Temperature Profile Classification - 2 Class system - Full DataSet Load

GMM classification of Southern Ocean Argo float temperature profile data. This notebook uses a previously created model, PCA and sample data.

Dask import

In [1]:

```
#Dask server setup cell
'''
target_version='0.19.0'
!pip install xarray=={target_version} --upgrade #--upgrade

import logging
import subprocess
from dask.distributed import Client
from dask_gateway import Gateway
from distributed import WorkerPlugin

import dask
dask.config.set({"array.slicing.split_large_chunks": True})

class PipPlugin(WorkerPlugin):
    """
    Install packages on a worker as it starts up.

    Parameters
    ----------
    packages : List[str]
        A list of packages to install with pip on startup.
    """
    def __init__(self, packages):
        self.packages = packages

    def setup(self, worker):
        logger = logging.getLogger("distributed.worker")
        subprocess.call(['python', '-m', 'pip', 'install', '--upgrade'] + self.packages)
        logger.info("Installed %s", self.packages)

def check():
    import xarray
    return xarray.__version__

gateway = Gateway()
cluster = gateway.new_cluster(worker_memory=8)
cluster.scale(20)
client = Client(cluster)
client

plugin = PipPlugin([f'xarray=={target_version}'])
client.register_worker_plugin(plugin)
client.run(check)
'''
blank=1
```

In [2]:

```
#client
```

Choices for data

In [3]:
```
#Experiment data for analysis
dataVariableId = 'thetao'
dataExperimentId = 'historical'
dataSourceId = 'UKESM1-0-LL'
dataInstitutionId = 'MOHC'
approvedIds = ["r3i1p1f2"] #insert start of approved member_ids

#File imports
maskName = "OceanMaskVolcello"
modelName = "GMM_UK_2Class_R3_v2"

#Data definitions
startDate = '1980-01'
endDate = '2009-12'
timeRange = slice(startDate, endDate)
levSel = slice(0, 2000) #Selected levels to be investigated
maxLat = -30 #Selected latitude to be investigated
runIdSel = 0
maskEnable = False #Decides if training data mask is applied, or if full data set is class
```

Libaries and Modules

Importing the necessary libaries and modules for the notebook.

In [174…
```
#Import cell
import calendar
#import cartopy.crs as ccrs
#import cartopy.feature as cfeature
import dask.dataframe as dd
import fsspec
import matplotlib.dates as mdates
import matplotlib as mpl ###
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import plotly.express as px
import pickle as pk
import matplotlib.ticker as ticker
import xarray as xr
import zarr

from dask import config
from dask import delayed
from joblib import dump, load
from matplotlib.pyplot import cm
from sklearn import mixture
from sklearn.decomposition import PCA
from sklearn import preprocessing

config.set(**{'array.slicing.split_large_chunks': True})
print("Imports complete")
```

```
Imports complete
```

Importing data sets

Importing the data for the models.

Import sample data set and corresponding time/geo data

In [5]:

```
#Importing UK ESM data cell

#Selecting data tables
df = pd.read_csv('https://storage.googleapis.com/cmip6/cmip6-zarr-consolidated-stores.csv'
dfFilt = df[df.variable_id.eq(dataVariableId) & df.experiment_id.eq(dataExperimentId) & df

memberArr = np.empty(shape=(0), dtype=bool)
for i in dfFilt["member_id"]:
    rowSel = i[:] in approvedIds #adapt i[:] to match size of approvedIds
    memberArr = np.append(memberArr, rowSel)

memberSer = pd.Series(memberArr, name='bools')
dfFilt = dfFilt[memberSer.values]

#Opening and counting number of tables
fileSetList = []
for i in range(len(dfFilt)):
    zstore = dfFilt.zstore.values[i]
    mapper = fsspec.get_mapper(zstore)
    fileRaw = xr.open_zarr(mapper, consolidated=True)
    fileSetList.append(fileRaw)
fileCount = len(fileSetList)
if fileCount:
    print(str(fileCount)+" "+dataSourceId+" data sets opened")
else:
    print("No UKESM data sets opened")

#Formatting dates into np.datetime64 format
for i in range(fileCount):
    startDateIterate = np.datetime64(fileSetList[i]['time'].values[0],'M')
    endDateIterate = np.datetime64(fileSetList[i]['time'].values[-1],'M') + np.timedelta64
    fileSetList[i]['time']=('time', np.arange(startDateIterate, endDateIterate, dtype='dat
    fileSetList[i]['time_bnds']=('time_bnds', np.arange(startDateIterate, endDateIterate,
fileSet = xr.combine_nested(fileSetList, concat_dim='RunId') #Combining data sets

dataRaw = fileSet.thetao
try: #Adjusting array names
    dataRaw = dataRaw.rename({"latitude":"lat", "longitude":"lon"})
except:
    pass

print("Data sets successfully merged and renamed into dataRaw. Data dimensions are "+str(d
#dataRaw
```

```
1 UKESM1-0-LL data sets opened
Data sets successfully merged and renamed into dataRaw. Data dimensions are Frozen({'RunI
d': 1, 'time': 1980, 'lev': 75, 'j': 330, 'i': 360}).
```

In [6]:

```
dfFilt
```

Out[6]:

	activity_id	institution_id	source_id	experiment_id	member_id	table_id	variable_id	grid_label	
213868	CMIP	MOHC	UKESM1-0-LL	historical	r3i1p1f2	Omon	thetao	gn	gs://cmip6/

In [7]:

```
#UK ESM raw processing cell
dfESMLev = dataRaw.sel(lev=levSel) #Selects level data down to 2k
dfESMLevT = dfESMLev.sel(time=timeRange)
dfESMLatLevT = dfESMLevT.where(dfESMLevT.lat < maxLat, drop=True) #Selection of latitude
dfESMLatLevT = dfESMLatLevT.squeeze()
#dfESMLatLevT = dfESMLatLevT.reset_coords(drop=True) #Removes lev if single value

globalStartDate = dfESMLatLevT["time"][0].values
globalDateInc = dfESMLatLevT["time"][1].values - globalStartDate
#np.datetime64(globalDateInc,'D')
globalEndDateIn = dfESMLatLevT["time"][-1].values
globalEndDateOut = globalEndDateIn + globalDateInc

globalStartDateStr = str(globalStartDate)[:7]
globalEndDateInStr = str(globalEndDateIn)[:7]
globalEndDateOutStr = str(globalEndDateOut)[:7]

print("UKESM data loaded and stored in dfESMLatLevT. Data dimensions are "+str(dfESMLatLev
#dfESMLatLevT #Uncomment to see data set
```

```
UKESM data loaded and stored in dfESMLatLevT. Data dimensions are Frozen({'time': 360, 'le
v': 54, 'j': 139, 'i': 360}).
```

Loading ocean Masks

In [8]:

```
#Ocean mask import cell
maskFile = xr.open_dataset(maskName)
oceanMask = maskFile.to_array()
maskFile = xr.open_dataset("OceanMaskUKESM1")
oceanMask2 = maskFile.to_array()
print("Mask Loaded and stored in oceanMask and oceanMask2 (volcello and UKESM).")
```

```
Mask Loaded and stored in oceanMask and oceanMask2 (volcello and UKESM).
```

Unpacking ocean masks

In [9]:

```
#Mask unpacking cell
geoRange = oceanMask #copying mask
geoRange = geoRange.rename({"variable":"cleanMe"}) #Dimension removal
geoRange = geoRange.sel(cleanMe = geoRange.cleanMe.values[0]) #Dimension removal
geoRange = geoRange.reset_coords("cleanMe", drop=True) #Dimension removal
geoRangeS = geoRange.stack(ij =("i", "j")) #Stacking
geoRangeFilt = geoRangeS.dropna("ij")
print("Ocean mask unpacked into geoRangeFilt.")

geoRange2 = oceanMask2 #copying mask
geoRange2S = geoRange2.stack(ij =("i", "j")) #Stacking
geoRangeFilt2 = geoRange2S.dropna("ij")
print("UKESM Ocean mask unpacked into geoRangeFilt2.")
```

```
Ocean mask unpacked into geoRangeFilt.
UKESM Ocean mask unpacked into geoRangeFilt2.
```

Date Calculations

In [10]:

```
#Date calculation cell
startDateNp = np.datetime64(startDate, 'M')
endDateNp = np.datetime64(endDate, 'M')
timeDiff = endDateNp - startDateNp
```

```
timeDiff = timeDiff.astype(int) + 1
print("Calculated date range.")
```

```
Calculated date range.
```

Calculation functions

Functions:

- pickRand - Takes in data frame and returns sampled data frame with a randomly selected number of rows from the input data frame, controled by the second input variable to the function.
- storeMeta - Returns a np array containing the latitude and longitude data for an input xarray and associated ij.
- loadModel - loadeds and returns GMM model named in input.
- saveModel - saves input GMM model to provided name, if no name provided default is GMMGenerated.

In [11]:

```
#Calculation functions cell
def pickRand(dataArray, sampleFactor):
    '''Returns a sample of the input array, size of sampled array is based on sampleFacto
    arrLen = len(dataArray)
    if sampleFactor > 1:
        sampleSize = int(sampleFactor)
    elif sampleFactor > 0:
        sampleSize = int(sampleFactor*arrLen)
    else:
        return 1

    filtArr = np.zeros(arrLen, dtype=bool) # empty mask
    sampleId = np.random.choice(arrLen, sampleSize, False) # np array of randomly generate
    for i in sampleId:
        filtArr[i] = True # populating mask
    return dataArray[filtArr] # applies mask


def pickRandMask(maskLen, maskQuantity, sampleFactor):
    '''Returns a linear mask for the input dimensions, size of mask is based on sampleFact
    if sampleFactor > 1:
        sampleSize = int(sampleFactor)
    elif sampleFactor > 0:
        sampleSize = int(sampleFactor*maskLen)
    else:
        return 1

    globalArr = np.empty(shape=(0), dtype=bool)
    for i in range(maskQuantity):
        filtArr = np.zeros(maskLen, dtype=bool) # empty mask
        sampleId = np.random.choice(maskLen, sampleSize, False) # np array of randomly ge
        for j in sampleId:
            filtArr[j] = True # populating mask
        globalArr = np.append(globalArr, filtArr)
    return globalArr


def storeMeta(dataArray):
    '''Returns a np array containing the latitude and longitude data for the input xarray
    storeLen = len(dataArray["lat"]) # assumes each lat has a corresponding lon
    storage = np.empty(shape=(0,storeLen))
    storage = np.append(storage, [dataArray["lat"].values], axis = 0)
    storage = np.append(storage, [dataArray["lon"].values], axis = 0)
    #storage = np.append(storage, [dataArray["time"].values], axis = 0)
```

```
    #storage = np.append(storage, [dataArray["ij"].values], axis = 0)
    return storage


def loadModel(modelName:str):
    '''Loades the input GMM model named in the functions input. Returns loaded model.'''
    means = np.load(modelName + '_means.npy')
    covar = np.load(modelName + '_covariances.npy')
    GMModel = mixture.GaussianMixture(n_components = len(means), covariance_type='full')
    GMModel.precisions_cholesky_ = np.linalg.cholesky(np.linalg.inv(covar))
    GMModel.weights_ = np.load(modelName + '_weights.npy')
    GMModel.means_ = means
    GMModel.covariances_ = covar
    return GMModel


def saveModel(GMModel, modelName = "GMMGenerated"):
    '''Saves the input GMM model's weights, means and covariances. Assigns input name if p
    GMModel_name = str(modelName)
    np.save(modelName + '_weights', GMModel.weights_, allow_pickle=False)
    np.save(modelName + '_means', GMModel.means_, allow_pickle=False)
    np.save(modelName + '_covariances', GMModel.covariances_, allow_pickle=False)
    return 0

print("Calculation functions defined.")
```

```
Calculation functions defined.
```

Plotting functions

Functions:

- bicPlot - Plots BIC score array against component number.
- locationPlotGroup - plots location and classification of data points for an input numpy array.
- locationPlotGroupDF - plots location and classification of data points for an input data frame.
- locationPlotGroupDFMonthly - plots location and classification of data points for an input data frame in monthly subplots.
- locationPlotTime - plots locations of an input data array on a map with a colour scale for time.
- locationPlotUncertaintyDF - plots uncertainty in classification on a location plot.
- tempPointPlot - Plots the temperature profile of a single point against depth.
- tempGroupPlot - Plots the mean/+-1std temperature profiles of all classes in input dataArrays (seperate mean and std).

In [12]:

```
#Plotting functions Cell
sampleDepthAxis = dfESMLatLevT["lev"]

def bicPlot(bicArray, startNo, endNo, skipNo, title, label, plotNo):
    '''Plots input BIC score array'''
    plt.figure(plotNo, figsize=(20, 8))
    plt.style.use("seaborn-darkgrid")
    componentRange = range(startNo, endNo, skipNo)
    plt.plot(componentRange, bicArray, label = str(label))

    bicArrayMax = np.max(bicArray)
    bicArrayMin = np.min(bicArray)
    bicRange = bicArrayMax-bicArrayMin
    if bicRange == 0:
        bicRange = 20 #provides border 1 if all bic values are identical
    plt.xticks(componentRange)
```

```
    plt.xlim([startNo-0.5, endNo+0.5])
    plt.ylim([bicArrayMin-0.05*bicRange, bicArrayMax+0.05*bicRange])

    plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.xlabel("Number of components")
    plt.ylabel("BIC score")
    plt.title(title)


def locationPlotGroup(metaDataArray, size, plotNo):
    '''Plots locations of numpy arrays with group colour scheme'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(metaDataArray[1], metaDataArray[0], transform=ccrs.PlateCarree(), c =
    cb = plt.colorbar(im)
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="
    plt.title("Grouped Sample Locations ("+str(len(metaDataArray[0]))+")")


def locationPlotGroupDFTime(dataFrame, title, size, plotNo):
    '''Plots locations of data frame points with group colour scheme'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(dataFrame["lon"], dataFrame["lat"], transform=ccrs.PlateCarree(), c =
    cb = plt.colorbar(im)
    loc = mdates.AutoDateLocator()
    cb.ax.yaxis.set_major_locator(loc)
    cb.ax.yaxis.set_major_formatter(mdates.ConciseDateFormatter(loc))
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="
    plt.title(str(title))


def locationPlotGroupDFLab(dataFrame, title, size, plotNo):
    '''Plots locations of data frame points with group colour scheme'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(dataFrame["lon"], dataFrame["lat"], transform=ccrs.PlateCarree(), c =
    cb = plt.colorbar(im)
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="
    plt.title(str(title))


def locationPlotGroupDFMonthly(dataFrame, title, plotNo):
    '''Plots locations of dataframe points by monthly subplot with group colour scheme'''
    fig = plt.figure(plotNo, figsize=(30,42))
    plt.title(str(title))
    for i in range(1, 13):
        timeData = dataFrame.where(dataFrame["time"].dt.month==i)
        ax = plt.subplot(4, 3, i, projection=ccrs.SouthPolarStereo())
        ax.add_feature(cfeature.OCEAN)
        ax.add_feature(cfeature.COASTLINE)
        ax.coastlines()
        ax.gridlines()
        im = ax.scatter(timeData["lon"], timeData["lat"], transform=ccrs.PlateCarree(), c
```

```
        plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), colo
        plt.title(calendar.month_abbr[i])
    plt.subplots_adjust(wspace=0, hspace=0.05)
    cb_ax = fig.add_axes([0.27, 0.1, 0.5, 0.02])
    cbar = fig.colorbar(im, cax=cb_ax, orientation="horizontal")


def locationPlotTime(dataArray, size, plotNo):
    '''Plots locations of numpy arrays with date colour scheme'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(dataArray[1], dataArray[0], transform=ccrs.PlateCarree(), c= mdates.da
    cb = plt.colorbar(im)
    loc = mdates.AutoDateLocator()
    cb.ax.yaxis.set_major_locator(loc)
    cb.ax.yaxis.set_major_formatter(mdates.ConciseDateFormatter(loc))
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="k
    plt.title("Sample Locations ("+str(len(dataArray[0]))+")")


def locationPlotUncertaintyDF(dataFrame, title, size, plotNo):
    '''Plots input data array classification uncertainties'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(dataFrame["lon"], dataFrame["lat"], transform=ccrs.PlateCarree(), c =
    cb = plt.colorbar(im)
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="k
    plt.title(str(title))


def locationPlotUncertaintyDFMonthly(dataFrame, title, plotNo):
    '''Plots locations of dataframe points by monthly subplot with group colour scheme'''
    fig = plt.figure(plotNo, figsize=(30,42))
    plt.title(str(title))
    for i in range(1, 13):
        timeData = dataFrame.where(dataFrame["time"].dt.month==i)
        ax = plt.subplot(4, 3, i, projection=ccrs.SouthPolarStereo())
        ax.add_feature(cfeature.OCEAN)
        ax.add_feature(cfeature.COASTLINE)
        ax.coastlines()
        ax.gridlines()
        im = ax.scatter(timeData["lon"], timeData["lat"], transform=ccrs.PlateCarree(), c
        #cb = plt.colorbar(im, fraction=0.046, pad=0.04)
        plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), colo
        plt.title(calendar.month_abbr[i])
    plt.subplots_adjust(wspace=0, hspace=0.05)
    cb_ax = fig.add_axes([0.27, 0.1, 0.5, 0.02])
    cbar = fig.colorbar(im, cax=cb_ax, orientation="horizontal")


def locationPlotXr(dataArray, size, plotNo):
    '''Plots locations of numpy arrays with date colour scheme'''
    plt.figure(plotNo, figsize=size)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
```

```
    im = ax.scatter(dataArray["lon"], dataArray["lat"], transform=ccrs.PlateCarree())
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="E
    plt.title("Sample Locations ("+str(len(dataArray["lat"]))+")")


def surfaceTempPlot(dataArray, plotNo):
    plt.figure(plotNo, figsize=(20,20))
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    im = ax.scatter(dataArray["lon"], dataArray["lat"], transform=ccrs.PlateCarree(), c =
    cb = plt.colorbar(im)
    plt.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="E
    plt.title("Surface Temperature of Samples")


def tempPointPlot(dataArray, label, title, plotNo):
    '''Displays temperature profile plot for a given data set, singular point'''
    plt.figure(plotNo)
    plt.plot(dataArray, sampleDepthAxis, label = label)
    plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.title(str(title))
    plt.gca().invert_yaxis()


def tempGroupProfile(dataArrayMean, dataArrayStd, plotNo):
    '''Displays mean /+-1 std temperature profiles for classes in dataArrayMean and dataAr
    dataCompNo = len(dataArrayMean)
    columnNames = sampleDFSortMeans.columns.values
    dataStart = np.where(columnNames == sampleDepthAxis[0].values)[0][0]
    subPlotX = int(np.ceil(dataCompNo/5))

    plt.figure(plotNo, figsize=(35, 10*subPlotX))
    plt.style.use("seaborn-darkgrid")
    palette = cm.coolwarm(np.linspace(0,1, dataCompNo))

    for i in range(dataCompNo):
        meanT = dataArrayMean.iloc[i, dataStart:].to_numpy()
        stdT = dataArrayStd.iloc[i, dataStart:].to_numpy()

        plt.subplot(subPlotX, 5, i+1)
        plt.plot(meanT, sampleDepthAxis, marker='', linestyle="solid", color=palette[i], l
        plt.plot(meanT+stdT, sampleDepthAxis, marker='', linestyle="dashed", color=palette
        plt.plot(meanT-stdT, sampleDepthAxis, marker='', linestyle="dashed", color=palette

        plt.xlim([-2,20])
        plt.ylim([0,1000])
        ax = plt.gca()
        ax.invert_yaxis()
        ax.grid(True)

        fs = 16 #font size
        plt.xlabel("Temperature (°C)", fontsize=fs)
        plt.ylabel("Depth (m)", fontsize=fs)
        plt.title("Class = "+str(i), fontsize=fs)
        mpl.rc("xtick", labelsize=fs)
        mpl.rc("ytick", labelsize=fs)

        '''
        textstr = '\n'.join((
            r'N profs. = %i' % (nprofs[nrow], ),
            r'Mean lon = %i' % (meanLon, ),
            r'Mean lat = %i' % (meanLat, ),
            r'Post. = %i' % (meanMaxPP, )))
```

```
        props = dict(boxstyle="round", facecolor="wheat", alpha=0.8)
        ax.text(0.45, 0.25, textstr, transform=ax.transAxes, fontsize=fs, verticalalignmen
        '''


print("Plotting functions defined.")
```

```
Plotting functions defined.
```

Plotting Ocean Mask

In [13]:

```
#Mask plotting cell
#locationPlotXr(geoRangeFilt, (10,10), 1) #OceanMaskVolcello
#locationPlotXr(geoRangeFilt2, (10,10), 2) #OceanMaskUKESM1
plt.show()
```

Generating Data Samples

Identifying, masking and stacking raw data

In [14]:

```
#Identifying, masking and stacking raw data cell
dfESMLatLevTStack = dfESMLatLevT.stack(ij =("i", "j"))
dfESMLatLevTStack = dfESMLatLevTStack.transpose('time', 'ij', 'lev')
dfESMLatLevTStackFilt = dfESMLatLevTStack.sel(ij = geoRangeFilt.ij.values) #Produces 2219
dfESMLatLevTStackFilt
print("Raw data identified, stacked and stored in dfESMLatLevTStackFilt. Data dimensions:
```

```
Raw data identified, stacked and stored in dfESMLatLevTStackFilt. Data dimensions: Frozen
({'time': 360, 'ij': 22194, 'lev': 54}).
```

In [15]:

```
#Plotting raw data locations cell
#locationPlotXr(dfESMLatLevTStackFilt, (10,10), 1)
plt.show()
```

Selecting sample data

In [16]:

```
#Mask loading cell
if maskEnable:
    importName = modelName + "_Mask.npy"
    mask = np.load(importName)
    print("Data mask loaded from "+ importName +".")
else:
    print("No mask loaded.")
```

```
No mask loaded.
```

In [17]:

```
#Selecting sample data cell
sampleDataRaw = dfESMLatLevTStackFilt.reset_index('ij')
sampleDataRaw = sampleDataRaw.stack(ijT = ('time', 'ij'))

if maskEnable:
    sampleData = sampleDataRaw[:,mask] #Training data mask applied
else:
    sampleData = sampleDataRaw #Full data set to be classified
```

```
sampleData = sampleData.transpose('ijT', 'lev')
print("Sample data calculated and stored in sampleData. Sample data dimensions: "+str(samp
```

```
Sample data calculated and stored in sampleData. Sample data dimensions: Frozen({'ijT': 79
89840, 'lev': 54}).
```

Placing sample data in tables

In [18]:

```
#Location and time data to table cell
metaData = {"lat":sampleData["lat"], "lon":sampleData["lon"], "time":sampleData["time"]}
sampleMetaDF = pd.DataFrame(metaData, columns=["lat", "lon", "time"])
print("Sample lat, lon and time converted to datafile (sampleMetaDF). "+str(len(sampleMeta
sampleMetaDF.head()
```

```
Sample lat, lon and time converted to datafile (sampleMetaDF). 7989840 samples identified.
```

Out[18]:

	lat	lon	time
0	-66.111519	73.5	1980-01-01
1	-65.703316	73.5	1980-01-01
2	-65.288567	73.5	1980-01-01
3	-64.867195	73.5	1980-01-01
4	-64.439102	73.5	1980-01-01

In [19]:

```
#Temperature data to table and table merging cell
#Generating surface temperature level value and column name
surfaceLev = sampleData["lev"][0].values
surfaceData = sampleData.sel(lev = surfaceLev)
surfaceLevName = "Surface Temp ("+str(np.round(surfaceLev,2))+")"

#Exporting sample data into pandas
if True:
    sampleDataDF = sampleData.to_pandas()
    sampleDataDFClean = sampleDataDF.reset_index()
    sampleDataDFClean = sampleDataDFClean.drop(columns=['ij'])
    sampleDF = pd.concat([sampleMetaDF, sampleDataDFClean.drop(columns=["time"])], axis=1)
else:
    sampleDF = sampleMetaDF

sampleDF["time"] = pd.to_datetime(sampleDF["time"])
print("SampleData converted to datafile (sampleDataDF).  Datafiles combined into sampleDF.
sampleDF.head()
```

```
SampleData converted to datafile (sampleDataDF).  Datafiles combined into sampleDF.
```

Out[19]:

	lat	lon	time	0.5057600140571594	1.5558552742004395	2.6676816940307617	3.8562798500061035	!
0	-66.111519	73.5	1980-01-01	-1.219205	-1.242823	-1.268785	-1.290418	
1	-65.703316	73.5	1980-01-01	-1.270198	-1.278426	-1.298570	-1.315566	
2	-65.288567	73.5	1980-01-01	-1.215177	-1.222939	-1.236639	-1.251741	
3	-64.867195	73.5	1980-01-01	-1.024736	-1.037267	-1.055844	-1.074038	
4	-64.439102	73.5	1980-01-01	-0.936650	-0.952341	-0.972782	-0.991520	

5 rows × 57 columns

Scaling

Scaling implementation

Applying scaling to the data set, ensuring all levels have same influence over data.

In [20]:

```
#Scaler loading and transform cell
importName = modelName + "_Scaler"
scalerLoad = load(importName)
sampleDataScaled = scalerLoad.transform(sampleData)
print("Scaling of sampleData complete using "+ importName +", stored in sampleDataScaled.'
```

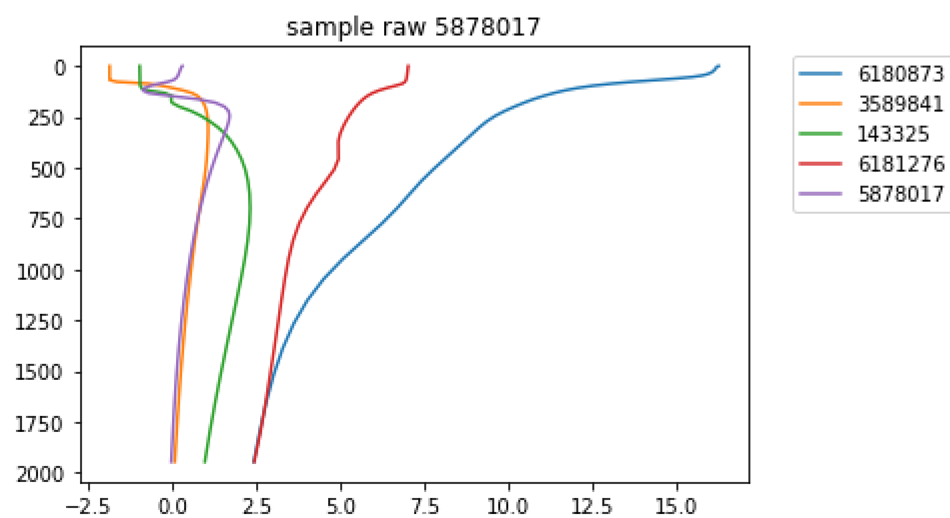
```
Scaling of sampleData complete using GMM_UK_2Class_R3_v2_Scaler, stored in sampleDataScale
d.
```

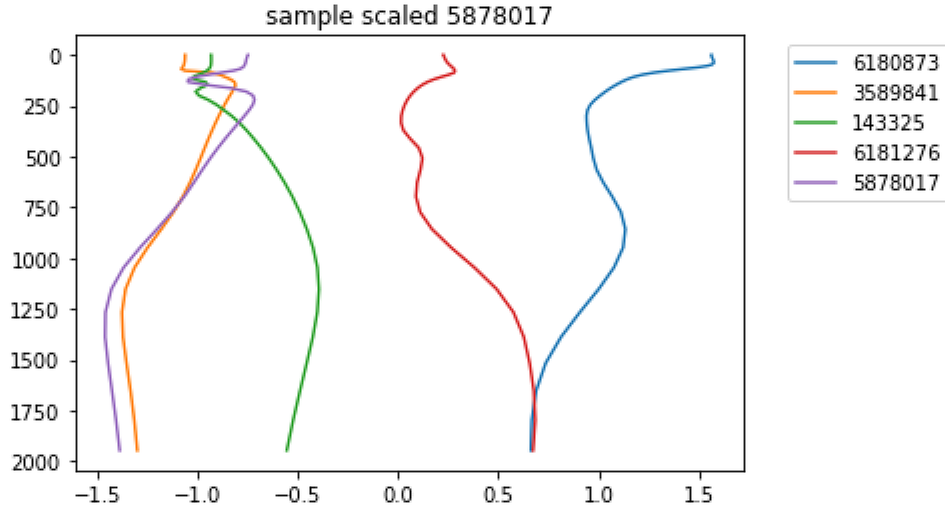
Scaling comparison

Comparing raw temperature profiles with their scaled equivalent. To show individual plots set solo to True.

In [21]:

```
#Scaled temperature profile plotting cell
solo = False #Set to true for seperate plots, false for combined plots.
for i in range(5):
    x = np.random.randint(len(sampleMetaDF))
    tempPointPlot(sampleData[x], x, "sample raw "+str(x), solo*2*i)
    tempPointPlot(sampleDataScaled[x], x, "sample scaled "+str(x), solo*2*i+1)
plt.show()
```





Principle Component Analysis

This process is performed to reduce the number of dimensions of the the data, as well as to improve overall model performance.

In [22]:
```
#PCA importing cell
importName = modelName + "_PCA.pkl"
pca = pk.load(open(importName, "rb"))
totalVarianceExplained = np.sum(pca.explained_variance_ratio_)
print(importName+"PCA loaded into pca. Total variance explained by PCA for "+str(pca.n_cor
```

```
GMM_UK_2Class_R3_v2_PCA.pklPCA loaded into pca. Total variance explained by PCA for 3 is
0.9908888941743108.
```

In [23]:
```
#PCA transform cell
sampleDataScaledPCA = pca.transform(sampleDataScaled) #converting input data into PCA repr
print("Data passed through PCA to sampleDataPCA.")
```

```
Data passed through PCA to sampleDataPCA.
```

Model import/BIC score calculation

The previously generated model is imported.

In [24]:
```
#Model import and BIC + Component Calculation Cell
bestGMModel = loadModel(modelName) #Loading model
bicMin = bestGMModel.bic(sampleDataScaledPCA) #BIC score calculation
bicComponentMin = bestGMModel.n_components #Identifying number of components in model (2 i

print("Model "+modelName+" loaded. The bicScore was "+str(np.round(bicMin, 2))+" for "+str
print("Imported model "+modelName+" in use. No calculations necessary.")
print("Imported model "+modelName+" in use. Model BIC score for training data: "+str(bicMi
```

```
Model GMM_UK_2Class_R3_v2 loaded. The bicScore was 84675719.33 for 2.
Imported model GMM_UK_2Class_R3_v2 in use. No calculations necessary.
Imported model GMM_UK_2Class_R3_v2 in use. Model BIC score for training data: 84675719.329
016.
```

Assigning class labels to each profile using the best GMM

Implementation of classification.

In [25]:
```
#Classification and classification probability cell
labels = bestGMModel.predict(sampleDataScaledPCA) #Assignment of class labels from best GM
posteriorProbs = bestGMModel.predict_proba(sampleDataScaledPCA) #Probability of profile be
maxPosteriorProbs = np.max(posteriorProbs, axis=1) #Evaluating assigned class probability
classUncertainty = 2 - 2*maxPosteriorProbs #I factor calculation for 2 class system (reduc
```

In [26]:
```
#Initial class labels to sampleDF table cell
try: #Removing label, maxposteriorprob and classUncertainty columns from sampleDF
    sampleDF = sampleDF.drop(columns=["label", "max posterior prob", "classUncertainty"])
except:
    pass

#Adding label, maxposteriorprob and classUncertainty columns to sampleDF
sampleDF.insert(3, "label", labels, True)
sampleDF.insert(4, "max posterior prob", maxPosteriorProbs, True)
sampleDF.insert(5, "classUncertainty", classUncertainty, True)
print("Labels identified for model ("+str(bicComponentMin)+" components) and added to samp
```

```
Labels identified for model (2 components) and added to sampleDF with associated probabili
ty.
```

Calculating class means for sorting

In [27]:
```
#Class Mean Calculation Cell
sampleDFGrouped = sampleDF.groupby("label") #group profiles according to label
sampleDFMeans = sampleDFGrouped.mean() #calculate mean of all profiles in each class
print("Sample dataframe grouped by label (sampleDFGrouped) and means taken (sampleDFMeans)
```

```
Sample dataframe grouped by label (sampleDFGrouped) and means taken (sampleDFMeans).
```

Sorting the labels based on mean class temperatures

In [28]:
```
#Sorted Dictionary creation cell
surfaceMeans = sampleDFMeans[surfaceLev].to_numpy() #Takes first temperature data column
surfaceMeansOrder = np.argsort(surfaceMeans)
di = dict(zip(surfaceMeansOrder, range(0, bicComponentMin)))
print("Surface temperature means taken and sorted. Label dictionary created and stored in
```

```
Surface temperature means taken and sorted. Label dictionary created and stored in di.
```

In [29]:
```
#Sorted label column to tables cell
try: #Removing labelSorted column from tables
    sampleMetaDF = sampleMetaDF.drop(columns = "labelSorted")
except:
    pass
try:
    sampleDF = sampleDF.drop(columns = "labelSorted")
except:
    pass

#Adding sorted label information to sampleMetaDF and sampleDF
sampleMetaDF.insert(3, "labelSorted", sampleDF["label"].map(di))
```

```
sampleDF.insert(5, "labelSorted", sampleDF["label"].map(di))
print("Sorted labels assigned to sampleDF based on surface temperature, coldest to warmest
```

```
Sorted labels assigned to sampleDF based on surface temperature, coldest to warmest.
```

In [30]:

```
#Probability data to sampleMeta table cell
try:
    sampleMetaDF = sampleMetaDF.drop(columns = ["max posterior prob", "classUncertainty"])
except:
    pass

sampleMetaDF.insert(4, "max posterior prob", maxPosteriorProbs, True)
sampleMetaDF.insert(5, "classUncertainty", classUncertainty, True)

sampleMetaDF.head()
```

Out[30]:

	lat	lon	time	labelSorted	max posterior prob	classUncertainty
0	-66.111519	73.5	1980-01-01	0	1.0	6.178388e-09
1	-65.703316	73.5	1980-01-01	0	1.0	2.965486e-10
2	-65.288567	73.5	1980-01-01	0	1.0	5.714185e-11
3	-64.867195	73.5	1980-01-01	0	1.0	3.317169e-11
4	-64.439102	73.5	1980-01-01	0	1.0	3.678746e-11

Use pandas to calculate the properties of the profiles by sorted label

In [31]:

```
#Class temperature means and stds cell
sampleDFSortGrouped = sampleDF.groupby("labelSorted")
sampleDFSortMeans = sampleDFSortGrouped.mean()
sampleDFSortStds = sampleDFSortGrouped.std()
profileCount = sampleDFSortGrouped[sampleDF.columns[0]].count().to_numpy()
print("sampleDF grouped by sorted label (sampleDFSortGrouped), with means and standard dev
print("Number of samples in each group calculated and stored in profileCount.")
```

```
sampleDF grouped by sorted label (sampleDFSortGrouped), with means and standard deviations
calculated for each group (sampleDFSortMeans, sampleDFSortStd).
Number of samples in each group calculated and stored in profileCount.
```

Confirmation of sorting

The means printed below should be ordered, going from coldest to warmest.

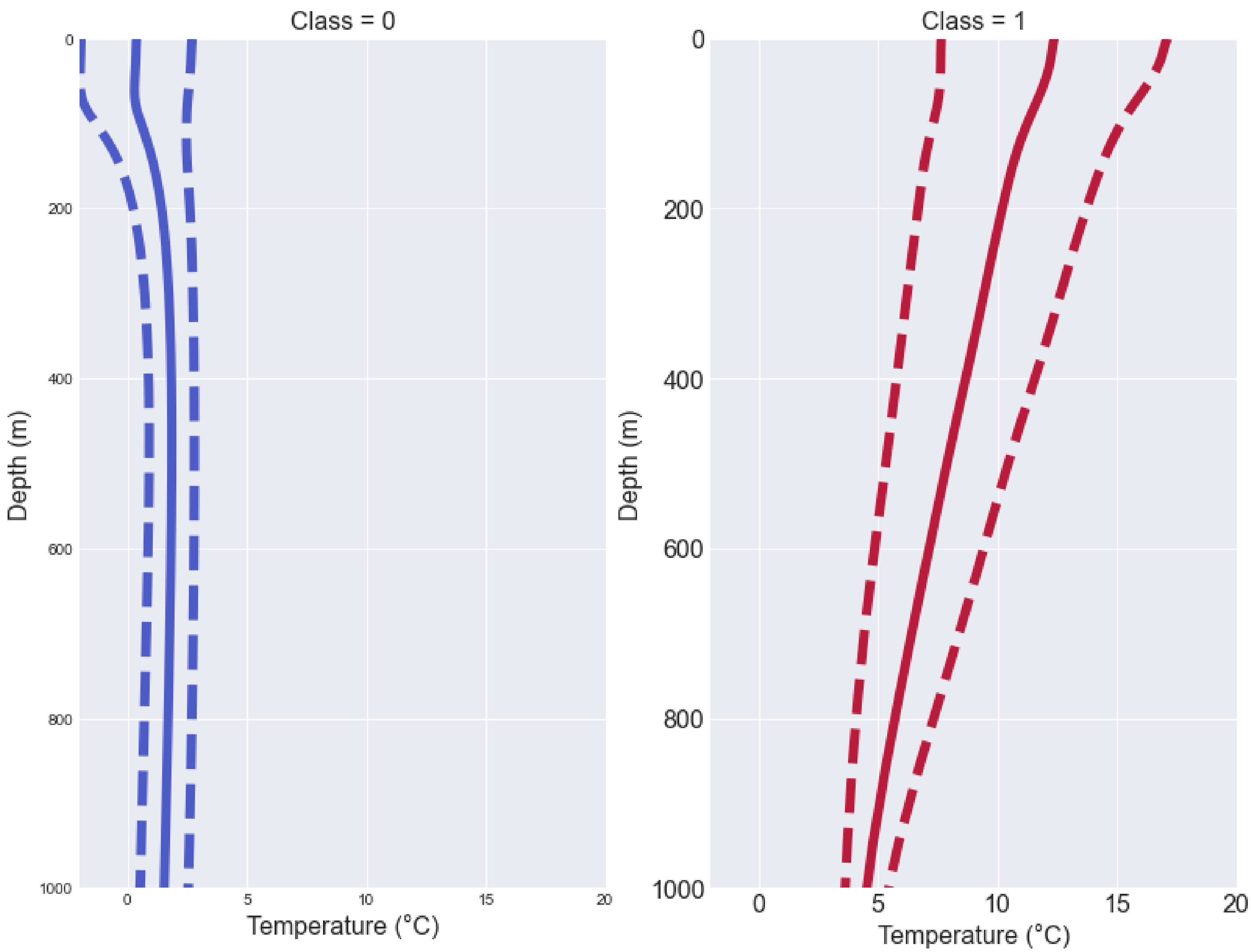
In [32]:

```
#Temperature display cell
print(sampleDFSortMeans[sampleDataDF.columns[0]])
```

```
labelSorted
0     0.395041
1    12.376642
Name: 0.5057600140571594, dtype: float32
```

Plotting the means and standard deviations of the classes by profile

In [33]:
```
#Plotting mean and std profiles cell
tempGroupProfile(sampleDFSortMeans, sampleDFSortStds, 1)
plt.show()
```



Plotting location and cluster

In [34]:
```
#surfaceTempPlot(sampleDF, 1)
plt.show()
```

In [35]:
```
#locationPlotGroupDFLab(sampleDF, "Location plot of grouping", (25,25), 1)
plt.show()
```

In [36]:
```
#locationPlotGroupDFMonthly(sampleDF, "Monthly summaries for training data set", 1)
print("Classifications, grouped by month.")
plt.show()
```

```
Classifications, grouped by month.
```

In [37]:
```
#locationPlotUncertaintyDFMonthly(sampleDF, "Monthly uncertainty", 1)
print("Uncertainty in classifications, grouped by month.")
plt.show()
```

```
Uncertainty in classifications, grouped by month.
```

Exporting Meta Data

In [38]:

```
sampleMetaDF.head()
```

Out[38]:

	lat	lon	time	labelSorted	max posterior prob	classUncertainty
0	-66.111519	73.5	1980-01-01	0	1.0	6.178388e-09
1	-65.703316	73.5	1980-01-01	0	1.0	2.965486e-10
2	-65.288567	73.5	1980-01-01	0	1.0	5.714185e-11
3	-64.867195	73.5	1980-01-01	0	1.0	3.317169e-11
4	-64.439102	73.5	1980-01-01	0	1.0	3.678746e-11

In [39]:

```
#Meta data export cell
exportName = modelName + "_Meta_Full"
sampleMetaDF.to_csv(exportName) #Exporting meta data
print("Meta data and mask exported to "+ exportName +".")
```

```
Meta data and mask exported to GMM_UK_2Class_R3_v2_Meta_Full.
```

In [40]:

```
#Meta data reload cell
importName = modelName + "_Meta_Full"
sampleMetaReload = pd.read_csv(importName)
print("Meta data reloaded from "+ importName +". "+str(len(sampleMetaReload))+" data point
sampleMetaReload.head()
```

```
Meta data reloaded from GMM_UK_2Class_R3_v2_Meta_Full. 7989840 data points.
```

Out[40]:

	Unnamed: 0	lat	lon	time	labelSorted	max posterior prob	classUncertainty
0	0	-66.111520	73.5	1980-01-01	0	1.0	6.178388e-09
1	1	-65.703316	73.5	1980-01-01	0	1.0	2.965486e-10
2	2	-65.288570	73.5	1980-01-01	0	1.0	5.714185e-11
3	3	-64.867195	73.5	1980-01-01	0	1.0	3.317169e-11
4	4	-64.439100	73.5	1980-01-01	0	1.0	3.678746e-11

In [41]:

```
#Mean temp profile calculation cell
meanProfiles = sampleDFSortMeans.iloc[:,5:].to_numpy()
meanProfilesScaled = scalerLoad.transform(meanProfiles)
print("Mean temperature profiles calculated and stored in meanProfiles and mean ProfilesSc
```

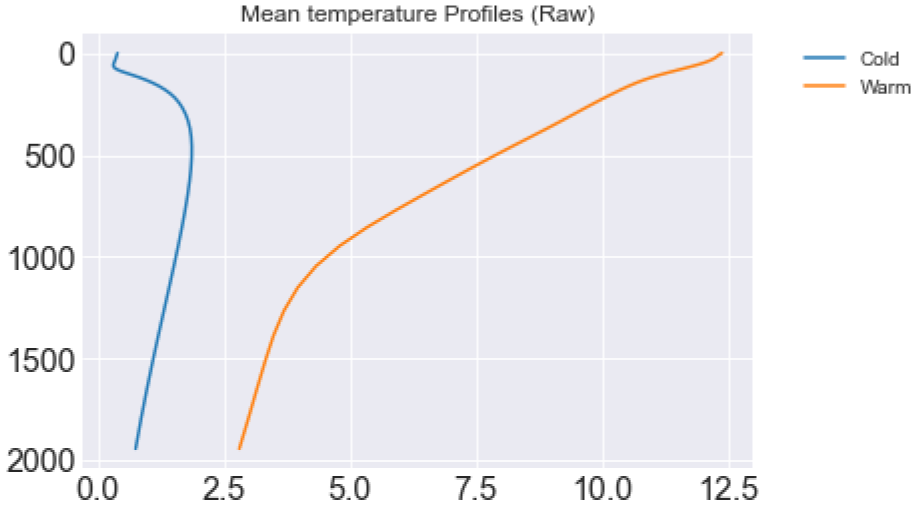
```
Mean temperature profiles calculated and stored in meanProfiles and mean ProfilesScaled.
```

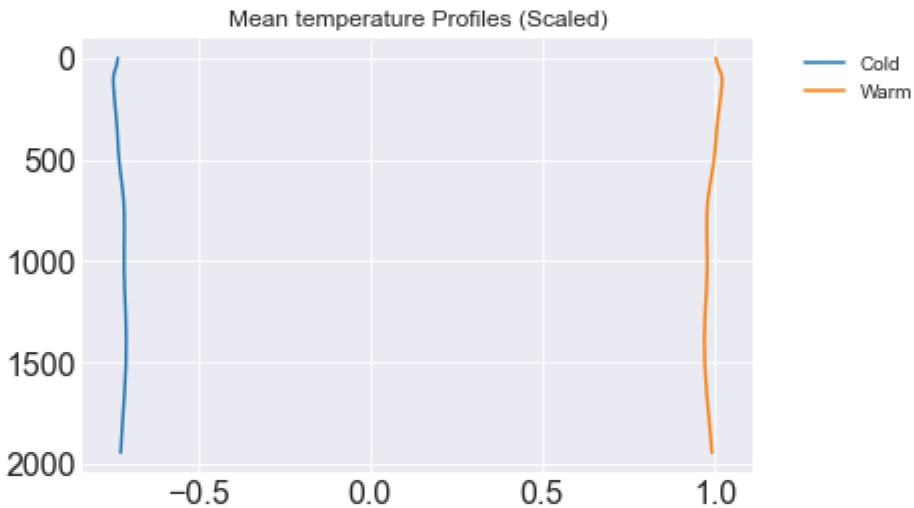
In [42]:

```
#Mean temp profile plotting cell
tempPointPlot(meanProfiles[0],"Cold", "Mean temperature Profiles (Raw)", 1)
tempPointPlot(meanProfiles[1],"Warm", "Mean temperature Profiles (Raw)", 1)
plt.gca().invert_yaxis()

tempPointPlot(meanProfilesScaled[0],"Cold", "Mean temperature Profiles (Scaled)", 2)
tempPointPlot(meanProfilesScaled[1],"Warm", "Mean temperature Profiles (Scaled)", 2)
plt.gca().invert_yaxis()
print("Mean profiles raw and scaled plotted")
plt.show()
```

```
Mean profiles raw and scaled plotted
```





In [43]:

```
#Antarctic anomalous classification identification cell
antarcticAnomDF = sampleMetaDF[np.logical_and(np.logical_and(sampleMetaDF["labelSorted"]==
anomIndex = antarcticAnomDF.index
print(str(len(antarcticAnomDF))+" anomalous classification points identified in the antarc
antarcticAnomDF.head()
```

```
654 anomalous classification points identified in the antarctic.
```

Out[43]:

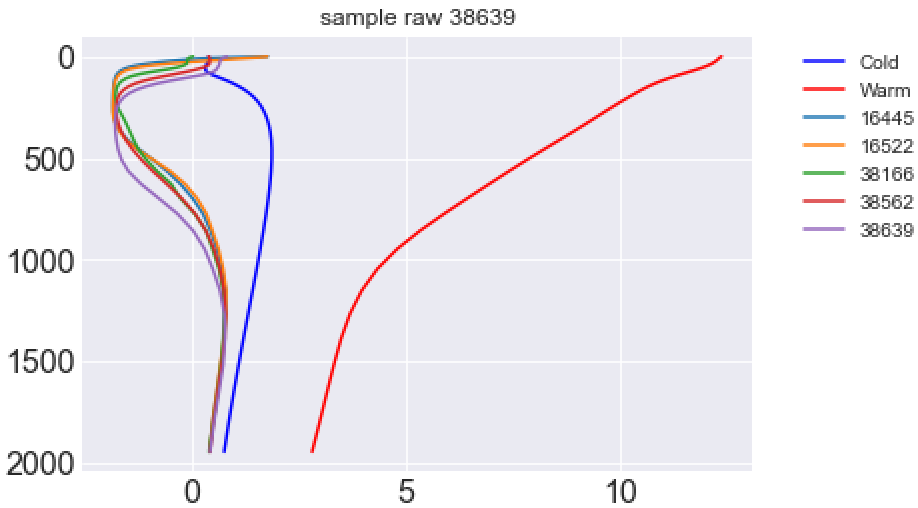
	lat	lon	time	labelSorted	max posterior prob	classUncertainty
16445	-72.696655	-19.462837	1980-01-01	1	0.690108	0.619783
16522	-72.397758	-18.470013	1980-01-01	1	0.788489	0.423022
38166	-73.858673	-25.431095	1980-02-01	1	0.633632	0.732735
38562	-72.699203	-20.463888	1980-02-01	1	0.941368	0.117264
38639	-72.696655	-19.462837	1980-02-01	1	0.999345	0.001311

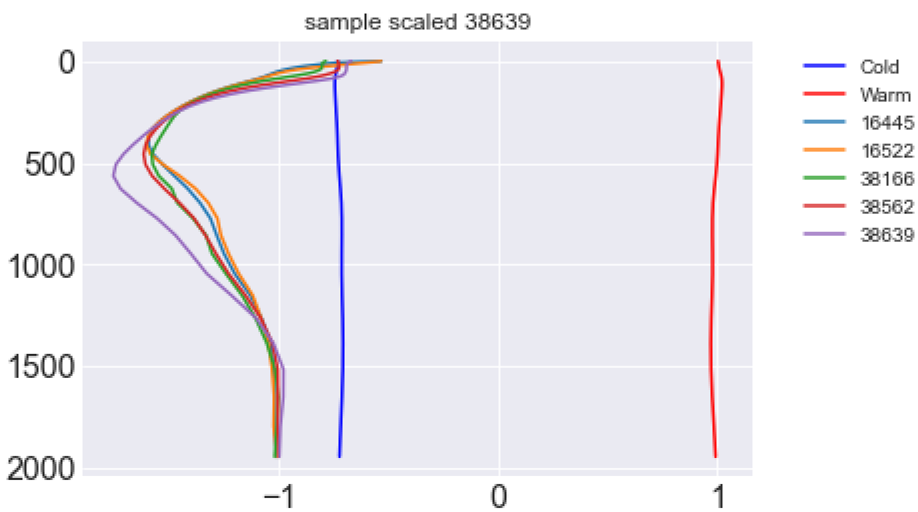
In [44]:

```
#Antarctic temperature profiles
plt.figure(1)
plt.plot(meanProfiles[0], sampleDepthAxis, label = "Cold", color="Blue")
plt.plot(meanProfiles[1], sampleDepthAxis, label = "Warm", color="Red")

plt.figure(2)
plt.plot(meanProfilesScaled[0], sampleDepthAxis, label = "Cold", color="Blue")
plt.plot(meanProfilesScaled[1], sampleDepthAxis, label = "Warm", color="Red")
```

```
for i in anomIndex[:5]:
    tempPointPlot(sampleData[i], i, "sample raw "+str(i), 1)
    tempPointPlot(sampleDataScaled[i], i, "sample scaled "+str(i), 2)
    #print(sampleMetaDF.iloc[i])
plt.show()
```





PCA Analysis

In [150…

```
dimMax = []
dimMin = []
for i in range(3):
    dimMax.append(max(sampleDataScaledPCA[:,i]))
    dimMin.append(min(sampleDataScaledPCA[:,i]))
print("PCA dimension mins: "+str(dimMin)+".\nPCA dimension maxs: "+ str(dimMax)+".")
```

```
PCA dimension mins: [-10.678736, -3.1982505, -3.3715334].
PCA dimension maxs: [19.699305, 5.4306393, 4.639458].
```

In [142…

```
#Antarctic anomalous classification identification cell
antarcticUncertDF = sampleMetaDF[np.logical_and(np.logical_and(sampleMetaDF["classUncertai
uncertIndex = antarcticUncertDF.index
print(str(len(antarcticUncertDF))+" anomalous classification points identified in the anta
antarcticUncertDF.head()
```

```
1094 anomalous classification points identified in the antarctic.
```

Out[142…

	lat	lon	time	labelSorted	max posterior prob	classUncertainty
16445	-72.696655	-19.462837	1980-01-01	1	0.690108	0.619783
16522	-72.397758	-18.470013	1980-01-01	1	0.788489	0.423022
16598	-72.094460	-17.476254	1980-01-01	0	0.873857	0.252286
38009	-74.414185	-27.411053	1980-02-01	0	0.868412	0.263176
38088	-74.138260	-26.421206	1980-02-01	0	0.715470	0.569060

In [143…

```
PCAValues = sampleDataScaledPCA[uncertIndex]
labelsPCA = sampleDF["labelSorted"][uncertIndex]
```

In [172…

```
fig = px.scatter_3d(PCAValues, x=0, y=1, z=2,  range_x=[dimMin[0],dimMax[0]], range_y=[dir
                    hover_data= {"Time":sampleDF["time"][uncertIndex], "Lat":sampleDF["lat
                    color=labelsPCA, title=f'PCA interpretation of model for Antarctic Unc
fig.update_layout(autosize=False, width=800, height=900)
print("Anomalous uncertainties in the antarctic.")
fig.show()
```

```
Anomalous uncertainties in the antarctic.
```

In [166…

```
sampleLen = len(sampleMetaDF)
displayCount = 10000
selectArr = uncertIndex
selectArr = np.append(selectArr, np.random.choice(sampleLen, displayCount-len(selectArr),
print("Uncertainty index  and additional random samples selected.")
```

```
Uncertainty index  and additional random samples selected.
```

In [167…

```
PCAValues2 = sampleDataScaledPCA[selectArr]
labelsPCA2 = sampleDF["labelSorted"][selectArr]
```

In [173…

```
fig = px.scatter_3d(PCAValues2, x=0, y=1, z=2, range_x=[dimMin[0],dimMax[0]], range_y=[dim
                    hover_data= {"Time":sampleDF["time"][selectArr], "Lat":sampleDF["lat"]
                    color=labelsPCA2, title=f'PCA interpretation of model, including Antar
fig.update_layout(autosize=False, width=800, height=900)
fig.show()
```

End of Notebook