

```
In [126... import glob
from netCDF4 import Dataset
import xarray as xr
import numpy as np
import matplotlib.pyplot as plt

import gsw
```

S-MODE Data Workshop: in-situ data demo

This is a simple demo of a workflow for downloading and working with S-MODE in-situ data. We will work with underway data collected by saildrones and R/V Oceanus during the S-MODE Pilot Campaign.

If you have any questions, do not hesitate in contacting me (cesar.rocha@uconn.edu).

Road map

1. Download saildrone data
2. Load and plot single dataset (one saildrone)
3. Load and merge multiple datasets (five saildrones)
4. Compare saildrone ADCP data with R/V Oceanus ADCP data

First, download the saildrone data

The saildrone data are organized into two different sets of files: ADCP (velocity measurements) and NON-ADCP (everything else). The ADCP data are available in 5-minute averages. The NON-ADCP data are available in 1-minute averages.

```
In [162... # constants for podaac-data-downloader
start_time = '2021-10-20T00:00:00Z'
end_time = '2021-11-08T00:00:00Z'
short_name = 'SMODE_LX_SAILDRONES_V1'
data_path = 'data/'
```

```
In [163... !podac-data-downloader -c $short_name -d $data_path$short_name --start-date
```

```
/Users/crocha/miniconda3/lib/python3.9/site-packages/requests/__init__.py:1
02: RequestsDependencyWarning: urllib3 (1.26.8) or chardet (5.0.0)/charset_
normalizer (2.0.4) doesn't match a supported version!
  warnings.warn("urllib3 ({}) or chardet ({})/charset_normalizer ({}) does
n't match a supported "
[2022-12-01 13:01:45,309] {podaac_data_downloader.py:243} INFO - Found 10 t
otal files to download
[2022-12-01 13:01:45,349] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.349657 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_adcp_1074.n
c
[2022-12-01 13:01:45,385] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.385347 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_adcp_1075.n
c
[2022-12-01 13:01:45,420] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.420814 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_adcp_1062.n
c
[2022-12-01 13:01:45,444] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.444329 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_nonadcp_106
2.nc
[2022-12-01 13:01:45,467] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.467157 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_nonadcp_107
4.nc
[2022-12-01 13:01:45,483] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.483276 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_nonadcp_107
5.nc
[2022-12-01 13:01:45,532] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.532101 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_adcp_1072.n
c
[2022-12-01 13:01:45,581] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.581074 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_adcp_1073.n
c
[2022-12-01 13:01:45,611] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.611799 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_nonadcp_107
2.nc
[2022-12-01 13:01:45,642] {podaac_data_downloader.py:268} INFO - 2022-12-01
13:01:45.642018 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SAILDRONES_V1/SMODE_PFC_saildrone_nonadcp_107
3.nc
[2022-12-01 13:01:45,642] {podaac_data_downloader.py:287} INFO - Downloaded
Files: 0
[2022-12-01 13:01:45,642] {podaac_data_downloader.py:288} INFO - Failed Fil
es: 0
[2022-12-01 13:01:45,642] {podaac_data_downloader.py:289} INFO - Skipped Fi
les: 10
[2022-12-01 13:01:46,087] {podaac_access.py:122} INFO - CMR token successfu
lly deleted
[2022-12-01 13:01:46,087] {podaac_data_downloader.py:299} INFO - END
```

Non-ADCP data

Single saildrone

```
In [164...] ds = xr.open_dataset(data_path + short_name + '/SMODE_PFC_saildrone_nonadcp_
```

```
In [165...] ds
```

```
Out[165]: xarray.Dataset
```

► Dimensions: (obs: 27360)

▼ Coordinates:

latitude	(obs)	float64	...		
longitude	(obs)	float64	...		
time	(obs)	datetime64[ns]	...		
trajectory	()	float32	1.073e+03		

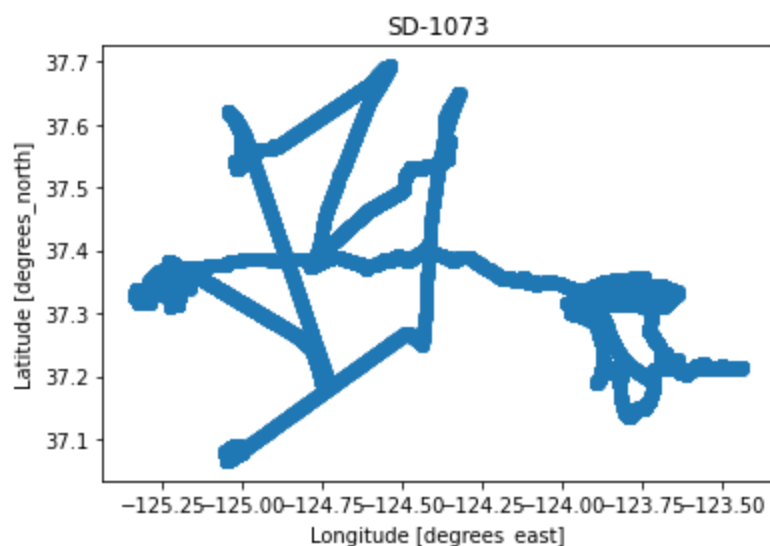
► Data variables:
(76)

► Attributes: (64)

A few quick-and-dirty plots

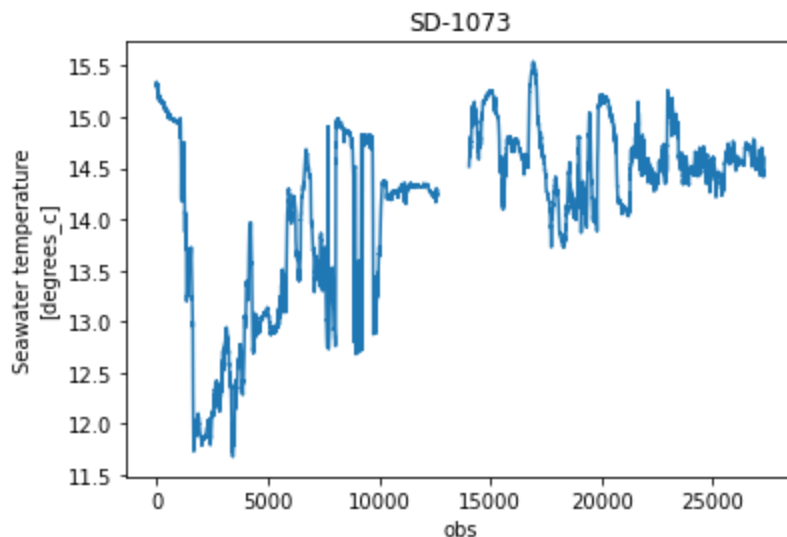
```
In [131...] ds.plot.scatter(x='longitude',y='latitude')  
plt.title('SD-'+str(int(ds.trajectory)))
```

```
Out[131]: Text(0.5, 1.0, 'SD-1073')
```



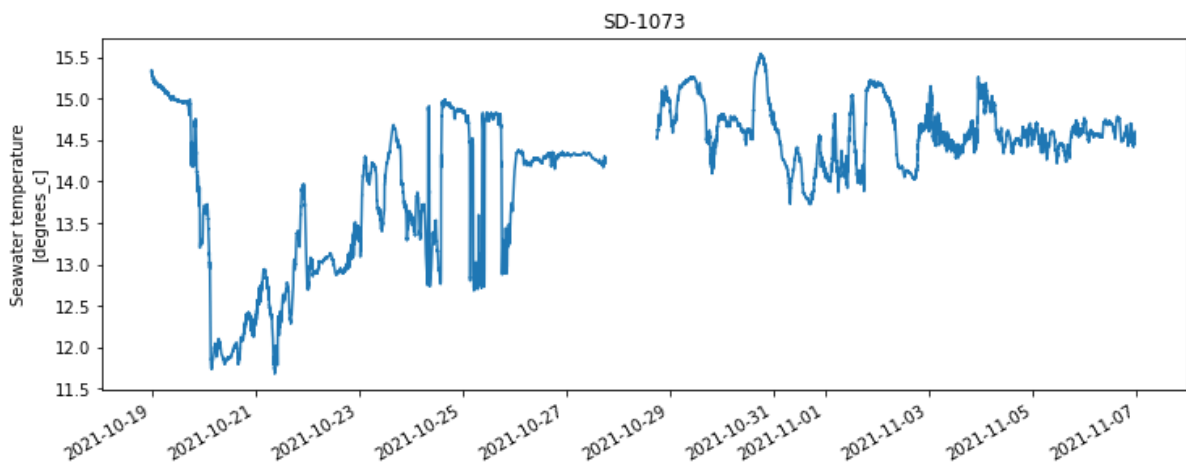
```
In [132]... # plot seabird-37 temperature data
ds.TEMP_SBE37_MEAN.plot()
plt.title('SD-'+str(int(ds.trajectory)))
```

Out[132]: Text(0.5, 1.0, 'SD-1073')



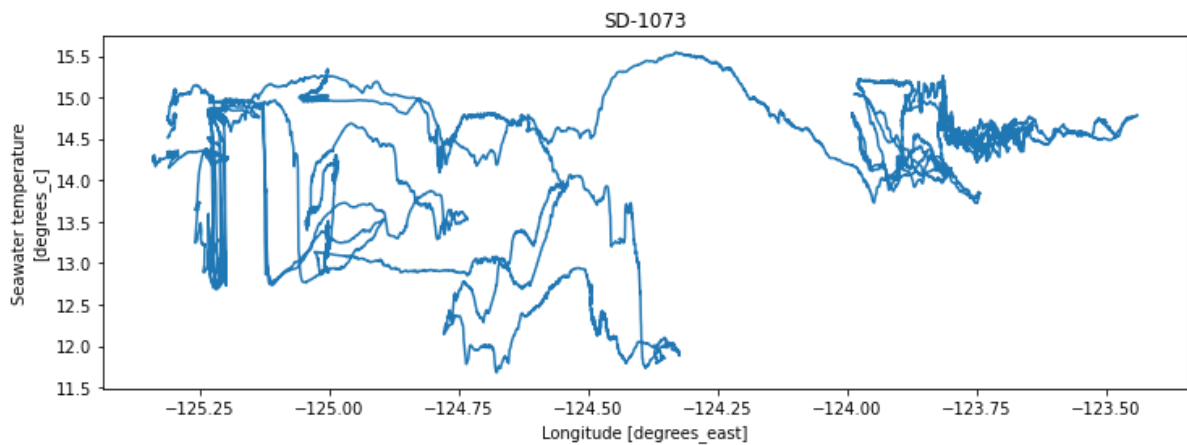
```
In [133]... # plot data as a timeseries
fig, ax = plt.subplots(figsize=(12,4))
ds.TEMP_SBE37_MEAN.plot(x='time',ax=ax)
ax.set_xlabel('')
plt.title('SD-'+str(int(ds.trajectory)))
```

Out[133]: Text(0.5, 1.0, 'SD-1073')



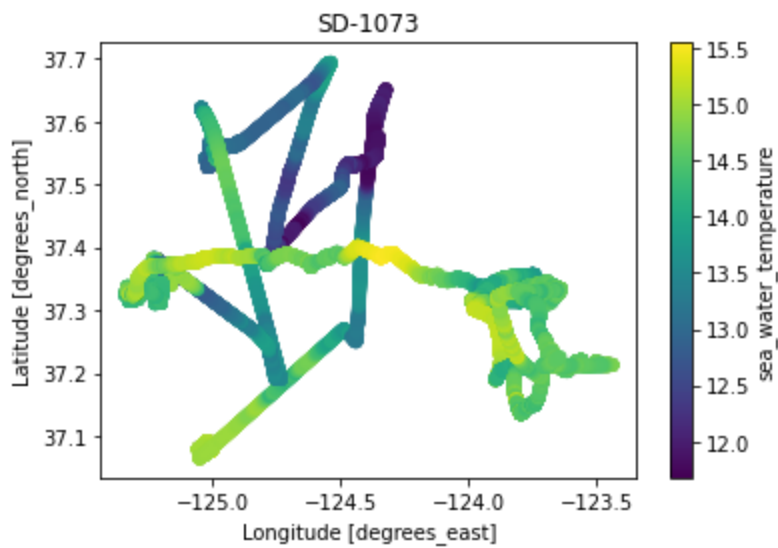
```
In [134]... # plot data as a function of longitude
fig, ax = plt.subplots(figsize=(12,4))
ds.TEMP_SBE37_MEAN.plot(x='longitude',ax=ax)
plt.title('SD-'+str(int(ds.trajectory)))
```

Out[134]: Text(0.5, 1.0, 'SD-1073')



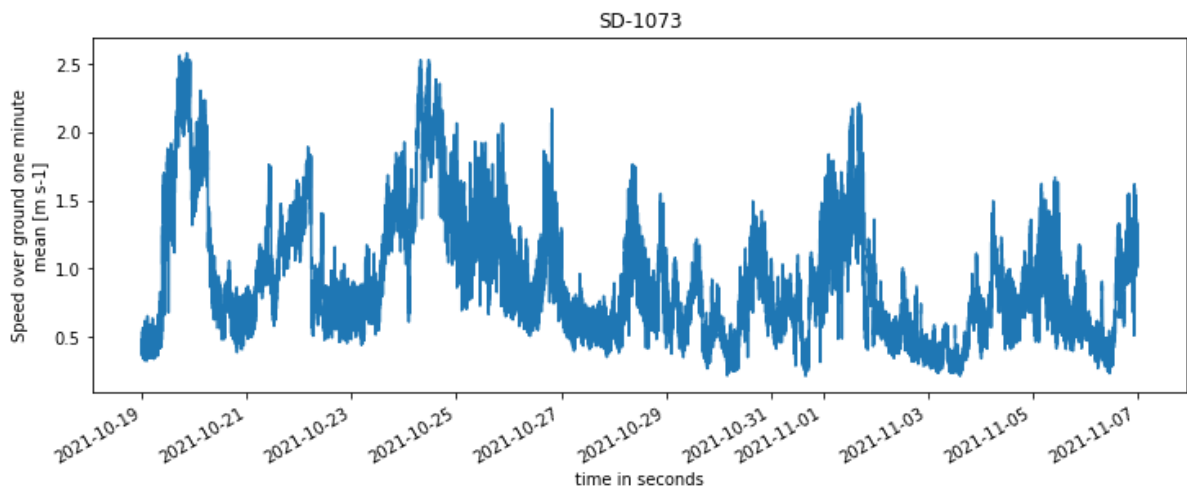
```
In [135]: im = ds.plot.scatter(x='longitude',y='latitude',c=ds.TEMP_SBE37_MEAN)
plt.colorbar(im,label=ds.TEMP_SBE37_MEAN.attrs['standard_name'])
plt.title('SD-'+str(int(ds.trajectory)))
```

Out[135]: Text(0.5, 1.0, 'SD-1073')



```
In [136]: # time speed of saildrone speed relative to ground
fig, ax = plt.subplots(figsize=(12,4))
ds.SOG_FILTERED_MEAN.plot(x='time')
plt.title('SD-'+str(int(ds.trajectory)))
```

Out[136]: Text(0.5, 1.0, 'SD-1073')



Example: calculate density, a derived quantity

In [137... `ds['sigma0'] = gsw.sigma0(ds.SAL_SBE37_MEAN, ds.TEMP_SBE37_MEAN)`

```
ds.sigma0.attrs['standard_name'] = 'sea_water_potential_density'
ds.sigma0.attrs['long_name'] = 'Seawater potential density'
ds.sigma0.attrs['units'] = 'kg m^{-3}'
```

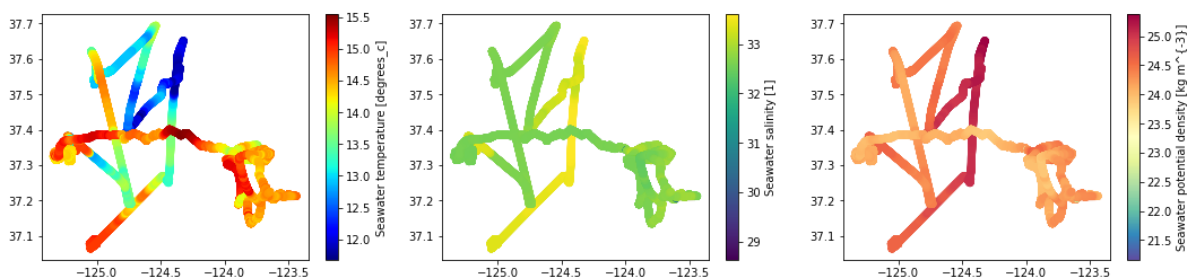
In [138... `# Now plot temperature, salinity and density`
`fig, axs = plt.subplots(1,3,figsize=(18,4))`

```
variables = [
    ds.TEMP_SBE37_MEAN,
    ds.SAL_SBE37_MEAN,
    ds.sigma0
]
```

```
cmaps = ['jet', 'viridis', 'Spectral_r']
```

```
for ax, var, cmap in zip(axs, variables, cmaps):
```

```
    im = ax.scatter(ds.longitude, ds.latitude, c=var, cmap=cmap)
    fig.colorbar(im, ax=ax, label=var.attrs['long_name'] + ' [' + var.attrs['u
```



All saildrones

Oftentimes it is convenient to have all saildrone data in a single dataset for easy manipulation and comparisons.

```

In [139... files = glob.glob(data_path + short_name + '/*_nonadcp_*')

drop_vars = ['TEMP_DEPTH_HALFMETER_MEAN',
             'TEMP_DEPTH_HALFMETER_STDDEV',
             'corrected_backscatter_at_650nm',
             'particulate_organic_carbon',
             'calibrated_chlorophyll'
            ]

# loop through files (i.e., different saildrones),
# open dataset, drop variables not available for all
# saildrones and concatenate datasets along the trajectory
# dimension

for file in files:

    foo = xr.open_dataset(file)

    for drop_var in drop_vars:
        if drop_var in foo.variables:
            foo = foo.drop(drop_var)

    foo = foo.isel(trajectory=0).swap_dims(
        {'obs': 'time'})
    ).expand_dims('trajectory')

    if file == files[0]:
        nonadcp = foo
    else:
        nonadcp = xr.concat([nonadcp, foo], dim='trajectory')

```

In [140... nonadcp

Out [140]: xarray.Dataset

► Dimensions: (time: 27360, trajectory: 5)

▼ Coordinates:

time	(time)	datetime64[ns]	2021-10-19 ... 2021-...		
latitude	(trajectory, time)	float64	37.08 37.08 37.08		
longitude	(trajectory, time)	float64	-125.0 -125.0 ... -12...		
trajectory	(trajectory)	float64	1.073e+03 1.062e+0...		

► Data variables: (71)

► Attributes: (64)

```

In [141... # single saildrone dataset is a subset of nonadcp dataset
nonadcp73 = nonadcp.sel(trajectory=1073.)

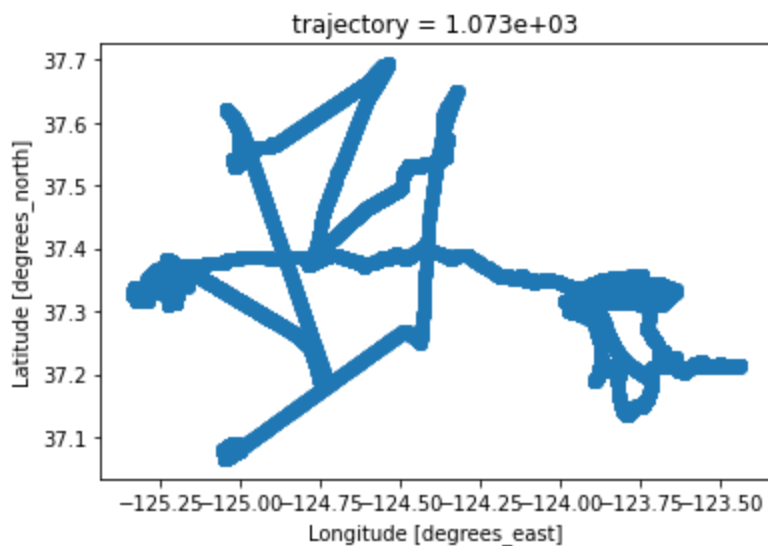
```

```

In [142... # project 1073's trajectory
nonadcp73.plot.scatter(x='longitude', y='latitude')

```

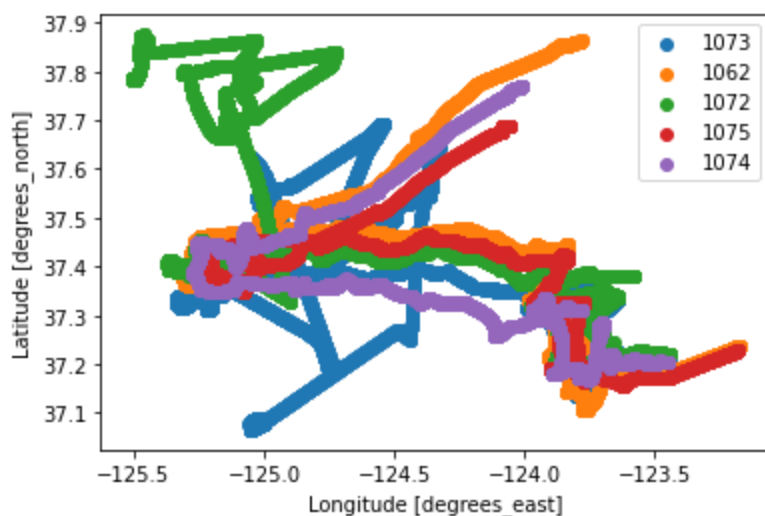
Out[142]: <matplotlib.collections.PathCollection at 0x7f93e9546ac0>



```
In [143]: # plot all trajectories
for sd in nonadcp.trajectory:
    nonadcp.sel(trajectory=sd).plot.scatter(x='longitude',y='latitude',label=sd)

plt.legend()
plt.title('')
```

Out[143]: Text(0.5, 1.0, '')



ADCP data

Single file: saildrone 1072

```
In [144]: adcp72 = xr.open_dataset(data_path + short_name + '/SMODE_PFC_saildrone_adcp
adcp73 = xr.open_dataset(data_path + short_name + '/SMODE_PFC_saildrone_adcp
```

```
In [145]: # Slice the data in time, assigning a 3-day subset

# virtual mooring
```



```
# t0 = np.datetime64('2021-11-23T12')
# t1 = np.datetime64('2021-11-28T12')

# formation sailing
# t0 = np.datetime64('2021-11-01T04')
# t1 = np.datetime64('2021-11-01T18')

# comparison with oceanus
t0 = np.datetime64('2021-11-06T16')
t1 = np.datetime64('2021-11-06T20')

subset72 = adcp72.where((adcp72.time>=t0)&(adcp72.time<=t1),drop=True)
subset73 = adcp73.where((adcp73.time>=t0)&(adcp73.time<=t1),drop=True)
```

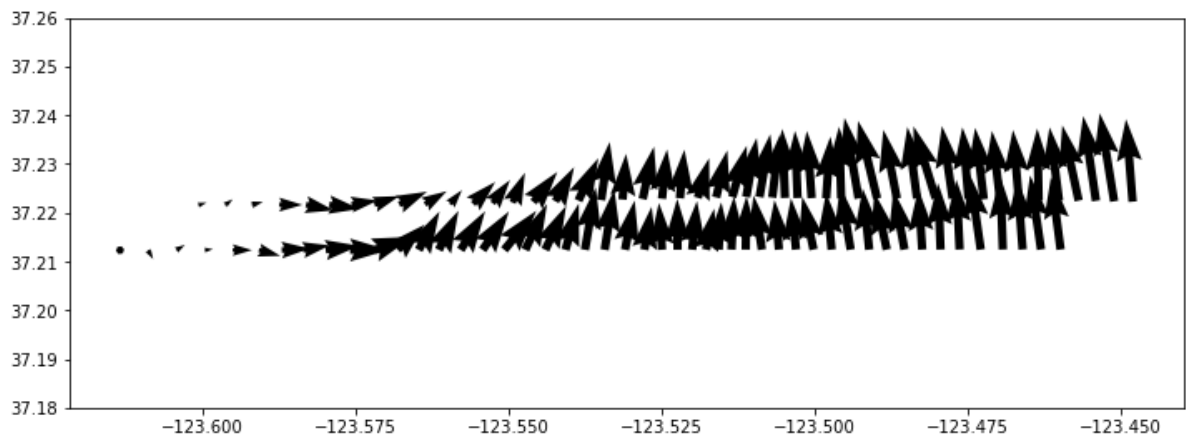
```
In [146... depth_bin = 2

fig, ax = plt.subplots(figsize=(12,8))

for subset in [subset72,subset73]:

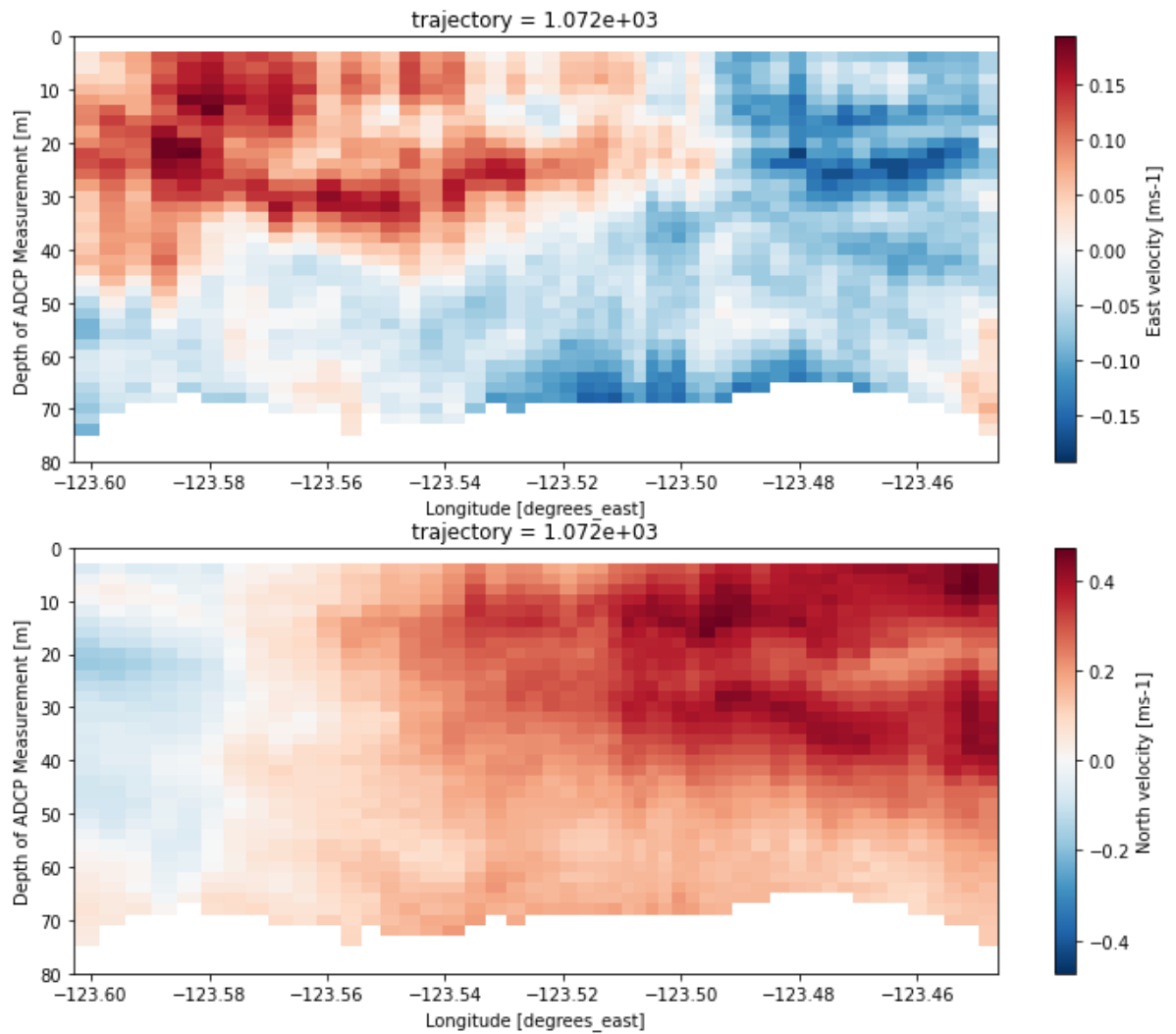
    ax.quiver(
        subset.longitude,
        subset.latitude,
        subset.vel_east.isel(cell_depth=depth_bin),
        subset.vel_north.isel(cell_depth=depth_bin),
        scale = 6
    )

ax.set_ylim(37.18,37.26)
ax.set_aspect(np.cos(37.22*np.pi/180))
```



```
In [147... # Example: vertical sections
fig, axs = plt.subplots(2,1, figsize=(12,10))
subset72.vel_east.where(subset72.percent_good>95).plot(x='longitude',y='cell
subset72.vel_north.where(subset72.percent_good>95).plot(x='longitude',y='cel
[ax.set_ylim(80,0) for ax in axs]
```

```
Out[147]: [(80.0, 0.0), (80.0, 0.0)]
```

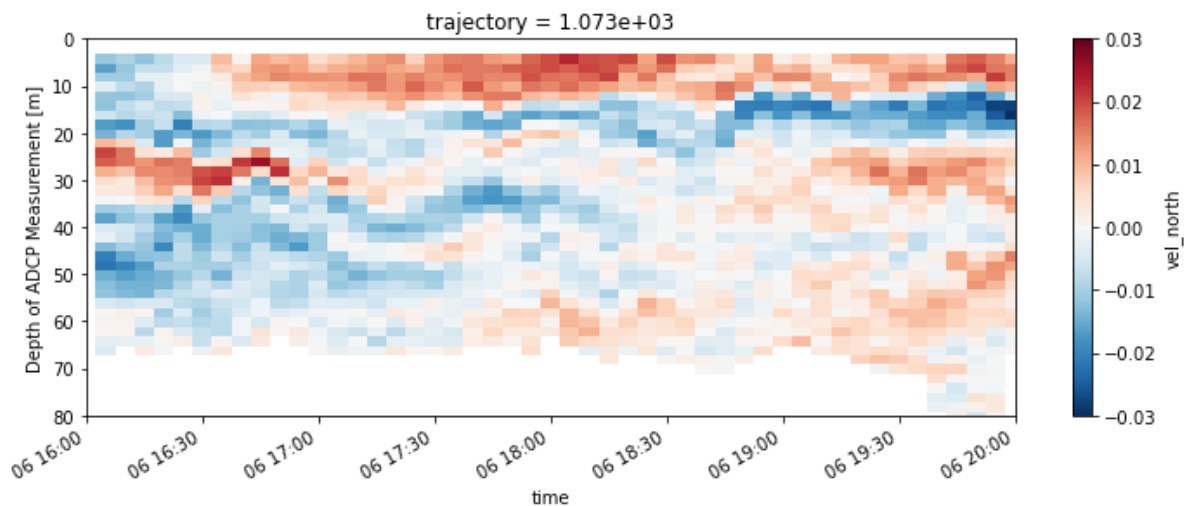


```
In [148... # Example: calculate and plot vertical shear
fig, ax = plt.subplots(figsize=(12,4))
kw = {'vmin': -0.03, 'vmax': 0.03, 'cmap': 'RdBu_r'}

subset.vel_north.differentiate('cell_depth').where(subset.percent_good>95).p

plt.ylim(80,0)
plt.xlim(t0,t1)
```

Out[148]: (18937.666666666668, 18937.833333333332)



Compare saildrone ADCP data with R/V Oceanus data

A major goal of the S-MODE Pilot was to compare saildrone ADCP data. Here's one example of a simple saildrone-Oceanus velocity comparison.

```
In [149... # this is not working for the Oceanus ADCP
start_time = '2021-10-20T00:00:00Z'
start_time = '2021-08-01T00:00:00Z'
end_time = '2021-11-08T00:00:00Z'

short_name = 'SMODE_LX_SHIPBOARD_ADCP_V1'
!podaac-data-downloader -c $short_name -d data/$short_name --start-date $sta
```

```

/Users/crocha/miniconda3/lib/python3.9/site-packages/requests/__init__.py:1
02: RequestsDependencyWarning: urllib3 (1.26.8) or chardet (5.0.0)/charset_
normalizer (2.0.4) doesn't match a supported version!
  warnings.warn("urllib3 ({}) or chardet ({})/charset_normalizer ({}) does
n't match a supported "
[2022-12-01 12:59:27,356] {podaac_data_downloader.py:243} INFO - Found 2 to
tal files to download
[2022-12-01 12:59:27,388] {podaac_data_downloader.py:268} INFO - 2022-12-01
12:59:27.388613 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SHIPBOARD_ADCP_V1/S-MODE_PFC_OC2108A_adcp_os7
5nb.nc4
[2022-12-01 12:59:27,465] {podaac_data_downloader.py:268} INFO - 2022-12-01
12:59:27.464927 SKIPPED: https://archive.podaac.earthdata.nasa.gov/podaac-o
ps-cumulus-protected/SMODE_LX_SHIPBOARD_ADCP_V1/S-MODE_PFC_OC2108A_adcp_wh3
00.nc4
[2022-12-01 12:59:27,465] {podaac_data_downloader.py:287} INFO - Downloaded
Files: 0
[2022-12-01 12:59:27,465] {podaac_data_downloader.py:288} INFO - Failed Fil
es: 0
[2022-12-01 12:59:27,465] {podaac_data_downloader.py:289} INFO - Skipped Fi
les: 2
[2022-12-01 12:59:27,675] {podaac_access.py:122} INFO - CMR token successfu
lly deleted
[2022-12-01 12:59:27,675] {podaac_data_downloader.py:299} INFO - END

```

```

In [150... ds = xr.open_dataset('data/SMODE_LX_SHIPBOARD_ADCP_V1/S-MODE_PFC_OC2108A_adcp_os75nb.nc')
ds['depth'] = Dataset('data/SMODE_LX_SHIPBOARD_ADCP_V1/S-MODE_PFC_OC2108A_adcp_os75nb.nc')

```

```

In [151... subset_oceanus = ds.where((ds.time>=t0)&(ds.time<=t1),drop=True)

```

```

In [152... # interpolate to subset72 time
# TODO: try to resample with averaging to 5 minutes before interpolating (e.g.
subset_oceanus = subset_oceanus.interp({'time': subset72.time})

```

```

/Users/crocha/miniconda3/lib/python3.9/site-packages/xarray/core/missing.p
y:562: FutureWarning: Passing method to DatetimeIndex.get_loc is deprecated
and will raise in a future version. Use index.get_indexer([item], method
=...) instead.
  imin = index.get_loc(minval, method="nearest")
/Users/crocha/miniconda3/lib/python3.9/site-packages/xarray/core/missing.p
y:563: FutureWarning: Passing method to DatetimeIndex.get_loc is deprecated
and will raise in a future version. Use index.get_indexer([item], method
=...) instead.
  imax = index.get_loc(maxval, method="nearest")

```

```

In [153... # interpolate to saildrone depth to oceanus depth
subset72['depth'] = subset72.cell_depth + 1.9 # add depth of the instrument
subset72 = subset72.swap_dims({'cell_depth': 'depth'})
subset72 = subset72.interp({'depth': subset_oceanus.depth})

```

```

/Users/crocha/miniconda3/lib/python3.9/site-packages/xarray/core/missing.p
y:562: FutureWarning: Passing method to Float64Index.get_loc is deprecated
and will raise in a future version. Use index.get_indexer([item], method
=...) instead.
    imin = index.get_loc(minval, method="nearest")
/Users/crocha/miniconda3/lib/python3.9/site-packages/xarray/core/missing.p
y:563: FutureWarning: Passing method to Float64Index.get_loc is deprecated
and will raise in a future version. Use index.get_indexer([item], method
=...) instead.
    imax = index.get_loc(maxval, method="nearest")

```

Visual comparison

```

In [154... depth_bin = 1
sc = 6

fig, ax = plt.subplots(figsize=(12,8))

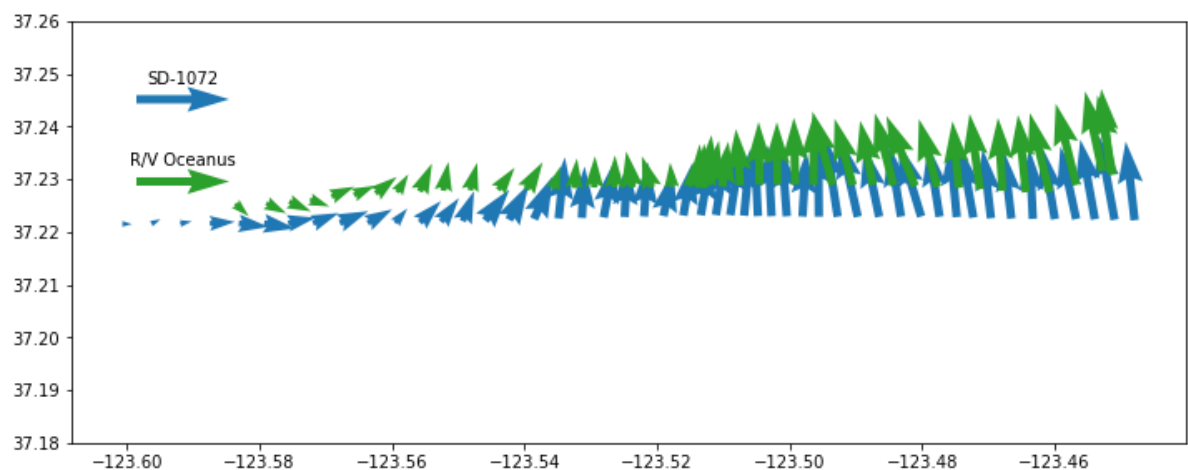
q1 = plt.quiver(
    subset72.longitude,
    subset72.latitude,
    subset72.vel_east.isel(depth=depth_bin),
    subset72.vel_north.isel(depth=depth_bin),
    color='C00', scale=sc
)

q2 = plt.quiver(
    subset_oceanus.longitude,
    subset_oceanus.latitude,
    subset_oceanus.zonal_velocity_component.isel(depth=depth_bin),
    subset_oceanus.meridional_velocity_component.isel(depth=depth_bin),
    color='C02', scale=sc
)

plt.quiverkey(q1, .1, 0.815, .5, 'SD-1072',)
plt.quiverkey(q2, .1, 0.620, .5, 'R/V Oceanus',)

ax.set_ylim(37.18,37.26)
ax.set_aspect(np.cos(37.22*np.pi/180))

```



```
In [155... fig, axs = plt.subplots(2,1,figsize=(12,14))

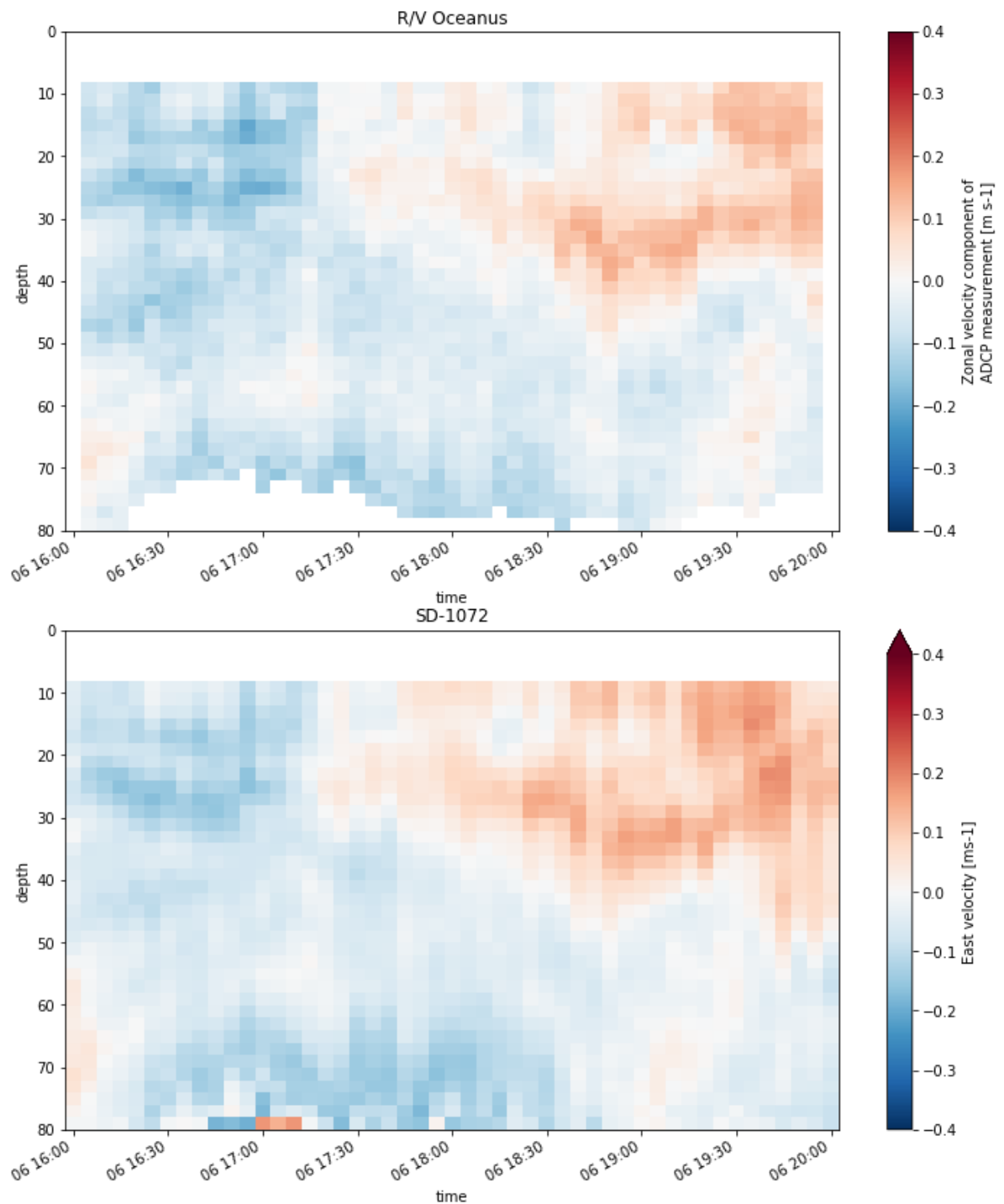
kw = {'vmin': -.4, 'vmax': +.4, 'cmap': 'RdBu_r'}

subset_oceanus.zonal_velocity_component.plot(x='time',y='depth',ax=axs[0],**kw)
subset72.vel_east.plot(x='time',y='depth',ax=axs[1],**kw)

axs[0].set_title('R/V Oceanus')
axs[1].set_title('SD-1072')

[ax.set_ylim(80,0) for ax in axs]
```

```
Out[155]: [(80.0, 0.0), (80.0, 0.0)]
```

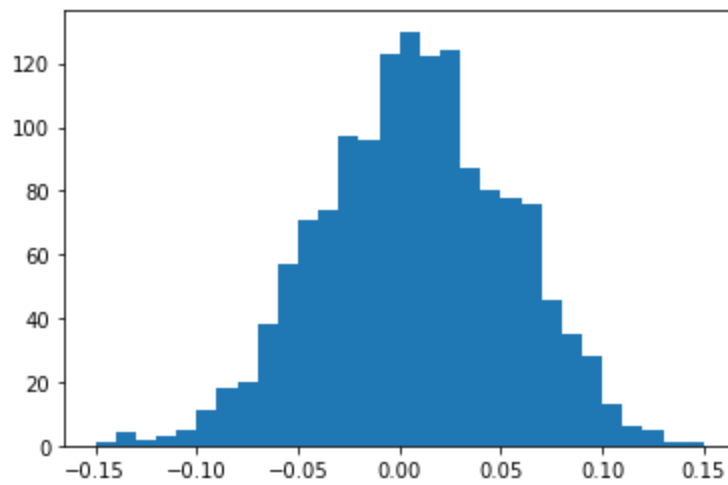


Quantitative comparison: calculate and plot velocity differences

```
In [156... subset_oceanus = subset_oceanus.where(subset_oceanus.depth<=70)
subset72 = subset72.where(subset_oceanus.depth<=70)
```

```
In [157... du = subset_oceanus.zonal_velocity_component-subset72.vel_east
dv = subset_oceanus.meridional_velocity_component-subset72.vel_north
```

```
In [158... # histogram of meridional velocity differences (Oceanus-SD1072)
_ = plt.hist(dv.values.flatten(),bins=np.arange(-.15,.156,.01))
```



```
In [159... du.mean().values, dv.mean().values
```

```
Out[159]: (array(-0.01207606), array(0.00744287))
```

```
In [160... du.std().values, dv.std().values
```

```
Out[160]: (array(0.03616049), array(0.04748247))
```

```
In [ ]:
```