Marine Heatwave Classification

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This notebook reads in data from a netCDF file containing daily sea surface tempeatures (SSTs) in the North Pacific. Marine heatwaves are defined as SST that exceeds the 90th percentile using a fixed 30-year climatology. Daily data is smoothed with a 31-day filter and the percentile is calculated using a pooled average centered in an 11-day sliding window.

Metrics are computed at each grid point:

- 90th percentile threshold climatology --> climatologoy_threshold
- seasonal 30-year climatology --> seasonal_climatology
- Marine heatwave anomaly above the seasonal climatology --> mhw_anomaly
- Marine heatwave duration index on day 1 of event --> mhw_duration
- Average marine heatwave duration --> avg_duration
- Average marine heatwave intensity --> avg_intensity
- Average number of events per year (frequency) --> mhw_freq

This code was adapted from Eric Oliver's marineHeatWaves (https://github.com/ecjoliver/marineHeatWaves) module that was based on Hobday et al. [2016]

Step #1: Data Acquisition

To download the Optimum Interpolation Sea Surface Temperature (OISST) dataset, run the shell script webgetOISST.txt (https://github.com/cse512-18s/marine-heatwave/blob/master/data/webgetOISSTnetCDF.txt). This script will download netCDF files from NOAA and create a new directory for files on your machine. *[warning: this data is about 18 GB total]*

- **New Directory**: ftp.cdc.noaa.gov/Datasets/noaa.oisst.v2.highres/

Data from year between 1981-present will be a seperate netCDF file. Step 2 describes how to concatenate these files along the time dimension and subsection files to extract data only from the North Pacific.

Step #2. Data Concatenation

After all the OISST netCDF files are download, go to the directory where the files are stored on your machine and run the shell script concatOISST.txt (https://github.com/cse512-18s/marine-heatwave/blob/master/data/concatOISST.txt) from the terminal. This script with stack the files from 1981-2018 along the time dimension and create a new file called *OISSTv2.1981.2018.nc*. It then extracts data from *OISSTv2.1981.2018.nc* between 20-65°N and 125°E-105°W. This will produce a new file called *OISSTv2.NP.1981.2018.nc* with daily SST data from 1981 to 2018 in the North Pacific.

Step #3. Import Python Libraries

In [12]:
```
get_ipython().magic('matplotlib inline')
import numpy as np
import numpy.ma as ma
import os
import matplotlib.pyplot as plt
import scipy as sp
import datetime
from datetime import date
import time
import pandas as pd
import netCDF4
from netCDF4 import Dataset
import sys
import cartopy.crs as ccrs
import scipy.ndimage as ndimage
from cartopy.mpl.ticker import LongitudeFormatter, LatitudeFormatter
import cartopy.feature as cfeature
import matplotlib.dates as mdates
import matplotlib.cbook as cbook
import scipy.ndimage as ndimage
```

Step #4. Set Parameters and Define Functions

In [13]:
```
# Call your local directory where OISSTv2.NP.1981.2018.nc is stored
fp = "/Users/Scannell/Desktop/marine-heatwave/data/ftp.cdc.noaa.gov/Data
sets/noaa.oisst.v2.highres/OISSTv2.NP.1981.2018.nc"

# Where to store calculated marine heatwave metrics
path = "/Users/Scannell/Desktop/marine-heatwave/data/"

# Boolean switch indicating whether to smooth the threshold percentile t
imeseries with a moving average
smoothPercentile=True

# Width of moving average window for smoothing threshold
smoothPercentileWidth=31

#Period over which climatology is calculated, specified as list of start
 and end years
climatologyPeriod=[1988,2017]

# Threshold percentile (%) for detection of extreme values
pctile=90

# Width of window (one sided) about day-of-year used for the pooling of
 values and calculation of threshold percentile
windowHalfWidth=5




def nonans(array):
    '''
    Return input array [1D numpy array] with
    all nan values removed
    '''
    return array[~np.isnan(array)]


def nans(shape, dtype=float):
    a = np.empty(shape, dtype)
    a.fill(np.nan)
    return a


def runavg(ts, w):
    '''
    Performs a running average of an input time series using uniform win
dow
    of width w. This function assumes that the input time series is peri
odic.
    Inputs:
      ts            Time series [1D numpy array]
      w             Integer length (must be odd) of running average wind
ow
    Outputs:
      ts_smooth     Smoothed time series
    Written by Eric Oliver, Institue for Marine and Antarctic Studies, U
niversity of Tasmania, Feb-Mar 2015
```

```
    '''
    # Original length of ts
    N = len(ts)
    # make ts three-fold periodic
    ts = np.append(ts, np.append(ts, ts))
    # smooth by convolution with a window of equal weights
    ts_smooth = np.convolve(ts, np.ones(w)/w, mode='same')
    # Only output central section, of length equal to the original lengt
h of ts
    ts = ts_smooth[N:2*N]

    return ts
```

Step #5. Load Data & Variable Information

In [24]:

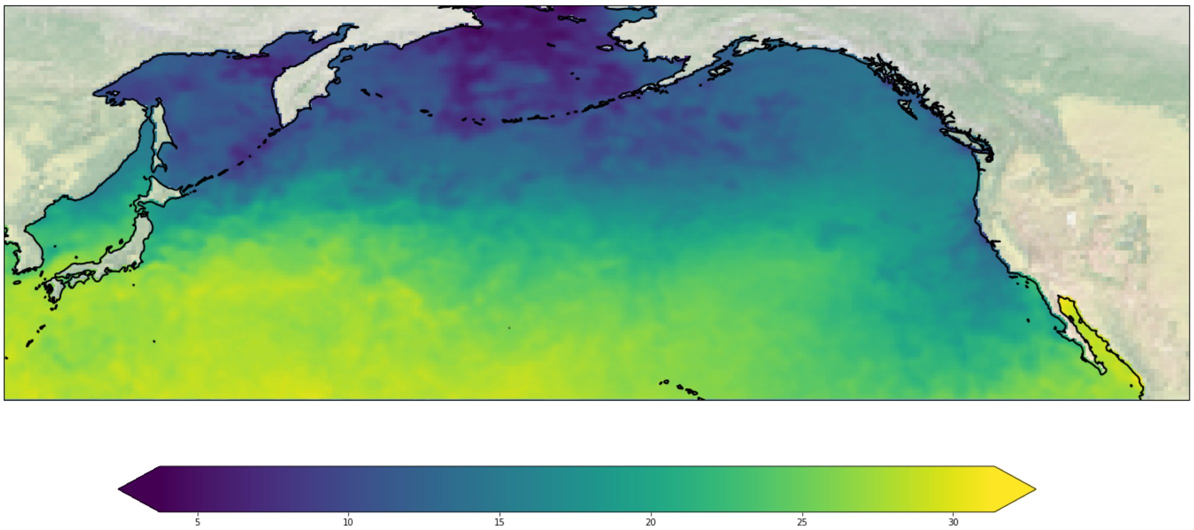
```
file2read = Dataset(fp) # reading the nc file and creating a dataset
for i in file2read.variables:
    print(file2read[i].name, file2read[i].dimensions, file2read[i].size)

t = file2read.variables['time'][:] # time is given in days since 1800-01
-01 00:00:00
ref = datetime.date(1800,1,1).toordinal()
time = ref + t
sst = file2read.variables['sst'][:]
lon = file2read.variables['lon'][:]
lat = file2read.variables['lat'][:]
```

```
lat ('lat',) 180
lon ('lon',) 520
sst ('time', 'lat', 'lon') 1255644000
time ('time',) 13415
```

Step #6. Preview Data

In [11]:
```
# Make quick checkpoint figure of SST
f=plt.figure(figsize=(24, 24))
ax = plt.axes(projection=ccrs.PlateCarree(central_longitude=180))
ax.set_extent([125,260,20,65], ccrs.PlateCarree())
ax.stock_img()
im = ax.pcolormesh(lon-180, lat, sst[0,:,:]); #plt.show(block=False)
ax.coastlines(resolution='50m', color='black', linewidth=2)
colorbar_ax = f.add_axes([0.2, 0.3, 0.6, 0.03])
_=plt.colorbar(im,cax=colorbar_ax,orientation='horizontal',extend='both'
)
```



Step #7. Convert time from proleptic Gregorian ordinal to a calendar dates *(year, month and day)* and day of year

Takes in to account leap years.

In [ ]:
```
T = len(time)
year = np.zeros((T))
month = np.zeros((T))
day = np.zeros((T))
doy = np.zeros((T))

for i in range(len(time)):
    year[i] = date.fromordinal(int(time[i])).year
    month[i] = date.fromordinal(int(time[i])).month
    day[i] = date.fromordinal(int(time[i])).day

# Leap-year baseline for defining day-of-year values
year_leapYear = 2012 # This year was a leap-year and therefore doy in ra
nge of 1 to 366
t_leapYear = np.arange(date(year_leapYear, 1, 1).toordinal(),date(year_l
eapYear, 12, 31).toordinal()+1)
dates_leapYear = [date.fromordinal(tt.astype(int)) for tt in t_leapYear]
month_leapYear = np.zeros((len(t_leapYear)))
day_leapYear = np.zeros((len(t_leapYear)))
doy_leapYear = np.zeros((len(t_leapYear)))
for tt in range(len(t_leapYear)):
    month_leapYear[tt] = date.fromordinal(t_leapYear[tt]).month
    day_leapYear[tt] = date.fromordinal(t_leapYear[tt]).day
    doy_leapYear[tt] = t_leapYear[tt] - date(date.fromordinal(t_leapYear
[tt]).year,1,1).toordinal() + 1

# Calculate day-of-year values
for tt in range(T):
    doy[tt] = doy_leapYear[(month_leapYear == month[tt]) * (day_leapYear
 == day[tt])]

# Constants (doy values for Feb-28 and Feb-29) for handling leap-years
feb28 = 59
feb29 = 60
```

Step #8. Loop through data to compute marine heatwave metrics

Returns (variable_name, size) :

- seasonal_climatology [13415,180,520]
- climatologoy_threshold [13415,180,520]
- mhw_anomaly [13415,180,520]
- mhw_duration [13415,180,520]
- avg_duration [180,520]
- avg_intensity [180,520]
- mhw_freq [180,520]

In [ ]:

```
# Initialize matrices
MHW_start_index =  nans([13415,180,520])
seasonal_climatology = nans([13415,180,520])
climatologoy_threshold = nans([13415,180,520])
mhw_anomaly = nans([13415,180,520])
mhw_duration = nans([13415,180,520])
mhw_freq = nans([1,180,520])
avg_intensity = nans([1,180,520])
avg_duration = nans([1,180,520])

# Loop through each lat-lon pair and calculate MHW metrics
for i in range(len(lat)):
    print((i+1)/180*100,'% complete')
    for j in range(len(lon)):

        ssti = np.ma.filled(sst[:,i,j], np.nan)
        if np.isnan(ssti).any():
                continue # continues with the next iteration of the loop

        tempClim = ssti.copy()
        TClim = np.array([T]).copy()[0]
        yearClim = year.copy()
        monthClim = month.copy()
        dayClim = day.copy()
        doyClim = doy.copy()

        # Length of climatological year
        lenClimYear = 366

        # Start and end indices
        clim_start = np.where(yearClim == climatologyPeriod[0])[0][0]
        clim_end = np.where(yearClim == climatologyPeriod[1])[0][-1]

        # Inialize arrays
        thresh_climYear = np.NaN*np.zeros(lenClimYear)
        seas_climYear = np.NaN*np.zeros(lenClimYear)
        clim = {}
        clim['thresh'] = np.NaN*np.zeros(TClim)
        clim['seas'] = np.NaN*np.zeros(TClim)

        # Loop over all day-of-year values, and calculate threshold and
 seasonal climatology across years
        for d in range(1,lenClimYear+1):
            # Special case for Feb 29
            if d == feb29:
                continue
            # find all indices for each day of the year +/- windowHalfWi
dth and from them calculate the threshold
            tt0 = np.where(doyClim[clim_start:clim_end+1] == d)[0]
            # If this doy value does not exist (i.e. in 360-day calendar
s) then skip it
            if len(tt0) == 0:
                continue
            tt = np.array([])
            for w in range(-windowHalfWidth, windowHalfWidth+1):
                tt = np.append(tt, clim_start+tt0 + w)
```

```
            tt = tt[tt>=0] # Reject indices "before" the first element
            tt = tt[tt<TClim] # Reject indices "after" the last element
            thresh_climYear[d-1] = np.percentile(nonans(tempClim[tt.asty
pe(int)]), pctile)
            seas_climYear[d-1] = np.mean(nonans(tempClim[tt.astype(int
)]))

        # Special case for Feb 29
        thresh_climYear[feb29-1] = 0.5*thresh_climYear[feb29-2] + 0.5*th
resh_climYear[feb29]
        seas_climYear[feb29-1] = 0.5*seas_climYear[feb29-2] + 0.5*seas_c
limYear[feb29]

        if smoothPercentile:
            # If the climatology contains NaNs, then assume it is a <365
-day year and deal accordingly
            if np.sum(np.isnan(seas_climYear)) + np.sum(np.isnan(thresh_
climYear)): # does data contain any nans
                valid = ~np.isnan(thresh_climYear)
                thresh_climYear[valid] = runavg(thresh_climYear[valid],
smoothPercentileWidth)
                valid = ~np.isnan(seas_climYear)
                seas_climYear[valid] = runavg(seas_climYear[valid], smoo
thPercentileWidth)
            # >= 365-day year
            else:
                thresh_climYear = runavg(thresh_climYear, smoothPercenti
leWidth)
                seas_climYear = runavg(seas_climYear, smoothPercentileWi
dth)

        # Generate threshold for full time series
        clim['thresh'] = thresh_climYear[doy.astype(int)-1]
        clim['seas'] = seas_climYear[doy.astype(int)-1]

        # Save vector indicating which points in temp are missing values
        clim['missing'] = np.isnan(ssti)
        # Set all remaining missing sst values equal to the climatology
        ssti[np.isnan(ssti)] = clim['seas'][np.isnan(ssti)]

        # Time series of "True" when threshold is exceeded, "False" othe
rwise
        exceed_bool = ssti - clim['thresh']
        exceed_bool[exceed_bool<=0] = False # normal SST
        exceed_bool[exceed_bool>0] = True # MHW

        # Find contiguous regions of exceed_bool = True
        events, n_events = ndimage.label(exceed_bool) # Label features i
n an array. non-zero values in input are counted as features and zero va
lues are considered the background.
            # events = An integer ndarray where each unique feature in i
nput has a unique label in the returned array.
            # n_events = Number of objects found.

        # Initialize MHW output variable
        mhw = {}
        mhw['time_start'] = [] # datetime format
```

```
        mhw['time_end'] = [] # datetime format

        minDuration=5
        for ev in range(1,n_events+1):
            event_duration = (events == ev).sum()
            if event_duration < minDuration:
                continue # continues with the next iteration of the loop
            mhw['time_start'].append(time[np.where(events == ev)[0][0]])
            mhw['time_end'].append(time[np.where(events == ev)[0][-1]])

        # Link heat waves that occur before and after a short gap (gap m
ust be no longer than maxGap)
        joinAcrossGaps= True
        maxGap=2
        if joinAcrossGaps:
            # Calculate gap length for each consecutive pair of events
            gaps = np.array(mhw['time_start'][1:]) - np.array(mhw['time_
end'][0:-1]) - 1
            if len(gaps) > 0:
                while gaps.min() <= maxGap:
                    # Find first short gap
                    ev = np.where(gaps <= maxGap)[0][0]
                    # Extend first MHW to encompass second MHW (includin
g gap)
                    mhw['time_end'][ev] = mhw['time_end'][ev+1]
                    # Remove second event from record
                    del mhw['time_start'][ev+1]
                    del mhw['time_end'][ev+1]
                    # Calculate gap length for each consecutive pair of
 events
                    gaps = np.array(mhw['time_start'][1:]) - np.array(mh
w['time_end'][0:-1]) - 1
                    if len(gaps) == 0:
                        break

        # Initialize MHW output variable
        mhw['time_peak'] = [] # datetime format
        mhw['date_start'] = [] # datetime format
        mhw['date_end'] = [] # datetime format
        mhw['date_peak'] = [] # datetime format
        mhw['index_start'] = []
        mhw['index_end'] = []
        mhw['index_peak'] = []
        mhw['duration'] = [] # [days]

        # Calculate marine heat wave properties
        mhw['n_events'] = len(mhw['time_start'])
        for ev in range(mhw['n_events']):
            mhw['date_start'].append(date.fromordinal(int(mhw['time_star
t'][ev])))
            mhw['date_end'].append(date.fromordinal(int(mhw['time_end'][
ev])))
        # Get SST series during MHW event, relative to both threshold an
d to seasonal climatology
            tt_start = np.where(time==mhw['time_start'][ev])[0][0]
            tt_end = np.where(time==mhw['time_end'][ev])[0][0]
            mhw['index_start'].append(tt_start)
```

```
            mhw['index_end'].append(tt_end)
            temp_mhw = ssti[tt_start:tt_end+1]
            thresh_mhw = clim['thresh'][tt_start:tt_end+1]
            seas_mhw = clim['seas'][tt_start:tt_end+1]
            mhw_relSeas = temp_mhw - seas_mhw
            mhw_relThresh = temp_mhw - thresh_mhw
            mhw_relThreshNorm = (temp_mhw - thresh_mhw) / (thresh_mhw -
seas_mhw)
            mhw_abs = temp_mhw
        # Find peak
            tt_peak = np.argmax(mhw_relSeas) # index of maiximum value
            mhw['time_peak'].append(mhw['time_start'][ev] + tt_peak)
            mhw['date_peak'].append(date.fromordinal(int(mhw['time_star
t'][ev]) + tt_peak)) # adding index of peak to start time
            mhw['index_peak'].append(tt_start + tt_peak)
        # MHW Duration
            mhw['duration'].append(len(mhw_relSeas))
        # MHW Anomaly above seasonal climatology
            mhw_anomaly[(np.arange(tt_start,tt_end+1)),i,j] = mhw_relSea
s # MHW tempeature anomaly

        # Store data for each lat-lon combination
        seasonal_climatology[:,i,j] = np.asarray(clim['seas'])
        climatologoy_threshold[:,i,j] = np.asarray(clim['thresh'])
        mhw_anomaly[(np.arange(tt_start,tt_end+1)),i,j] = mhw_relSeas #
 MHW tempeature anomaly
        mhw_duration[mhw['index_start'],i,j] = np.asarray(mhw['duration'
]) # event duration index on day 1
        avg_duration[0,i,j] = np.asarray(mhw['duration']).mean() # avera
ge duration
        avg_intensity[0,i,j] = mhw_relSeas.mean() # average intensity
        mhw_freq[0,i,j] = np.asarray(mhw['n_events'])/37 # average no. o
f events per year (averaged over 37 years)

ssta = sst - seasonal_climatology
```

Step #9. Save New Variables (mhw_stats_NP.npz)

mhw_stats_NP.npz

- ssta[13415,180,520]
- seasonal_climatology [13415,180,520]
- climatologoy_threshold [13415,180,520]
- mhw_anomaly [13415,180,520]
- mhw_duration [13415,180,520]
- avg_duration [180,520]
- avg_intensity [180,520]
- mhw_freq [180,520]

In [ ]:
```
# Save Output in directory specified as "path" in Step #4
os.chdir(path)
print ('where this data will be saved: ',os.getcwd())

np.savez('mhw_stats_NP', seasonal_climatology=seasonal_climatology, clim
atologoy_threshold=climatologoy_threshold,mhw_anomaly=mhw_anomaly,mhw_du
ration=mhw_duration,avg_duration=avg_duration,avg_intensity=avg_intensit
y,mhw_freq=mhw_freq,ssta=ssta)
```

In [15]:
```
## To reload saved data without re-running previous cells, uncomment the
 code below and re-run Step #3 (Python libraries) and Step #5 (SST data)

# data = np.load('mhw_stats_NP.npz')
# print(data.keys())
# seasonal_climatology = data["seasonal_climatology"]
# climatologoy_threshold = data['climatologoy_threshold']
# avg_intensity = data['avg_intensity']
# avg_duration = data['avg_duration']
# mhw_freq = data['mhw_freq']
# ssta = data['ssta']
```

```
['seasonal_climatology', 'climatologoy_threshold', 'mhw_anomaly', 'mhw_
duration', 'avg_duration', 'avg_intensity', 'mhw_freq']
```

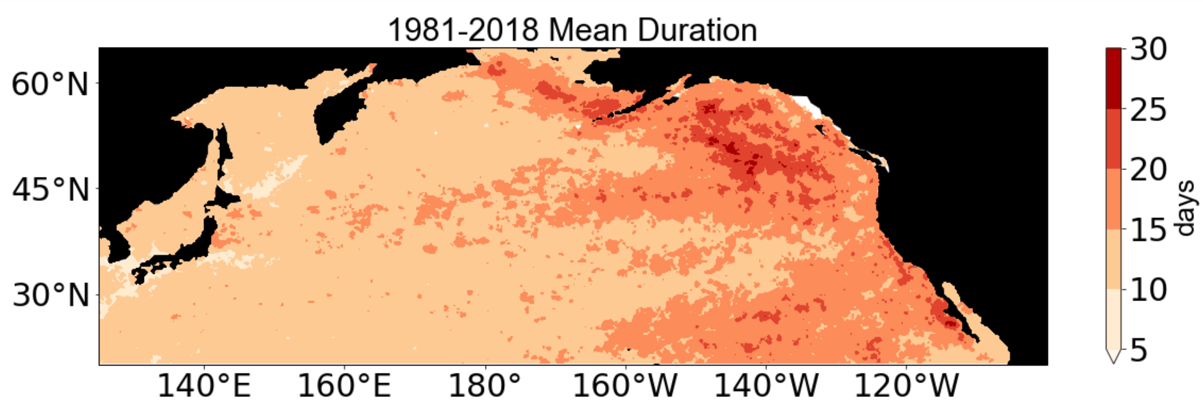
Step #10. Plot 1981-2018 Mean Marine Heatwave Duration

Saves as *meanMHWduration.png* in current working directory

In [20]:
```
plt.rc('xtick', labelsize=30)
plt.rc('ytick', labelsize=30)
fig = plt.figure(figsize=(20, 20)) # 8,10

# Label axes of a Plate Carree projection with a central longitude of 18
0:
ax1 = plt.subplot(211, projection=ccrs.PlateCarree(central_longitude=180
))
ax1.set_global()
ax1.set_extent([-55, 80, 20, 65], crs=ccrs.PlateCarree(central_longitude
=180))
ax1.set_xticks([140,160,180,200,220,240], crs=ccrs.PlateCarree())
ax1.set_yticks([30,45,60], crs=ccrs.PlateCarree())
lon_formatter = LongitudeFormatter(zero_direction_label=True)
lat_formatter = LatitudeFormatter()
ax1.xaxis.set_major_formatter(lon_formatter)
ax1.yaxis.set_major_formatter(lat_formatter)
levels = [5,10,15,20,25,30]
CS = plt.contourf(lon-180, lat, np.squeeze(avg_duration), levels, cmap=p
lt.cm.OrRd,extend ='min')
cbar = plt.colorbar(CS, shrink=0.6, extend ='both')
ax1.add_feature(cfeature.LAND,facecolor='k')
ttl = plt.title('1981-2018 Mean Duration',fontname='Arial',fontsize=30,l
oc='center')
cbar.ax.set_ylabel('days',fontname='Arial',fontsize=26)

fig.savefig('meanMHWduration.png',bbox_inches='tight')
```



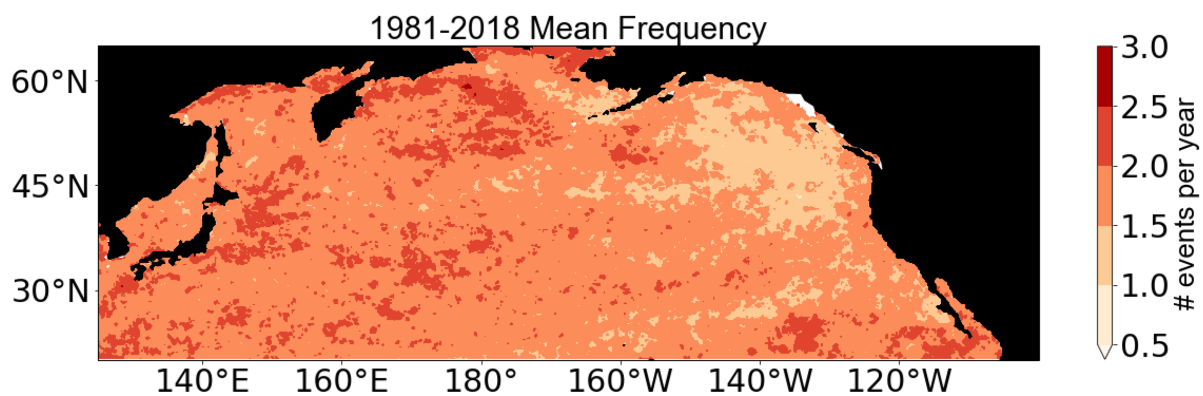
Step #11. Plot 1981-2018 Mean Marine Heatwave Frequency

Saves as *meanMHWfrequency.png* in current working directory

In [21]:
```
plt.rc('xtick', labelsize=30)
plt.rc('ytick', labelsize=30)
fig = plt.figure(figsize=(20, 20)) # 8,10

# Label axes of a Plate Carree projection with a central longitude of 18
0:
ax1 = plt.subplot(211, projection=ccrs.PlateCarree(central_longitude=180
))
ax1.set_global()
ax1.set_extent([-55, 80, 20, 65], crs=ccrs.PlateCarree(central_longitude
=180))
ax1.set_xticks([140,160,180,200,220,240], crs=ccrs.PlateCarree())
ax1.set_yticks([30,45,60], crs=ccrs.PlateCarree())
lon_formatter = LongitudeFormatter(zero_direction_label=True)
lat_formatter = LatitudeFormatter()
ax1.xaxis.set_major_formatter(lon_formatter)
ax1.yaxis.set_major_formatter(lat_formatter)
levels = [0.5,1,1.5,2,2.5,3]
CS = plt.contourf(lon-180, lat, np.squeeze(mhw_freq), levels, cmap=plt.c
m.OrRd,extend ='min')
cbar = plt.colorbar(CS, shrink=0.6)
ax1.add_feature(cfeature.LAND,facecolor='k')
ttl = plt.title('1981-2018 Mean Frequency',fontname='Arial',fontsize=30,
loc='center')
cbar.ax.set_ylabel('# events per year',fontname='Arial',fontsize=26)

fig.savefig('meanMHWfrequency.png',bbox_inches='tight')
```



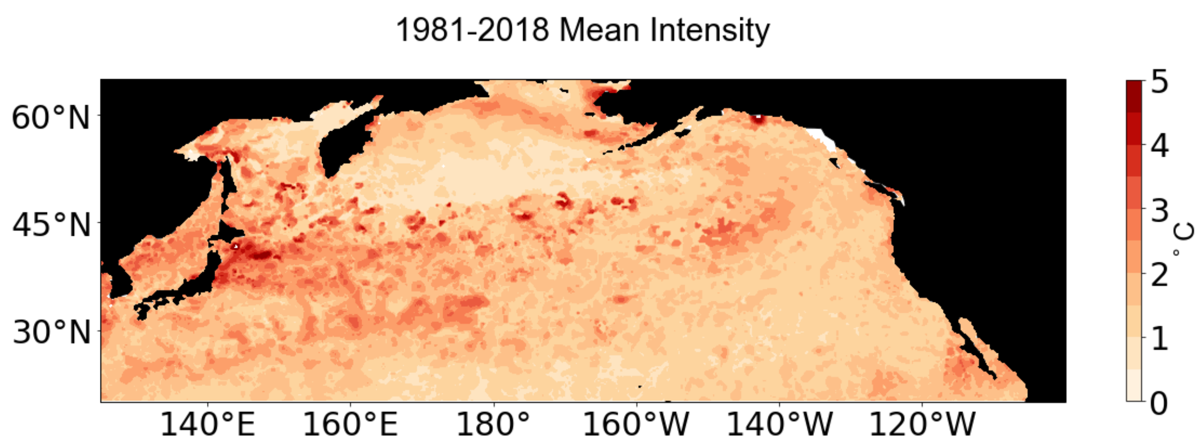
Step #12. Plot 1981-2018 Mean Marine Heatwave Intensity

Saves as *meanMHWintensity.png* in current working directory

In [22]:
```
plt.rc('xtick', labelsize=30)
plt.rc('ytick', labelsize=30)
fig = plt.figure(figsize=(20, 20)) # 8,10

# Label axes of a Plate Carree projection with a central longitude of 18
0:
ax1 = plt.subplot(211, projection=ccrs.PlateCarree(central_longitude=180
))
ax1.set_global()
ax1.set_extent([-55, 80, 20, 65], crs=ccrs.PlateCarree(central_longitude
=180))
ax1.set_xticks([140,160,180,200,220,240], crs=ccrs.PlateCarree())
ax1.set_yticks([30,45,60], crs=ccrs.PlateCarree())
lon_formatter = LongitudeFormatter(zero_direction_label=True)
lat_formatter = LatitudeFormatter()
ax1.xaxis.set_major_formatter(lon_formatter)
ax1.yaxis.set_major_formatter(lat_formatter)
levels = [0,0.5,1,1.5,2,2.5,3,3.5,4,4.5,5]
CS = plt.contourf(lon-180, lat, np.squeeze(avg_intensity), levels, cmap=
plt.cm.OrRd)
cbar = plt.colorbar(CS, shrink=0.6, extend ='both')
ax1.add_feature(cfeature.LAND,facecolor='k')
ttl = plt.title('1981-2018 Mean Intensity',fontname='Arial',fontsize=30,
loc='center')
ttl.set_position([.5, 1.10])
cbar.ax.set_ylabel('$^\circ$C',fontname='Arial',fontsize=26)

fig.savefig('meanMHWintensity.png',bbox_inches='tight')
```



Step #13. Plot Marine Heatwave Classification Figure

Saves as *definingMHW.png* in current working directory

In [32]:

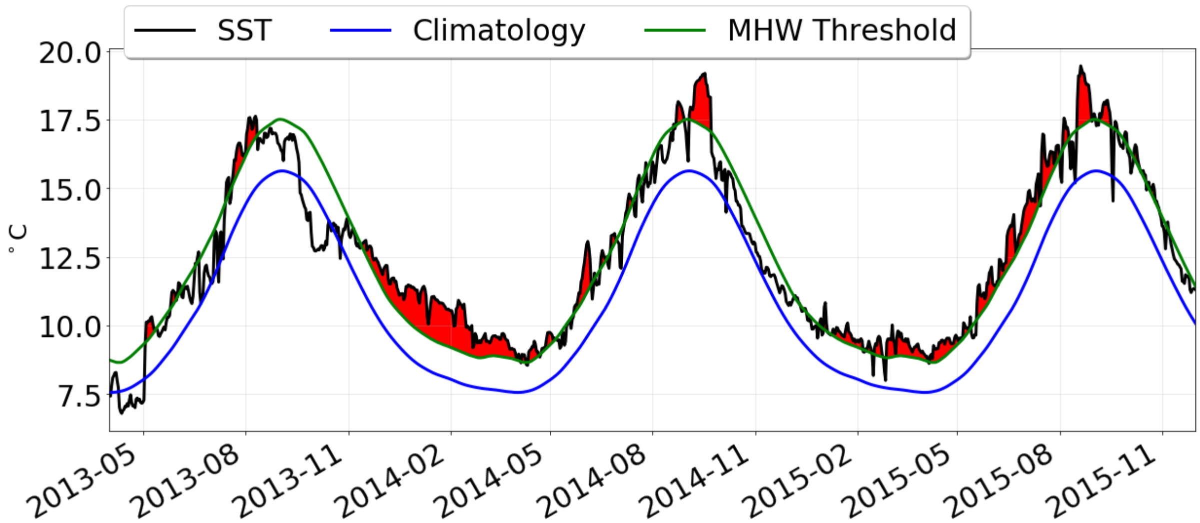
```
# Index in to time to get time slice between April-1-2013 and December-1
-2015
T = len(time)
t_start= int(date(2013, 4, 1).toordinal())
t_end = int(date(2015, 12, 1).toordinal())
index_start = np.asscalar(np.where(time==t_start)[0])
index_end = np.asscalar(np.where(time == t_end)[0])
time_slice = np.arange(time[index_start],time[index_end+1])
dates = [date.fromordinal(tt.astype(int)) for tt in time_slice]

# Find a coordinate in the Pacific marine heatwave region (46ºN, 144ºW)
print(np.where(lat==46.125),np.where(lon==216.125))
print('latitude',lat[104],'ºN and longitude',180-(lon[364]-180),'ºW')
i = 104
j = 364

fig = plt.figure(figsize=(20, 8))
plt.rc('xtick', labelsize=30)
plt.rc('ytick', labelsize=30)
y1 = sst[index_start:index_end+1,i,j]
y2 = climatologoy_threshold[index_start:index_end+1,i,j]
plt.plot(dates, y1, dates, y2, color='k')
plt.fill_between(dates, y1, y2, where=y2 <= y1, facecolor='red', interpo
late=True)
a= plt.plot(dates,np.squeeze(sst[index_start:index_end+1,i,j]),'k',label
="SST",linewidth = 3)
b= plt.plot(dates,np.squeeze(seasonal_climatology[index_start:index_end+
1,i,j]),'b',label="Climatology",linewidth = 3)
c= plt.plot(dates,np.squeeze(climatologoy_threshold[index_start:index_en
d+1,i,j]),'g',label="MHW Threshold",linewidth = 3)
plt.legend(loc="upper left", bbox_to_anchor=[0, 1.15],ncol=3, shadow=Tru
e, fancybox=True,fontsize=30)
_=plt.ylabel('$^\circ$C',size=25)
plt.gcf().autofmt_xdate()
plt.grid(True,alpha = 0.3)
plt.xlim(dates[0], dates[-1])
ttl = plt.title('Defining Marine Heatwaves',fontname='Arial',fontsize=45
,loc='center')

fig.savefig('definingMHW.png',bbox_inches='tight')
```

```
(array([104]),) (array([364]),)
latitude 46.125 ºN and longitude 143.875 ºW
```



Step #14. Plot SST Anomalies on February-01-2014

Saves as _Feb1_2014*SSTA.png* in current working directory

In [37]:
```
# Index time
t_val= int(date(2014,2, 1).toordinal())
t_ind = np.asscalar(np.where(time==t_val)[0])

fig = plt.figure(figsize=(20, 20)) # 8,10
# Label axes of a Plate Carree projection with a central longitude of 18
0:
ax1 = plt.subplot(211, projection=ccrs.PlateCarree(central_longitude=180
))
ax1.set_global()
ax1.set_extent([-55, 80, 20, 65], crs=ccrs.PlateCarree(central_longitude
=180))
ax1.set_xticks([140,160,180,200,220,240], crs=ccrs.PlateCarree())
ax1.set_yticks([30,45,60], crs=ccrs.PlateCarree())
lon_formatter = LongitudeFormatter(zero_direction_label=True)
lat_formatter = LatitudeFormatter()
ax1.xaxis.set_major_formatter(lon_formatter)
ax1.yaxis.set_major_formatter(lat_formatter)
levels = [-3,-2.5,-2,-1.5,-1,-0.5,0,0.5,1,1.5,2,2.5,3]
CS = plt.contourf(lon-180, lat, np.squeeze(ssta[t_ind,:,:]), levels, cma
p=plt.cm.RdYlBu_r,extend='both')
cbar = plt.colorbar(CS, shrink=0.6, extend ='both')
ax1.add_feature(cfeature.LAND,facecolor='k')
ttl = plt.title('February 1, 2014',fontname='Arial',fontsize=30,loc='cen
ter')
cbar.ax.set_ylabel('SST Anomaly [$^\circ$C]',fontname='Arial',fontsize=2
6)

# plot marker to indicate location of timeseries in Step #13 figure
plt.plot(216,46,color='white',markeredgecolor='black',linewidth=3,marker
='o',markersize=12,transform=ccrs.Geodetic())

fig.savefig('Feb1_2014_SSTA.png',bbox_inches='tight')
```