for_wintertime_users

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1 NetCDF Tutorial

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This tutorial was given at the meeting of the Numerical Ecology in Oceanography Laboratory (NEOLab), Université Laval, on April 21, 2023.

This Jupyter notebook is part of the project for_wintertime_users containing documentation and examples on how to use the outputs of the default simulation EXP-0 described in Benoît-Gagné et al. (submitted).

The documentation and examples are available on https://github.com/maximebenoitgagne/for_wintertime_users/

The original project of Benoît-Gagné et al. (submitted) can be found on https://github.com/maximebenoitgagne/wintertime/tree/v1.5.

2 Definitions

NetCDF file for a region: A NetCDF file for many latitudes and many longitudes, for example, a NetCDF file for the whole Baffin Bay.

NetCDF file for a specific location: A NetCDF file for only one latitude and one longitude, for example, a NetCDF file for the location of an ice camp.

Results of Benoît-Gagné et al. (submitted): NetCDF files containing the results of the default simulation of Benoît-Gagné et al. (submitted). The simulation was adapted to the location of the Qikiqtarjuaq sea ice camp in western Baffin Bay (67.4797°N, -63.7895°E) in 2016 during the Green Edge sea ice camp mission. The model was run with a spinup of 10 years to stabilise the system. Use the data of that tenth year. The dimensions of the data are the depth steps and the time steps.

3 What you will learn in this tutorial

- Find the results of Benoît-Gagné et al. (submitted).
- Understand the structure of the results of Benoît-Gagné et al. (submitted).
- Explore the structure of a NetCDF file for a specific location with Panoply.
- Plot a NetCDF file for a specific location with Panoply.
- Read a NetCDF file for a specific location with Python.*

- Export a NetCDF file for a specific location into a comma-separated values (CSV) file with Python.*
- Plot a variable from the results of Benoît-Gagné et al. (submitted) with Python.*
- Find more examples of Python scripts reading the results of Benoît-Gagné et al. (submitted).*

Note: The goals with an asterisk (*) have the following prerequisites: * Knowledge of Anaconda. * Basic knowledge of Python.

4 What you will not learn in this tutorial

- Anaconda.
- Python.
- Use a NetCDF file for a specific location when the metadata doesn't contain sufficient information to retrieve the depth steps and the time steps of the file. Actually, the only solution would be to ask someone who knows the answer, for example, the human author of the files.
- Export a NetCDF file for a specific location into a CSV file with Panoply.
- Write a NetCDF file.
- Read a NetCDF file for a specific location in R.
- Use a NetCDF file for a region.

5 Installation steps

These installation steps were tested for MacOS X 10.13 (High Sierra).

- Install Panoply (https://www.giss.nasa.gov/tools/panoply/download/).
- Install Anaconda for Python 3 (see https://datacarpentry.org/python-ecology-lesson/setup.html).
- Enter the following commands in the Terminal. The creation of the conda environment can take approximately 15 minutes.

```
git clone --depth 1 --branch v1.0 git@github.com:maximebenoitgagne/for_wintertime_users.git

cd for_wintertime_users/

conda env create -f for_wintertime_users.yml

conda activate for_wintertime_users

jupyter notebook
```

Once the environment for_wintertime_users is created, the Jupyter notebook can be launched simply with:

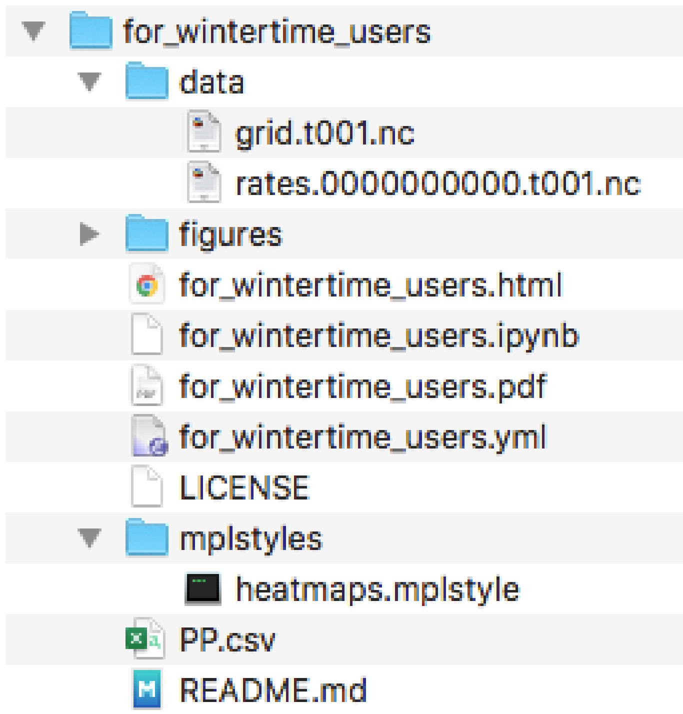
```
cd for_wintertime_users/

conda activate for_wintertime_users

jupyter notebook
```

6 Find the data

The results of Benoît-Gagné et al. (submitted) are available on https://github.com/maximebenoitgagne/wintertime/tree/v1.5/data/DataS8_output_mitgcm/exp0. Two relatively small files of these results are also in the directory `data` of this project.

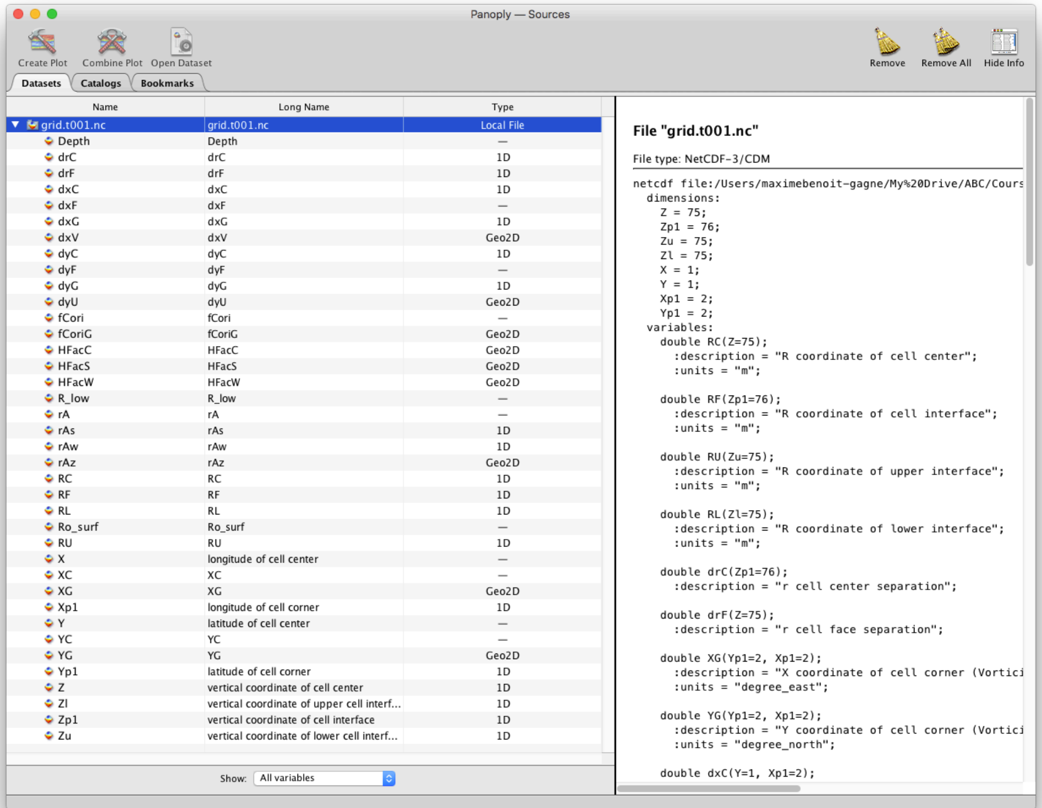


7 Read a NetCDF file with Panoply

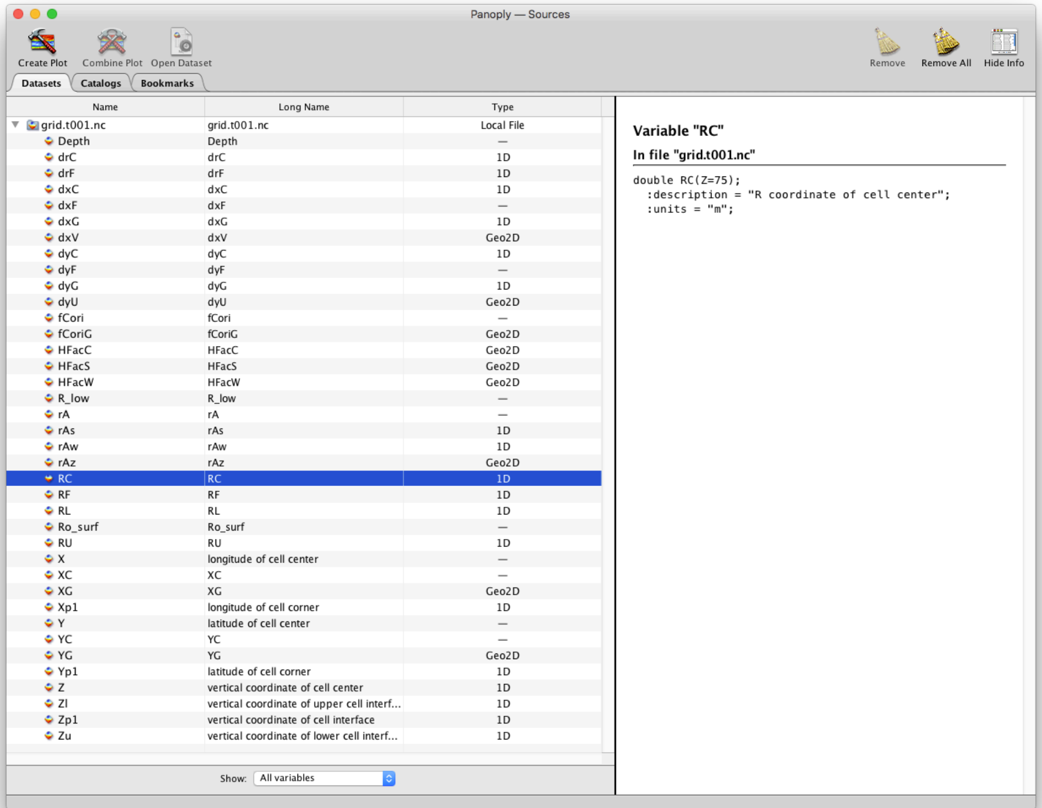
Panoply is a graphical user interface (GUI) tool to explore and plot NetCDF files.

Steps

- Click on Panoply.
- Select grid.t001.nc.

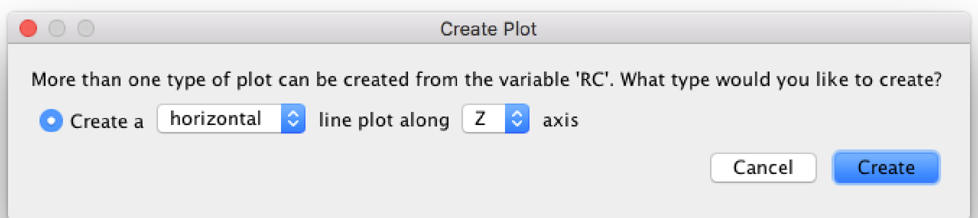


- Select the variable RC.

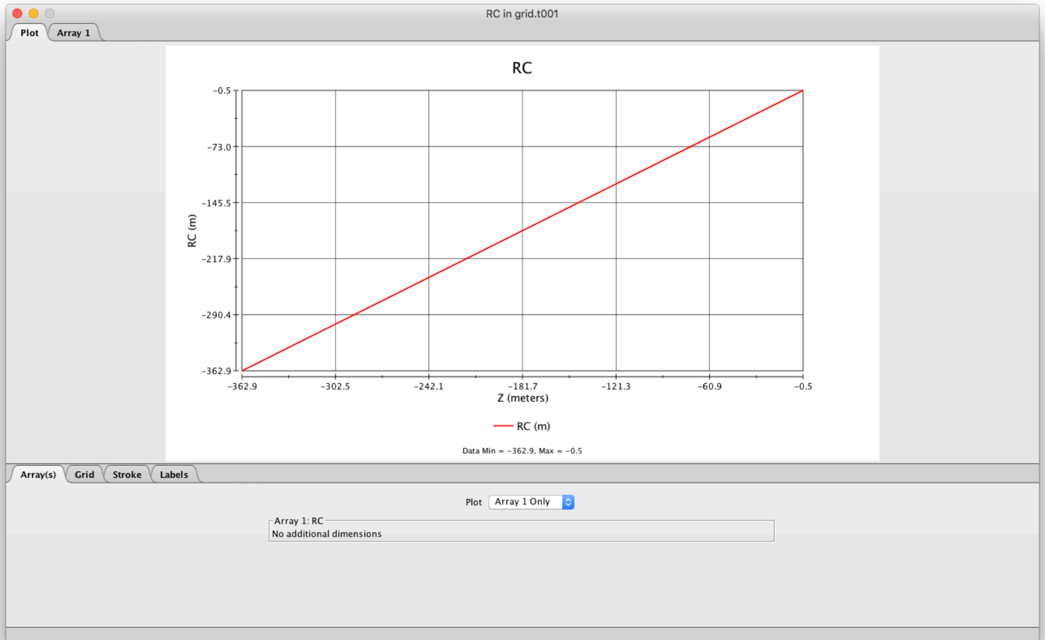


We see that the variable RC in grid.t001.nc contains the values of the 75 depth steps.

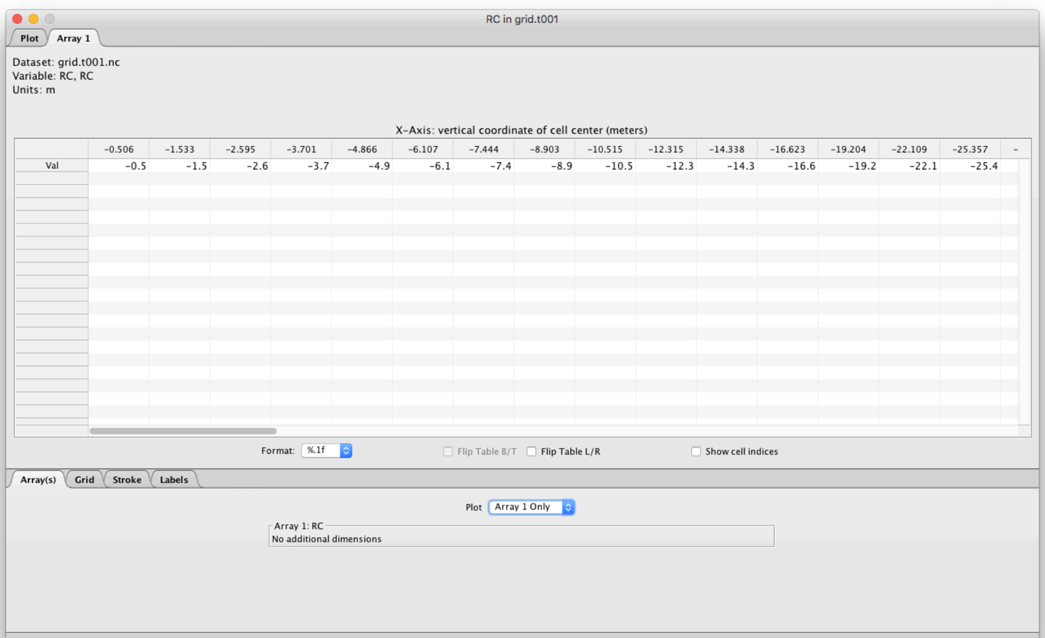
- Double-click on RC.



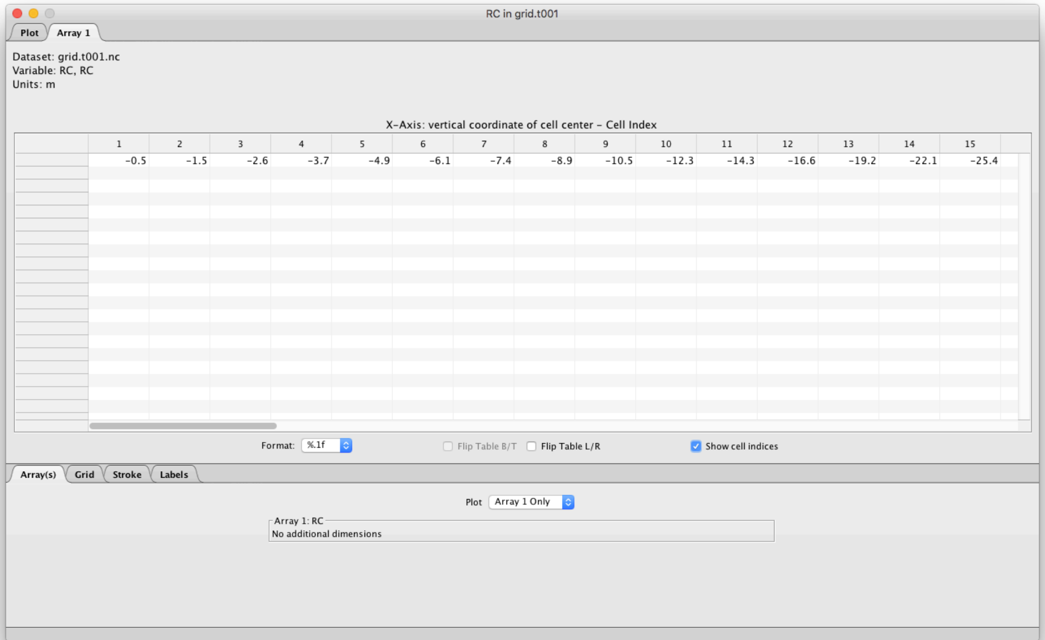
- Click Create.



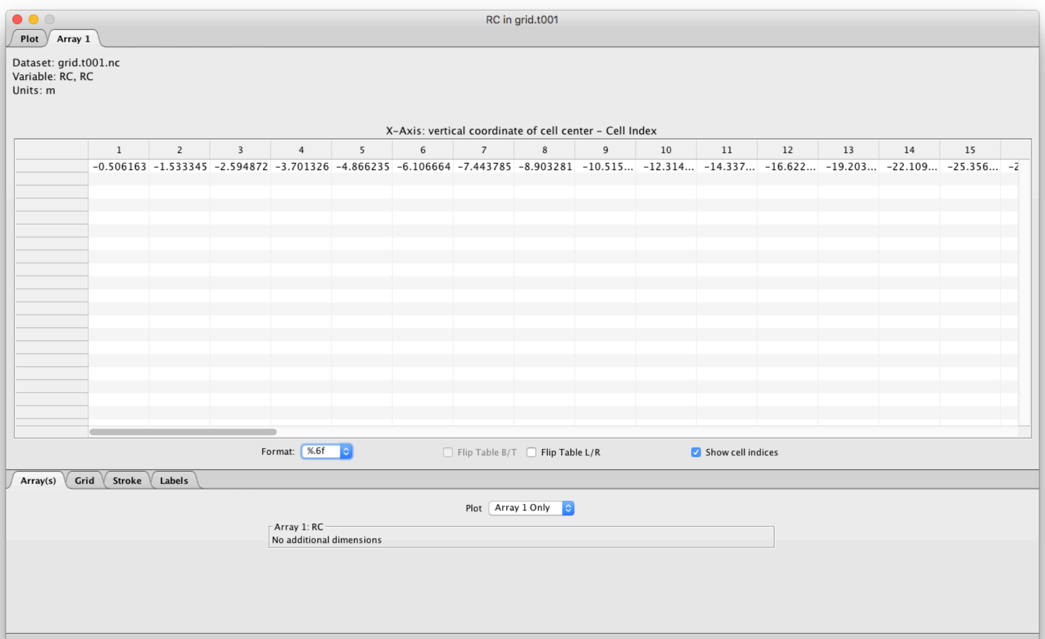
- Select tab Array 1.



- Check Show cell indices.



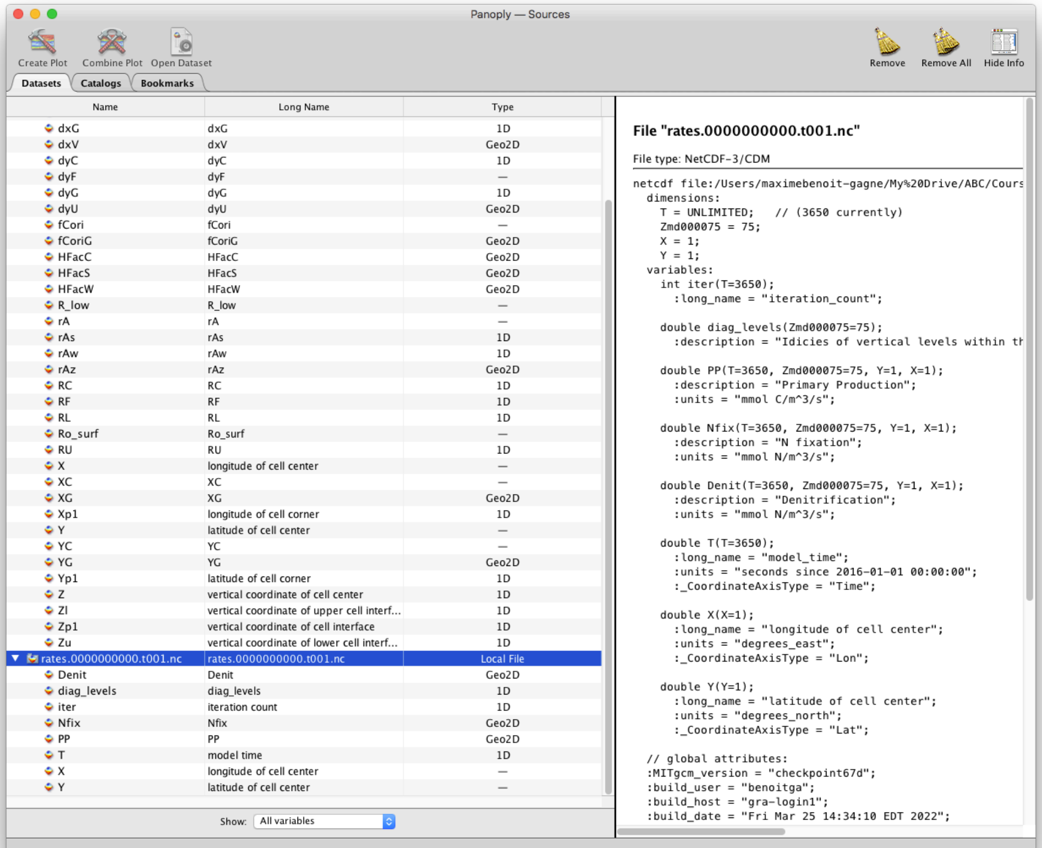
- Select Format %.6f.



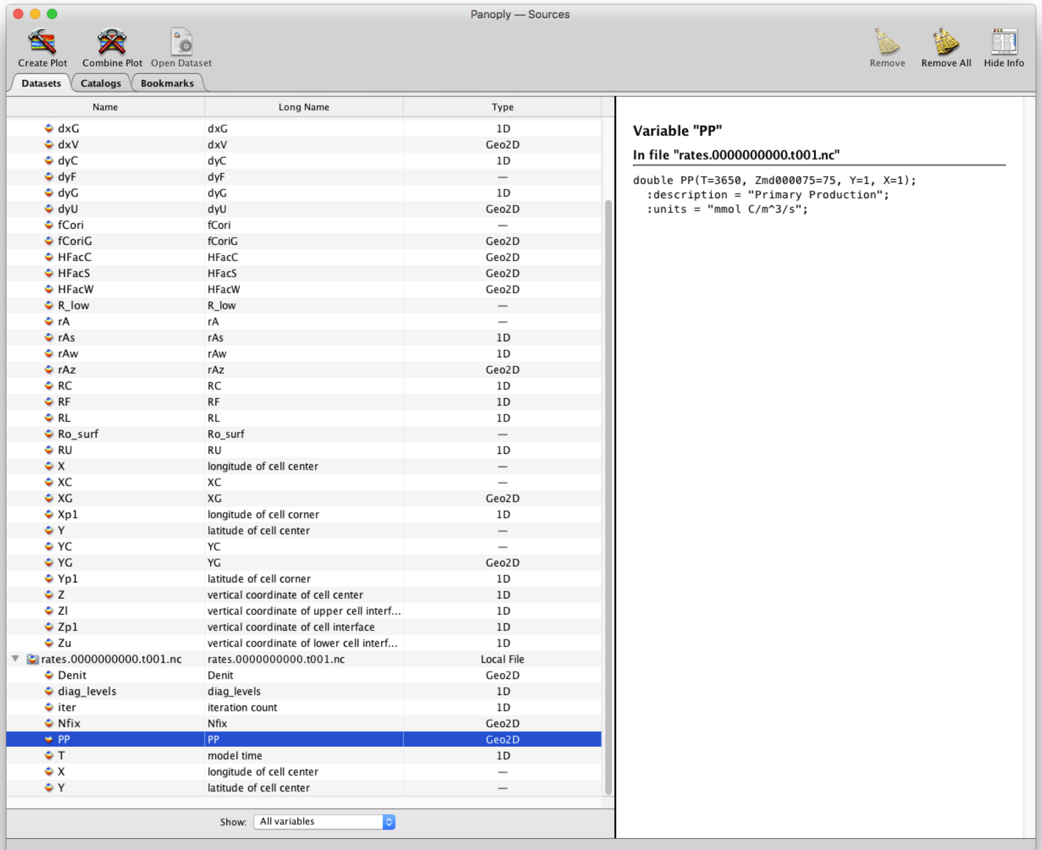
We now see explicitely the values of the 75 depth steps. Note that the vertical grid is irregular. We have to take that into account if we want to transform units by m^{-3} into units by m^{-2}.

We will now open another NetCDF file. We will open rates.0000000000.t001.nc.

- File > Open > rates.0000000000.t001.nc.



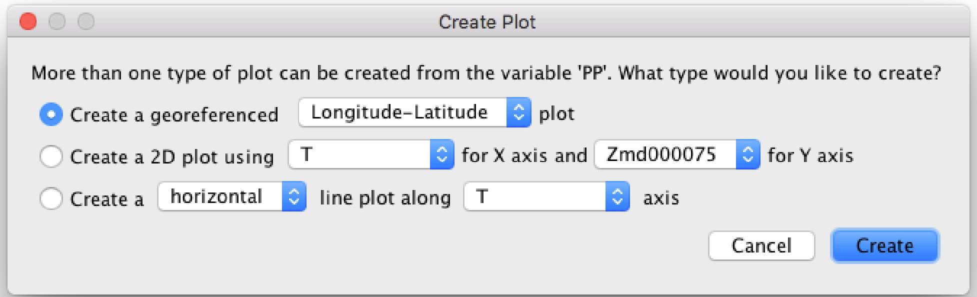
- Select the variable PP.



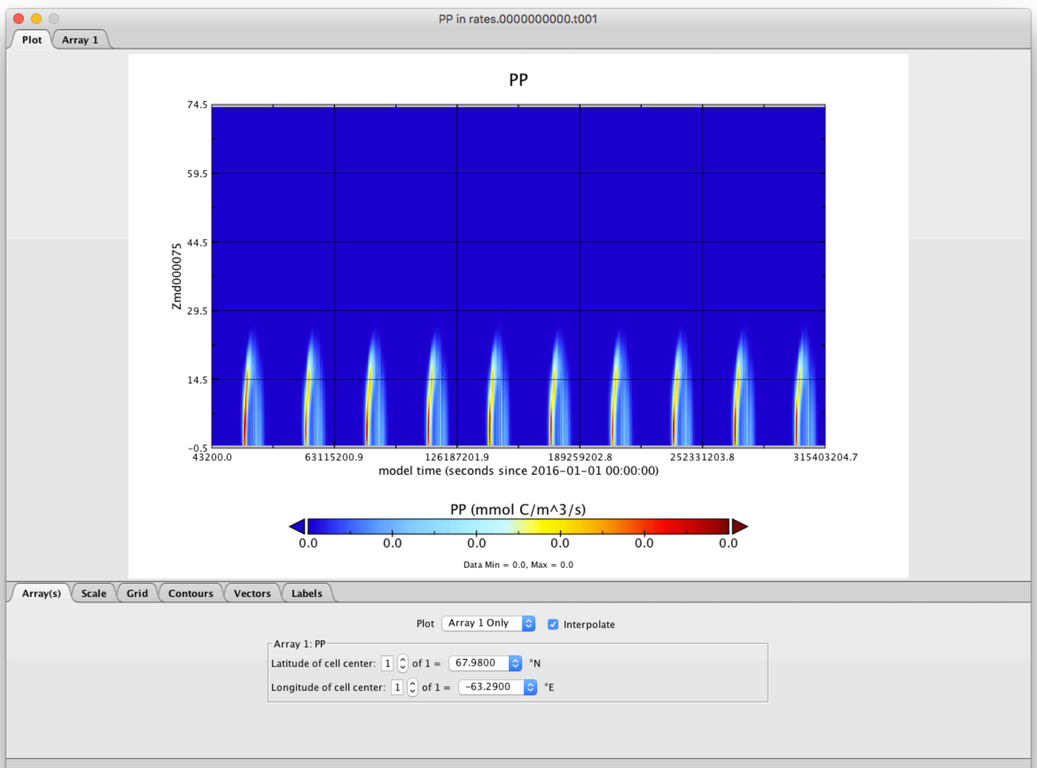
We see that the variable PP is the primary production in mmol C m^{-3} s^{-1}. The dimension T is the daily time steps over 10 years (10*365=3650). The dimension Zmd000075 is the 75 depth steps.

8 Plot a NetCDF file with Panoply

- Double-click on PP.



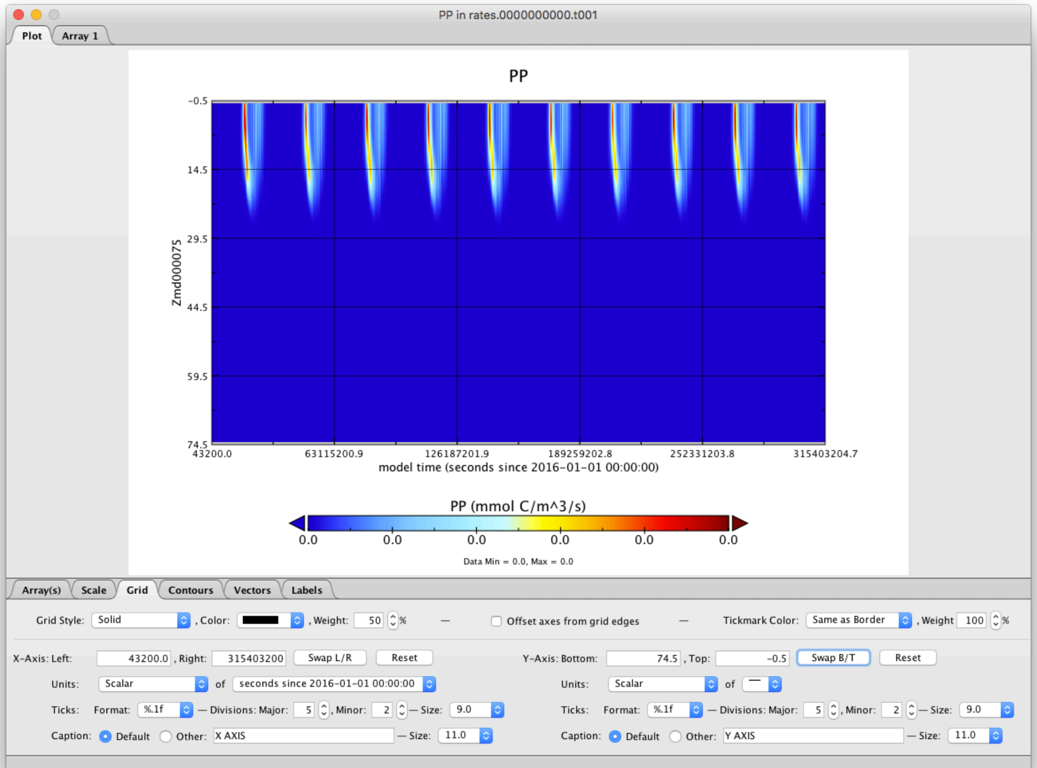
- Check Create a 2D plot using T for X axis and Zmd000075 for Y axis.
- Click Create.



Note that the Y axis contains the indices of the depths and not the values of the depths. The values of the depths are not in the file rates.0000000000.nc. They are only in the variable RC of grid.t001.nc.

Note also that the depths on the Y axis are in the reverse order. This is because the first depth index is at the water surface and is shown at the bottom of the plot. We would rather show it at the top of the plot.

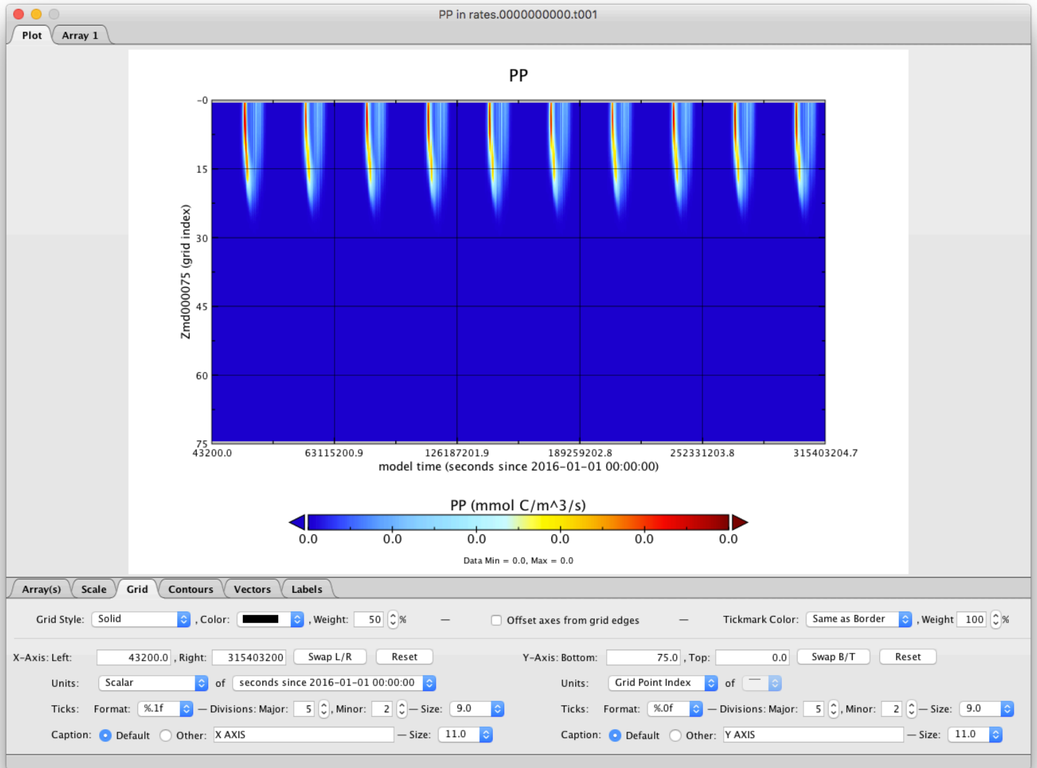
- Grid > Swap B/T.



We now see the primary productivity over 10 years. We can see the 10 yearly spring blooms. It worths noting again that the Y axis contains the indices of the depths from 0 to 74 and not the values of the depths.

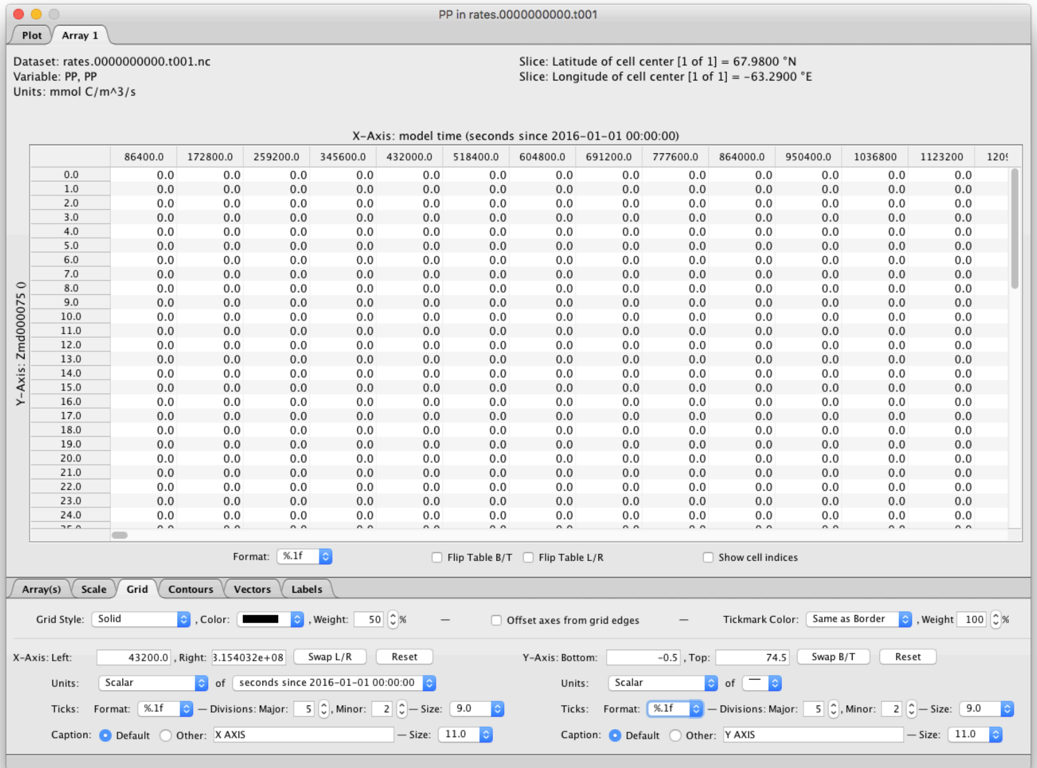
To make it clearer, we will show the indices of the depths from 1 to 75 instead of 0 to 74. In order to do that:

- Y-Axis: Units: Grid Point Index.
- Y-Axis: Ticks: Format %.0f.
- Swap B/T.

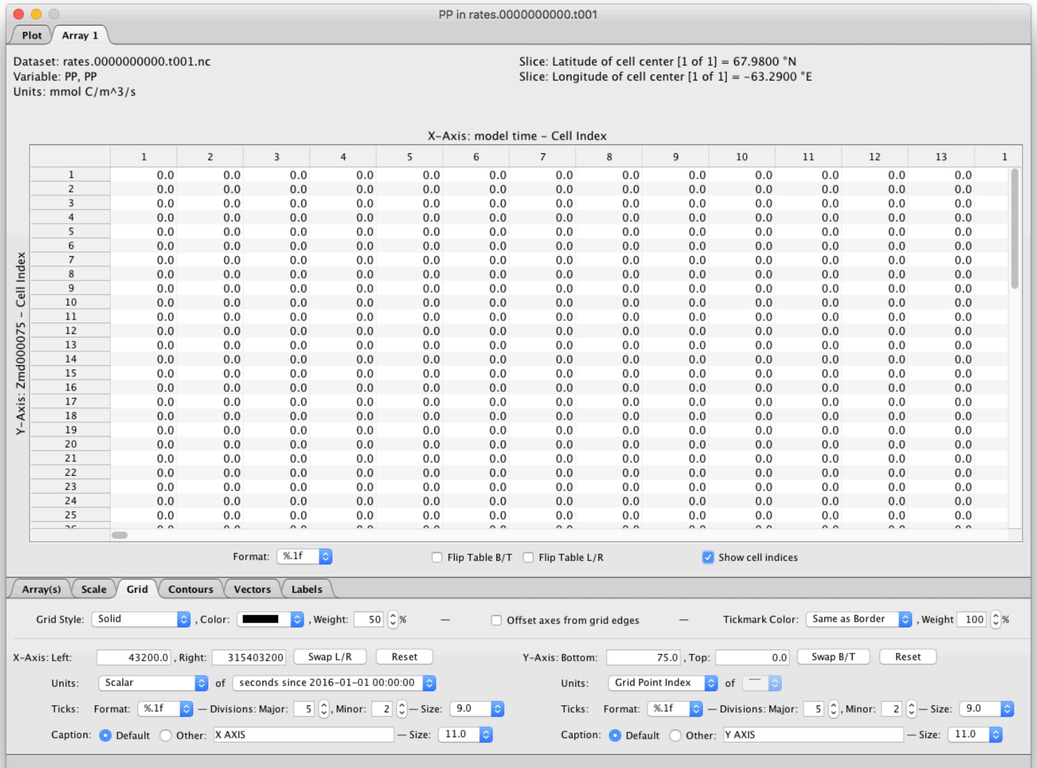


Verify.

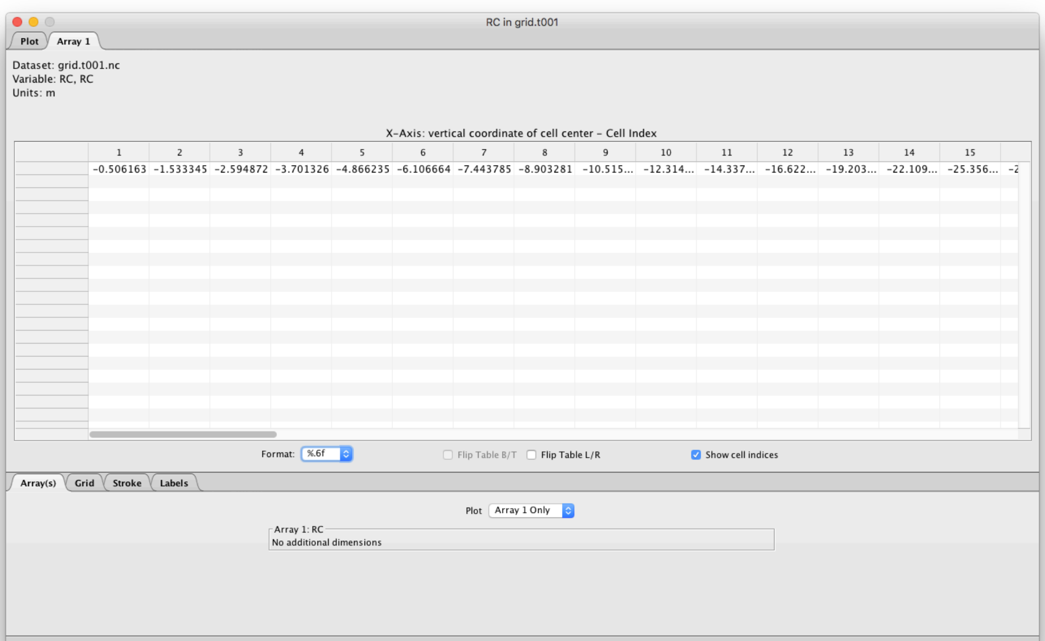
- Select tab Array 1.



- Show cell indices.

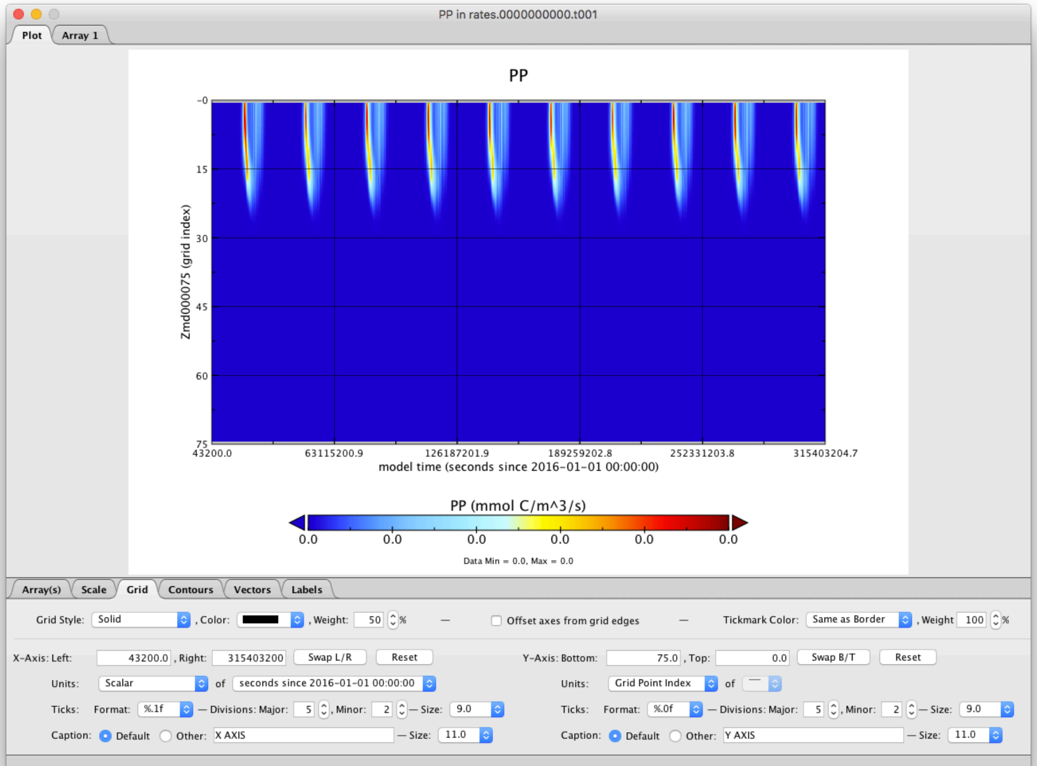


We will retrieve the value of the depth at the depth index 15 using the variable RC in grid.t001.nc.



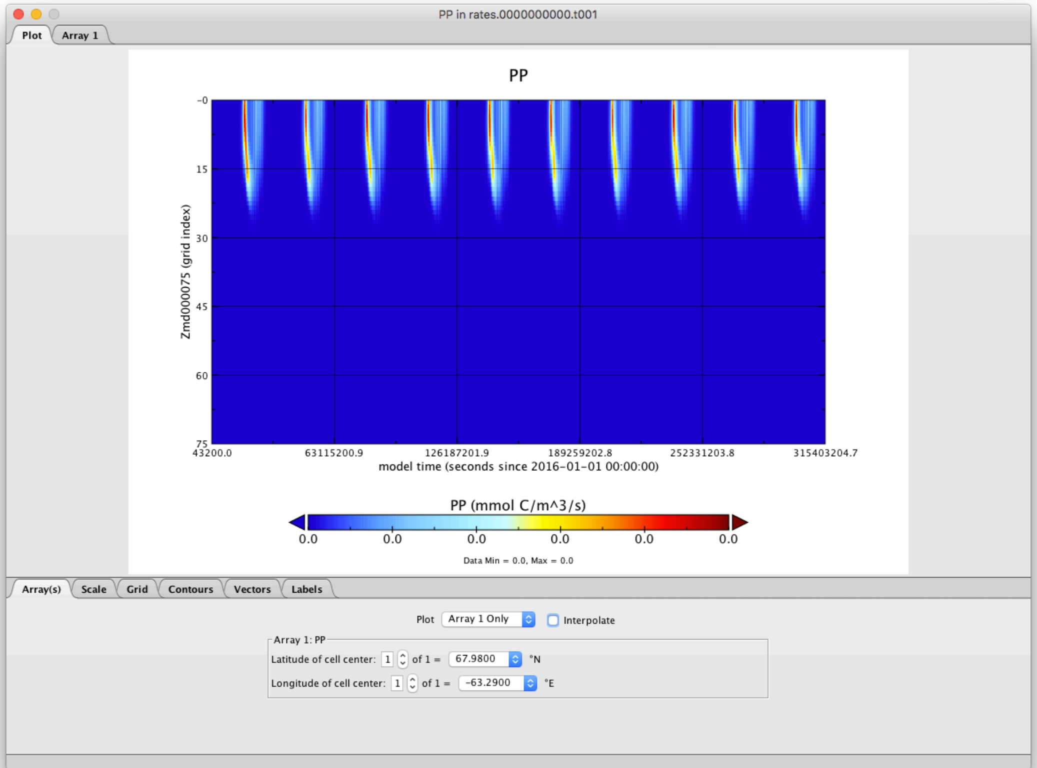
We see that the value of the depth at the depth index 15 is 25.356 m.

- Select the tab Plot.



To make the rows corresponding to each depth clearer:

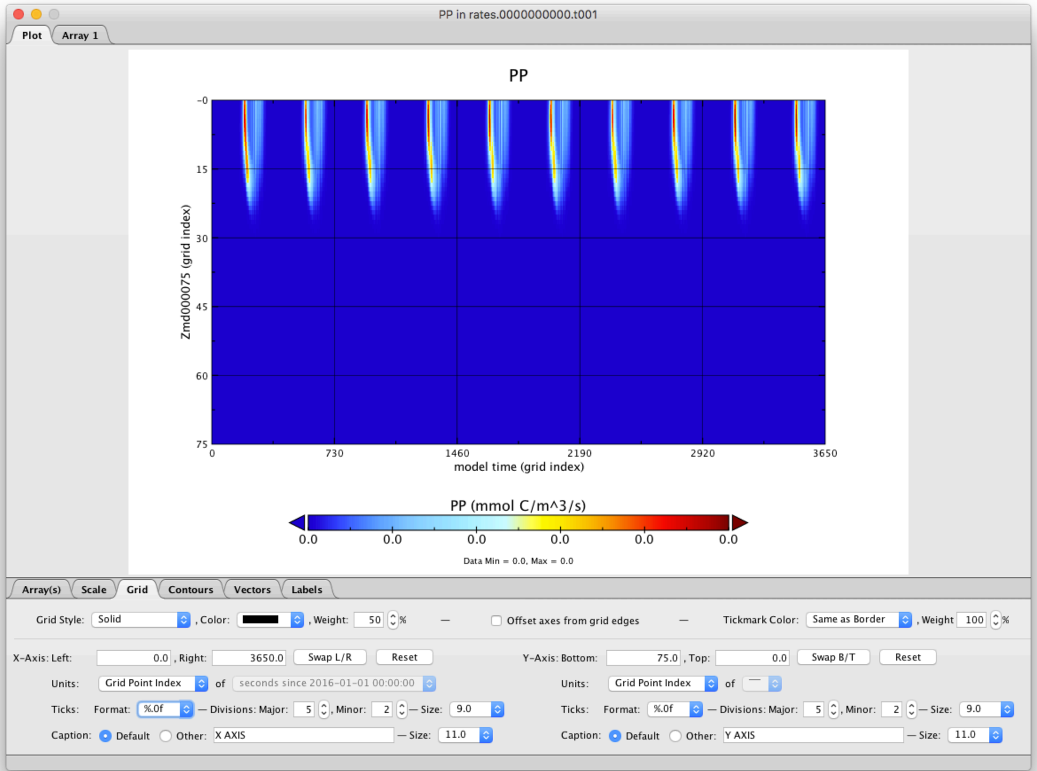
- Select the tab Array(s).
- Uncheck Interpolate.



The fifteenth row, just above the tick 15 on the Y-Axis, corresponds to a depth of 25.356 m.

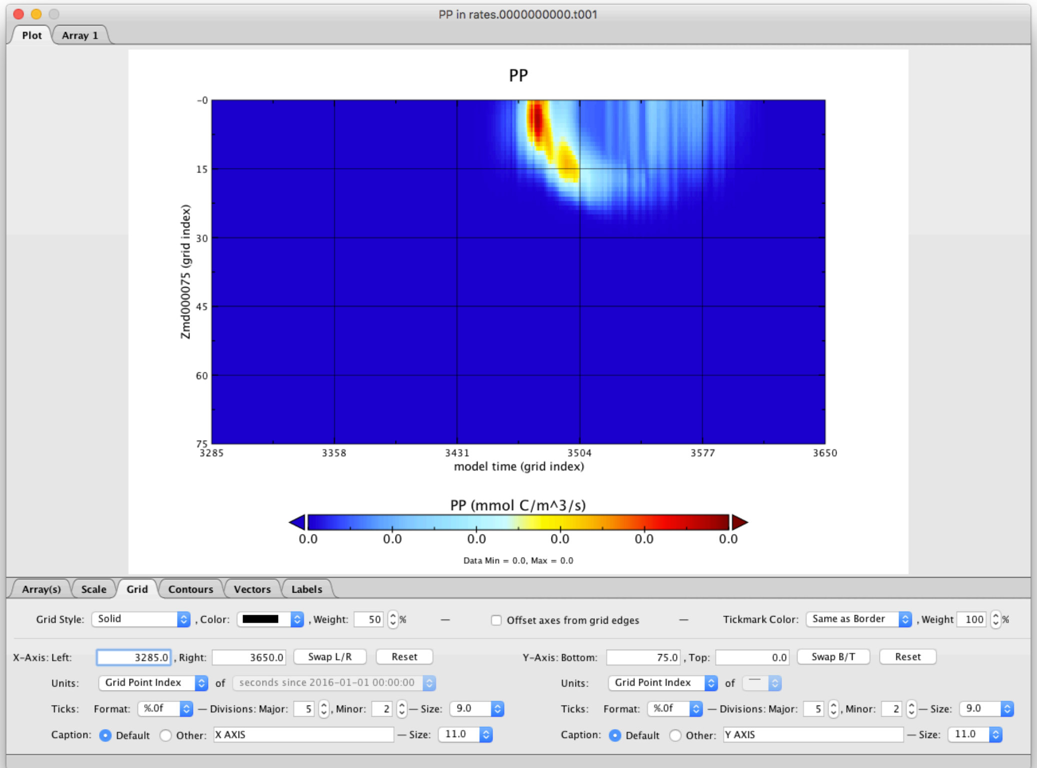
We will now make the X-Axis clearer by showing the indices of the time steps.

- Select the tab Grid.
- X-Axis: Units: Grid Point Index.
- X-Axis: Ticks: Format: %.0f.



The X axis is now the index of the day over the 10 years of the spinup. We want to select only the tenth year. The indices of the X axis will be 365*9=3285 (inclusive) to 365*10=3650 (exclusive).

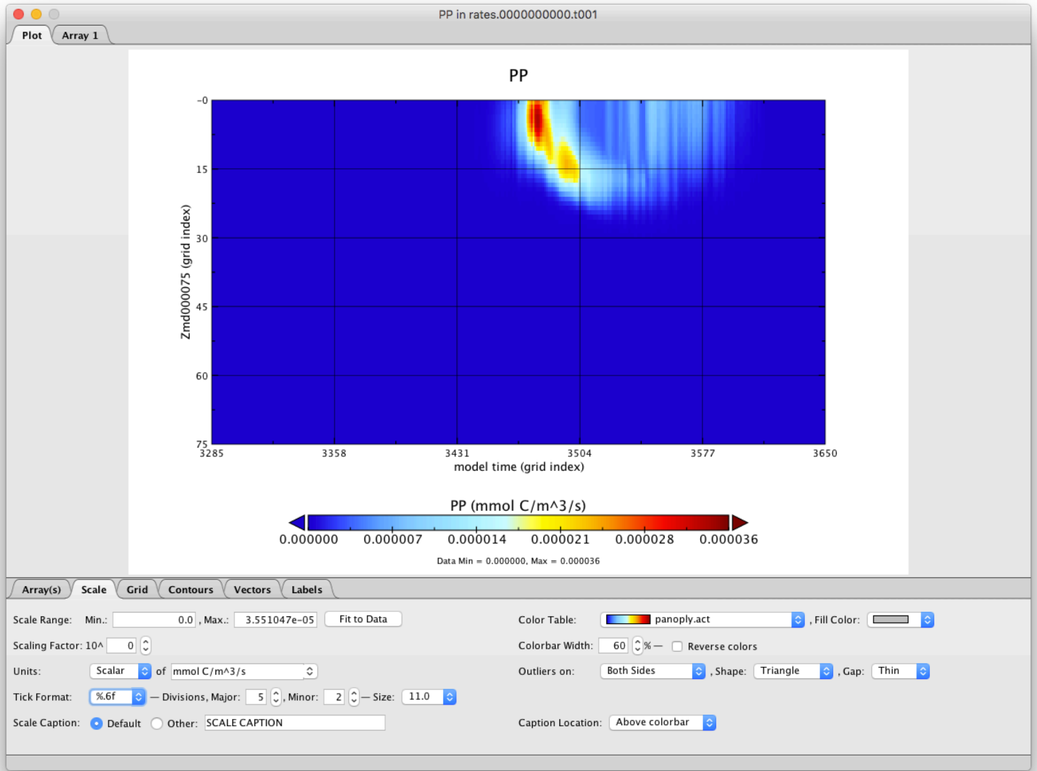
- X-Axis: Left: 3285.



It worths noting that the selection of the tenth year in the Grid tab affects only the plot in the tab Plot. It doesn't affect the array in the tab Array 1. The array in the tab Array 1 will continue to contain the values for the 10 years.

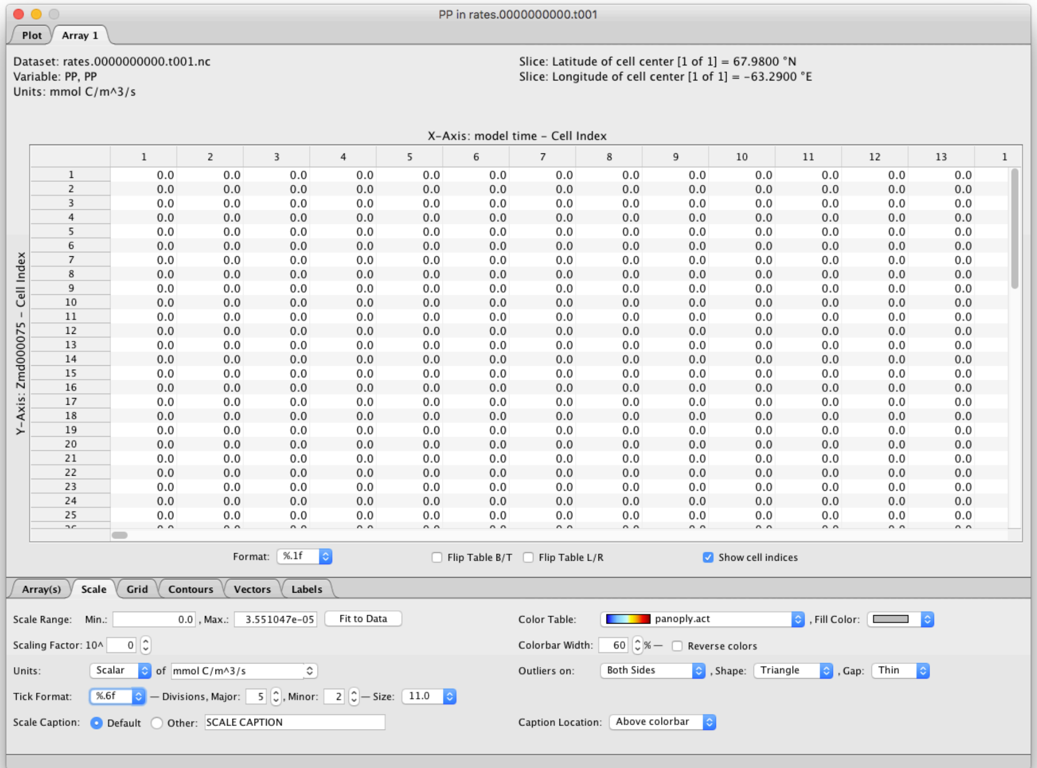
We can improve the precision of the colour bar:

- Select tab Scale.
- Tick Format: %.6f.



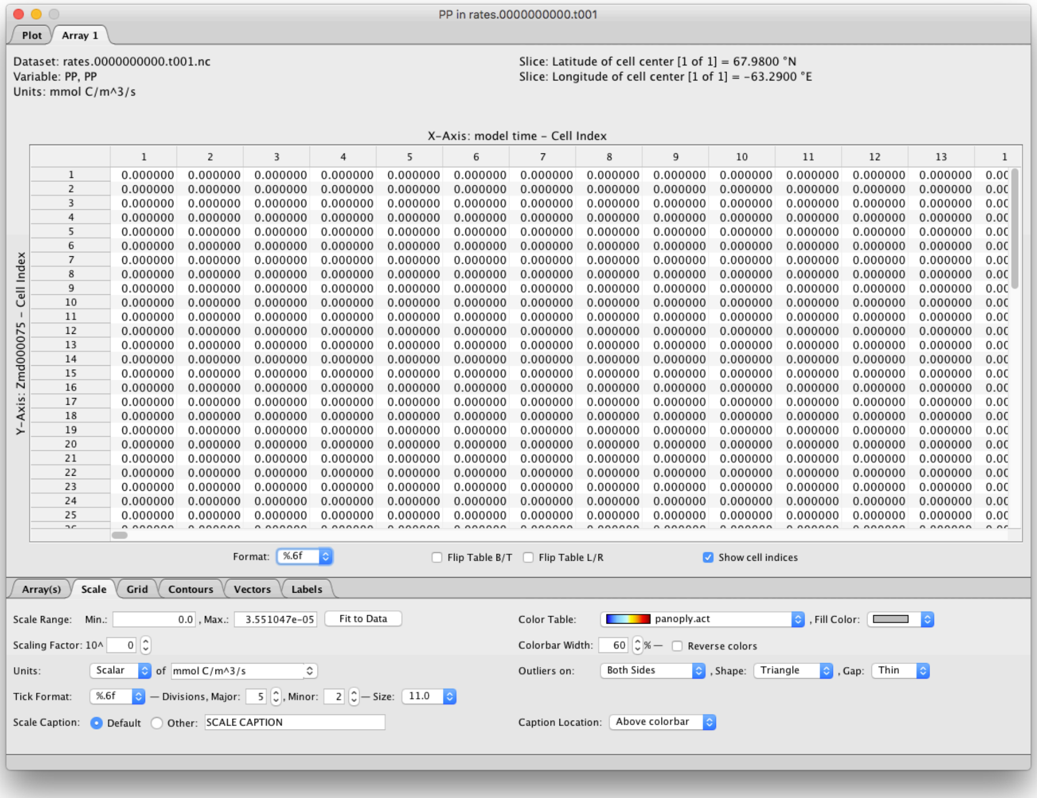
We can find a specific numeric value in the tab Array 1.

- Select tab Array 1.



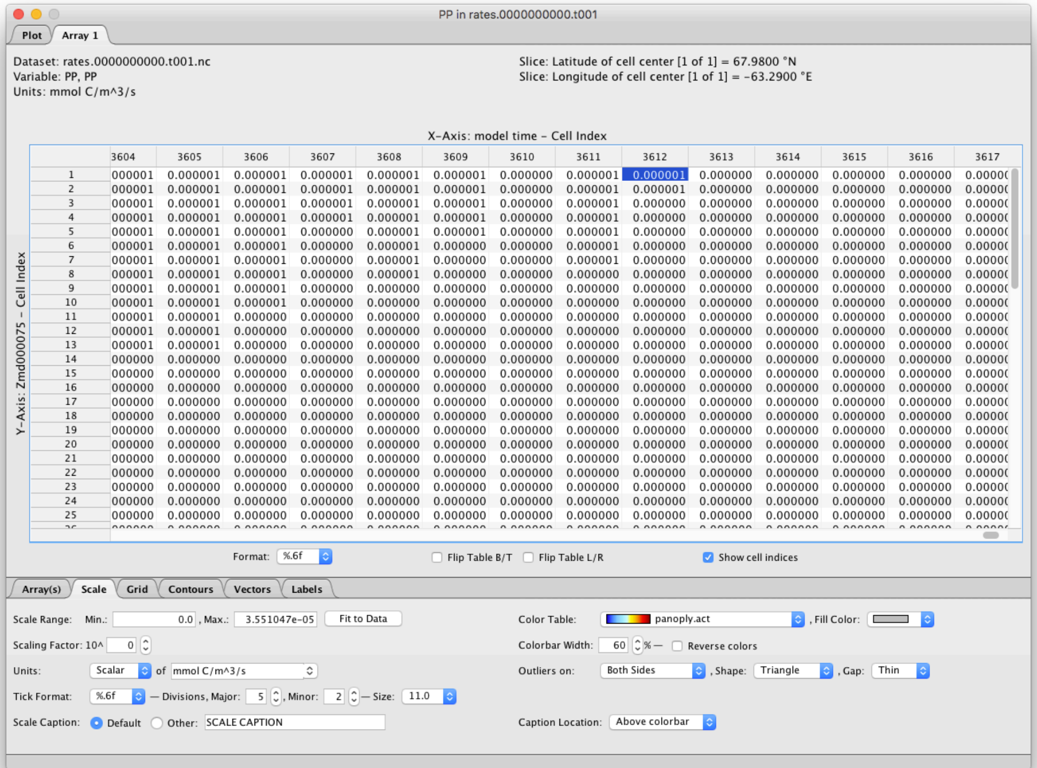
We can improve the precision.

- Format: %.6f.



We now see explicitely the values of the 75*3650 primary productivities.

Move the horizontal scroll bar to the right to see some values above 0.



9 Read a NetCDF file with Python

9.1 First, load libraries

[1]:
```
import netCDF4
import numpy as np
```

9.2 Select year

[2]:
```
nbyears=10
last_year=np.arange(365*(nbyears-1),365*(nbyears))
last_year.shape
```

[2]: (365,)

[3]:
```
for i,v in enumerate(last_year):
    print(i,v)
```

0 3285
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317 3602
318 3603
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323 3608
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9.3 Grid

See the documentation on the grid of the output of the MITgcm model: https://darwin3.readthedocs.io/en/latest/getting_started/getting_started.html#grid.

RC is the r coordinate of cell center (in m).

[4]:
```
gridfile='data/grid.t001.nc'
```

[5]:
```
ncfile=gridfile
variable='RC'
try:
    # open the netCDF file for reading
    fh=netCDF4.Dataset(ncfile,'r')
except:
    raise IOError("File not found: {}.".format(ncfile))
try:
```

```
    # read the data in variable named v
    RC=fh.variables[variable][:]
except:
    raise IOError("Variable {} not found in {}.".format(variable, ncfile))
fh.close()
```

We switch sign to have positive depths.

[6]:
```
# swith sign
RC=-RC
RC.shape
```

[6]: (75,)

[7]:
```
for i,v in enumerate(RC):
    print(i,v)
```

```
0 0.5061625
1 1.5333449999999997
2 2.5948719999999996
3 3.7013264999999995
4 4.866235
5 6.106664499999999
6 7.443784999999999
7 8.903281
8 10.5154235
9 12.314566000000001
10 14.337813500000001
11 16.6226945
12 19.203892000000003
13 22.109410500000003
14 25.356929
15 28.9512475
16 32.883559500000004
17 37.1327755
18 41.6684945
19 46.454799
20 51.453981
21 56.6295605
22 61.9483055
23 67.381287
24 72.9041905
25 78.4971245
26 84.1441395
27 89.832647
28 95.5528315
29 101.2971055
30 107.0596445
```

```
31 112.836004
32 118.622804
33 124.417478
34 130.2180915
35 136.02317200000002
36 141.8316135
37 147.6425875
38 153.4554685
39 159.269784
40 165.08516799999998
41 170.9013685
42 176.718179
43 182.5354395
44 188.35304349999998
45 194.17090699999997
46 199.98896899999997
47 205.80717599999997
48 211.62548949999996
49 217.44388699999996
50 223.26235349999996
51 229.08086549999996
52 234.89940799999997
53 240.71797349999997
54 246.53655399999997
55 252.35515749999996
56 258.17376899999994
57 263.99238799999995
58 269.8110219999999
59 275.6296559999999
60 281.4482899999999
61 287.26692399999985
62 293.08557349999984
63 298.90422299999983
64 304.7228569999998
65 310.5415064999998
66 316.3601559999998
67 322.17878999999976
68 327.99743949999976
69 333.81608899999975
70 339.63473849999974
71 345.45338799999973
72 351.2720374999997
73 357.0906869999997
74 362.9093209999997
```

9.4 Primary productivity

[8]:
```
ppfile='data/rates.0000000000.t001.nc'
```

PP is the primary production (in mmol C m^{-3} s^{-1}).

[9]:
```
ncfile=ppfile
variable='PP'
try:
    # open the netCDF file for reading
    fh=netCDF4.Dataset(ncfile,'r')
except:
    raise IOError("File not found: {}.".format(ncfile))
try:
    # read the data in variable named v
    array2d_idepth_iT_ppfull=fh.variables[variable][:]
except:
    raise IOError("Variable {} not found in {}.".format(variable, ncfile))
fh.close()
array2d_idepth_iT_ppfull.shape
```

[9]:
```
(3650, 75, 1, 1)
```

[10]:
```
array2d_idepth_iT_ppfull=array2d_idepth_iT_ppfull.squeeze()
array2d_idepth_iT_ppfull.shape
```

[10]:
```
(3650, 75)
```

[11]:
```
array2d_idepth_iT_ppfull=array2d_idepth_iT_ppfull.transpose()
array2d_idepth_iT_ppfull.shape
```

[11]:
```
(75, 3650)
```

[12]:
```
array2d_idepth_iT_pp=array2d_idepth_iT_ppfull[:,last_year]
array2d_idepth_iT_pp.shape
```

[12]:
```
(75, 365)
```

The row is the index of the depth (0-based). The column is the index of the day of year of the tenth year (0-based).

10 Export a NetCDF file into a CSV file with Python

Suppose we want the comma-separated values (CSV) file PP.csv in a wide form (not data matrix form, a.k.a. tidy form) with 366 columns. The first column is the depth in m. The 365 following columns are the days of year. The first row is the headers. The 75 following rows are the depths.

```
depth_m,doy_001,doy_002,...,doy_365
0.5061625,...
...
362.9093209999997,...
```

First, load libraries.

[13]:
```python
import pandas as pd
```

[14]:
```python
df_depth=pd.DataFrame({'depth_m':RC})
df_depth
```

[14]:
```
       depth_m
0     0.506162
1     1.533345
2     2.594872
3     3.701326
4     4.866235
..         …
70  339.634738
71  345.453388
72  351.272037
73  357.090687
74  362.909321

[75 rows x 1 columns]
```

[15]:
```python
df_PP_names=['doy_{0:03}'.format(i) for i in range(1,366)]
df_PP_names
```

[15]:
```
['doy_001',
 'doy_002',
 'doy_003',
 'doy_004',
 'doy_005',
 'doy_006',
 'doy_007',
 'doy_008',
 'doy_009',
 'doy_010',
 'doy_011',
 'doy_012',
 'doy_013',
 'doy_014',
 'doy_015',
 'doy_016',
 'doy_017',
 'doy_018',
```

```
'doy_019',
'doy_020',
'doy_021',
'doy_022',
'doy_023',
'doy_024',
'doy_025',
'doy_026',
'doy_027',
'doy_028',
'doy_029',
'doy_030',
'doy_031',
'doy_032',
'doy_033',
'doy_034',
'doy_035',
'doy_036',
'doy_037',
'doy_038',
'doy_039',
'doy_040',
'doy_041',
'doy_042',
'doy_043',
'doy_044',
'doy_045',
'doy_046',
'doy_047',
'doy_048',
'doy_049',
'doy_050',
'doy_051',
'doy_052',
'doy_053',
'doy_054',
'doy_055',
'doy_056',
'doy_057',
'doy_058',
'doy_059',
'doy_060',
'doy_061',
'doy_062',
'doy_063',
'doy_064',
'doy_065',
```

```
'doy_066',
'doy_067',
'doy_068',
'doy_069',
'doy_070',
'doy_071',
'doy_072',
'doy_073',
'doy_074',
'doy_075',
'doy_076',
'doy_077',
'doy_078',
'doy_079',
'doy_080',
'doy_081',
'doy_082',
'doy_083',
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'doy_102',
'doy_103',
'doy_104',
'doy_105',
'doy_106',
'doy_107',
'doy_108',
'doy_109',
'doy_110',
'doy_111',
'doy_112',
```

```
'doy_113',
'doy_114',
'doy_115',
'doy_116',
'doy_117',
'doy_118',
'doy_119',
'doy_120',
'doy_121',
'doy_122',
'doy_123',
'doy_124',
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'doy_154',
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'doy_156',
'doy_157',
'doy_158',
'doy_159',
```

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'doy_160',
'doy_161',
'doy_162',
'doy_163',
'doy_164',
'doy_165',
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'doy_167',
'doy_168',
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'doy_199',
'doy_200',
'doy_201',
'doy_202',
'doy_203',
'doy_204',
'doy_205',
'doy_206',
```

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'doy_207',
'doy_208',
'doy_209',
'doy_210',
'doy_211',
'doy_212',
'doy_213',
'doy_214',
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'doy_247',
'doy_248',
'doy_249',
'doy_250',
'doy_251',
'doy_252',
'doy_253',
```

```
'doy_254',
'doy_255',
'doy_256',
'doy_257',
'doy_258',
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'doy_263',
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'doy_292',
'doy_293',
'doy_294',
'doy_295',
'doy_296',
'doy_297',
'doy_298',
'doy_299',
'doy_300',
```

```
'doy_301',
'doy_302',
'doy_303',
'doy_304',
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'doy_306',
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'doy_308',
'doy_309',
'doy_310',
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'doy_334',
'doy_335',
'doy_336',
'doy_337',
'doy_338',
'doy_339',
'doy_340',
'doy_341',
'doy_342',
'doy_343',
'doy_344',
'doy_345',
'doy_346',
'doy_347',
```

```
 'doy_348',
 'doy_349',
 'doy_350',
 'doy_351',
 'doy_352',
 'doy_353',
 'doy_354',
 'doy_355',
 'doy_356',
 'doy_357',
 'doy_358',
 'doy_359',
 'doy_360',
 'doy_361',
 'doy_362',
 'doy_363',
 'doy_364',
 'doy_365']
```

[16]:
```
df_PP=pd.DataFrame(array2d_idepth_iT_pp)
df_PP.columns=df_PP_names
df_PP
```

[16]:
```
    doy_001  doy_002  doy_003  doy_004  doy_005       doy_006       doy_007  \
0       0.0      0.0      0.0      0.0      0.0  3.003517e-12  9.562626e-12
1       0.0      0.0      0.0      0.0      0.0  2.746950e-12  9.208227e-12
2       0.0      0.0      0.0      0.0      0.0  2.635478e-12  8.835832e-12
3       0.0      0.0      0.0      0.0      0.0  2.376848e-12  8.455584e-12
4       0.0      0.0      0.0      0.0      0.0  2.267716e-12  8.068476e-12
..      …        …        …        …        …             …             …
70      0.0      0.0      0.0      0.0      0.0  0.000000e+00  0.000000e+00
71      0.0      0.0      0.0      0.0      0.0  0.000000e+00  0.000000e+00
72      0.0      0.0      0.0      0.0      0.0  0.000000e+00  0.000000e+00
73      0.0      0.0      0.0      0.0      0.0  0.000000e+00  0.000000e+00
74      0.0      0.0      0.0      0.0      0.0  0.000000e+00  0.000000e+00

         doy_008       doy_009       doy_010  …  doy_356  doy_357  doy_358  \
0   3.982557e-11  6.567130e-11  6.554848e-11  …      0.0      0.0      0.0
1   3.840060e-11  6.336488e-11  6.324807e-11  …      0.0      0.0      0.0
2   3.689539e-11  6.092277e-11  6.081262e-11  …      0.0      0.0      0.0
3   3.535327e-11  5.841642e-11  5.831308e-11  …      0.0      0.0      0.0
4   3.377870e-11  5.585338e-11  5.575687e-11  …      0.0      0.0      0.0
..           …             …             …  …      …        …
70  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
71  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
72  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
73  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
```

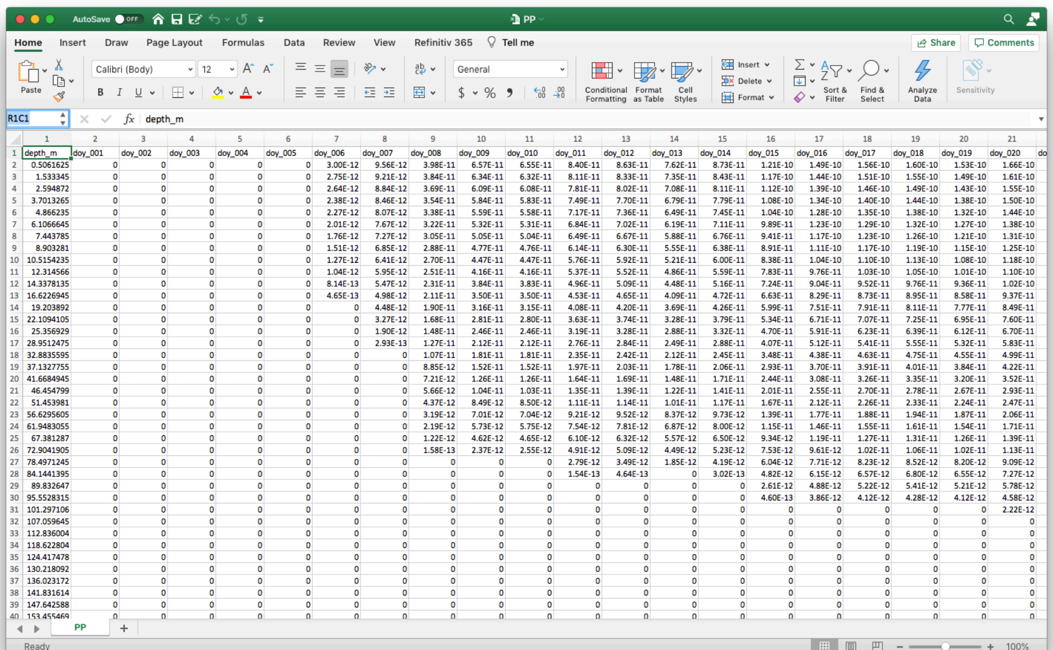
```
74  0.000000e+00  0.000000e+00  0.000000e+00  …       0.0       0.0       0.0

    doy_359  doy_360  doy_361  doy_362  doy_363  doy_364  doy_365
0       0.0      0.0      0.0      0.0      0.0      0.0      0.0
1       0.0      0.0      0.0      0.0      0.0      0.0      0.0
2       0.0      0.0      0.0      0.0      0.0      0.0      0.0
3       0.0      0.0      0.0      0.0      0.0      0.0      0.0
4       0.0      0.0      0.0      0.0      0.0      0.0      0.0
..        …        …        …        …        …        …        …
70      0.0      0.0      0.0      0.0      0.0      0.0      0.0
71      0.0      0.0      0.0      0.0      0.0      0.0      0.0
72      0.0      0.0      0.0      0.0      0.0      0.0      0.0
73      0.0      0.0      0.0      0.0      0.0      0.0      0.0
74      0.0      0.0      0.0      0.0      0.0      0.0      0.0

[75 rows x 365 columns]
```

[17]:
```python
df=pd.concat([df_depth,df_PP],axis='columns')
df
```

[17]:
```
       depth_m  doy_001  doy_002  doy_003  doy_004  doy_005       doy_006  \
0     0.506162      0.0      0.0      0.0      0.0      0.0  3.003517e-12
1     1.533345      0.0      0.0      0.0      0.0      0.0  2.746950e-12
2     2.594872      0.0      0.0      0.0      0.0      0.0  2.635478e-12
3     3.701326      0.0      0.0      0.0      0.0      0.0  2.376848e-12
4     4.866235      0.0      0.0      0.0      0.0      0.0  2.267716e-12
..           …        …        …        …        …        …             …
70  339.634738      0.0      0.0      0.0      0.0      0.0  0.000000e+00
71  345.453388      0.0      0.0      0.0      0.0      0.0  0.000000e+00
72  351.272037      0.0      0.0      0.0      0.0      0.0  0.000000e+00
73  357.090687      0.0      0.0      0.0      0.0      0.0  0.000000e+00
74  362.909321      0.0      0.0      0.0      0.0      0.0  0.000000e+00

         doy_007       doy_008       doy_009  …  doy_356  doy_357  doy_358  \
0   9.562626e-12  3.982557e-11  6.567130e-11  …      0.0      0.0      0.0
1   9.208227e-12  3.840060e-11  6.336488e-11  …      0.0      0.0      0.0
2   8.835832e-12  3.689539e-11  6.092277e-11  …      0.0      0.0      0.0
3   8.455584e-12  3.535327e-11  5.841642e-11  …      0.0      0.0      0.0
4   8.068476e-12  3.377870e-11  5.585338e-11  …      0.0      0.0      0.0
..             …             …             …  …        …        …        …
70  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
71  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
72  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
73  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0
74  0.000000e+00  0.000000e+00  0.000000e+00  …      0.0      0.0      0.0

    doy_359  doy_360  doy_361  doy_362  doy_363  doy_364  doy_365
```

```
0     0.0    0.0    0.0    0.0    0.0    0.0    0.0
1     0.0    0.0    0.0    0.0    0.0    0.0    0.0
2     0.0    0.0    0.0    0.0    0.0    0.0    0.0
3     0.0    0.0    0.0    0.0    0.0    0.0    0.0
4     0.0    0.0    0.0    0.0    0.0    0.0    0.0
..    …      …      …      …      …      …      …
70    0.0    0.0    0.0    0.0    0.0    0.0    0.0
71    0.0    0.0    0.0    0.0    0.0    0.0    0.0
72    0.0    0.0    0.0    0.0    0.0    0.0    0.0
73    0.0    0.0    0.0    0.0    0.0    0.0    0.0
74    0.0    0.0    0.0    0.0    0.0    0.0    0.0

[75 rows x 366 columns]
```

[18]:
```python
outfile='PP.csv'
df.to_csv(outfile,index=False)
```



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	depth_m	doy_001	doy_002	doy_003	doy_004	doy_005	doy_006	doy_007	doy_008	doy_009	doy_010	doy_011	doy_012	doy_013	doy_014	doy_015	doy_016	doy_017	doy_018	doy_019	doy_020
2	0.5061625	0	0	0	0	0	3.00E-12	9.56E-12	3.98E-11	6.57E-11	6.55E-11	8.40E-11	8.63E-11	7.62E-11	8.73E-11	1.21E-10	1.49E-10	1.56E-10	1.60E-10	1.53E-10	1.66E-10
3	1.533345	0	0	0	0	0	2.75E-12	9.21E-12	3.84E-11	6.34E-11	6.32E-11	8.11E-11	8.33E-11	7.35E-11	8.43E-11	1.17E-10	1.44E-10	1.51E-10	1.55E-10	1.49E-10	1.61E-10
4	2.594872	0	0	0	0	0	2.64E-12	8.84E-12	3.69E-11	6.09E-11	6.08E-11	7.81E-11	8.02E-11	7.08E-11	8.11E-11	1.12E-10	1.39E-10	1.46E-10	1.49E-10	1.43E-10	1.55E-10
5	3.7013265	0	0	0	0	0	2.38E-12	8.46E-12	3.54E-11	5.84E-11	5.83E-11	7.49E-11	7.70E-11	6.79E-11	7.79E-11	1.08E-10	1.34E-10	1.40E-10	1.44E-10	1.38E-10	1.50E-10
6	4.866235	0	0	0	0	0	2.27E-12	8.07E-12	3.38E-11	5.59E-11	5.58E-11	7.17E-11	7.36E-11	6.49E-11	7.45E-11	1.04E-10	1.28E-10	1.35E-10	1.38E-10	1.32E-10	1.44E-10
7	6.1066645	0	0	0	0	0	2.01E-12	7.67E-12	3.22E-11	5.32E-11	5.31E-11	6.84E-11	7.02E-11	6.19E-11	7.11E-11	9.89E-11	1.23E-10	1.29E-10	1.32E-10	1.27E-10	1.38E-10
8	7.443785	0	0	0	0	0	1.76E-12	7.27E-12	3.05E-11	5.05E-11	5.04E-11	6.49E-11	6.67E-11	5.88E-11	6.76E-11	9.41E-11	1.17E-10	1.23E-10	1.26E-10	1.21E-10	1.31E-10
9	8.903281	0	0	0	0	0	1.51E-12	6.85E-12	2.88E-11	4.77E-11	4.76E-11	6.14E-11	6.30E-11	5.55E-11	6.38E-11	8.91E-11	1.11E-10	1.17E-10	1.19E-10	1.15E-10	1.25E-10
10	10.5154235	0	0	0	0	0	1.27E-12	6.41E-12	2.70E-11	4.47E-11	4.47E-11	5.76E-11	5.92E-11	5.21E-11	6.00E-11	8.38E-11	1.04E-10	1.10E-10	1.13E-10	1.08E-10	1.18E-10
11	12.314566	0	0	0	0	0	1.04E-12	5.95E-12	2.51E-11	4.16E-11	4.16E-11	5.37E-11	5.52E-11	4.86E-11	5.59E-11	7.83E-11	9.76E-11	1.03E-10	1.05E-10	1.01E-10	1.10E-10
12	14.3378135	0	0	0	0	0	8.14E-13	5.47E-12	2.31E-11	3.84E-11	3.83E-11	4.96E-11	5.09E-11	4.48E-11	5.16E-11	7.24E-11	9.04E-11	9.52E-11	9.76E-11	9.36E-11	1.02E-10
13	16.6226945	0	0	0	0	0	4.65E-13	4.98E-12	2.11E-11	3.50E-11	3.50E-11	4.53E-11	4.65E-11	4.09E-11	4.72E-11	6.63E-11	8.29E-11	8.73E-11	8.95E-11	8.58E-11	9.37E-11
14	19.203892	0	0	0	0	0	0	4.48E-12	1.90E-11	3.16E-11	3.15E-11	4.08E-11	4.20E-11	3.69E-11	4.26E-11	5.99E-11	7.51E-11	7.91E-11	8.11E-11	7.77E-11	8.49E-11
15	22.1094105	0	0	0	0	0	0	3.27E-12	1.68E-11	2.81E-11	2.80E-11	3.63E-11	3.74E-11	3.28E-11	3.79E-11	5.34E-11	6.71E-11	7.07E-11	7.25E-11	6.95E-11	7.60E-11
16	25.356929	0	0	0	0	0	0	1.90E-12	1.48E-11	2.46E-11	2.46E-11	3.19E-11	3.28E-11	2.88E-11	3.32E-11	4.70E-11	5.91E-11	6.23E-11	6.39E-11	6.12E-11	6.70E-11
17	28.9512475	0	0	0	0	0	0	2.93E-13	1.27E-11	2.12E-11	2.12E-11	2.76E-11	2.84E-11	2.49E-11	2.88E-11	4.07E-11	5.12E-11	5.41E-11	5.55E-11	5.32E-11	5.83E-11
18	32.8835595	0	0	0	0	0	0	0	1.07E-11	1.81E-11	1.81E-11	2.35E-11	2.42E-11	2.12E-11	2.45E-11	3.48E-11	4.38E-11	4.63E-11	4.75E-11	4.55E-11	4.99E-11
19	37.1327755	0	0	0	0	0	0	0	8.85E-12	1.52E-11	1.52E-11	1.97E-11	2.03E-11	1.78E-11	2.06E-11	2.93E-11	3.70E-11	3.91E-11	4.01E-11	3.84E-11	4.22E-11
20	41.6684945	0	0	0	0	0	0	0	7.21E-12	1.26E-11	1.26E-11	1.64E-11	1.69E-11	1.48E-11	1.71E-11	2.44E-11	3.08E-11	3.26E-11	3.35E-11	3.20E-11	3.52E-11
21	46.454799	0	0	0	0	0	0	0	5.66E-12	1.04E-11	1.03E-11	1.35E-11	1.39E-11	1.22E-11	1.41E-11	2.01E-11	2.55E-11	2.70E-11	2.78E-11	2.67E-11	2.93E-11
22	51.453981	0	0	0	0	0	0	0	4.37E-12	8.49E-12	8.50E-12	1.11E-11	1.14E-11	1.01E-11	1.17E-11	1.67E-11	2.12E-11	2.26E-11	2.33E-11	2.24E-11	2.47E-11
23	56.6295605	0	0	0	0	0	0	0	3.19E-12	7.01E-12	7.04E-12	9.21E-12	9.52E-12	8.37E-12	9.73E-12	1.39E-11	1.77E-11	1.88E-11	1.94E-11	1.87E-11	2.06E-11
24	61.9483055	0	0	0	0	0	0	0	2.19E-12	5.73E-12	5.75E-12	7.54E-12	7.81E-12	6.87E-12	8.00E-12	1.15E-11	1.46E-11	1.55E-11	1.61E-11	1.54E-11	1.71E-11
25	67.381287	0	0	0	0	0	0	0	1.22E-12	4.62E-12	4.65E-12	6.10E-12	6.32E-12	5.57E-12	6.50E-12	9.34E-12	1.19E-11	1.27E-11	1.31E-11	1.26E-11	1.39E-11
26	72.9041905	0	0	0	0	0	0	0	1.58E-13	2.37E-12	2.55E-12	4.91E-12	5.09E-12	4.49E-12	5.23E-12	7.53E-12	9.61E-12	1.02E-11	1.06E-11	1.02E-11	1.13E-11
27	78.4971245	0	0	0	0	0	0	0	0	0	0	2.79E-12	3.49E-12	1.85E-12	4.19E-12	6.04E-12	7.71E-12	8.23E-12	8.52E-12	8.20E-12	9.09E-12
28	84.1441395	0	0	0	0	0	0	0	0	0	0	1.54E-13	4.64E-13	0	3.02E-13	4.82E-12	6.15E-12	6.57E-12	6.80E-12	6.55E-12	7.27E-12
29	89.832647	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.61E-12	4.88E-12	5.22E-12	5.41E-12	5.21E-12	5.78E-12
30	95.5528315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.60E-13	3.86E-12	4.12E-12	4.28E-12	4.12E-12	4.58E-12
31	101.297106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.22E-12
32	107.059645	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	112.836004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	118.622804	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	124.417478	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	130.218092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	136.023172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	141.831614	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	147.642588	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	153.455469	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

11 Plot a NetCDF file with Python

First, load libraries.

[19]:
```python
import matplotlib as mpl
import matplotlib.pyplot as plt
```

[20]:
```
plt.close("all")
```

one_year_for_heatmaps is the coordinates on the X-Axis of the corners of quadrilaterals of the pcolormesh (see https://matplotlib.org/stable/api/_as_gen/matplotlib.pyplot.pcolormesh.html).

[21]:
```
one_year_for_heatmaps=np.arange(0,366)
```

RF_above100 is the coordinates on the Y-Axis of the corners of quadrilaterals of the pcolormesh. We decide to show only the top 100 m.

See the documentation on the grid of the output of the MITgcm model: https://darwin3.readthedocs.io/en/latest/getting_started/getting_started.html#grid.

RF is the r coordinate of cell interface (in m).

[22]:
```
gridfile='data/grid.t001.nc'
```

[23]:
```
ncfile=gridfile
variable='RF'
try:
    # open the netCDF file for reading
    fh=netCDF4.Dataset(ncfile,'r')
except:
    raise IOError("File not found: {}.".format(ncfile))
try:
    # read the data in variable named v
    RF=fh.variables[variable][:]
except:
    raise IOError("Variable {} not found in {}.".format(variable, ncfile))
fh.close()
```

We switch sign to have positive depths.

[24]:
```
# swith sign
RF=-RF
RF.shape
```

[24]:
```
(76,)
```

[25]:
```
for i,v in enumerate(RF):
    print(i,v)
```

```
0 -0.0
1 1.012325
2 2.0543649999999998
3 3.1353789999999995
4 4.267274
5 5.465196
6 6.748132999999999
```

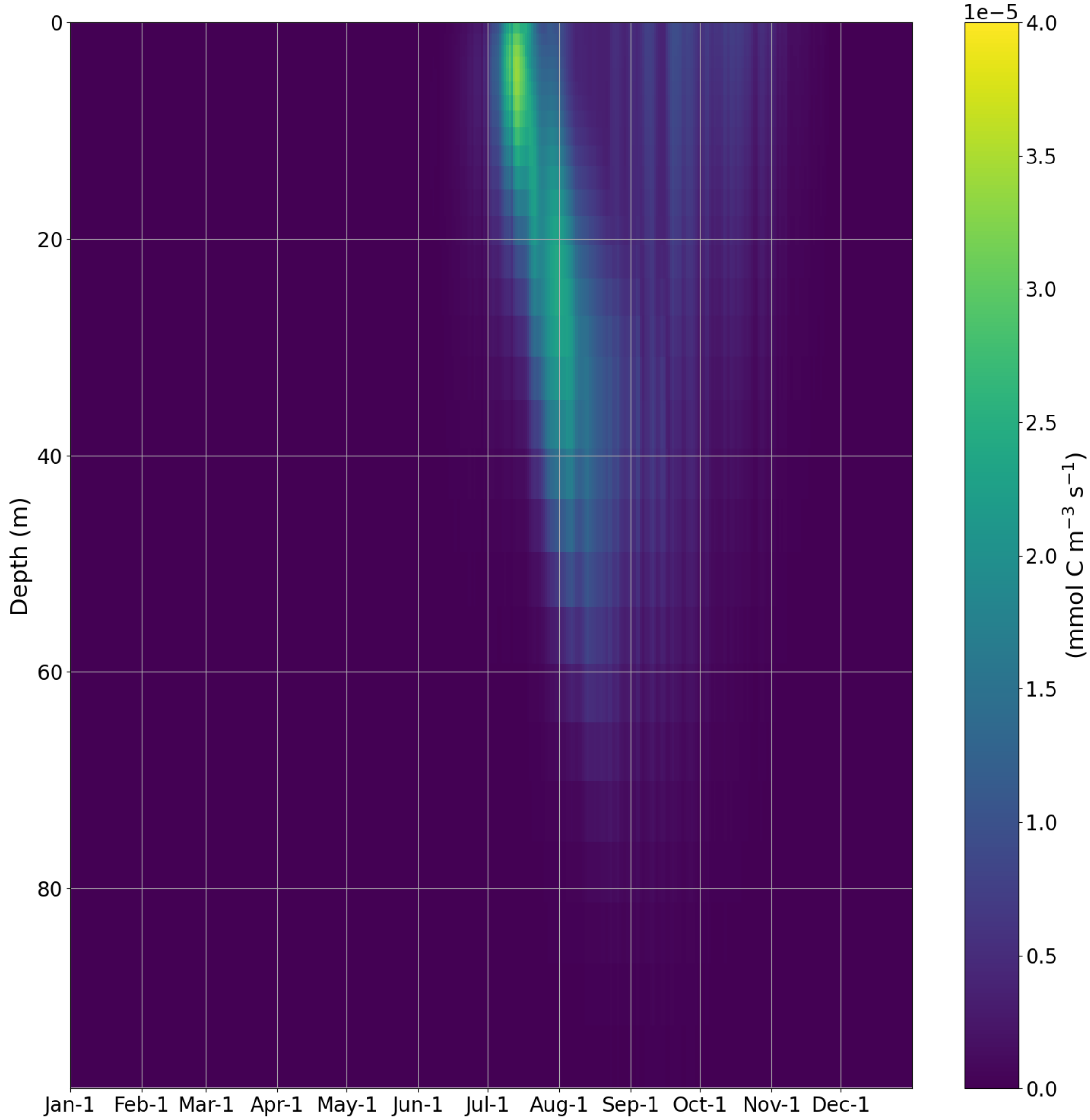
```
7 8.139437
8 9.667124999999999
9 11.363722
10 13.26541
11 15.410217
12 17.835172
13 20.572612
14 23.646209
15 27.067649
16 30.834846
17 34.932272999999995
18 39.33327799999999
19 44.003710999999996
20 48.90588699999999
21 54.00207499999999
22 59.25704599999999
23 64.63956499999999
24 70.123009
25 75.685372
26 81.308877
27 86.979402
28 92.685892
29 98.419771
30 104.17444
31 109.944849
32 115.727159
33 121.518449
34 127.316507
35 133.119676
36 138.926668
37 144.736559
38 150.548616
39 156.362321
40 162.17724700000002
41 167.99308900000003
42 173.80964800000004
43 179.62671000000003
44 185.44416900000004
45 191.26191800000004
46 197.07989600000005
47 202.89804200000006
48 208.71631000000005
49 214.53466900000004
50 220.35310500000003
51 226.17160200000004
52 231.99012900000002
53 237.80868700000002
54 243.62726
```

```
55 249.445848
56 255.26446700000002
57 261.083071
58 266.901705
59 272.72033899999997
60 278.53897299999994
61 284.3576069999999
62 290.1762409999999
63 295.9949059999999
64 301.8135399999999
65 307.63217399999985
66 313.45083899999986
67 319.26947299999983
68 325.0881069999998
69 330.9067719999998
70 336.7254059999998
71 342.5440709999998
72 348.3627049999998
73 354.1813699999998
74 360.00000399999976
75 365.81863799999974
```

[26]:
```
RF_above100=np.array(RF[RF<100])
```

[27]:
```
def make_plots(ax):
    locs=np.array([0, 31, 59, 90, 120, 151,
                   181, 212, 243, 273, 304, 334])
    labels=('Jan-1','Feb-1','Mar-1','Apr-1','May-1','Jun-1',
            'Jul-1','Aug-1','Sep-1','Oct-1','Nov-1','Dec-1')
    h=ax.pcolormesh(one_year_for_heatmaps,
                    RF_above100,
                    array2d_idepth_iT_pp[0:(RF_above100.size)-1,:],
                    cmap='viridis',
                    vmin=0,
                    vmax=0.00004)
    ax.set_xticklabels([])
    ax.set_xticks(locs)
    ax.set_xticklabels(labels)
    ax.set_ylabel('Depth (m)')
    ax.set_ylim(98.5,0)
    ax.grid()
    cbar=plt.colorbar(h)
    cbar.set_label('($\mathrm{ mmol\ C\ m^{-3}\ s^{-1} }$)')

    plt.tight_layout()

with plt.style.context('mplstyles/heatmaps.mplstyle'):
```

```python
# Plot
fig=plt.figure(figsize=(16, 16))
ax=fig.add_subplot(111)
make_plots(ax)

# --- SAVE
plt.savefig('figures/PP.png')
plt.show()
```



11.1 More examples in Python

Other examples of Python scripts reading the results of Benoît-Gagné et al. (submitted) are available on https://github.com/maximebenoitgagne/wintertime/blob/v1.5/wintertime.ipynb.