MAPS 2022 Cartopy, NetCDF and maybe a little geopandas.

Maps

Today we are going to use Python to make maps. Many people use ARCgis or google maps etc. But once you have data in python it is nice to be able to make maps right there in python. Especially if you are doing analyses. You can run an analysis and make maps in one fell swoop. It is quite nice. Then if you have multiple parameters you could also make lots of maps quickly! So we are going to try and make a map.

We are going to try and do two mapping libraries for two reasons. This is a relatively new notebook so lets see how it goes. These are the mapping libraries you may hear about.

Mapping is a little bit of the wild west in Python. Not quite a perfect consensus on what people do yet. But once you learn one library it is easier to learn the next one.

- Basemap - Publication quality maps. This was my favorite and they stopped updating it. They just started updating it again but we are not going to use it yet.
- Folium. This makes interactive maps for web. Here is an example I made for the Red Hook Lead Project. https://bmaillou.github.io/RedHookLead/
- Cartopy is supposed to replace basemap. It sort of does it. We will use it some.
- Geopandas. This is becoming more popular. I haven't learned it well yet. But I am trying and will introduce a bit of it.
- contextily. I just learned about contextily. Seems like it could be really helpful.

We are going to do 2 things today.

These are two essential things you always do with data.

- Plot points on a map
- Make contour maps

First run to turn on the libraries below.

You will probably get errors for not installed. If not installed we can install them.

In [1]:
```python
# The usual libraries
import pandas as pd
import numpy as np
import matplotlib.pylab as plt

from scipy import stats
from matplotlib.backends.backend_pdf import PdfPages

%matplotlib inline
```

```
#################################
# The new ones
import netCDF4

import cartopy.crs as ccrs
import cartopy.feature
from cartopy.util import add_cyclic_point
#import contextily as ctx

import datetime
```

ERROR! You should get an error that you don't have netCDF4 installed. :(So you need to install it!

The power of python is the installation of libraries!

1. First Try insalling from the Anaconda Navigator. Click on environment and then all packages and search for it. If this fails follow below.
2. I use conda to do my installation.
3. google conda install netcd4
4. You should get to this webpage. https://anaconda.org/anaconda/netcdf4
5. scroll down and copy the install instructions. conda install -c anaconda netcdf4
6. Now open a new terminal window or conda shell on windows.
7. paste in conda install -c anaconda netcdf4 and hit return
8. It should install.
9. then go up to Kernal->Restart and see if that error went away.
10. If you can't do it from the terminal or command prompt you can do it in jupyter notebook. Here is a link describing how. https://medium.com/@thabangline/how-to-use-conda-and-pip-to-install-packages-within-jupyter-notebook-d0f2ed23b059 I did it in the next cell.
11. If it works then do the same for cartopy
12. There are 1000's of more python packages online you can install!
13. We are going to skip contextily for now. I couldn't get conda to work. I did "pip install contextily"

In [177…
```
import sys
!conda install --yes --prefix {sys.prefix} -c anaconda netcdf4
```

```
Collecting package metadata (current_repodata.json): done
Solving environment: done

## Package Plan ##

  environment location: /Users/bmaillou/anaconda3

  added / updated specs:
    - netcdf4


The following packages will be downloaded:

    package                    |            build
    ---------------------------|-----------------
    ca-certificates-2020.10.14 |                0         127 KB  anaconda
    certifi-2020.6.20          |           py38_0         159 KB  anaconda
    netcdf4-1.5.3              |   py38h28545a2_0         480 KB  anaconda
    openssl-1.1.1h             |       haf1e3a3_0         3.4 MB  anaconda
    ------------------------------------------------------------
                                           Total:         4.2 MB

The following packages will be SUPERSEDED by a higher-priority channel:

  ca-certificates    pkgs/main::ca-certificates-2021.10.26~ --> anaconda::ca-certificates-2
020.10.14-0
```

```
  certifi           conda-forge::certifi-2021.10.8-py38h5~ --> anaconda::certifi-2020.6.20
-py38_0
  netcdf4                                        pkgs/main --> anaconda
  openssl           conda-forge::openssl-1.1.1l-h0d85af4_0 --> anaconda::openssl-1.1.1h-ha
f1e3a3_0



Downloading and Extracting Packages
openssl-1.1.1h       | 3.4 MB    | ##################################### | 100%
certifi-2020.6.20    | 159 KB    | ##################################### | 100%
netcdf4-1.5.3        | 480 KB    | ##################################### | 100%
ca-certificates-2020 | 127 KB    | ##################################### | 100%
Preparing transaction: done
Verifying transaction: done
Executing transaction: done
```

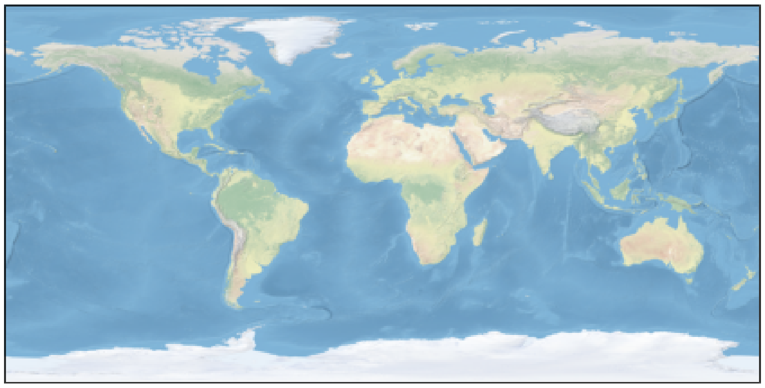
Now lets make our first map

ccrs is cartopy!!!! It is a mapping function

- Start like normal
- then do plt.axes and add a projection.
- Then I add the iamge of the earth

In [2]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree())
ax.stock_img()
```

Out[2]:
```
<matplotlib.image.AxesImage at 0x7fade5354f10>
```

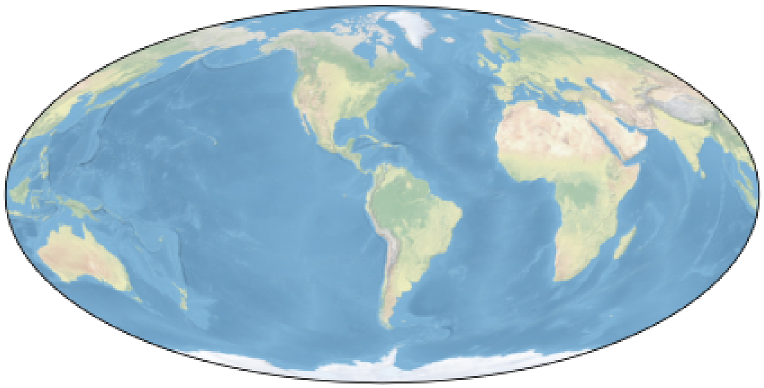


The fig,ax=plt.subplots is a little fake as we overwrite ax a few lines down. But I feel like it keeps our brains consistent and in line

Now you can change projections. just google cartopy projections.
https://scitools.org.uk/cartopy/docs/v0.15/crs/projections.html

In [3]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

#I centered it on new york!!!
ax = plt.axes(projection=ccrs.Mollweide(central_longitude=-73))
ax.stock_img()
```

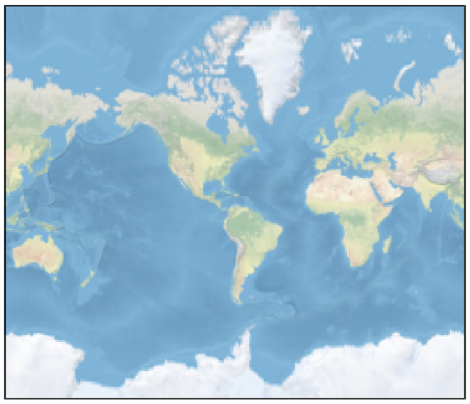
Out[3]:
```
<matplotlib.image.AxesImage at 0x7fade668fa30>
```



One more projection. They all have strengths and weaknesses. remember you CANNOT take a sphere and perfectly project on paper. Greenland is not that big!

In [4]:
```
fig,ax=plt.subplots()
#I centered it on new york!!!
ax = plt.axes(projection=ccrs.Mercator(central_longitude=-73))
ax.stock_img()
```

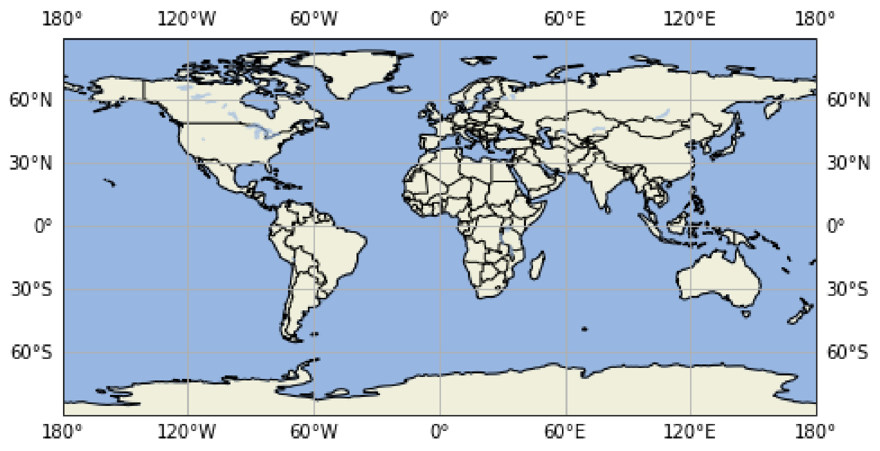
Out[4]:
```
<matplotlib.image.AxesImage at 0x7fadcd2cda90>
```



Instead of the image you could add different features.

In [5]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)
ax = plt.axes(projection=ccrs.PlateCarree())
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)

ax.gridlines(draw_labels=True)
```

Out[5]:
```
<cartopy.mpl.gridliner.Gridliner at 0x7fadcb72dd60>
```



Now let's plot all the CO2 stations from Scripps on the map.

Grab the file from the website. read it in. check it out. Then we can plot. I used the xkcd colors! https://xkcd.com/color/rgb/ and here is an appropriate xkcd for us. https://xkcd.com/2537

In [6]:
```
df=pd.read_excel('CO2Stations.xlsx')
```

In [7]:
```
df
```

Out[7]:

	StationName	StationCode	Latitude	Longitude	Elevation	Dates
0	Alert, NWT, Canada	ALT	82.3	-62.3	210	1985 - present
1	Point Barrow, Alaska	PTB	71.3	-156.6	11	1961 - present
2	La Jolla Pier, California	LJO	32.9	-117.3	10	1957 - present
3	Mauna Loa Observatory, Hawaii	MLO	19.5	-155.6	3397	1958 - present
4	Cape Kumukahi, Hawaii	KUM	19.5	-154.8	3	1979 - present
5	Christmas Island	CHR	2.0	-157.3	2	1974 - present
6	American Samoa	SAM	-14.2	-170.6	30	1981 - present
7	Kermadec Island	KER	-29.2	-177.9	2	1982 -present
8	Baring Head, New Zealand	NZD	-41.4	-174.9	85	1977 - present
9	South Pole	SPO	-90.0	-90.0	2810	1957 - present

Lat/Long

But to plot points we need to remember what latitude and longitude are. So look at the figure!

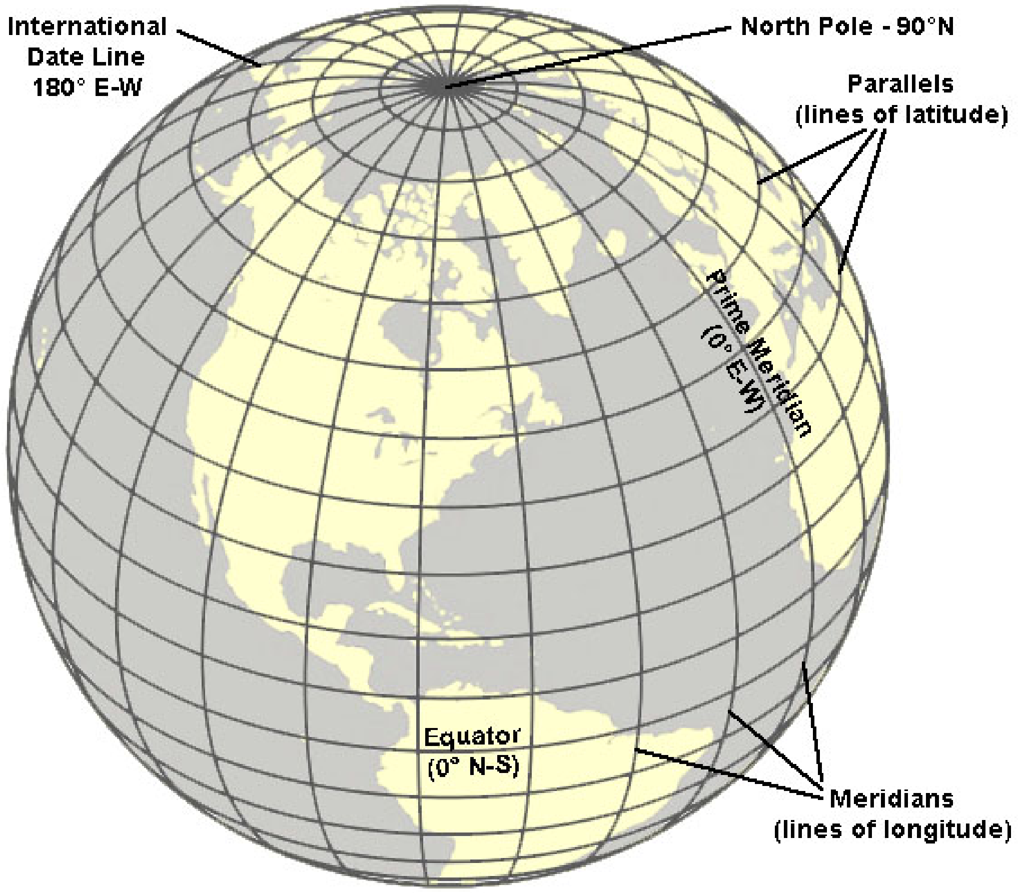
This wrecks my mind and I just memorized it. We always plot x,y. But we always say lat/long. Latitude then longitude. But x=Longitude and y=Latitude.

So when we plot ax.scatter(x,y). We need to do a flip when we plot locations and need to plot ax.scatter(long,lat).

Make any sense?????

In [8]:
```
from IPython.display import Image
Image('globe.jpg')
```

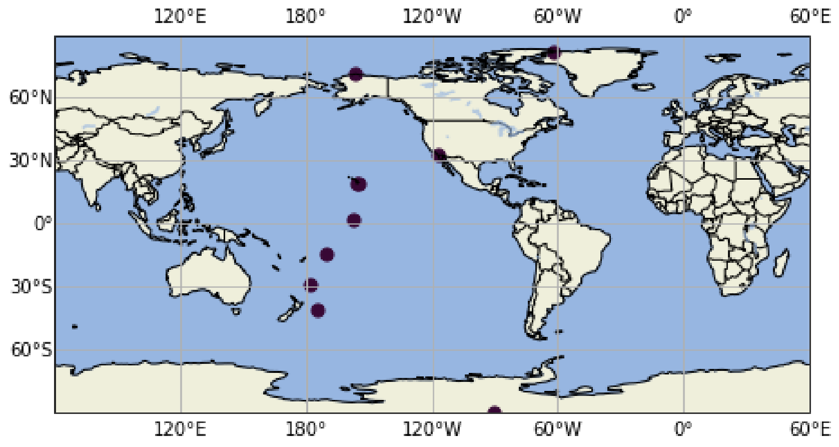
Out[8]:


International Date Line 180° E-W
North Pole - 90°N
Parallels (lines of latitude)
Prime Meridian (0° E-W)
Equator (0° N-S)
Meridians (lines of longitude)

plotting points is easy!

- Use your ax.scatter like normal
- reverse the order from how you say it (remember this!!!!!)
- transform your axes. This means it takes the lat/long coordinates and plots them nicely.

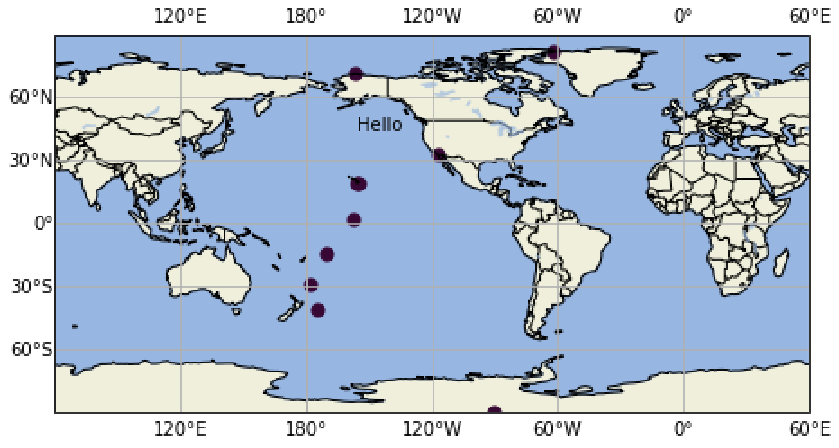
In [8]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)
ax.set_global()
```



Lets add Text to the map

- Grab your ax.text nomenclature.
- if you do transform=ax.transAxes remember then you plot as a fractional location in x and y.
- I put mine at x=0.4, y=0.75

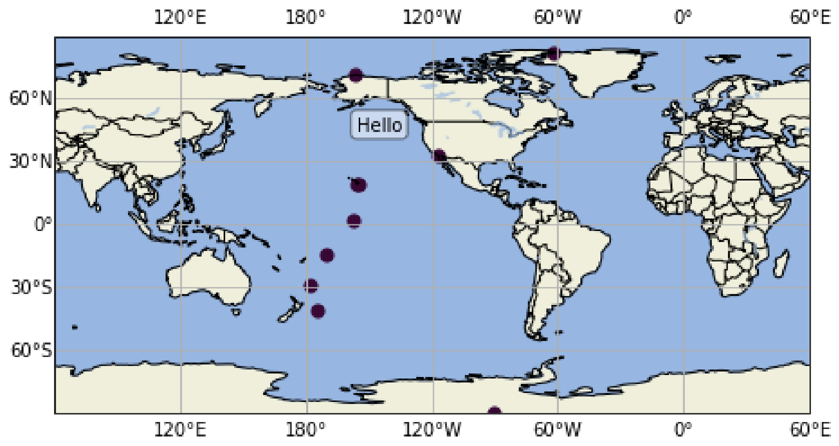
In [9]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)

ax.text(0.4,0.75,'Hello',transform=ax.transAxes)

ax.set_global()
```



Now you can add you props to make a bbox (bounding box)

In [10]:
```
props=dict(boxstyle='round',facecolor='white',alpha=0.5)

fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)
```

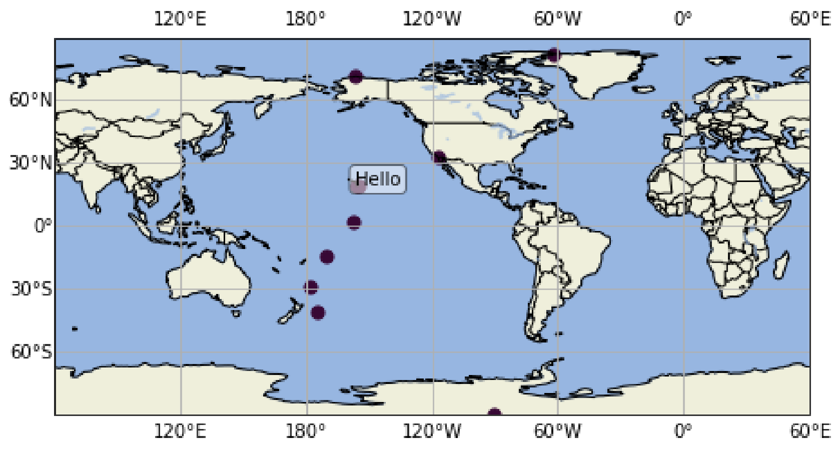
```
ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)

ax.text(0.4,0.75,'Hello',transform=ax.transAxes,bbox=props)

ax.set_global()
```



But we want to place the text with the points. So we want to plot lat long. So lets do the lat/long transformation.

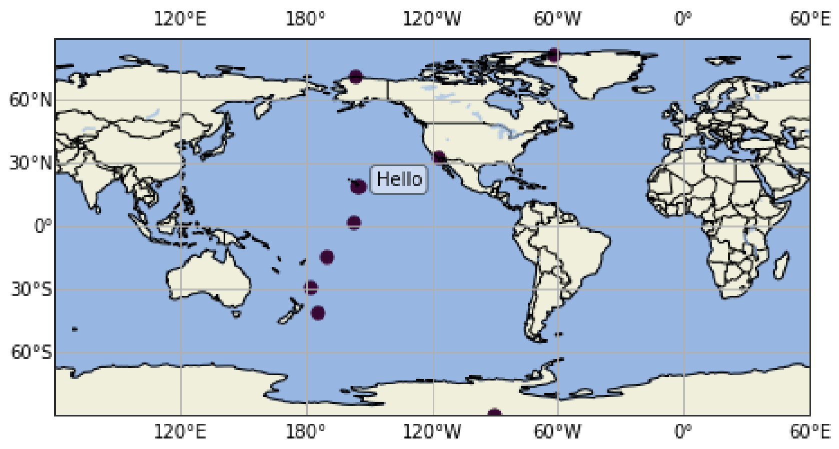
Let's try Mauna Loa first.It is Lat=19.5 Long=-155.6

In [11]:
```
props=dict(boxstyle='round',facecolor='white',alpha=0.5)

fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)

ax.text(-156.6,19.5,'Hello',transform=ccrs.PlateCarree(),bbox=props)

ax.set_global()
```



It covers the point. This is annoying to fix in python so I would just add 10 to the longitude.

```
In [12]: props=dict(boxstyle='round',facecolor='white',alpha=0.5)

fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)
ax.text(-156.6+10,19.5,'Hello',transform=ccrs.PlateCarree(),bbox=props)

ax.set_global()
```



What is coming next?

- ax.text is annoying. You can not just pass all the locations from the dataframe.
- you need to for loop over each row one by one and add the text. You do this with iterrows.
- iterrows returns the row and the index of the row.
- so lets try. We can do df.itterrows():
- I call my output idx=index and dfR=dataframe of that row

```
In [13]: for idx,dfR in df.iterrows():
    print(idx,dfR)
```

```
0 StationName    Alert, NWT, Canada
StationCode                   ALT
Latitude                     82.3
Longitude                   -62.3
Elevation                     210
Dates                1985 - present
Name: 0, dtype: object
1 StationName    Point Barrow, Alaska
StationCode                     PTB
Latitude                       71.3
Longitude                    -156.6
Elevation                        11
Dates                  1961 - present
Name: 1, dtype: object
2 StationName    La Jolla Pier, California
StationCode                          LJO
Latitude                            32.9
Longitude                         -117.3
Elevation                             10
Dates                       1957 - present
Name: 2, dtype: object
3 StationName    Mauna Loa Observatory, Hawaii
StationCode                              MLO
Latitude                                19.5
Longitude                             -155.6
Elevation                               3397
Dates                           1958 - present
Name: 3, dtype: object
4 StationName    Cape Kumukahi, Hawaii
StationCode                      KUM
Latitude                        19.5
Longitude                     -154.8
Elevation                          3
Dates                   1979 - present
Name: 4, dtype: object
5 StationName    Christmas Island
StationCode                 CHR
Latitude                      2
Longitude                -157.3
Elevation                     2
Dates            1974 - present
Name: 5, dtype: object
6 StationName    American Samoa
StationCode               SAM
Latitude                -14.2
Longitude              -170.6
Elevation                  30
Dates          1981 - present
Name: 6, dtype: object
7 StationName    Kermadec Island
StationCode                KER
Latitude                 -29.2
Longitude               -177.9
Elevation                    2
Dates            1982 -present
Name: 7, dtype: object
8 StationName    Baring Head, New Zealand
StationCode                         NZD
Latitude                          -41.4
Longitude                        -174.9
Elevation                            85
Dates                      1977 - present
Name: 8, dtype: object
9 StationName        South Pole
StationCode               SPO
Latitude                  -90
Longitude                 -90
Elevation                2810
Dates          1957 - present
Name: 9, dtype: object
```

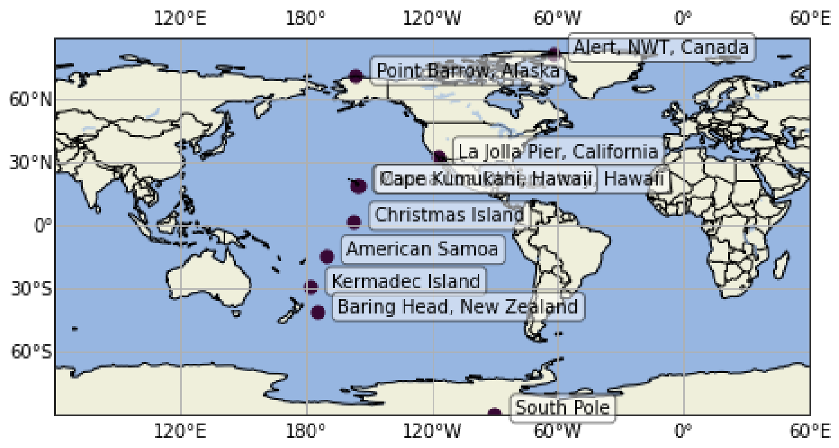
But now what we want is the longitude, latitude, name. So lets just print them

In [14]:
```python
for idx,dfR in df.iterrows():
    print(dfR['Longitude'],dfR['Latitude'],dfR['StationName'])
```

```
-62.3 82.3 Alert, NWT, Canada
-156.6 71.3 Point Barrow, Alaska
-117.3 32.9 La Jolla Pier, California
-155.6 19.5 Mauna Loa Observatory, Hawaii
-154.8 19.5 Cape Kumukahi, Hawaii
-157.3 2.0 Christmas Island
-170.6 -14.2 American Samoa
-177.9 -29.2 Kermadec Island
-174.9 -41.4 Baring Head, New Zealand
-90.0 -90.0 South Pole
```

Now put it together and make your labeled map!!!

In [15]:



HOMEWORK

- Do a world map.
- Show and label five places you want to travel to
- use an excel file to load your five places.

In [ ]:

Now something really cool. Lets plot surface temperatures on the day we were born!!!!

We will use this NOAA website to retrieve the data. https://psl.noaa.gov/data/composites/day/

- Choose Variable ->air temperature
- choose anaylis level -> surface
- add your birthday to a box. look at order it is year-month-day
- move down and do plot type mean
- do region of globe all
- press create plot
- just enjoy the graph/map. But we want to do better on python.
- make sure it is the correct date and parameter
- Click on "Get a copy of the netCDF data file used for the plot"
- This will downlaod the netcdf file
- move the NetCDF file to the directory where you work and we are readyto work!
- Do the next two cells and then try to read the metadata and make sense of it!

NetCDF

But you also need NetCDF.

You can learn about NetCDF at https://www.unidata.ucar.edu/software/netcdf/. From the website. "NetCDF (Network Common Data Form) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. It is also a community standard for sharing scientific data. The Unidata Program Center supports and maintains netCDF programming interfaces for C, C++, Java, and Fortran. Programming interfaces are also available for Python, IDL, MATLAB, R, Ruby, and Perl."

This is going to be weird to you. netcdf files are in binary format so you can never "see" them. I feel like csv files are intuitive. You can see the columns. NetCDF files are have headers that tell you what is in them. I see them a lot with spatial data for example sea surface temperatures. But they also have a funny format. They list types of data one at a time and not in a table. So it is all latitude data, then all longitude data, then all time data, then all temperature data etc. It takes get used to.

In the past students have told me that they have stood out in internships becuase they knew about NetCDF files.

So lets start. file is the name of the file you downloaded

You read the data into a parameter called f. This is just what people do. f then contains all the information you need. it is sort of like a dataframe for netcdf but you never see the data. you probe at it.

In [25]:
```
file=('compday.14irvFWHtn.nc')
f=netCDF4.Dataset(file)
```

In [27]:
```
print (f)
```

```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF3_CLASSIC data model, file format NETCDF3):
    title: Composite Value
    history: Created via daily composite webtool at NOAA/ESRL PSD
    description: Computed from the web page http://www.esrl.noaa.gov/psd/data/composites/da
y/ NOAA/ESRL PSD
    Conventions: COARDS
    dimensions(sizes): lon(144), lat(73), time(1)
    variables(dimensions): float32 lat(lat), float32 lon(lon), float64 time(time), float32
air(time,lat,lon)
    groups:
```

```
<ipython-input-27-b30fe898003a>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f)
```

Read what it just said. Ignore the warning. It tells you all the variables and how big the are. So we want the lat,long,time, and air. This will give us the location for the data so we can map it

Now we will print the metada for each variable.

These are crazy file formats. Just go along with it and learn.

In [20]:
```
print (f.variables['lat'])
```

```
<class 'netCDF4._netCDF4.Variable'>
float32 lat(lat)
    units: degrees_north
    actual_range: [ 90. -90.]
    long_name: Latitude
unlimited dimensions:
```

```
current shape = (73,)
filling on, default _FillValue of 9.969209968386869e+36 used
<ipython-input-20-bd934758bff6>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f.variables['lat'])
```

In [21]:
```
print (f.variables['lon'])
```

```
<class 'netCDF4._netCDF4.Variable'>
float32 lon(lon)
    units: degrees_east
    long_name: Longitude
    actual_range: [  0.   357.5]
unlimited dimensions:
current shape = (144,)
filling on, default _FillValue of 9.969209968386869e+36 used
<ipython-input-21-3928fc27ac36>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f.variables['lon'])
```

In [22]:
```
print (f.variables['time'])
```

```
<class 'netCDF4._netCDF4.Variable'>
float64 time(time)
    units: hours since 1800-1-1 00:00:0.0
    long_name: Time
    actual_range: [1509000. 1509000.]
    delta_t: 0000-01-00 00:00:00
unlimited dimensions: time
current shape = (1,)
filling on, default _FillValue of 9.969209968386869e+36 used
<ipython-input-22-bcbaa96a41be>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f.variables['time'])
```

In [23]:
```
print (f.variables['air'])
```

```
<class 'netCDF4._netCDF4.Variable'>
float32 air(time, lat, lon)
    long_name: Air Temperature
    valid_range: [-99999.  99999.]
    actual_range: [ 93.03 377.2 ]
    units: degK
    add_offset: 0.0
    scale_factor: 1.0
    missing_value: -9.96921e+36
    precision: 99
    least_significant_digit: 99
    var_desc: Air Temperature
    dataset: CDC Derived NCEP Reanalysis Products
    level_desc: Surface
    statistic: Composite
    parent_stat: Other
unlimited dimensions: time
current shape = (1, 73, 144)
filling on, default _FillValue of 9.969209968386869e+36 used
<ipython-input-23-18b48fa1db64>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f.variables['air'])
```

Now to actually see the data.

In [28]:
```
 f.variables['lat'][:]
```

Out[28]:
```
masked_array(data=[ 90. ,  87.5,  85. ,  82.5,  80. ,  77.5,  75. ,  72.5,
                    70. ,  67.5,  65. ,  62.5,  60. ,  57.5,  55. ,  52.5,
                    50. ,  47.5,  45. ,  42.5,  40. ,  37.5,  35. ,  32.5,
                    30. ,  27.5,  25. ,  22.5,  20. ,  17.5,  15. ,  12.5,
                    10. ,   7.5,   5. ,   2.5,   0. ,  -2.5,  -5. ,  -7.5,
                   -10. , -12.5, -15. , -17.5, -20. , -22.5, -25. , -27.5,
                   -30. , -32.5, -35. , -37.5, -40. , -42.5, -45. , -47.5,
                       -50.  , -52.5, -55.  , -57.5, -60.  , -62.5, -65.  , -67.5,
                       -70.  , -72.5, -75.  , -77.5, -80.  , -82.5, -85.  , -87.5,
                       -90. ],
                 mask=False,
           fill_value=1e+20,
                dtype=float32)
```

In [ ]:

```

```

As you can see latititude goes from 90 to -90.

Now to make life easier we can set parameters to the variables to make them easy to use

In [29]:
```
lon=f.variables['lon'][:]
lat=f.variables['lat'][:]
air=f.variables['air'][:]
time=f.variables['time'][:]
```

In [30]:
```
air
```

Out[30]:
```
masked_array(
  data=[[[240.43   , 240.43   , 240.43   , ..., 240.43   , 240.43   ,
          240.43   ],
         [239.45001, 239.43   , 239.4    , ..., 239.55002, 239.48001,
          239.48001],
         [242.30002, 242.33002, 242.36002, ..., 241.93   , 242.05002,
          242.20999],
         ...,
         [230.36002, 230.45999, 230.61002, ..., 230.78   , 230.53   ,
          230.38   ],
         [231.70001, 231.61002, 231.55002, ..., 232.11002, 231.98001,
          231.78   ],
         [231.38   , 231.38   , 231.38   , ..., 231.38   , 231.38   ,
          231.38   ]]],
  mask=False,
  fill_value=1e+20,
  dtype=float32)
```

Now do you remember the units on the air temperature? Look up above for air. it is kelvin! Now what real scientist uses Kelvin? i am going ot convert to good ole fahrenheit!

In [33]:
```
air=air-273.15
air=air*9/5+32
```

But how does the air temperature work? Lets look at it and figure it out.

In [22]:
```
np.shape(air)
```

Out[22]:
```
(1, 73, 144)
```

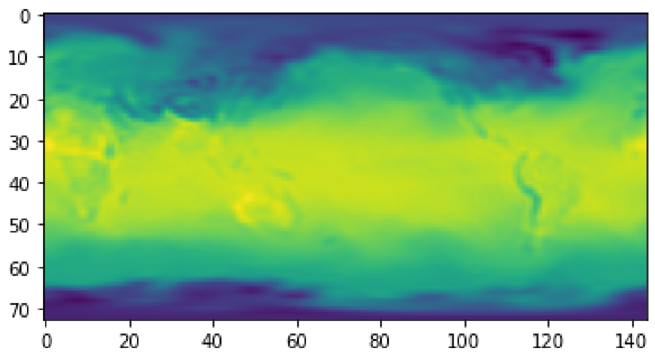
In [23]:
```
print(np.shape(lat))
print(np.shape(lon))
print(np.shape(time))
print(np.shape(air))
```

```
(73,)
(144,)
(1,)
(1, 73, 144)
```

It is a three dimensional array. It has only 1 data dimenssion and is then 73 by 144. Remember 73 is latitude. So it has 73 entries north south and then 144 east west. So it is a big array of temperatures. Sort of like when we did the "Brian.csv" lab! Lets do the simplest thing to look at it.

In [24]:
```
fig,ax=plt.subplots()
ax.imshow(air[0])
```

Out[24]:
```
<matplotlib.image.AxesImage at 0x7f8080fdff40>
```

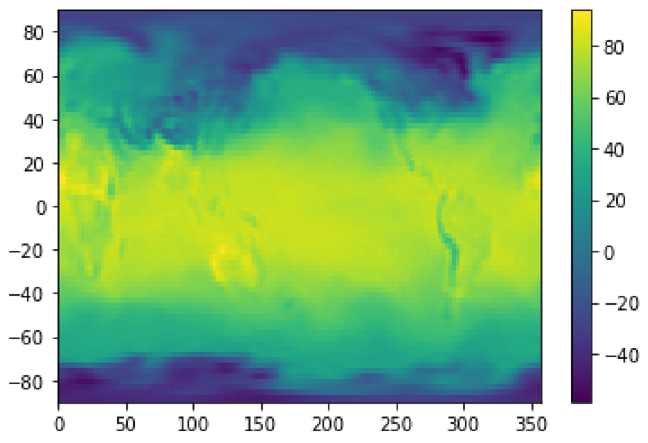


I can sort of pick out the continents but the axes make no sense. Instead we can use pcolormeash with the lat and lon to make a plot. Then we can add a colorbar.

In [25]:
```
fig,ax=plt.subplots()
pc=ax.pcolormesh(lon,lat,air[0])
fig.colorbar(pc)
```

```
<ipython-input-25-85d2513a2bb2>:2: MatplotlibDeprecationWarning: shading='flat' when X and
Y have the same dimensions as C is deprecated since 3.3.  Either specify the corners of the
quadrilaterals with X and Y, or pass shading='auto', 'nearest' or 'gouraud', or set rcParam
s['pcolor.shading'].  This will become an error two minor releases later.
  pc=ax.pcolormesh(lon,lat,air[0])
```

Out[25]:
```
<matplotlib.colorbar.Colorbar at 0x7f8080366940>
```

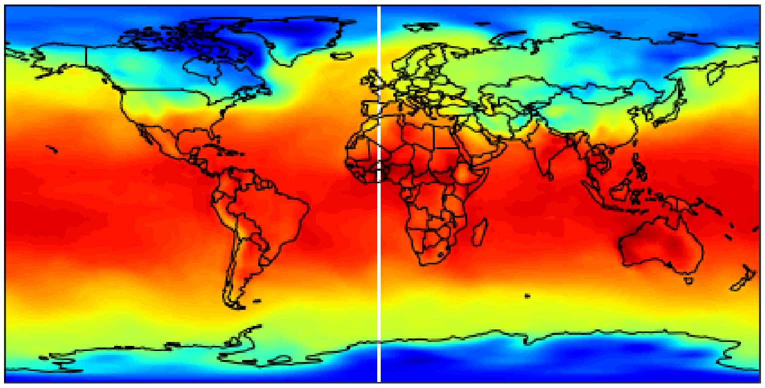


Let's make a real map instead!

- Grab your map from above
- Just show the ax.coastline() and countries.
- Now we are going to add countouf. the f is for filled.
- Here is the example https://scitools.org.uk/cartopy/docs/v0.13/matplotlib/advanced_plotting.html
- add lon, lat, air[0], transform, choose your cmap, and levels.
- I did a lot of levels to really smooth it.

In [31]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree())
ax.coastlines()
ax.add_feature(cartopy.feature.BORDERS)

ax.contourf(lon, lat, air[0],
            transform=ccrs.PlateCarree(),
            cmap='jet',levels=100)
```

Out[31]:
```
<cartopy.mpl.contour.GeoContourSet at 0x7fadcc7184f0>
```

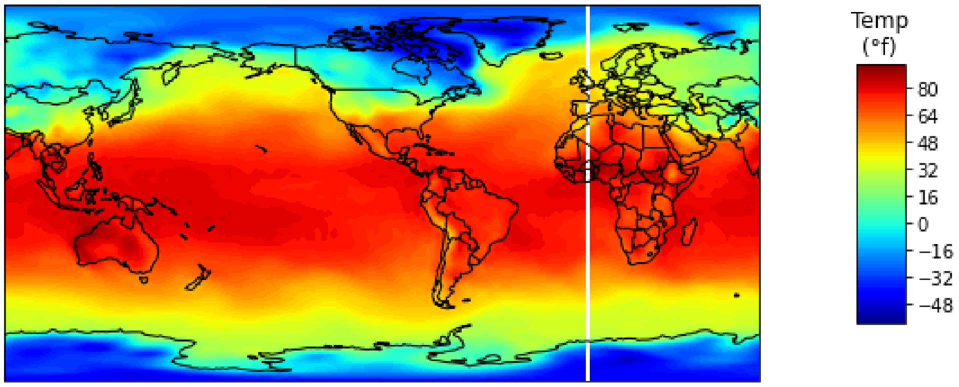


That looks sharp! Let's now add a colorbar. There are two ways to add a colorbar. This is way 1.

- Set the contourf equal to someting.
- add a new set of axes where you want tthe color bar.
- turn on the colorbar
- add a title

In [34]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-100))
ax.coastlines()
ax.add_feature(cartopy.feature.BORDERS)

air_contour=ax.contourf(lon, lat, air[0],
            transform=ccrs.PlateCarree(),
            cmap='jet',levels=100)

cbar_ax = fig.add_axes([1.0, 0.3, .05, 0.4])  #x, y, xwidth, y height
fig.colorbar(air_contour, cax=cbar_ax)
cbar_ax.set_title('Temp\n(\N{DEGREE SIGN}f)')
```

Out[34]:
```
Text(0.5, 1.0, 'Temp\n(°f)')
```

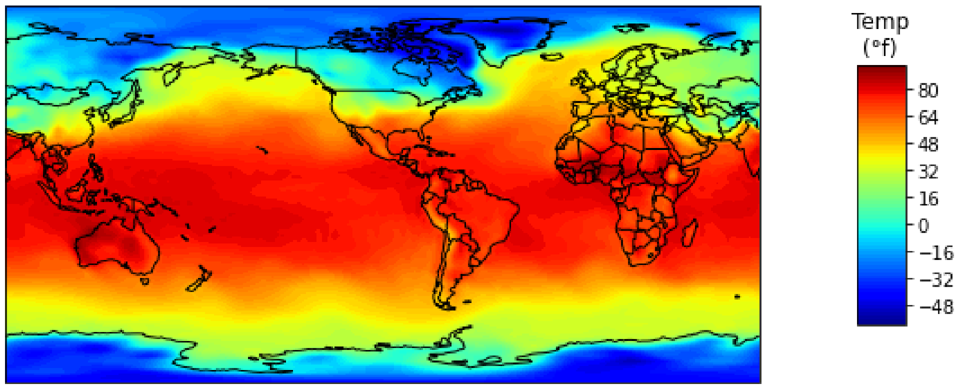


If you want to get rid of the white line you can google it. https://stackoverflow.com/questions/56348136/white-line-in-contour-plot-in-cartopy-on-center-longitude

- I added the one line
- I used "data" in contourf

In [35]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-100))
ax.coastlines()
ax.add_feature(cartopy.feature.BORDERS)

# gets rid of white line and use data for plot.
data, lonW = add_cyclic_point(air[0], coord=lon)


air_contour=ax.contourf(lonW, lat, data,
            transform=ccrs.PlateCarree(),
            cmap='jet',levels=100)

cbar_ax = fig.add_axes([1.0, 0.3, .05, 0.4])  #x, y, xwidth, y height
fig.colorbar(air_contour, cax=cbar_ax)
cbar_ax.set_title('Temp\n(\N{DEGREE SIGN}f)')
```

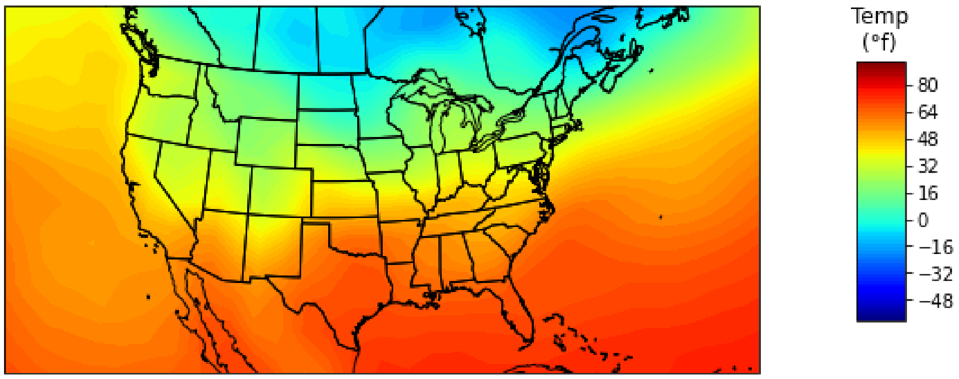
Out[35]:
```
Text(0.5, 1.0, 'Temp\n(°f)')
```



Let's just look at the US on my birthday! But also, since we did the cyclic function we need to keep using data. it altered the arrays and we need to keep with them or reread the data

In [36]:
```
fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.AlbersEqualArea(central_longitude=-100))

air_contour=ax.contourf(lon, lat, air[0],
            transform=ccrs.PlateCarree(),
            cmap='jet',levels=100)
ax.coastlines()
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.STATES)
ax.set_extent([-130,-60,20,50])

cbar_ax = fig.add_axes([1.0, 0.3, .05, 0.4])  #x, y, xwidth, y height
fig.colorbar(air_contour, cax=cbar_ax)
cbar_ax.set_title('Temp\n(\N{DEGREE SIGN}f)')
```

Out[36]:
```
Text(0.5, 1.0, 'Temp\n(°f)')
```

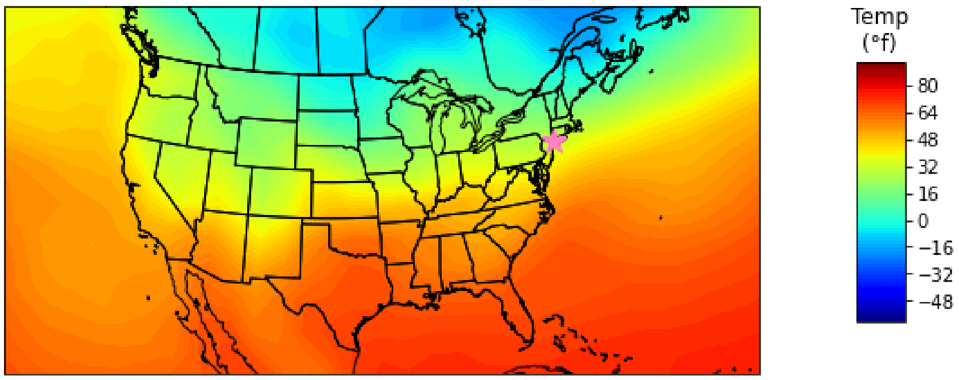


Now add a star (*) to where you were born

- Choose a fun xkcd color
- make the symbol big
- make it a star! or something else fun
- If you were born in another part of the world show it off!!!!! If you don't want me to know; lie and make something up.
- If your star is getting stuck behind some drawings add the key worder "zorder=10". zorder tells it where to plot on top of each other and the higher number is on top.

In [109…

Out[109…
```
Text(0.5, 1.0, 'Temp\n(°f)')
```



That is a great map. But to understand if we did thing correctly we need to understand the time. (add bad time pun here). So Let's add a nice date to the graph that we get from the netcdf file.

In [30]:
```
print (f.variables['time'])
```

```
<class 'netCDF4._netCDF4.Variable'>
float64 time(time)
    units: hours since 1800-1-1 00:00:0.0
    long_name: Time
    actual_range: [1509000. 1509000.]
    delta_t: 0000-01-00 00:00:00
unlimited dimensions: time
current shape = (1,)
filling on, default _FillValue of 9.969209968386869e+36 used
<ipython-input-30-bcbaa96a41be>:1: DeprecationWarning: tostring() is deprecated. Use tobyte
s() instead.
  print (f.variables['time'])
```

What does this mean????? Time since 1800. In hours! Holy crazy. Lets look. But excel does this also. You choose a starting date and just keep track of the days since that time. I think excel starts at 1/1/1900. Lets check and see if it makes sense. The number of hours is 1509000. Divide that by 365/24 and lets see if it is year until when I was born.

In [31]:
```
time
```

Out[31]:
```
masked_array(data=[1509000.],
             mask=False,
       fill_value=1e+20)
```

In [32]:
```
1509000/365/24
```

Out[32]:
```
172.26027397260273
```

Luckily python offers ways to deal with it.

Luckily Python has a datetime module!!! We have been using it in Pandas w/o you realizing it. https://docs.python.org/2/library/datetime.html

In [ ]:
```
datetime.
```

We can use dateime and make a dateime parameter. Just like we have strings, ints, and floats we can make a datetime that we can play with

So lets add the year,month,day and see what happens

In [38]:
```
datetime.datetime(2024,4,1)
```

Out[38]:
```
datetime.datetime(2024, 4, 1, 0, 0)
```

In [39]:
```
today=datetime.datetime(2021,11,20)
print (today)
type(today)
```

```
2021-11-20 00:00:00
```

Out[39]:
```
datetime.datetime
```

See how the type is a datetime!

So we can make ourselves a datetime! plus datetime has a function called timedelta.... It figures out how long given leap years and all that! You create a timedelta type. So it tells you how long

In [40]:
```
?datetime.timedelta
```

so we need to make a timedelta. Remember delta means change in math terminology!

In [41]:
```
datedelta=datetime.timedelta(hours=1509000)
print (datedelta)
print(type(datedelta))
```

```
62875 days, 0:00:00
<class 'datetime.timedelta'>
```

So timedelta is an anount of time. so we can put in our value and get a timedelta

In [42]:
```
datedelta=datetime.timedelta(hours=time[0])
print (datedelta)
print(type(datedelta))
```

```
62875 days, 0:00:00
<class 'datetime.timedelta'>
```

We can now do time math! This is crazy again. But we first need to set a start date

In [43]:
```
startdate=datetime.datetime(1800,1,1)
print (startdate)
print(type(startdate))
```

```
1800-01-01 00:00:00
<class 'datetime.datetime'>
```

Now we can just add them.

In [44]:
```
print (startdate+datedelta)
```

```
1972-02-24 00:00:00
```

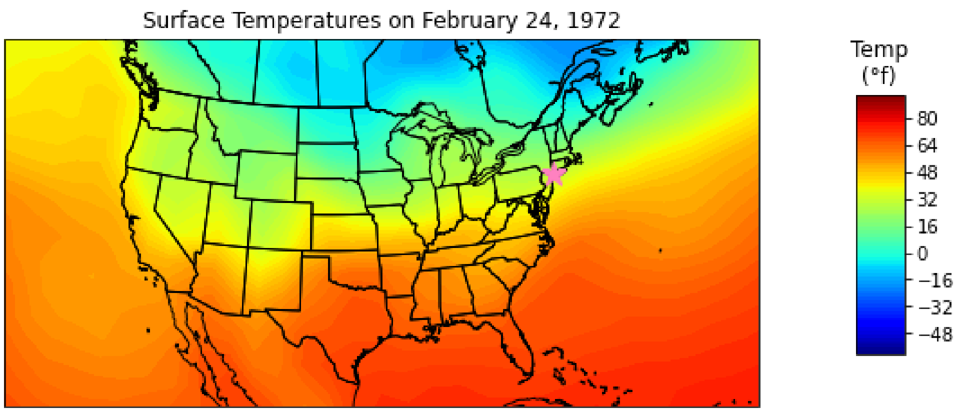
Lets set the date and print it nicely. Here is a summary of printing dates
https://stackoverflow.com/questions/311627/how-to-print-a-date-in-a-regular-format

In [45]:
```
mapdate=startdate+datedelta
print ("The date is {:%B %d, %Y}".format(mapdate))
```

```
The date is February 24, 1972
```

So lets go back and make our map look great! Add a title. Save it and send to family or friends! Ask someone who remembers when you wer born if the temperature makes sense. Plus hand it in for homework.

In [115…
```
```



In [ ]:

In [ ]:

In [ ]:

In [ ]:

In [ ]:

In [ ]:

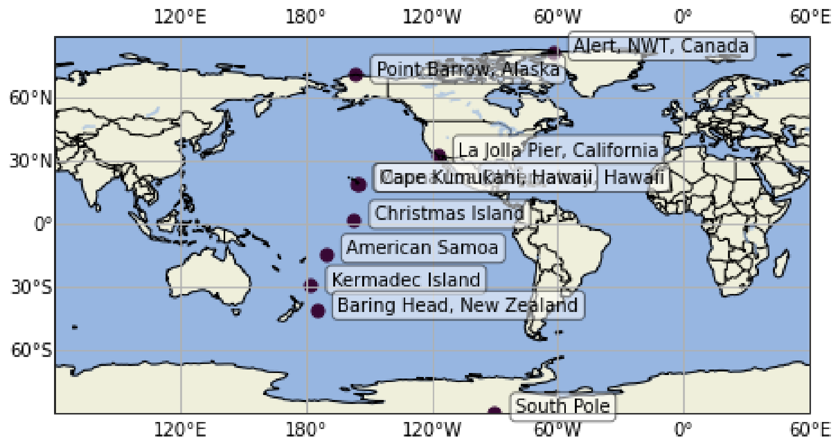
In [ ]:

In [ ]:

In [ ]:

Answers

In [16]:
```
props=dict(boxstyle='round',facecolor='white',alpha=0.5)

fig,ax=plt.subplots()
fig.set_size_inches(7.5,5)

ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=-120))
ax.add_feature(cartopy.feature.LAND)
ax.add_feature(cartopy.feature.OCEAN)
ax.add_feature(cartopy.feature.COASTLINE)
ax.add_feature(cartopy.feature.BORDERS)
ax.add_feature(cartopy.feature.LAKES, alpha=0.5)
ax.gridlines(draw_labels=True)
ax.scatter(df.Longitude,df.Latitude,color='xkcd:eggplant'
           ,transform=ccrs.PlateCarree(),s=50)

for idx,dfR in df.iterrows():
    ax.text(dfR['Longitude']+10,dfR['Latitude'],dfR['StationName'],transform=ccrs.PlateCar

ax.set_global()
```



In [ ]: