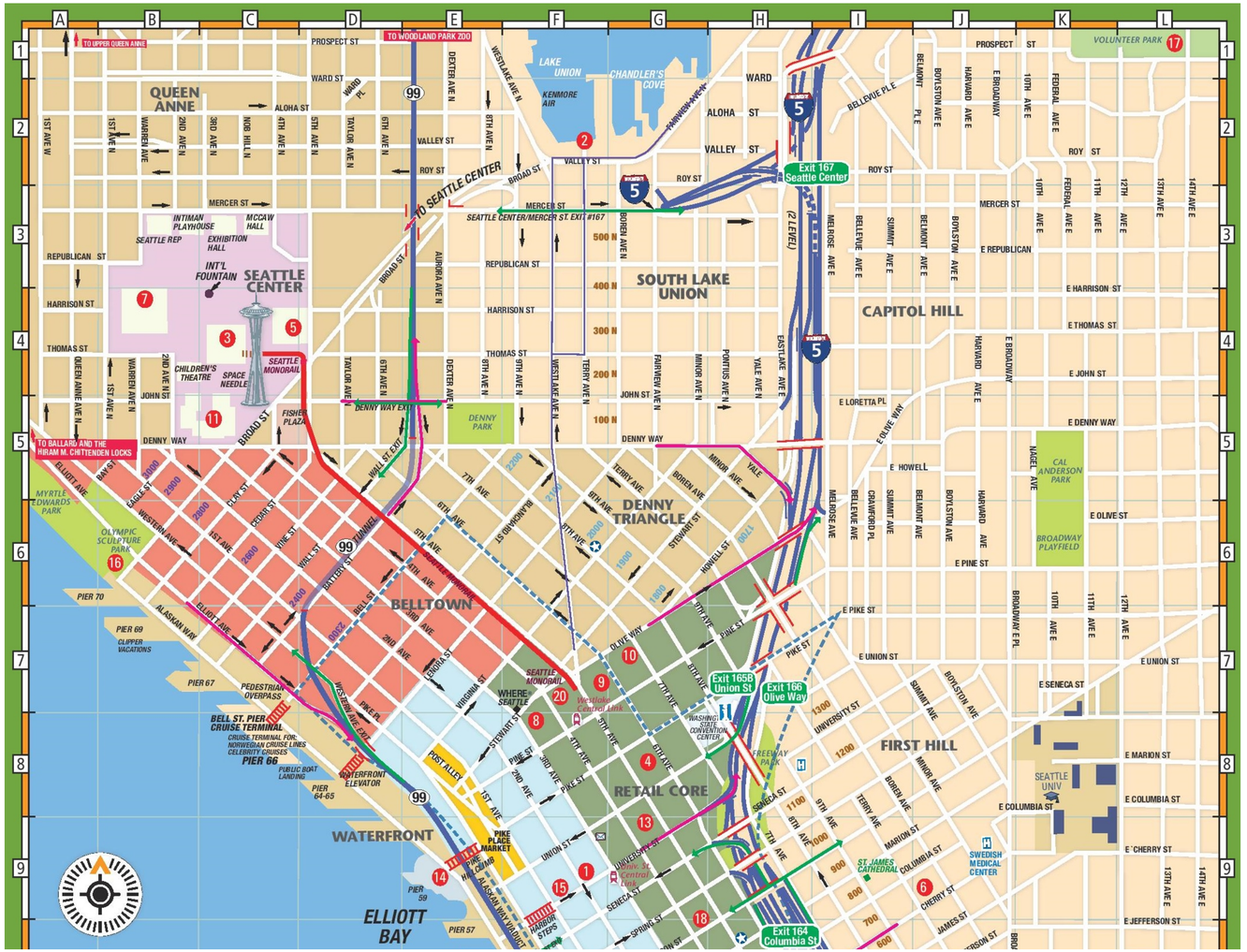


Source: O'Reilly

Coordinates along axes let us identify real-world locations

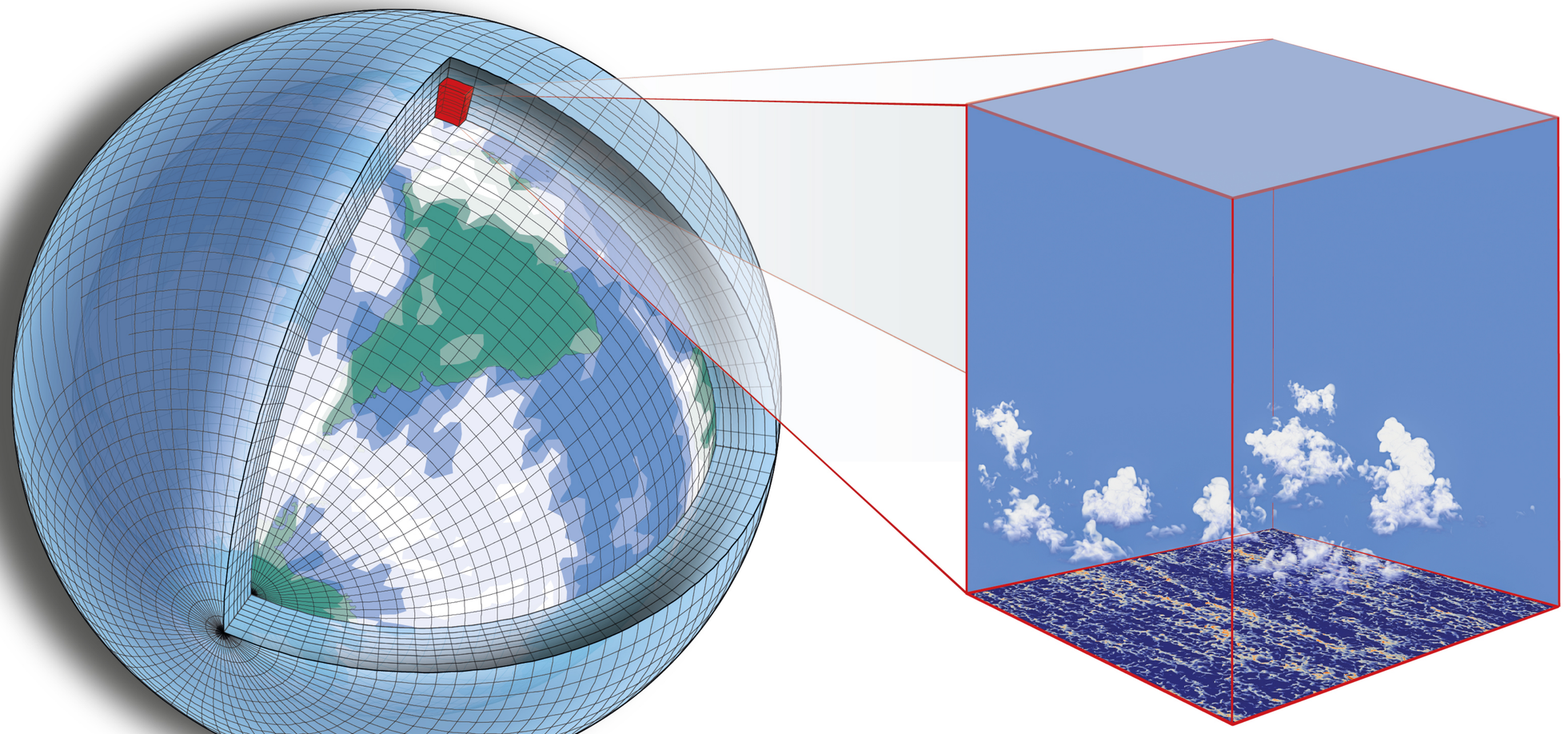
W ⟷ **E**

N ↕ **S**



Source: Where Maps

Models, satellites, and data providers divide the world into grid cells



Source: Caltech

`xarray` lets us deal with gridded data...

... and gridded data is usually provided in a **netCDF file (.nc)**

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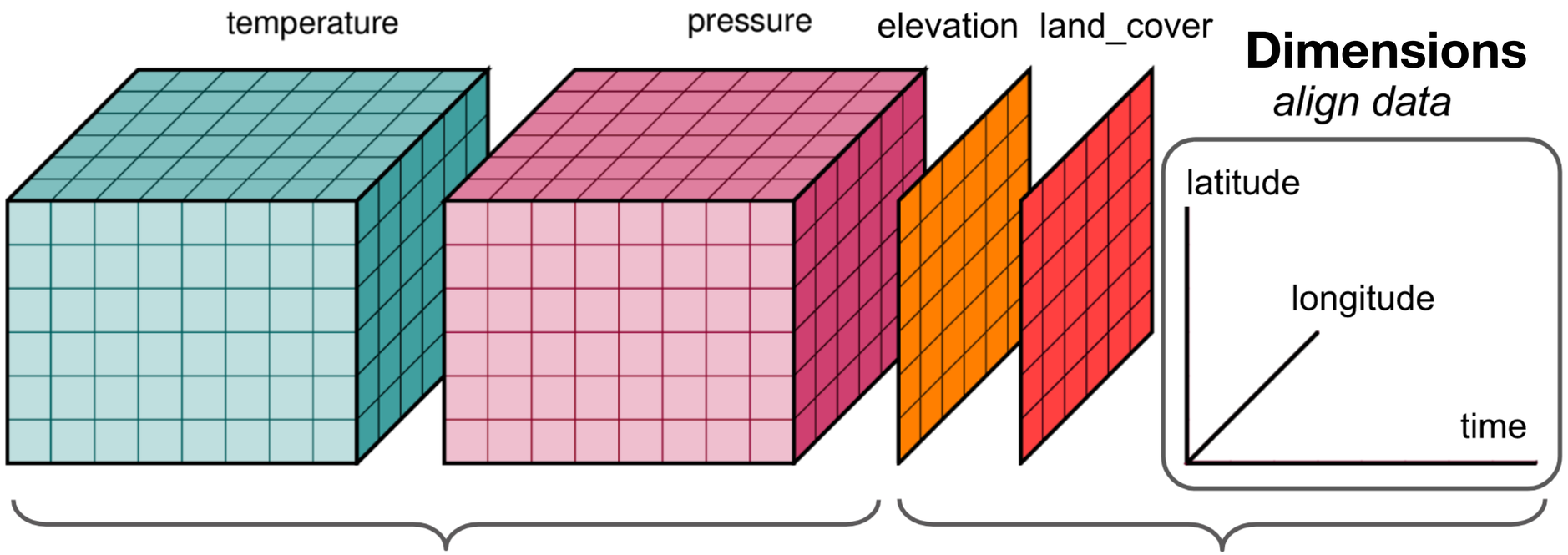
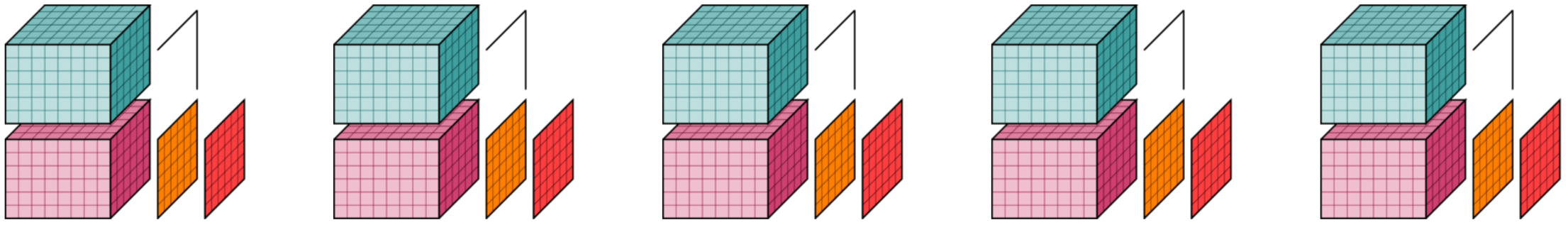
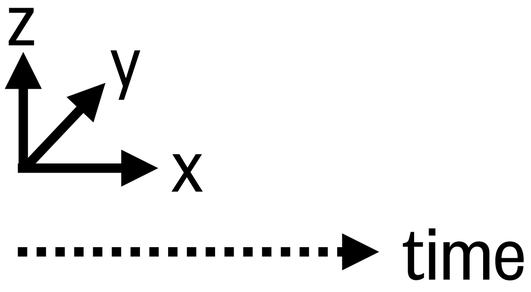


Source: Matthew Rocklin

4-D data is usually 3-D in space (x, y, z) + time

January **February** **March** **April** **May** **...**





Source: xarray

Importing `xarray` and loading the `netCDF4` library

```
import xarray as xr
```

```
!pip install netcdf4
```

You should only have to run this line once per Colab notebook.

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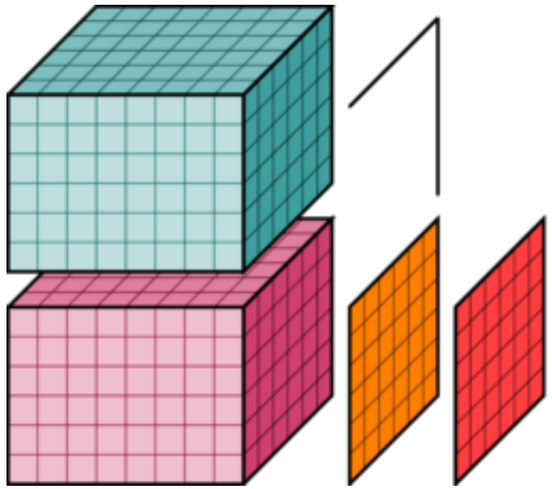
Loading a netCDF file as an `xarray Dataset`

Read a netCDF file as a `Dataset`:

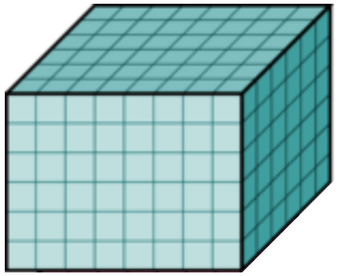
```
data = xr.open_dataset('filepath/including/filename.nc')
```

→ Documentation (API): http://xarray.pydata.org/en/stable/generated/xarray.open_dataset.html

`Dataset` object:



`DataArray` object:



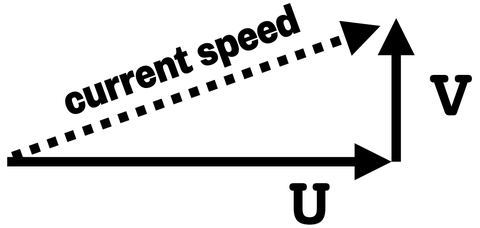
Demo: Southern Ocean current velocities from a climate model

File (~400 MB):
`bsose_monthly_velocities.nc`

Data source:
B-SOSE (Southern Ocean State Estimate) model output

Data resolution:
Time: monthly for 2012
Horizontal: 1/3° lat-lon grid
Vertical: 13 depth levels

Variables:
`U`: eastward velocity
`V`: northward velocity



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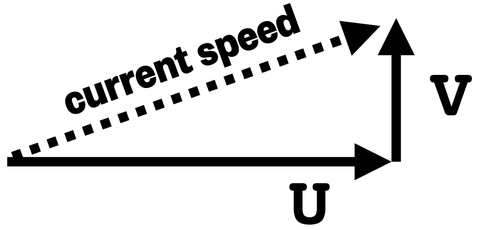

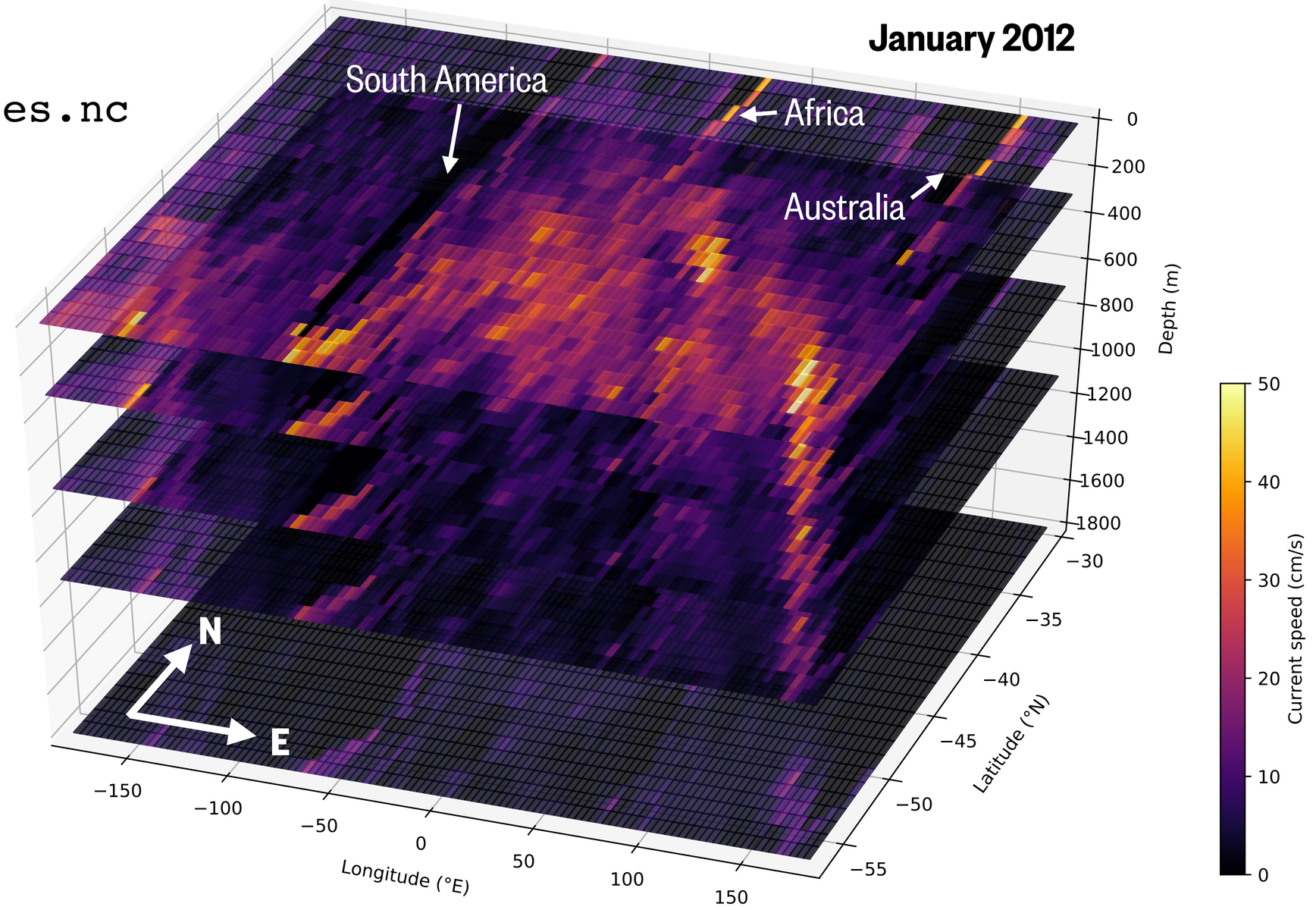

What we'll cover in this lesson

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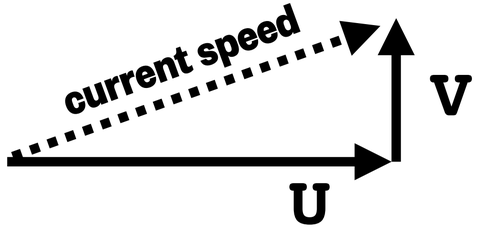
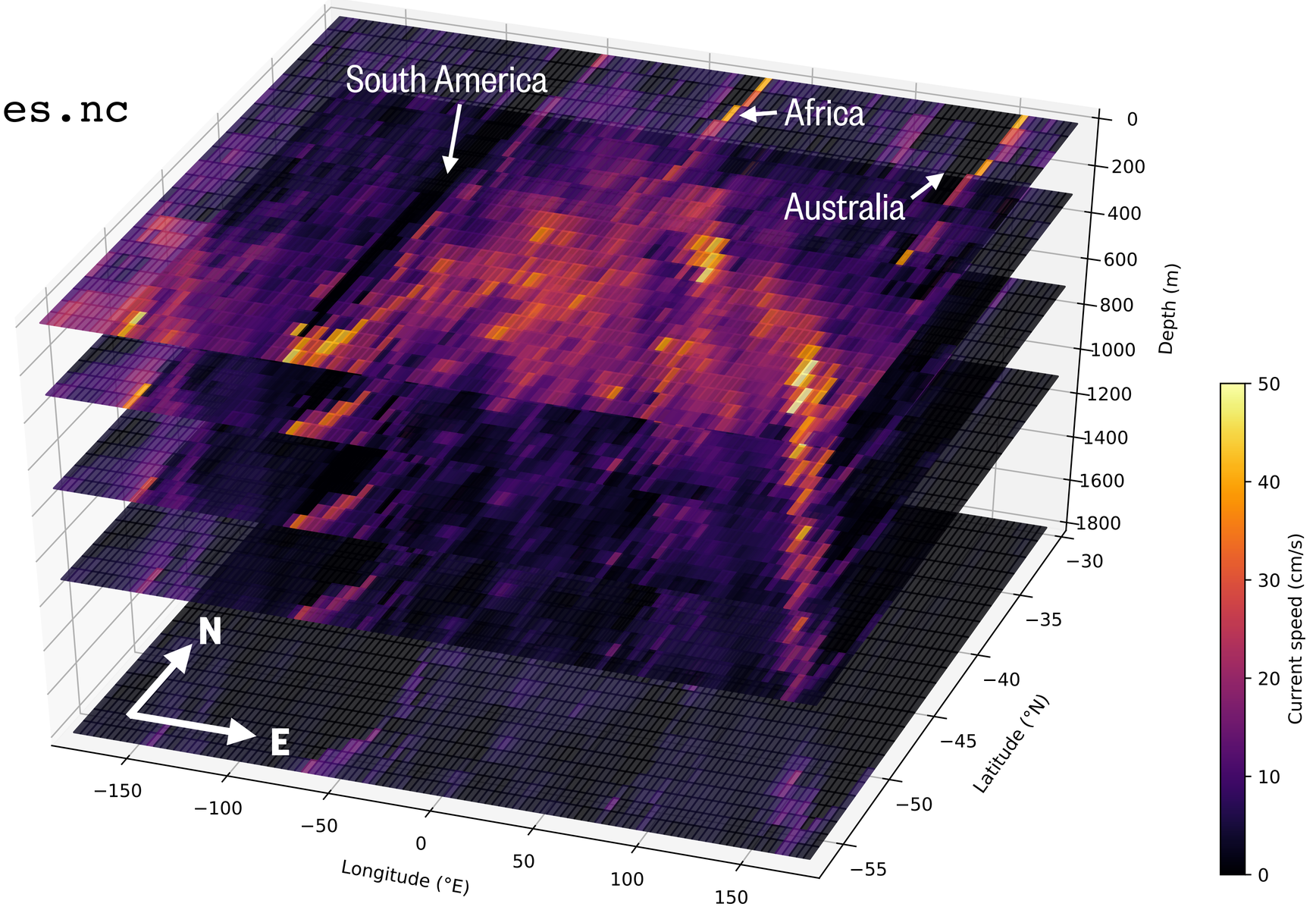




Getting information about a `Dataset`

`display(`<Dataset variable>**`)`**

xarray.Dataset

▶ Dimensions: (**depth**: 13, **lat**: 294, **lon**: 1080, **time**: 12)

▼ Coordinates:

time	(time)	datetime64[ns]	2012-01-30T20:00:00 ... 2012-12-30T1…
lat	(lat)	float32	-77.96525 -77.89555 ... -29.789328
lon	(lon)	float32	-179.66667 -179.33333 ... 180.0
depth	(depth)	float32	2.1 26.25 65.0 ... 3000.0 4600.0

▼ Data variables:

U	(time, depth, lat, lon)	float32	0.0 0.0 0.0 0.0 ... 0.0 0.0 0.0 0.0
V	(time, depth, lat, lon)	float32	0.0 0.0 0.0 0.0 ... 0.0 0.0 0.0 0.0

▶ Attributes: (0)

Extracting a single variable's `DataArray` from a `Dataset`

Syntax: <Dataset> **[** <variable name as a string> **]**

```
1 display(data['U'])
```

xarray.DataArray 'U' (**time**: 12, **depth**: 13, **lat**: 294, **lon**: 1080)

...

▼ Coordinates:

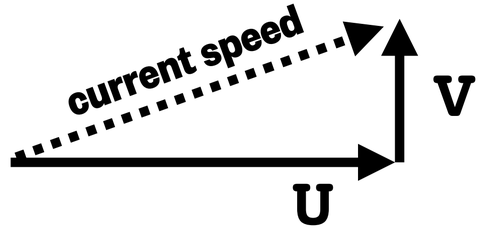
time	(time)	datetime64[ns]	2012-01-30T20:00:00 ... 2012-12-30T12:00:00	
lat	(lat)	float32	-77.96525 -77.89555 ... -29.789328	
lon	(lon)	float32	-179.66667 -179.33333 ... 180.0	
depth	(depth)	float32	2.1 26.25 65.0 ... 3000.0 4600.0	

▼ Attributes:

units :	m/s
long_name :	Zonal Component of Velocity (m/s)
standard_name :	UVEL
mate :	VVEL

Mathematical calculations with `xarray` objects works like NumPy

```
# Example: calculate current speed using Pythagorean theorem:
#          speed = sqrt(U^2 + V^2)
speed = (data['U']**2 + data['V']**2)**0.5
display(speed)
```



xarray.DataArray (**time**: 12, **depth**: 13, **lat**: 294, **lon**: 1080)

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 ... 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

▼ Coordinates:

time	(time)	datetime64[ns]	2012-01-30T20:00:00 ... 2012-12-30T12:00:00
lat	(lat)	float32	-77.96525 -77.89555 ... -29.789328
lon	(lon)	float32	-179.66667 -179.33333 ... 180.0
depth	(depth)	float32	2.1 26.25 65.0 ... 3000.0 4600.0

▶ Attributes: (0)

Accessing and changing attributes (metadata) of `xarray` objects

Syntax: <Dataset or DataArray>**`.attrs`** is a Python dictionary (a set of keys and values)

```
1 print(data['U'].attrs)
```

```
{'units': 'm/s', 'long_name': 'Zonal Component of Velocity (m/s)', 'standard_name': 'UVEL', 'mate': 'VVEL'}
```

Syntax: <Dataset or DataArray>**`.attrs[`**<attribute name as string>**`]`** gets the value of an attribute

```
1 print(data['U'].attrs['units'])
```

```
m/s
```

Syntax: <Dataset or DataArray>**`.attrs[`**<attribute name>**`]`** **`=`** <new value> changes its value

```
1 data['U'].attrs['units'] = 'meters/second'
```

Selecting data from `xarray` objects using `.isel()` (selection by integer index)

<DataArray or Dataset>`.isel(`<coordinate name>=<a single integer index>

OR <list or array of indices>

OR `slice(`<start>`,`<stop>`),...)`

Like Python/NumPy slicing, the end value is exclusive!

Example:

```
1 data['U'].isel(time=0,lat=200,lon=500,depth=0)
```

xarray.DataArray 'U'

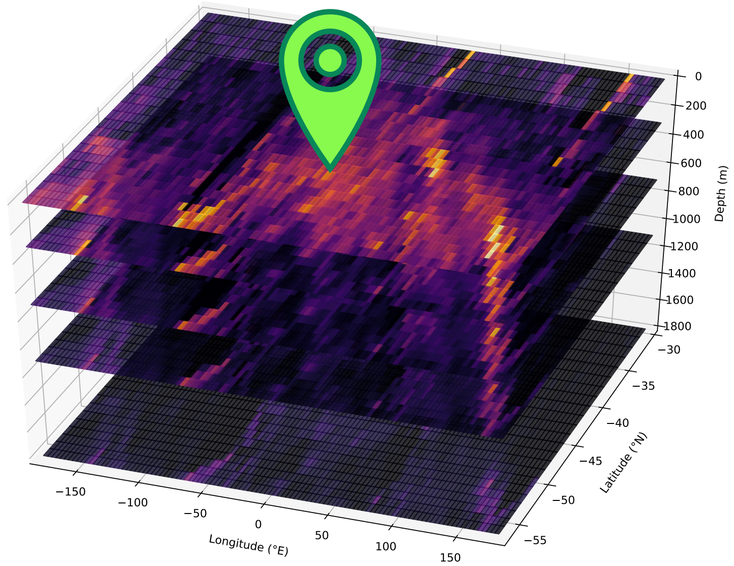
0.12588988

▼ Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00
lat	()	float32	-52.70605
lon	()	float32	-13.0
depth	()	float32	2.1

▼ Attributes:

units :	m/s
long_name :	Zonal Component of Velocity (m/s)
standard_name :	UVEL
mate :	VVEL



Convert a single-value `Dataset` to a number using `float()` or `item()`

<DataArray or Dataset>**`.isel(...).item()`**

OR...

`float(`<DataArray or Dataset>**`.isel(...))`**

Example:

```
1 data['U'].isel(time=0,lat=200,lon=500,depth=0).item()
```

```
0.1258898824453354
```

```
1 float(data['U'].isel(time=0,lat=200,lon=500,depth=0))
```

```
0.1258898824453354
```

Selecting data from `xarray` objects using `.isel()` (selection by integer index)

<DataArray or Dataset>`.isel(`<coordinate name>=<a single integer index>

OR <list or array of indices>

OR `slice(`<start>`,`<stop>`),...)`

Example:

```
1 data['U'].isel(time=0,lat=200,lon=500,depth=[0,1,2,3,4])
2 data['U'].isel(time=0,lat=200,lon=500,depth=slice(0,5))
```

xarray.DataArray 'U' (**depth**: 5)

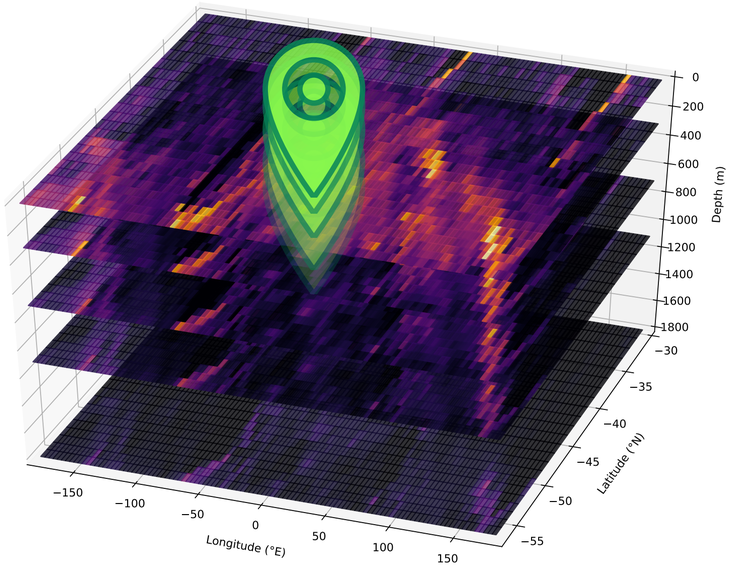
0.12588988 0.050398406 0.057173315 0.061554562 0.057381995

▼ Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00
lat	()	float32	-52.70605
lon	()	float32	-13.0
depth	(depth)	float32	2.1 26.25 65.0 105.0 146.5

▼ Attributes:

units :	m/s
long_name :	Zonal Component of Velocity (m/s)
standard_name :	UVEL
mate :	VVEL



Convert a `Dataset` with multiple values to a NumPy array using `.values`

<DataArray or Dataset>**`.values`**

<DataArray or Dataset>**`.isel(…).values`**

Example:

```
1 data['U'].isel(time=0,lat=200,lon=500,depth=slice(0,5)).values
```

```
array([0.12588988, 0.05039841, 0.05717332, 0.06155456, 0.057382  ],
      dtype=float32)
```

Selecting data from `xarray` objects using `.sel()` (selection by coordinate value)

<DataArray or Dataset>`.sel(`<coordinate name>=<a single coordinate value>

OR <list or array of coordinate values>

OR `slice(`<start>`,`<stop>`),...)`

Unlike Python/NumPy slicing, the end value is inclusive!

Example:

```
1 data['U'].sel(time=datetime(2012,1,30,20),lat=-52.70605,lon=-13.0,depth=2.1)
```

xarray.DataArray 'U'

0.12588988

▼ Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00
lat	()	float32	-52.70605
lon	()	float32	-13.0
depth	()	float32	2.1

▼ Attributes:

units :	meters/second
long_name :	Zonal Component of Velocity (m/s)
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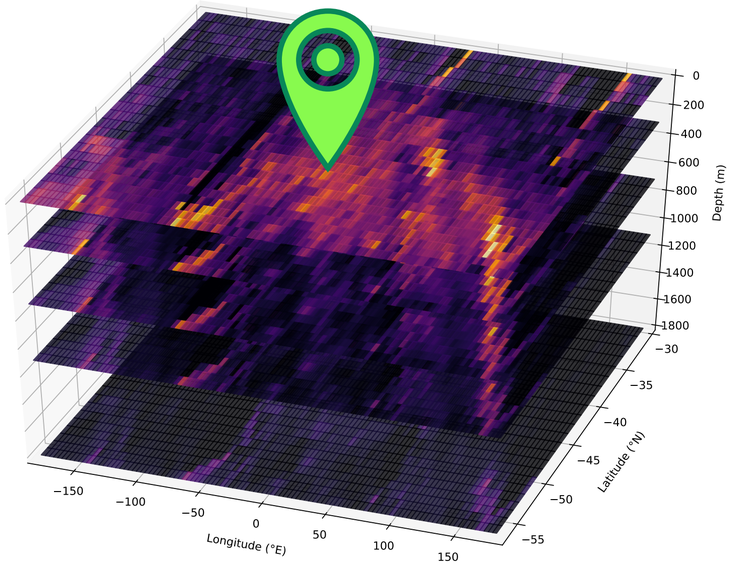

Selecting data from `xarray` objects using `.sel()` (selection by coordinate value)

<DataArray or Dataset>**`.sel(`**<coordinate name>=<a single coordinate value>

OR <list or array of coordinate values>

OR `slice(`<start>`,`<stop>`),...)`

Example:

```
1 data['U'].sel(time=datetime(2012,1,30,20,0,0),lat=-52.70605,lon=-13.0,depth=slice(2,147))
```

xarray.DataArray 'U' (**depth**: 5)

0.12588988 0.050398406 0.057173315 0.061554562 0.057381995

▼Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00	
lat	()	float32	-52.70605	
lon	()	float32	-13.0	
depth	(depth)	float32	2.1 26.25 65.0 105.0 146.5	

▼Attributes:

units :	meters/second
long_name :	Zonal Component of Velocity (m/s)
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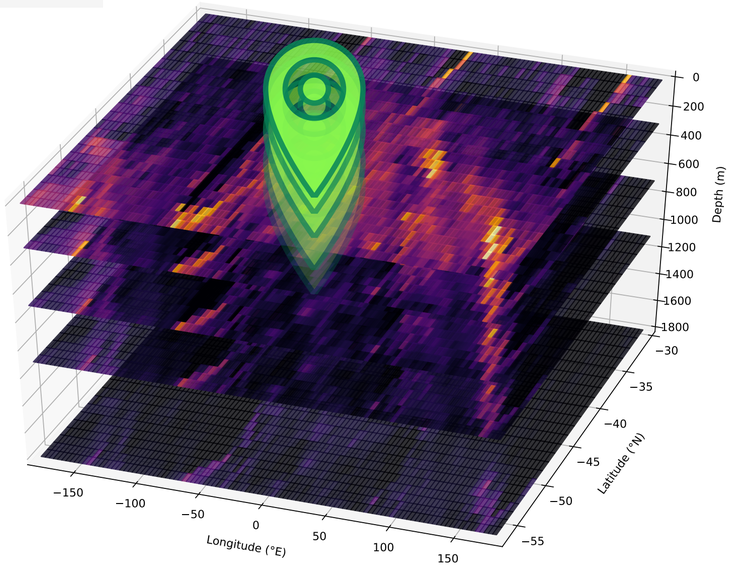

Selecting data from `xarray` objects using `.sel()` (selection by coordinate value)

Use method='nearest' when you don't know the exact coordinate values...

<DataArray or Dataset>`.sel(`<coordinate name>=<a single coordinate value>`, ..., method='nearest')`

Example:

```
1 data['U'].sel(time=datetime(2012,1,30),lat=-53,lon=-13,depth=2,method='nearest')
```

xarray.DataArray 'U'

0.12865335

▼ Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00
lat	()	float32	-52.90755
lon	()	float32	-13.0
depth	()	float32	2.1

▼ Attributes:

units :	meters/second
long_name :	Zonal Component of Velocity (m/s)
standard_name :	UVEL
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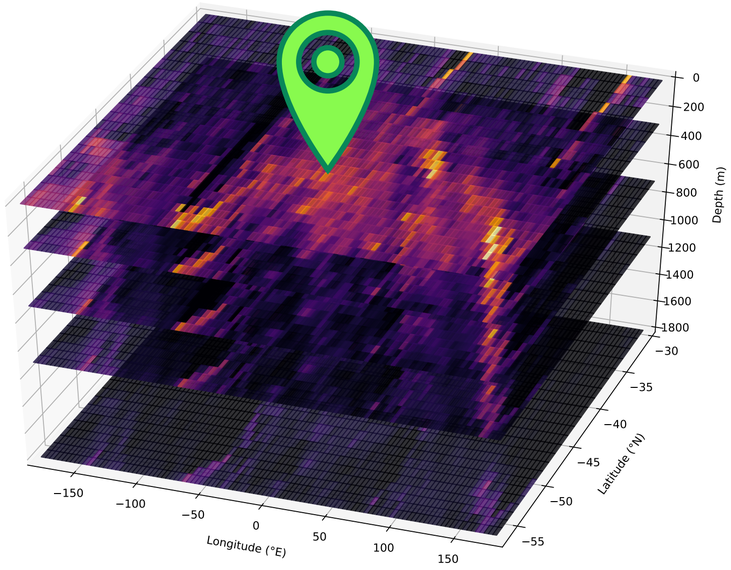
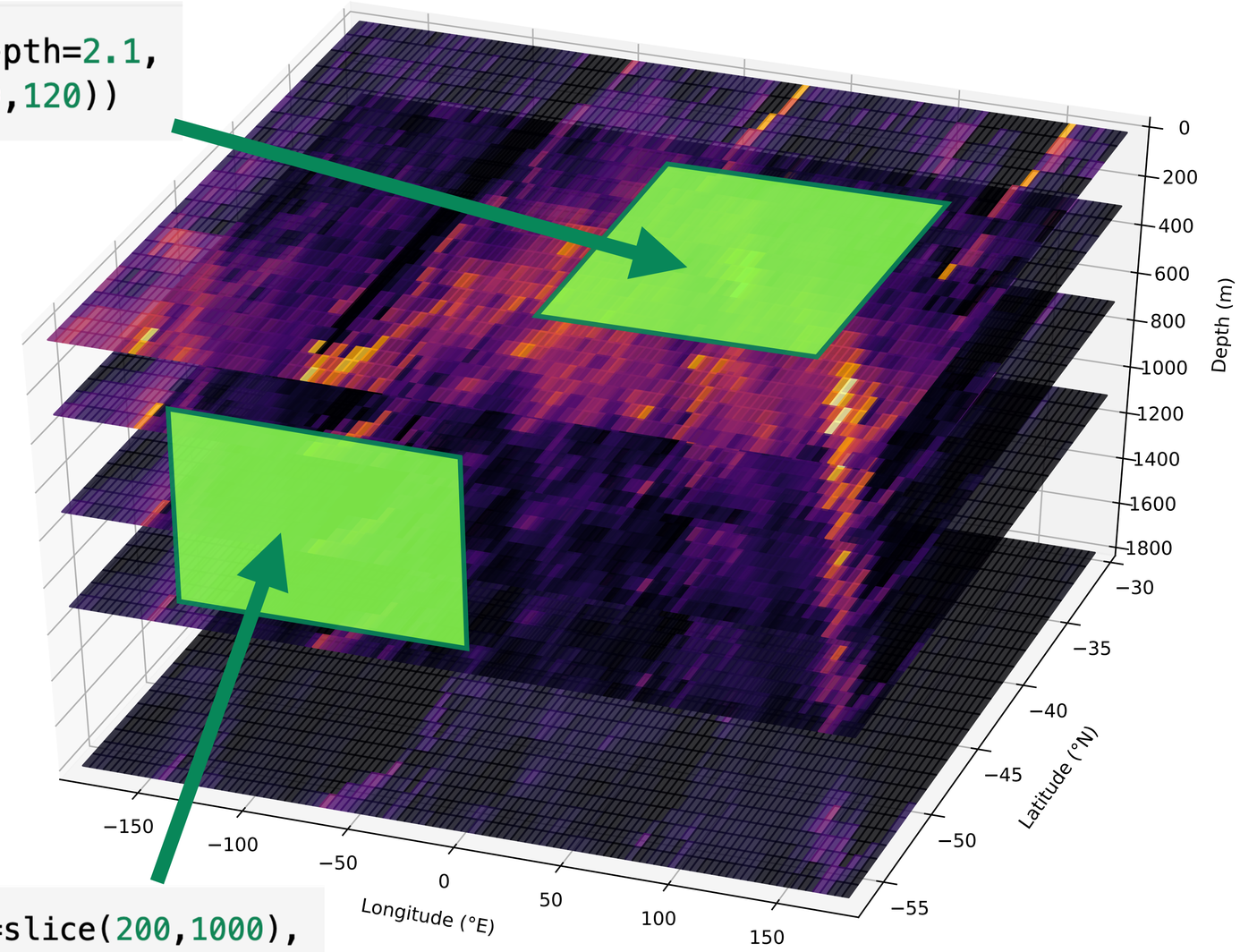


Selecting data from `xarray` objects using `.sel()` (selection by coordinate value)

```
data['U'].sel(time=datetime(2012,1,30,20),depth=2.1,
              lat=slice(-50,-40),lon=slice(0,120))
```

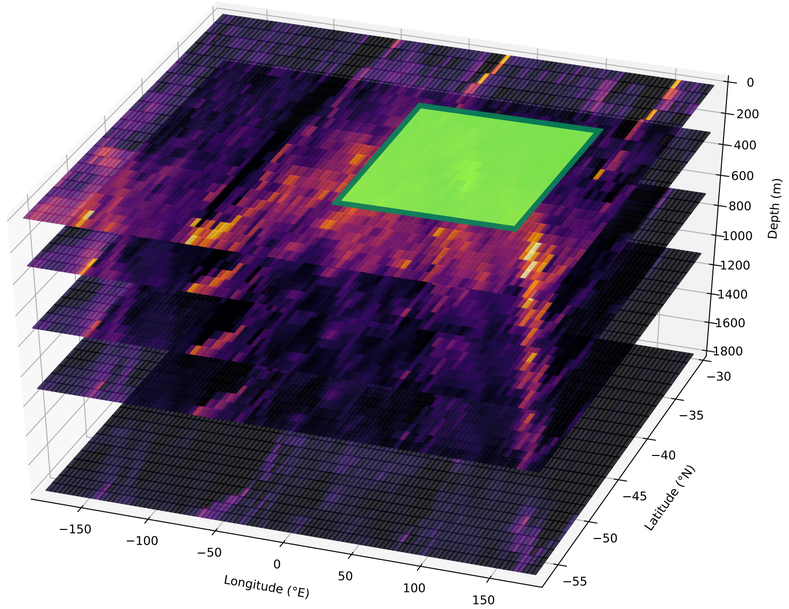



```
data['U'].sel(time=datetime(2012,1,30,20),depth=slice(200,1000),
              lon=slice(-120,0)).sel(lat=-57,method='nearest')
```

Applying NumPy functions to an `xarray` object (or selection from an object)

Take the average across ALL the dimensions:

<DataArray or Dataset>`.mean()`



Example:

```
1 data['U'].sel(time=datetime(2012,1,30,20),depth=2.1,
2                lat=slice(-50,-40),lon=slice(0,120)).mean().item()
```

```
0.16497819125652313
```

Applying NumPy functions to an `xarray` object (or selection from an object)

Take the average across certain dimension(s):

<DataArray or Dataset>`.mean(dim=`<dimension name(s) as string or list of strings>`)`

Example:

```
1 display(data['U'].sel(time=datetime(2012,1,30,20),depth=2.1,
2                       lat=slice(-50,-40),lon=slice(0,120)).mean(dim='lon'))
```

xarray.DataArray 'U' (**lat**: 42)

0.19636832 0.19726074 0.19570175 ... 0.112251155 0.108821966

▼Coordinates:

time	()	datetime64[ns]	2012-01-30T20:00:00	
lat	(lat)	float32	-49.78614 -49.570454 ... -40.151318	
depth	()	float32	2.1	

Applying NumPy functions to an `xarray` object (or selection from an object)