# Temperature Profile Classification - 2 Class system - r2

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

## Choices for data

In [1]:
```
#Experiment data for analysis
dataVariableId = 'thetao'
dataExperimentId = 'historical'
dataSourceId = 'UKESM1-0-LL'
dataInstitutionId = 'MOHC'
approvedIds = ["r1i1p1f2", "r2i1p1f2", "r3i1p1f2"] #insert start of approved member_ids

#File imports
maskName = "OceanMaskVolcello"
modelName = "GMM_UK_2Class_R2"

#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
```

## Libaries and Modules

Importing the necessary libaries and modules for the notebook.

In [2]:
```
#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 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
from scipy import signal
```

```
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 [3]:

```
importName = modelName + "_Meta_Full"
sampleMetaDFL = pd.read_csv(importName)
sampleMetaDFL = sampleMetaDFL.drop(columns=["Unnamed: 0"])
sampleMetaDFL["time"] = pd.to_datetime(sampleMetaDFL["time"])
print("Labeled sample meta data loaded from "+ importName +" and stored in sampleMetaDFL.
sampleMetaDFL.head()
```

```
Labeled sample meta data loaded from GMM_UK_2Class_R2_Meta_Full and stored in sampleMetaDF
L. 7989840 samples loaded.
```

Out[3]:

| | lat | lon | time | labelSorted | max posterior prob | classUncertainty |
|---|---|---|---|---|---|---|
| **0** | -66.111520 | 73.5 | 1980-01-01 | 0 | 1.0 | 3.899727e-09 |
| **1** | -65.703316 | 73.5 | 1980-01-01 | 0 | 1.0 | 6.174536e-10 |
| **2** | -65.288570 | 73.5 | 1980-01-01 | 0 | 1.0 | 1.859135e-10 |
| **3** | -64.867195 | 73.5 | 1980-01-01 | 0 | 1.0 | 1.053628e-10 |
| **4** | -64.439100 | 73.5 | 1980-01-01 | 0 | 1.0 | 9.551204e-11 |

In [4]:

```
#Meta data date processing cell
globalStartDate = sampleMetaDFL["time"][0]
globalDateInc = sampleMetaDFL["time"].unique()[1] - globalStartDate
globalEndDateIn = sampleMetaDFL["time"].iloc[-1]
globalEndDateOut = globalEndDateIn + globalDateInc

globalStartDateStr = str(globalStartDate)[:7]
globalEndDateInStr = str(globalEndDateIn)[:7]
globalEndDateOutStr = str(globalEndDateOut)[:7]
print("Sample meta data dates manipulated and stored in globalStartDate etc.")
```

```
Sample meta data dates manipulated and stored in globalStartDate etc.
```

#### Loading ocean Masks

In [5]:

```
#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 [6]:
```
#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 [7]:
```
#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 [8]:
```
#Calculation functions cell
def butter_lowpass(data,cut,order=4,sample_freq=1) :
    nyq = 0.5*sample_freq
    pass_freq =1./cut/nyq
    sos=signal.butter(order, pass_freq, 'low', output='sos')
    filt=signal.sosfiltfilt(sos,data)
    return filt

def pickRand(dataArray, sampleFactor):
    '''Returns a sample of the input array, size of sampled array is based on sampleFactor
    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 ger
        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:**

- 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.

In [9]:

```python
#Plotting functions Cell
#sampleDepthAxis = dfESMLatLevT["lev"]
decadeColours = ["green", "yellow", "red"]
timeList = sampleMetaDFL["time"].unique()

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) #normal dt info
```

```
        timeData = dataFrame.where(dataFrame["time"] ==i) #groupby dt info
        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="
    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="
    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) #normal dt info
        timeData = dataFrame.where(dataFrame["time"] ==i) #groupby dt info
        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")
```

```python
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="B
    plt.title("Sample Locations ("+str(len(dataArray["lat"]))+")")


def locationUncertaintyMean(decadeMeanList, decadeStdList, uncertaintyThreshold, figSize,
    '''Plots mean latitude for classification uncertainty with +- 1 std'''
    plt.figure(plotNo, figsize=figSize)
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    for i in range(len(decades)):
        ax.plot(decadeMeanList[i].index, decadeMeanList[i]["lat"], transform=ccrs.PlateCar
        ax.plot(decadeMeanList[i].index, decadeMeanList[i]["lat"] + decadeStdList[i]["lat'
        ax.plot(decadeMeanList[i].index, decadeMeanList[i]["lat"] - decadeStdList[i]["lat'

    ax.plot(np.arange(0,361,1),np.ones(361)*-29.5, transform=ccrs.PlateCarree(), color="Bl
    plt.title("Classification Uncertainty above "+str(uncertaintyThreshold)+" Mean Latituc
    plt.legend()


def timeSingleLatMean(meanLatArr, lineStyle , arrThreshold, arrSmoothFact, plotNo):
    plt.figure(plotNo, figsize=(20,10))
    plt.plot(timeList, meanLatArr, lw=1, ls=lineStyle ,label="Thresh_"+str(arrThreshold)+'
    plt.xlabel("Date")
    plt.ylabel("Singular Mean Latitude")
    plt.title("Classification Uncertainty Mean Latitude over time")
    plt.legend()
    #plt.gca().invert_yaxis()


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

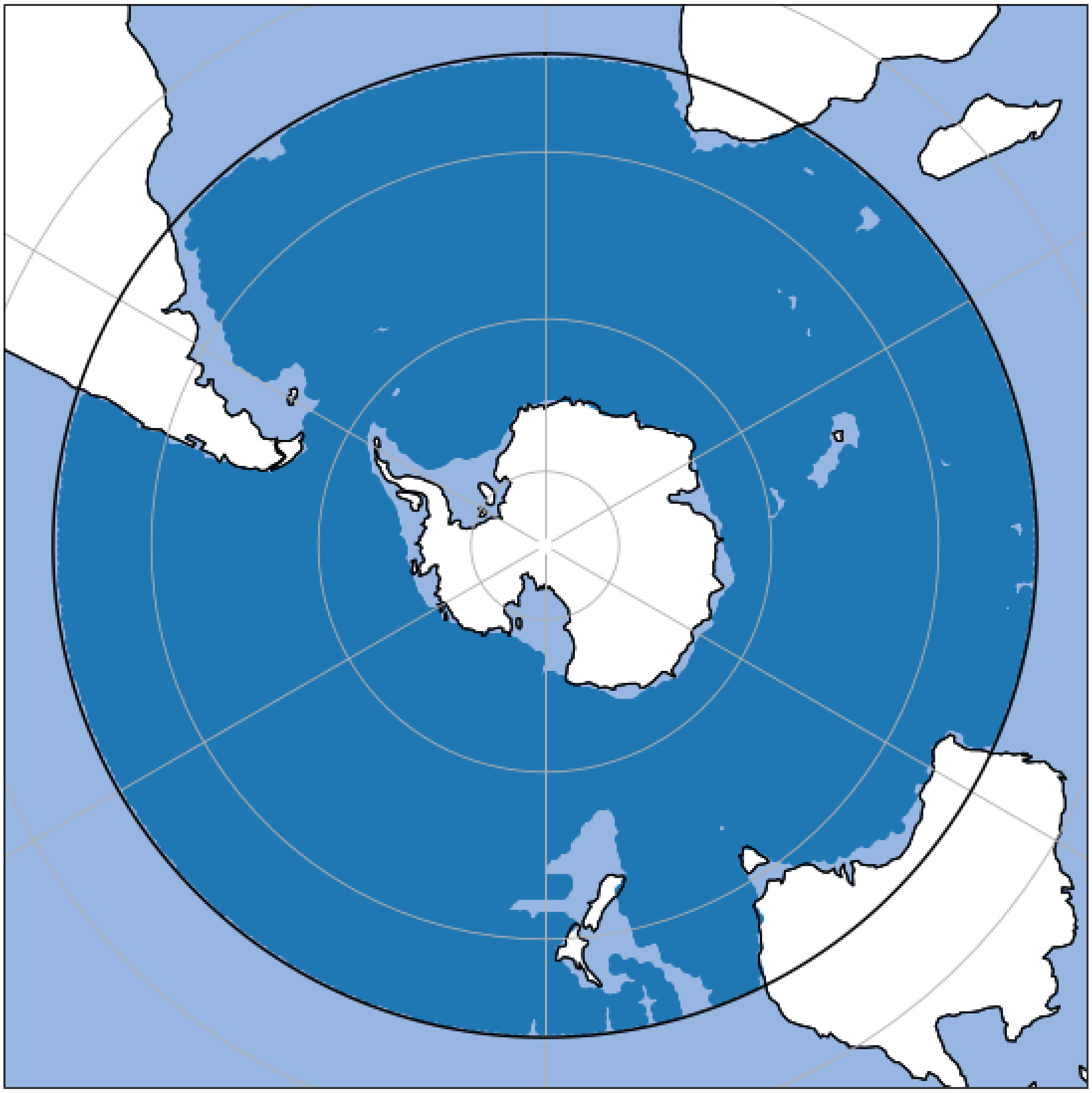
```
Plotting functions defined.
```

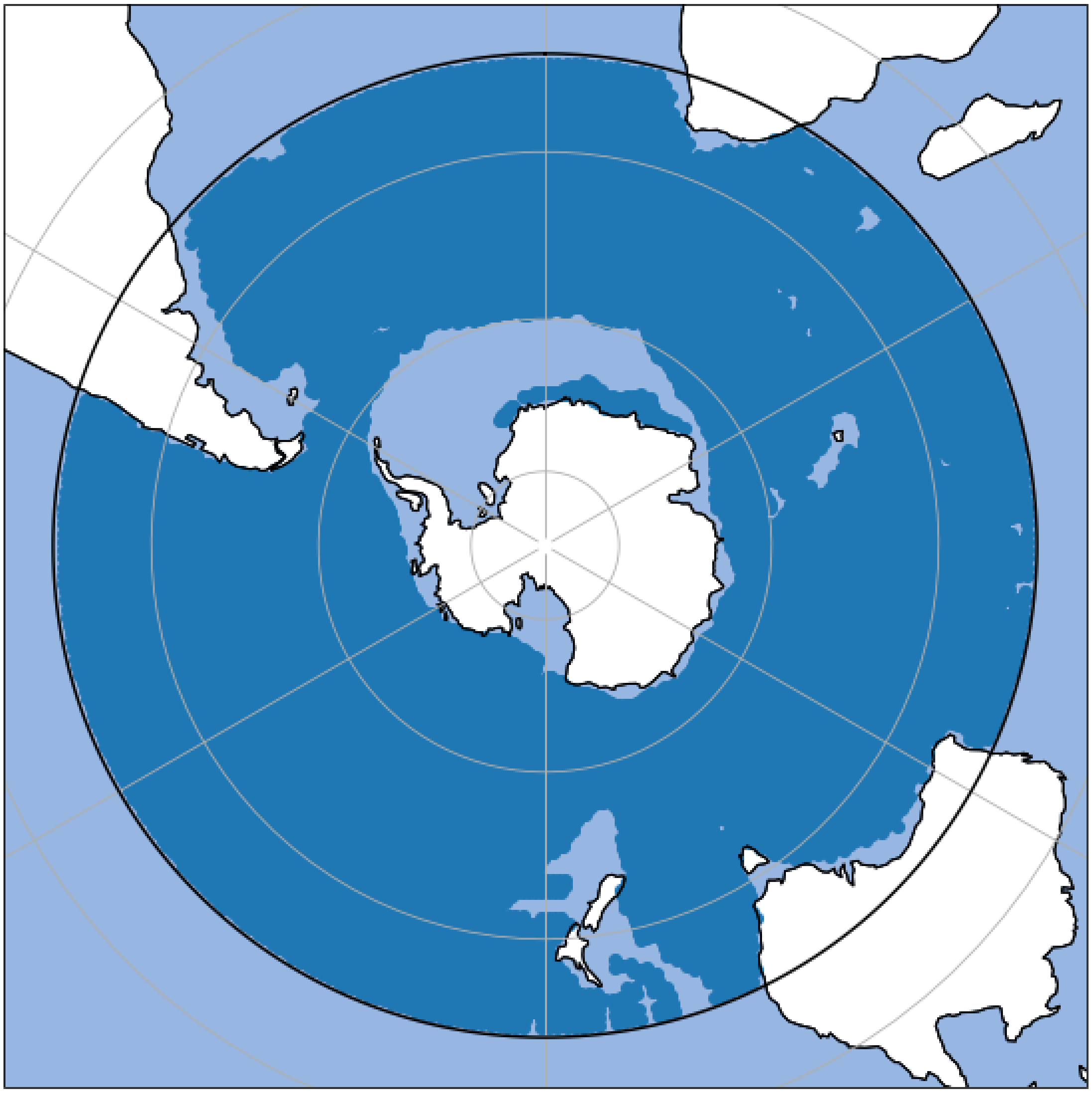
## Plotting Ocean Mask

In [10]:

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

Sample Locations (22194)






## Anomalies

In [11]:

```
#Initial anomalous data point df creation cell
labelAnomDF = sampleMetaDFL[np.logical_or(np.logical_and(sampleMetaDFL["lat"]<-60, sampleM
print("Class 0 above -45 and Class 1 below -60 lat. Stored in labelAnomDF. "+str(len(label
```

```
Class 0 above -45 and Class 1 below -60 lat. Stored in labelAnomDF. 3843 anomalous points
detected.
```

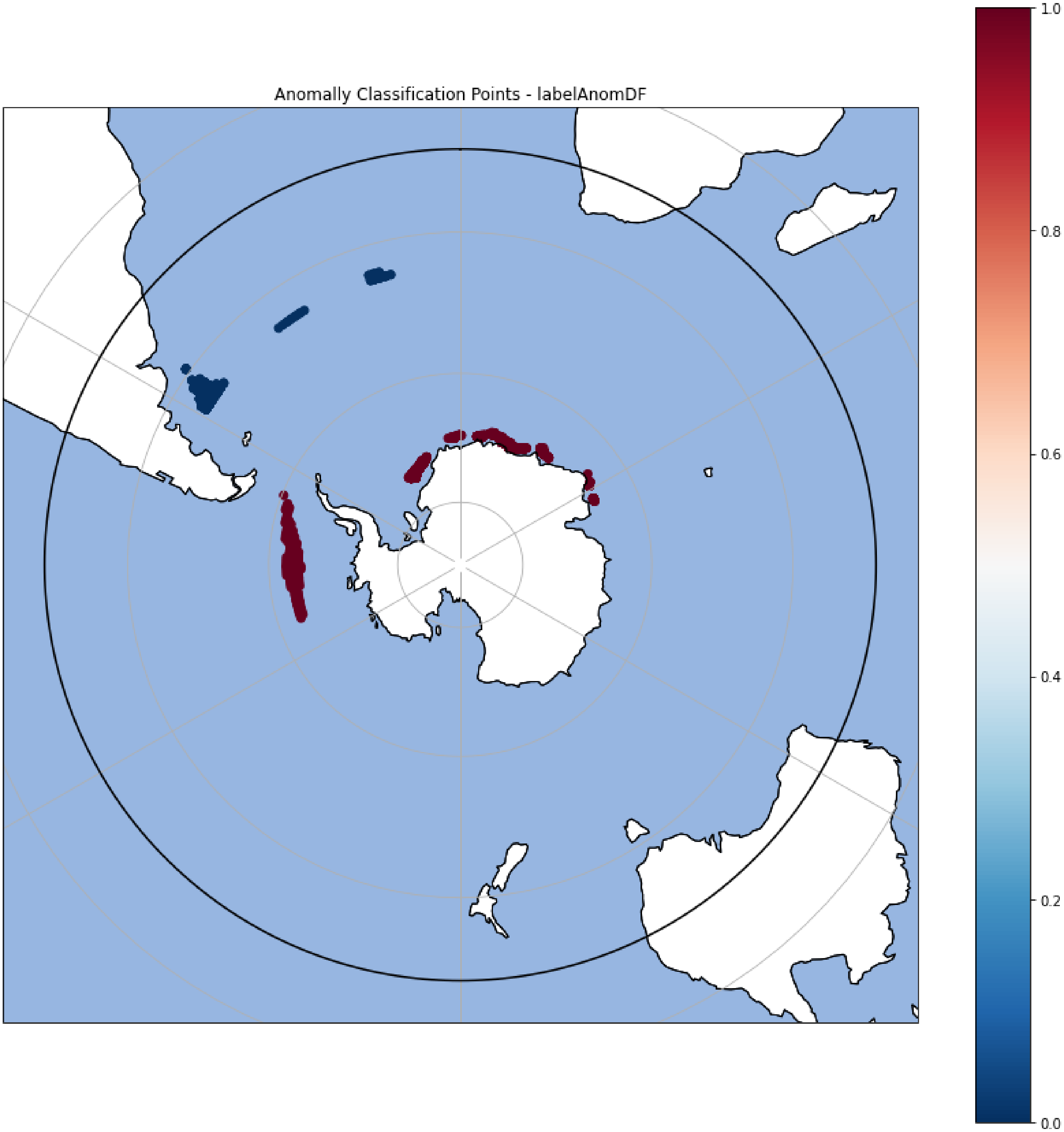
In [12]:

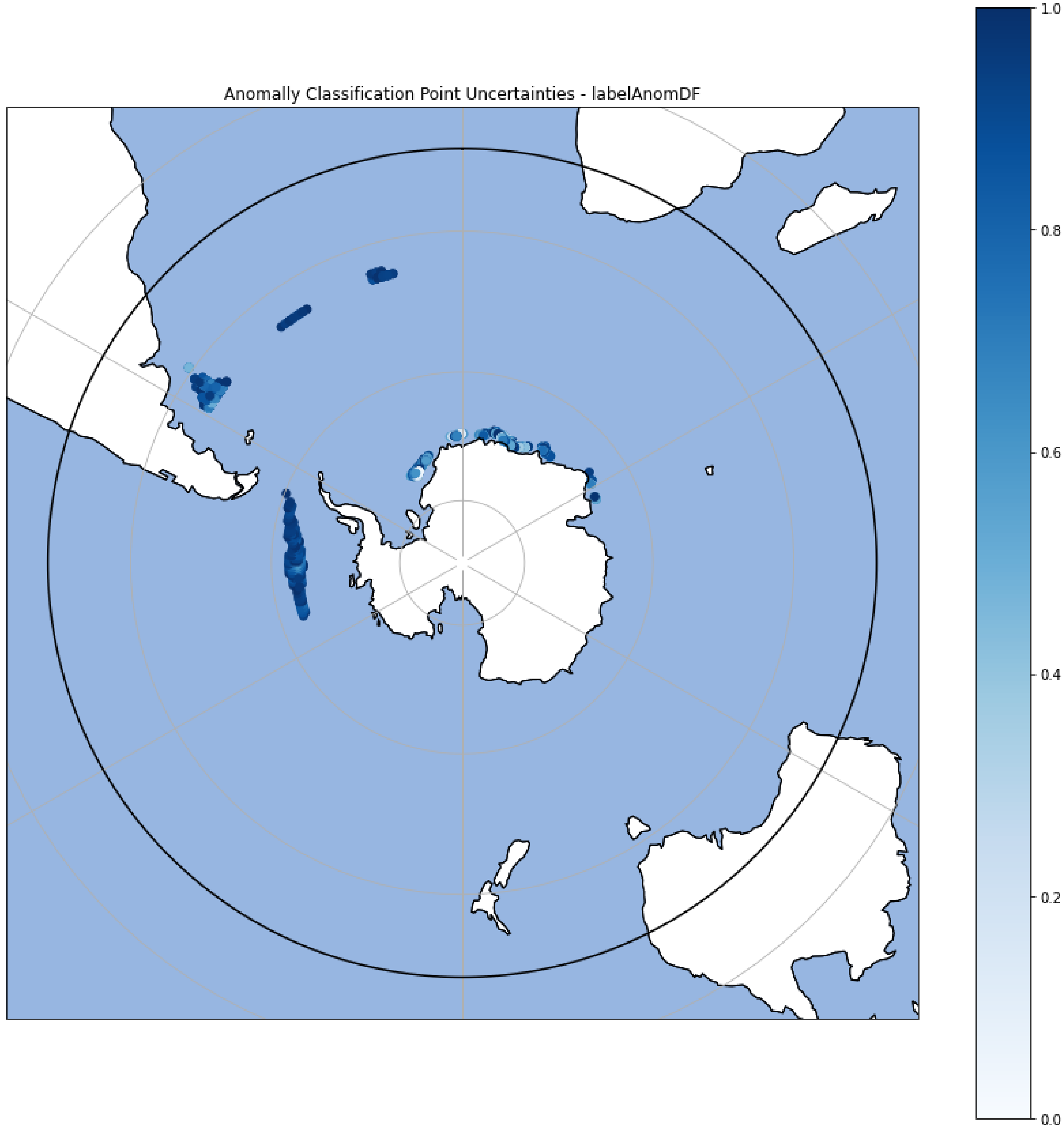
```
#High confidence anomalous data point df creation cell
labelAnomConDF = labelAnomDF[labelAnomDF["classUncertainty"]<0.25]
print("High Classification Confidence DF of labelAnomDF (<0.25). "+str(len(labelAnomConDF)
```

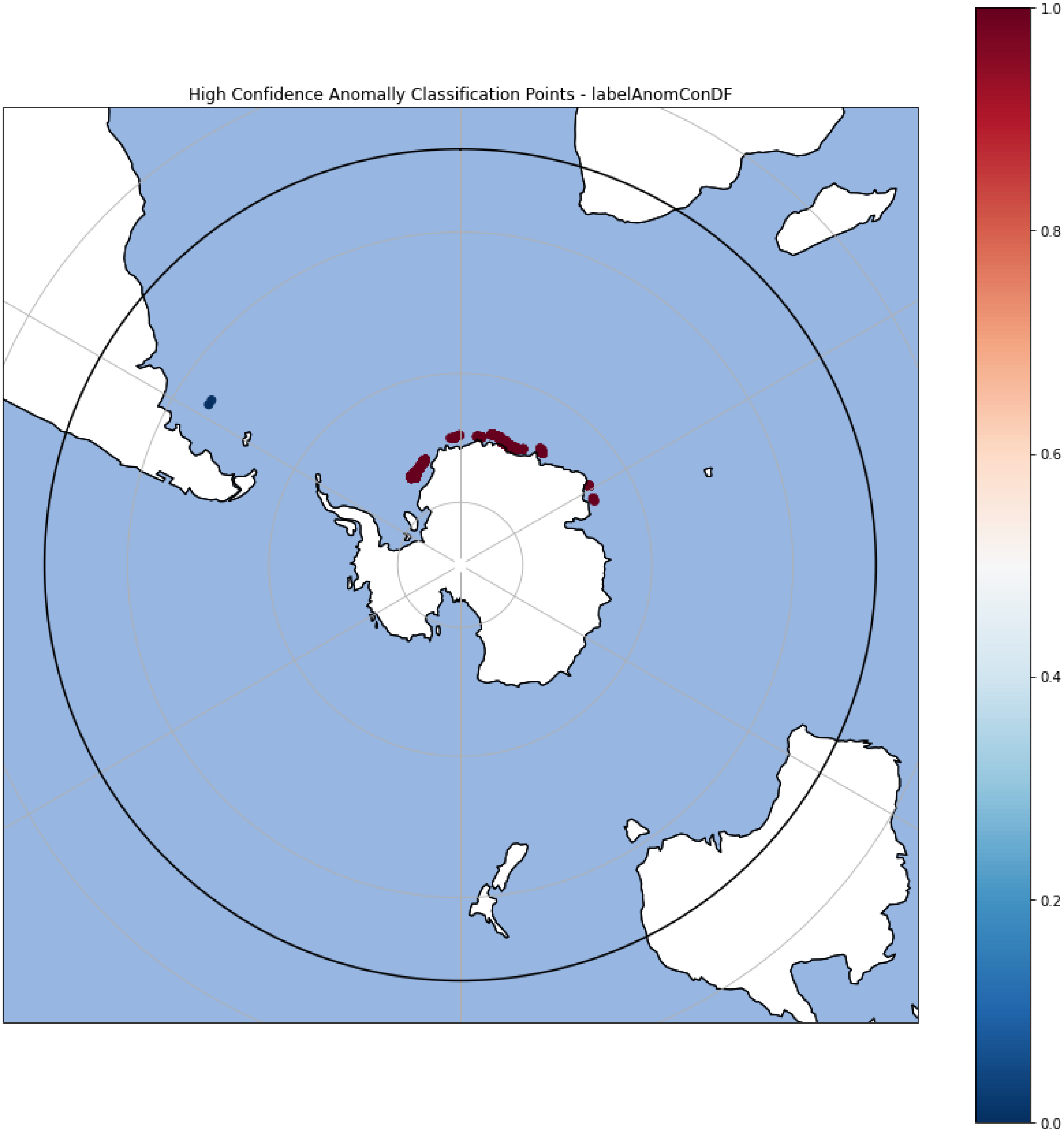
```
High Classification Confidence DF of labelAnomDF (<0.25). 1245 anomalous points detected.
```

In [13]:

```
locationPlotGroupDFLab(labelAnomDF, "Anomaly Classification Points - labelAnomDF", (15,15
locationPlotUncertaintyDF(labelAnomDF, "Anomaly Classification Point Uncertainties - labe
locationPlotGroupDFLab(labelAnomConDF, "High Confidence Anomaly Classification Points - l
plt.show()
```


Anomally Classification Points - labelAnomDF
1.0
0.8
0.6
0.4
0.2
0.0


Anomally Classification Point Uncertainties - labelAnomDF
1.0
0.8
0.6
0.4
0.2
0.0

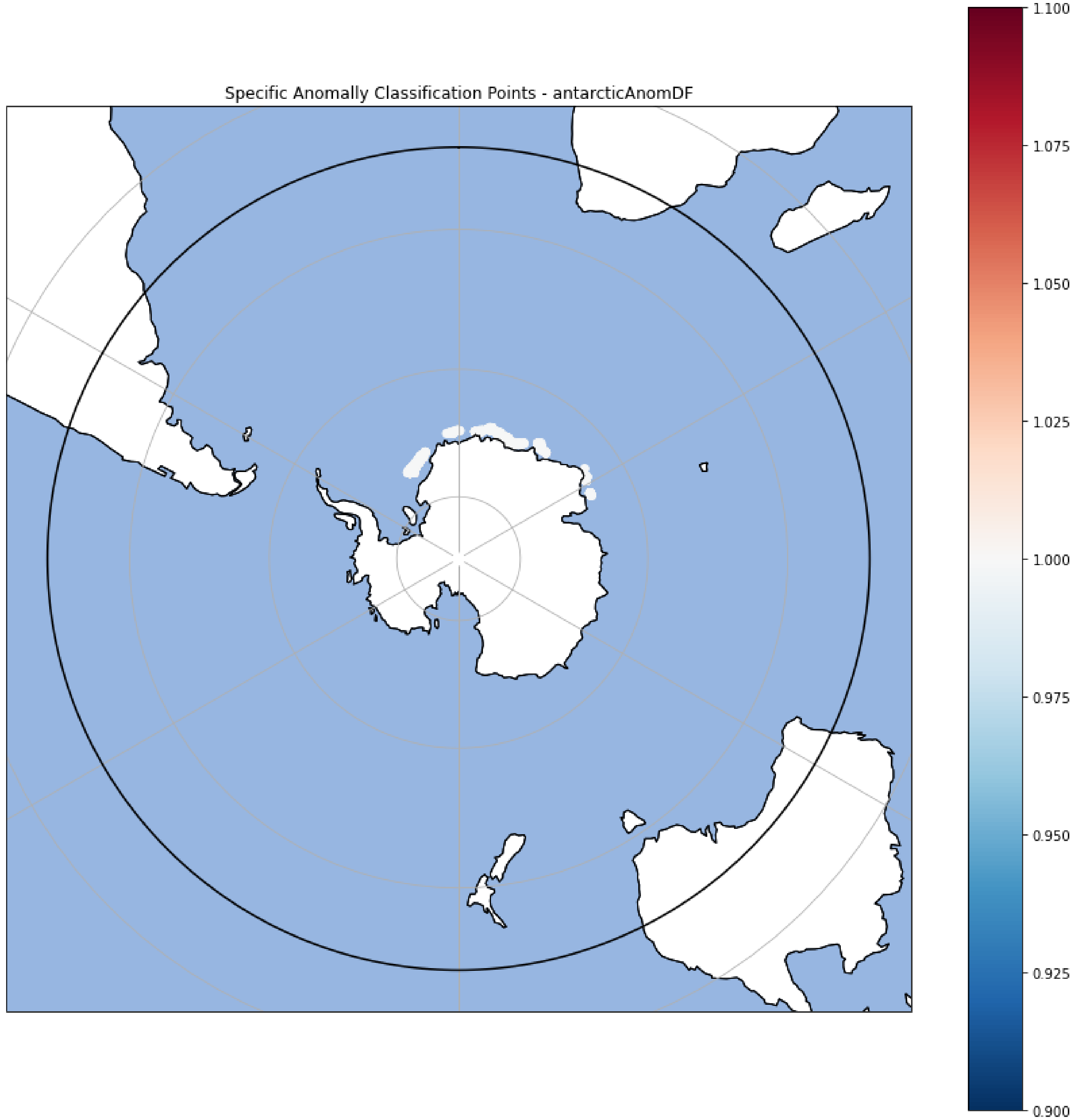



### Antarctic Anomalous Classifications

In [14]:

```
antarcticAnomDF = sampleMetaDFL[np.logical_and(np.logical_and(sampleMetaDFL["labelSorted"]
locationPlotGroupDFLab(antarcticAnomDF, "Specific Anomally Classification Points - antarct
print(str(len(antarcticAnomDF))+" anomalous samples found. (Lat<-65, Lon<70, Lon>-60)")
plt.show()
```

```
2809 anomalous samples found. (Lat<-65, Lon<70, Lon>-60)
```

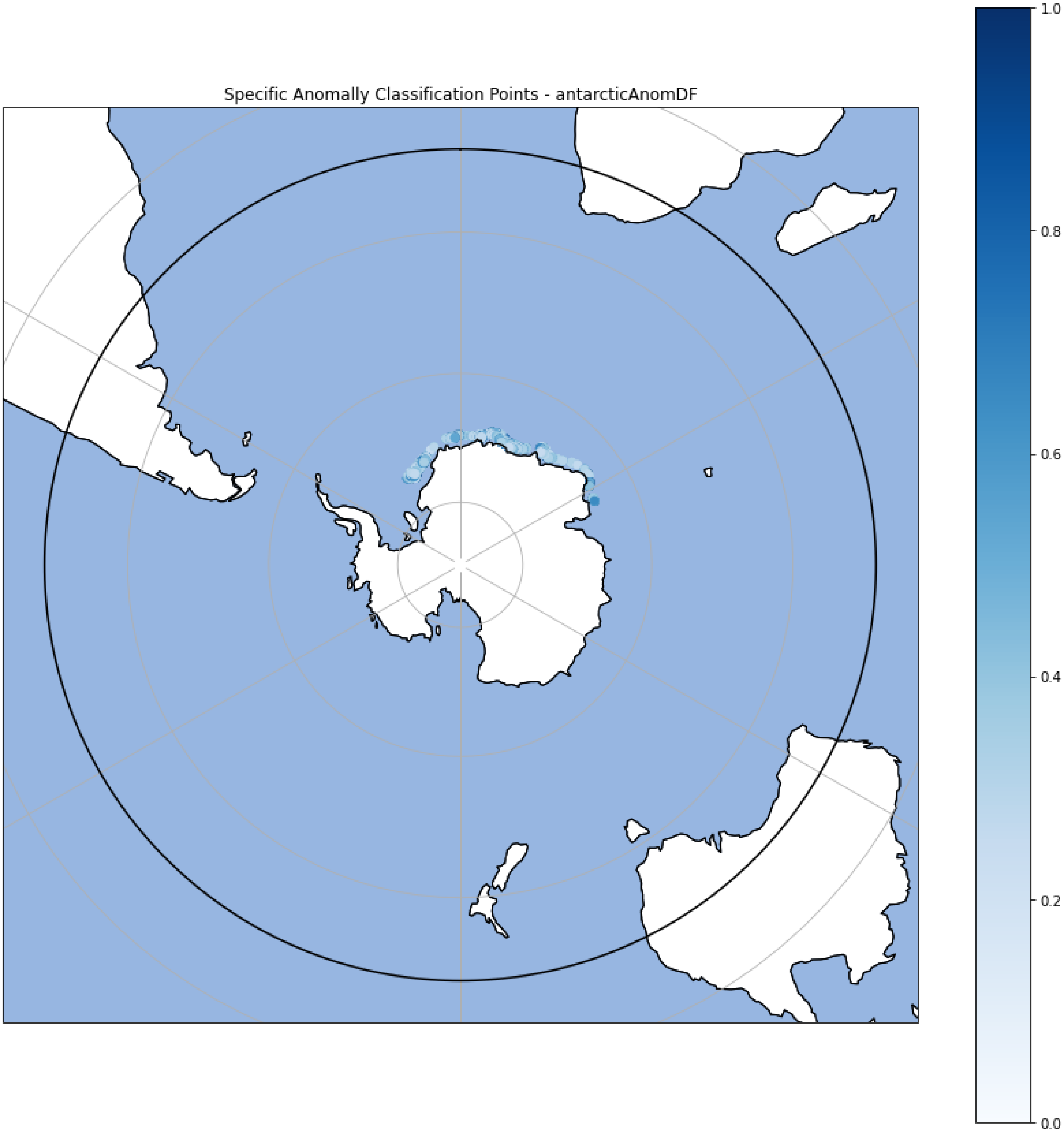



**Antarctic Anomalous Classification Uncertainty**

In [15]:

```
antarcticUncertDF = sampleMetaDFL[np.logical_and(np.logical_and(sampleMetaDFL["classUncert
locationPlotUncertaintyDF(antarcticUncertDF, "Specific Anomally Classification Points - ar
print(str(len(antarcticUncertDF))+" anomalous samples found. (Lat<-65, Lon<70, Lon>-60)")
plt.show()
```

```
4564 anomalous samples found. (Lat<-65, Lon<70, Lon>-60)
```

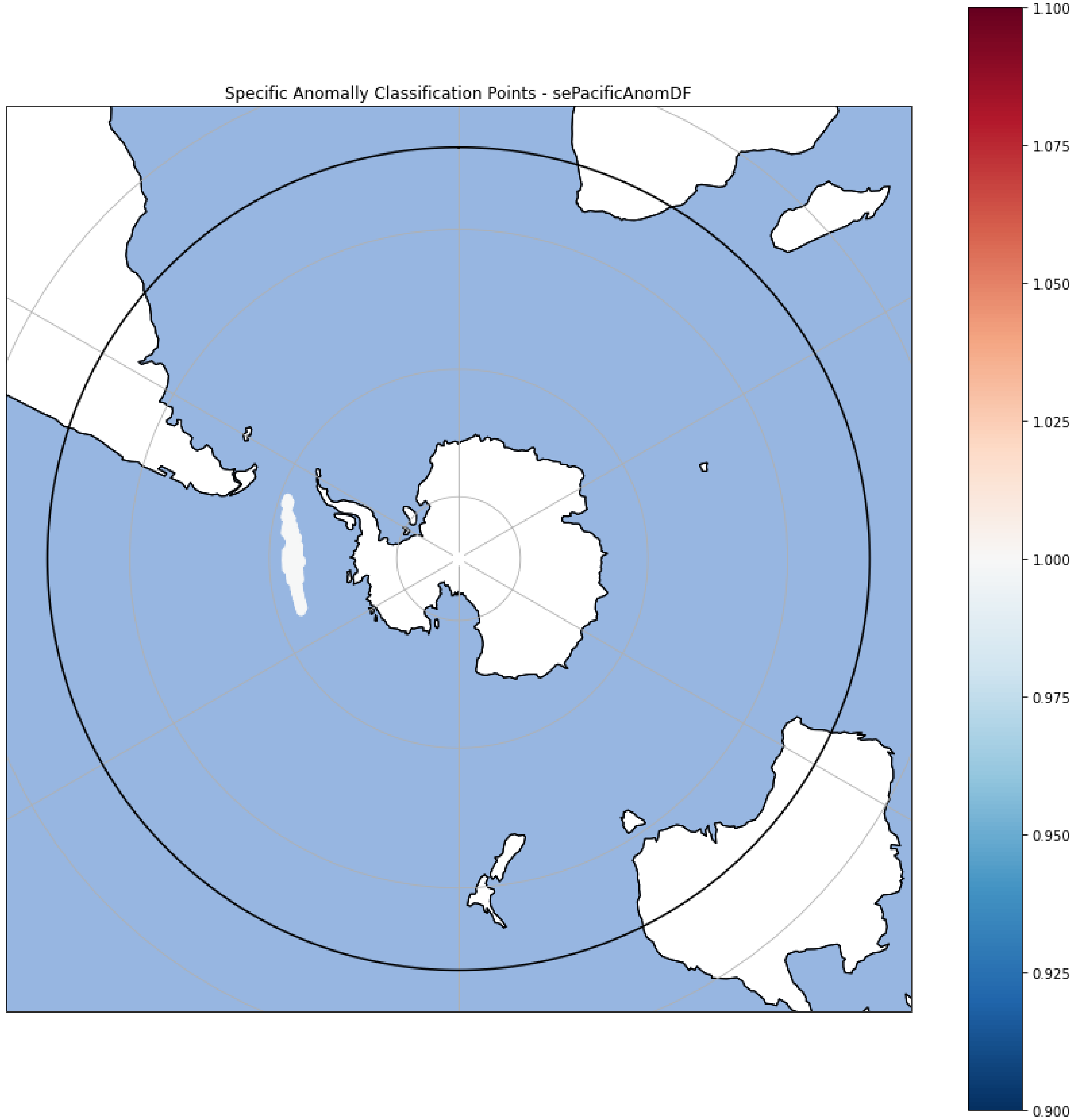



**South-East Pacific Classifications**

In [16]:

```
sePacificAnomDF = sampleMetaDFL[np.logical_and(np.logical_and(sampleMetaDFL["labelSorted"]
locationPlotGroupDFLab(sePacificAnomDF, "Specific Anomally Classification Points - sePaci
print(str(len(sePacificAnomDF))+" anomalous samples found. (Lat<-61, Lon<-60, Lon>-140)")
plt.show()
```

```
215 anomalous samples found. (Lat<-61, Lon<-60, Lon>-140)
```




In [17]:

```
print("South-East Pacific Anomaly Count (Lat<-61, Lon<-60, Lon>-140)")
sePacificAnomDF.groupby("time")["labelSorted"].value_counts()
```

Out[17]:

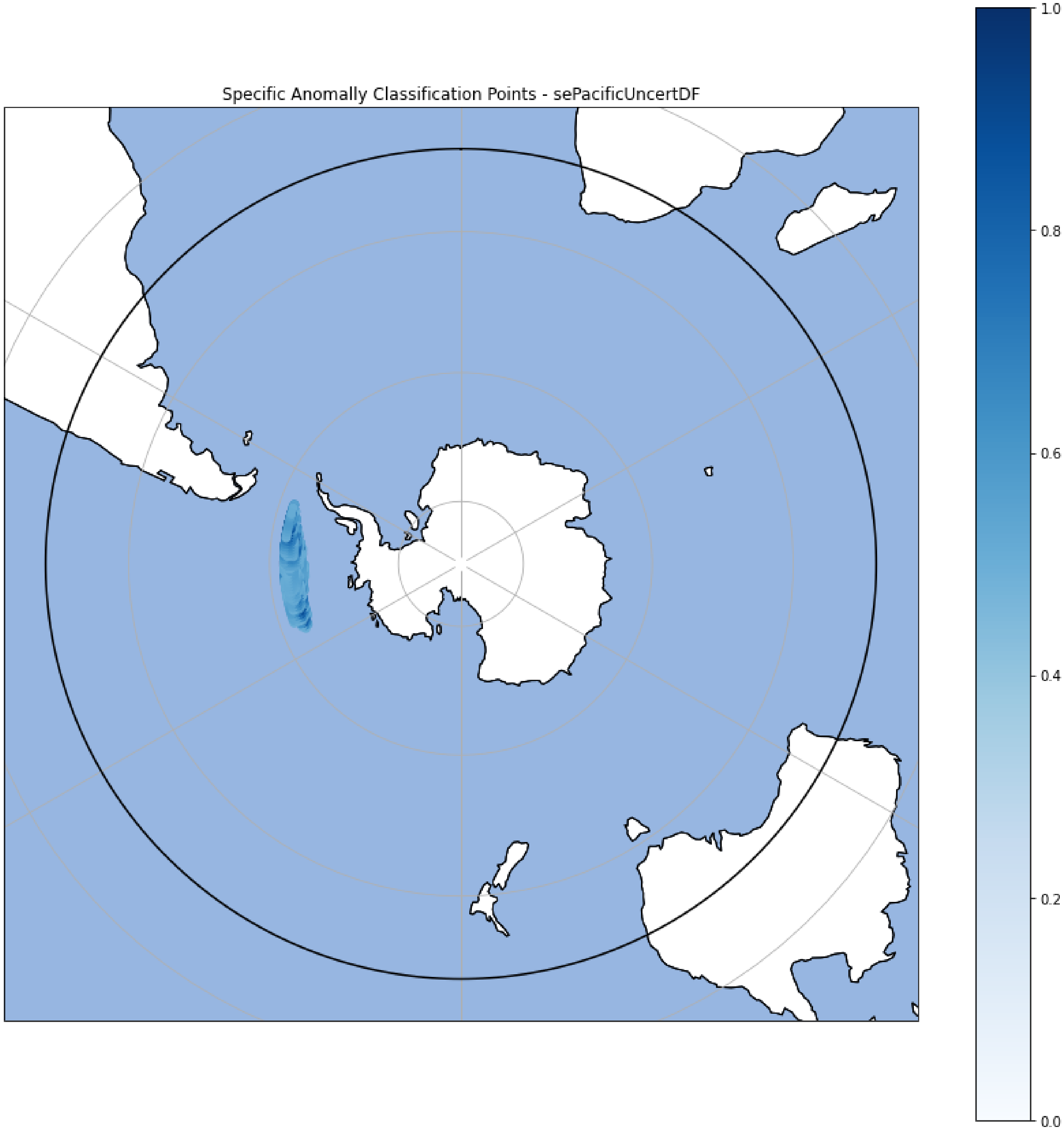
```
South-East Pacific Anomaly Count (Lat<-61, Lon<-60, Lon>-140)
time        labelSorted
1994-09-01  1              74
1994-10-01  1              67
1994-11-01  1              14
1996-11-01  1               5
2006-10-01  1              19
2006-11-01  1              11
2007-08-01  1               1
2007-09-01  1              24
Name: labelSorted, dtype: int64
```

**South-East Pacific Classification Uncertainties**

In [18]:

```
timeRange = np.arange(np.datetime64("1980-01"), np.datetime64("2000-01"), np.timedelta64(1

sePacificUncertDF = sampleMetaDFL[np.logical_and(np.logical_and(sampleMetaDFL["classUncert
locationPlotUncertaintyDF(sePacificUncertDF, "Specific Anomally Classification Points - se
print(str(len(sePacificUncertDF))+" anomalous samples found. (Lat<-62, Lon<-60, Lon>-140)"
plt.show()
```

```
1998 anomalous samples found. (Lat<-62, Lon<-60, Lon>-140)
```




In [19]:

```
i = 0
sePacificUncertStack = sePacificUncertDF.groupby("time")["time"].value_counts()
print("South-East Pacific Uncertainty Count (Lat<-62, Lon<-60, Lon>-140)")
print("Time\t\t", "Count")
for x in sePacificUncertStack:
    strIndex = str(sePacificUncertStack.index[i])
```

```
    print(strIndex[12:22]+"\t", x)
    i +=1
```

```
South-East Pacific Uncertainty Count (Lat<-62, Lon<-60, Lon>-140)
Time                Count
1980-01-01          3
1980-02-01          45
1988-10-01          20
1988-11-01          23
1988-12-01          6
1989-02-01          24
1990-10-01          86
1990-11-01          45
1994-01-01          43
1994-02-01          73
1994-08-01          92
1994-09-01          179
1994-10-01          175
1994-11-01          135
1994-12-01          72
1995-01-01          63
1995-02-01          48
1995-03-01          30
1996-10-01          53
1996-11-01          68
1996-12-01          50
1997-01-01          25
1997-02-01          24
1997-03-01          12
1997-07-01          15
1997-09-01          6
2006-10-01          119
2006-11-01          103
2006-12-01          60
2007-01-01          43
2007-02-01          31
2007-07-01          31
2007-08-01          68
2007-09-01          74
2007-10-01          45
2007-11-01          9
```

## Data Readjustment

In [20]:

```
preAdLen = len(sampleMetaDFL)
if True:
    sampleMetaDFL = pd.concat([sampleMetaDFL, antarcticAnomDF, antarcticAnomDF]).drop_dupl
    print("Removing antarcticAnomDF.")
    sampleMetaDFL = pd.concat([sampleMetaDFL, antarcticUncertDF, antarcticUncertDF]).drop_
    print("Removing antarcticUncertDF.")
    sampleMetaDFL = pd.concat([sampleMetaDFL, sePacificAnomDF, sePacificAnomDF]).drop_dupl
    print("Removing sePacificAnomDF.")
    sampleMetaDFL = pd.concat([sampleMetaDFL, sePacificUncertDF, sePacificUncertDF]).drop_
    print("Removing sePacificUncertDF.\n")

postAdLen = len(sampleMetaDFL)
lenDiff = preAdLen - postAdLen
print("SampleMetaDFL adjusted from "+str(preAdLen)+" to "+str(postAdLen)+". "+str(lenDiff)
```

```
Removing antarcticAnomDF.
Removing antarcticUncertDF.
Removing sePacificAnomDF.
```

```
Removing sePacificUncertDF.

SampleMetaDFL adjusted from 7989840 to 7982024. 7816 samples dropped.
```

In [21]:

```python
print("Last data point in set (expected 2009-12):")
sampleMetaDFL.iloc[-1]
```

```
Last data point in set (expected 2009-12):
```

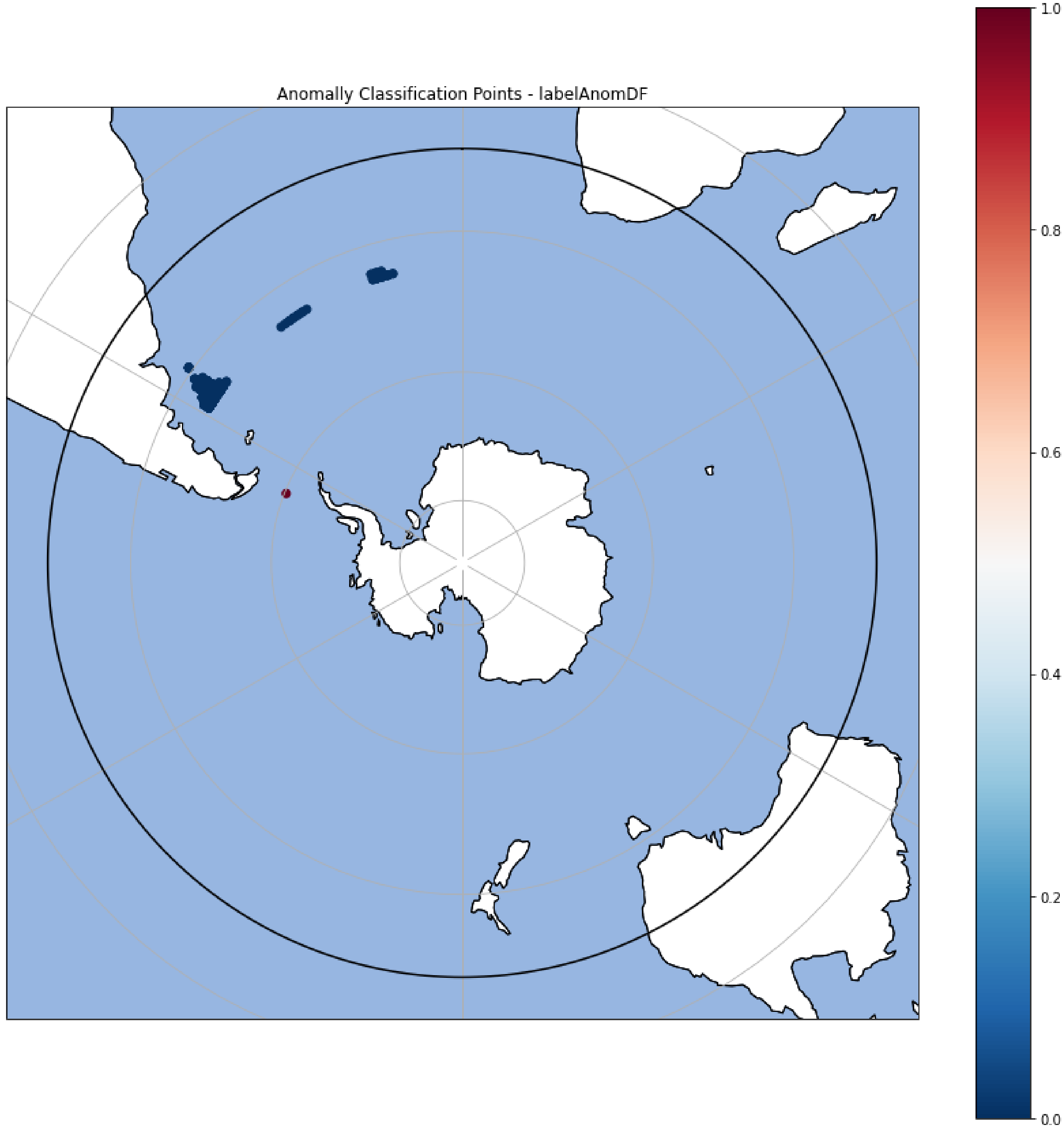
Out[21]:

```
lat                                -30.455408
lon                                 72.500000
time                      2009-12-01 00:00:00
labelSorted                                 1
max posterior prob                   1.000000
classUncertainty                     0.000000
Name: 7989839, dtype: object
```

In [22]:

```python
labelAnomDF = sampleMetaDFL[np.logical_or(np.logical_and(sampleMetaDFL["lat"]<-60, sampleM
print("Class 0 above -45 and Class 1 below -60 lat. Stored in labelAnomDF. "+str(len(label
locationPlotGroupDFLab(labelAnomDF, "Anomally Classification Points - labelAnomDF", (15,15
```

```
Class 0 above -45 and Class 1 below -60 lat. Stored in labelAnomDF. 819 anomalous points d
etected.
```




In [23]:

```
antarcticAnomDF = sampleMetaDFL[np.logical_and(np.logical_and(sampleMetaDFL["labelSorted"]
antarcticLen = len(antarcticAnomDF)
if antarcticLen:
    locationPlotGroupDFLab(antarcticAnomDF, "Specific Anomally Classification Points - ant
print(str(antarcticLen)+" Antarctic anomalous samples found (Lat<-65, Lon<70, Lon>-60.")
plt.show()
```

```
0 Antarctic anomalous samples found (Lat<-65, Lon<70, Lon>-60.
```

## Average location information

In [24]:

```
#Average classification per location cell
averageGeoG = sampleMetaDFL.groupby(["lat", "lon"])
averageGeo = averageGeoG.mean(["lat", "lon"])
```

```
averageGeo = averageGeo.reset_index()
print("Average location information calculated and stored in averageGeo.")
```

```
Average location information calculated and stored in averageGeo.
```

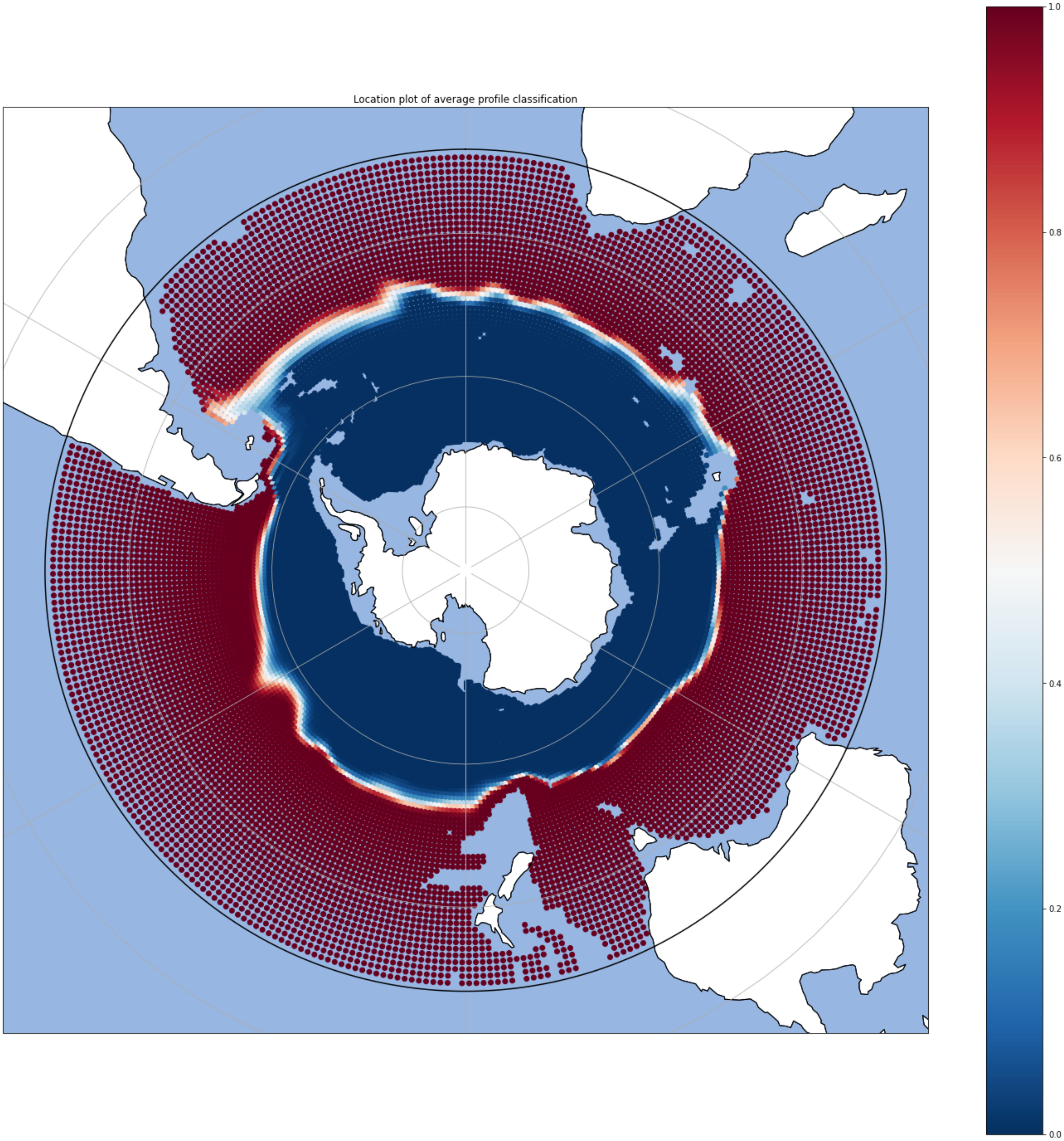
In [25]:

```
#Average classification per location and month cell
averageMonthGeoG = sampleMetaDFL.groupby([sampleMetaDFL.time.dt.month, "lat", "lon"])
averageMonthGeo = averageMonthGeoG.mean(["lat", "lon"])
averageMonthGeo = averageMonthGeo.reset_index()
print("Average monthly location information calculated and stored in averageMonthGeo.")
```

```
Average monthly location information calculated and stored in averageMonthGeo.
```

In [26]:

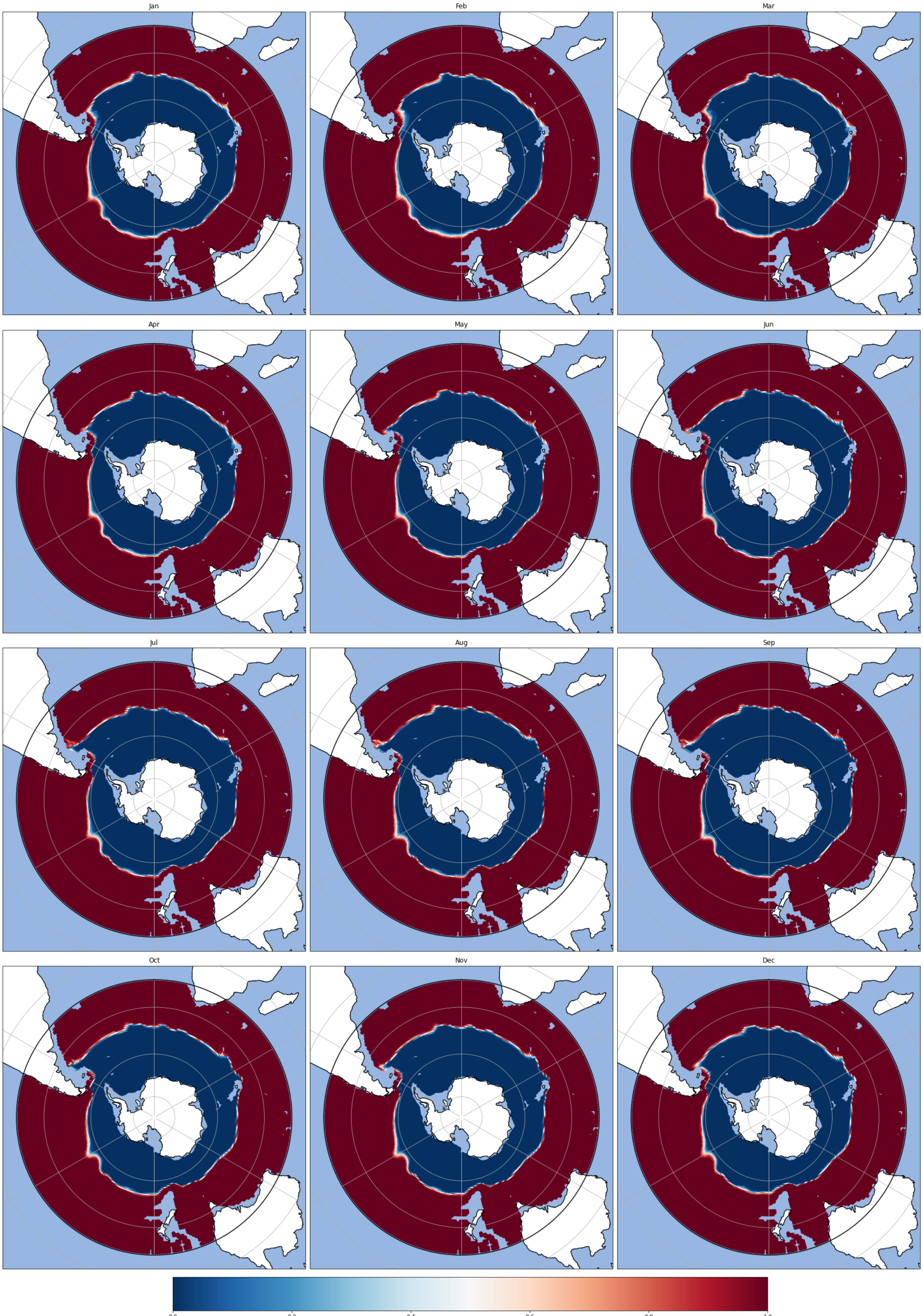
```
#Average classification location plot cell
locationPlotGroupDFLab(averageGeo, "Location plot of average profile classification", (25,
plt.show()
```




In [27]:

```
locationPlotGroupDFMonthly(averageMonthGeo, "Monthly summaries for training data set", 1)
print("Average Classifications, grouped by month.")
plt.show()
```

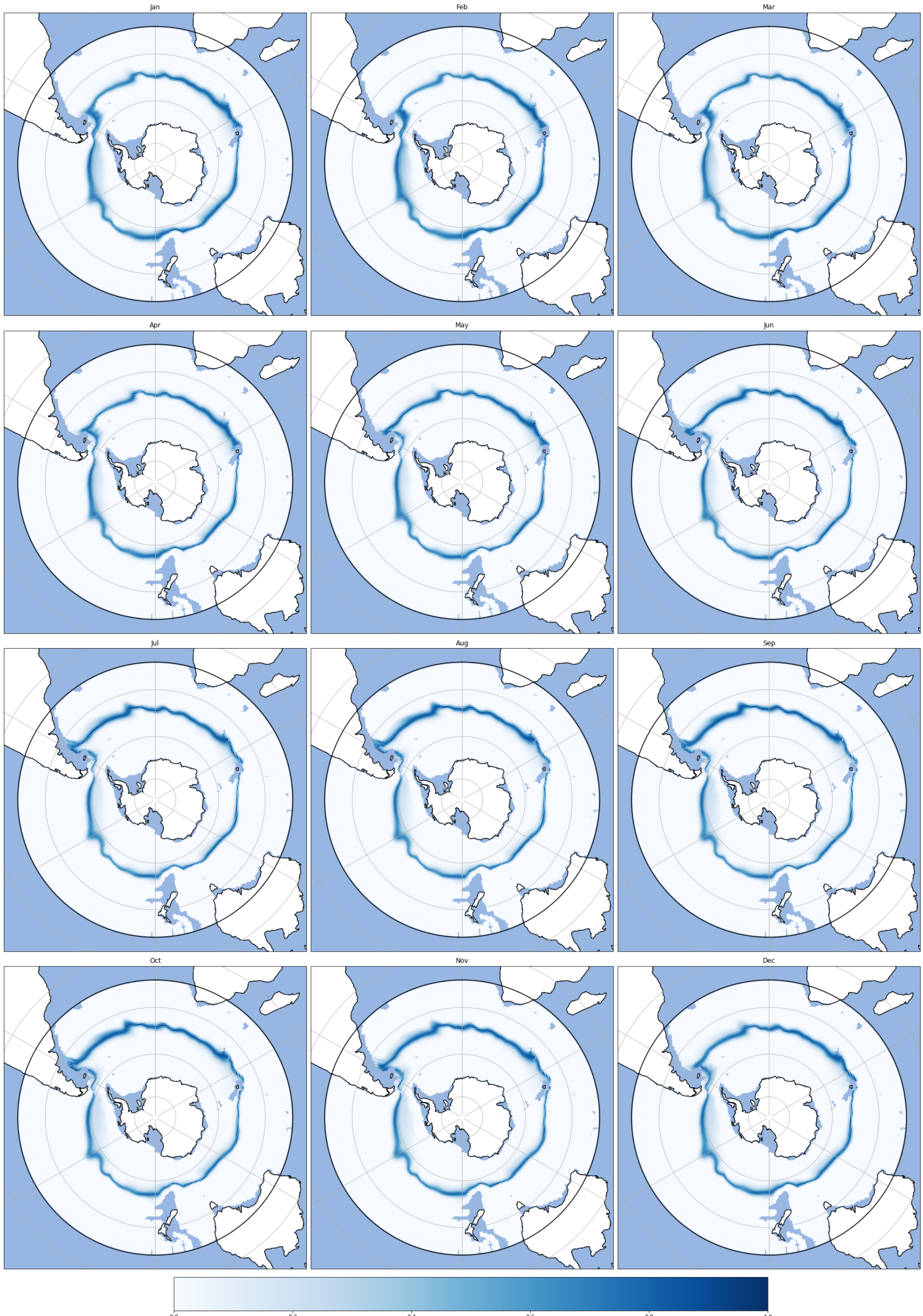
```
Average Classifications, grouped by month.
```




In [28]:

```
locationPlotUncertaintyDFMonthly(averageMonthGeo, "Monthly uncertainty", 1)
print("Average Uncertainty in classifications, grouped by month.")
plt.show()
```

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

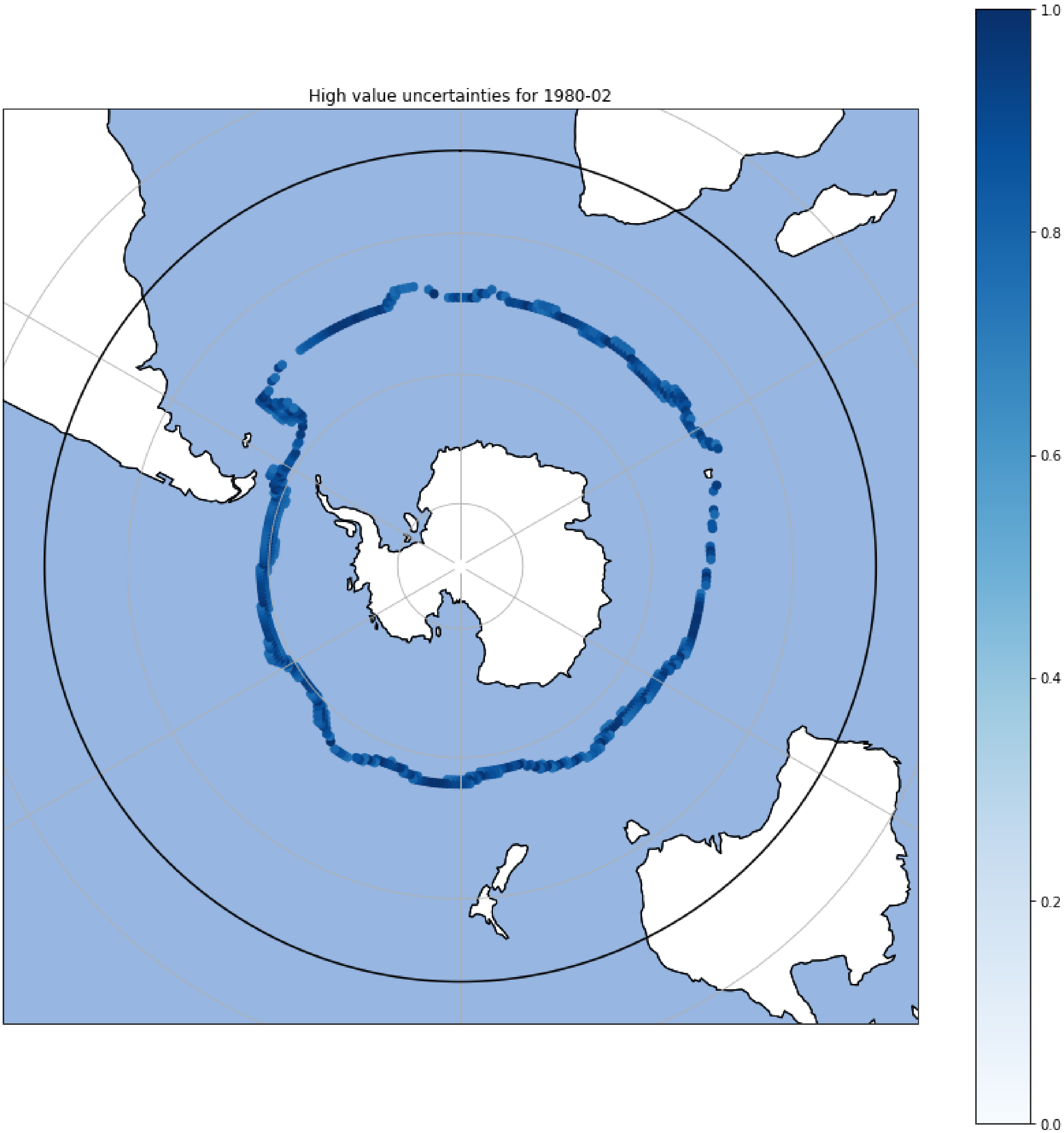


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0.0
0.2
0.4
0.6
0.8
1.0

## Single Month Properities

In [29]:

```
testTime = "1980-02"
uncertaintyDFL = sampleMetaDFL[sampleMetaDFL["classUncertainty"] > 0.75]
monthlyData = uncertaintyDFL[uncertaintyDFL["time"]=="1980-02"]#["lon"].unique()
locationPlotUncertaintyDF(monthlyData, "High value uncertainties for "+testTime, (15,15),
plt.show()
print("Single Month data identified and plotted and stored in monthlyData. "+str(len(montl
```




```
Single Month data identified and plotted and stored in monthlyData. 607 high classificatio
n uncertainty points identified.
```

## Mean Singular Latitudes over time

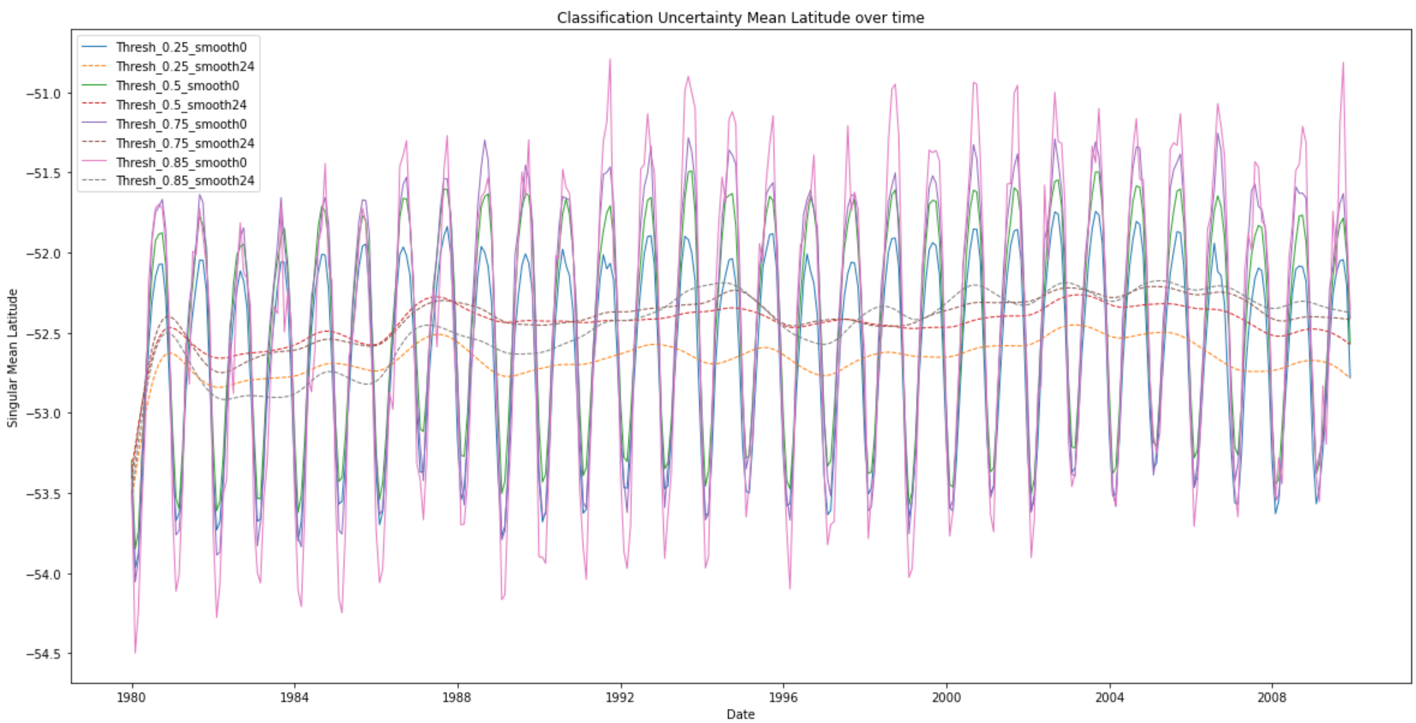
In [30]:

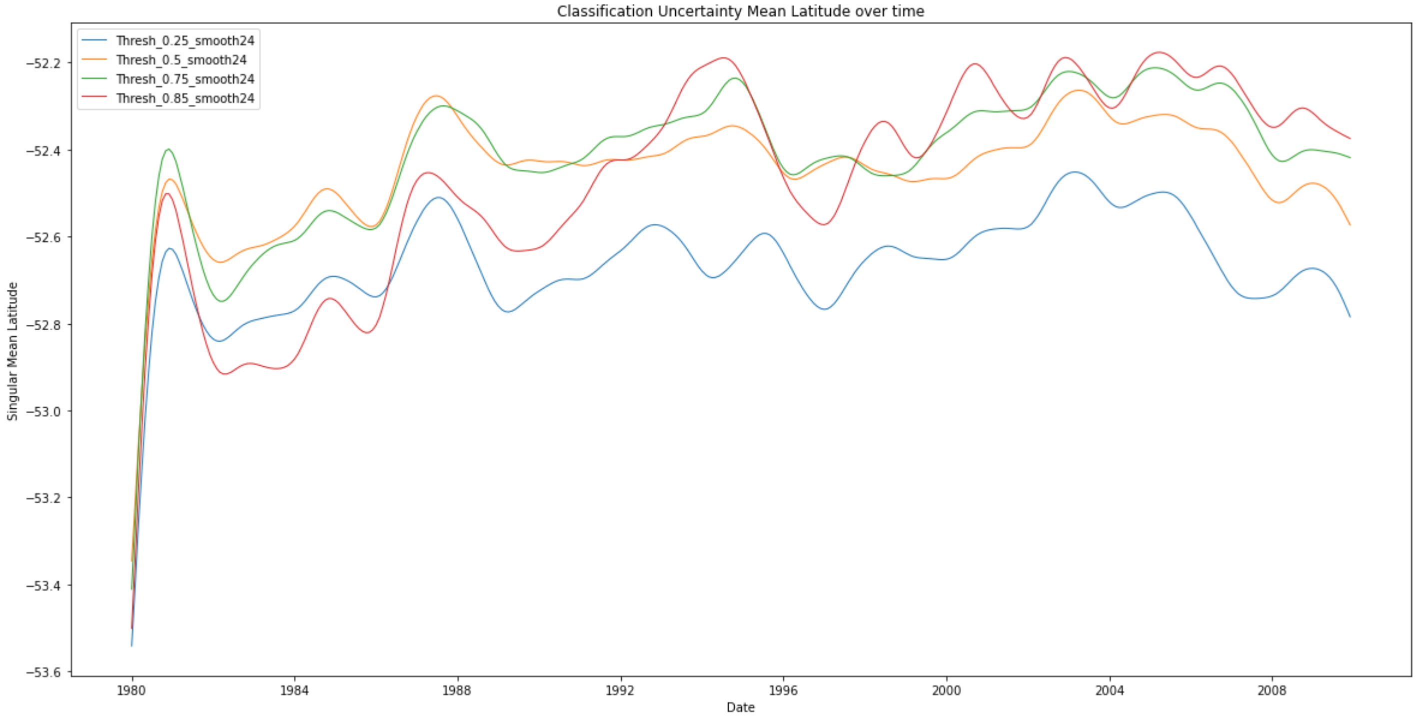
```
thresholds = [0.25, 0.50, 0.75, 0.85]
smoothFactor1 = 24
smoothFactor2 = 120
monthlyLatMMList = []
monthlyLatMMS1List = []
monthlyLatMMS2List = []

for i in range(len(thresholds)):
    uncertaintyDFL = sampleMetaDFL[sampleMetaDFL["classUncertainty"] > thresholds[i]]

    uncertaintyDFLLonTimeG = uncertaintyDFL.groupby(["lon","time"])
    uncertaintyDFLLonM = uncertaintyDFLLonTimeG.mean("lon")
    uncertaintyDFLLonM = uncertaintyDFLLonM.reorder_levels(['time', 'lon']).sort_index()
    uncertaintyDFLLonMTimeG = uncertaintyDFLLonM.groupby("time")

    monthlyLatMMList.append(uncertaintyDFLLonMTimeG.mean()[["lat"]])
    monthlyLatMMS1List.append(butter_lowpass(monthlyLatMMList[i]["lat"], smoothFactor1))
    monthlyLatMMS2List.append(butter_lowpass(monthlyLatMMList[i]["lat"], smoothFactor2))
print("Monthly Singular Mean Latitudes calculated, with smoothing.")
```

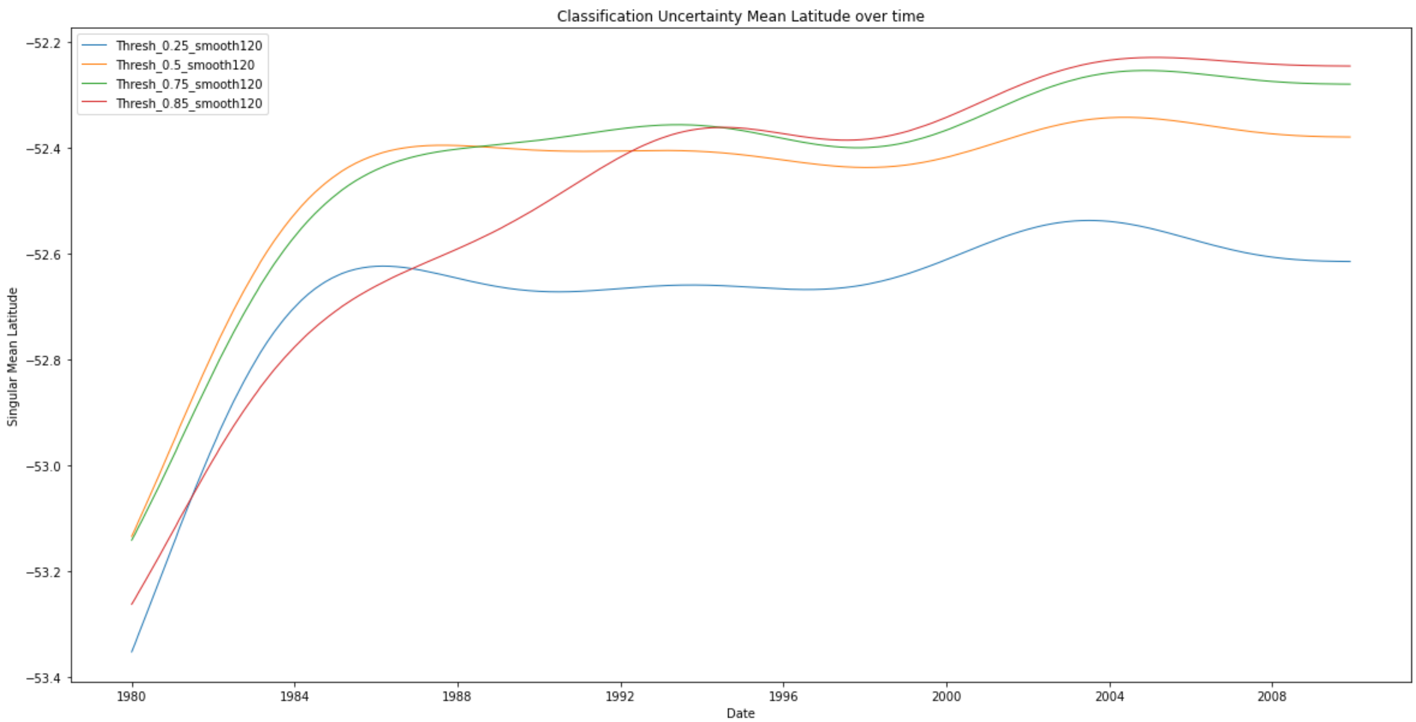
```
Monthly Singular Mean Latitudes calculated, with smoothing.
```

In [31]:

```
for i in range(len(thresholds)):
    timeSingleLatMean(monthlyLatMMList[i], "-", thresholds[i], 0, 1)
    timeSingleLatMean(monthlyLatMMS1List[i], "--", thresholds[i], smoothFactor1, 1)

    timeSingleLatMean(monthlyLatMMS1List[i], "-", thresholds[i], smoothFactor1, 2)
    timeSingleLatMean(monthlyLatMMS2List[i], "-", thresholds[i], smoothFactor2, 3)

for i in range(1, 4):
    plt.figure(i)
    #plt.gca().invert_yaxis()

plt.show()
```





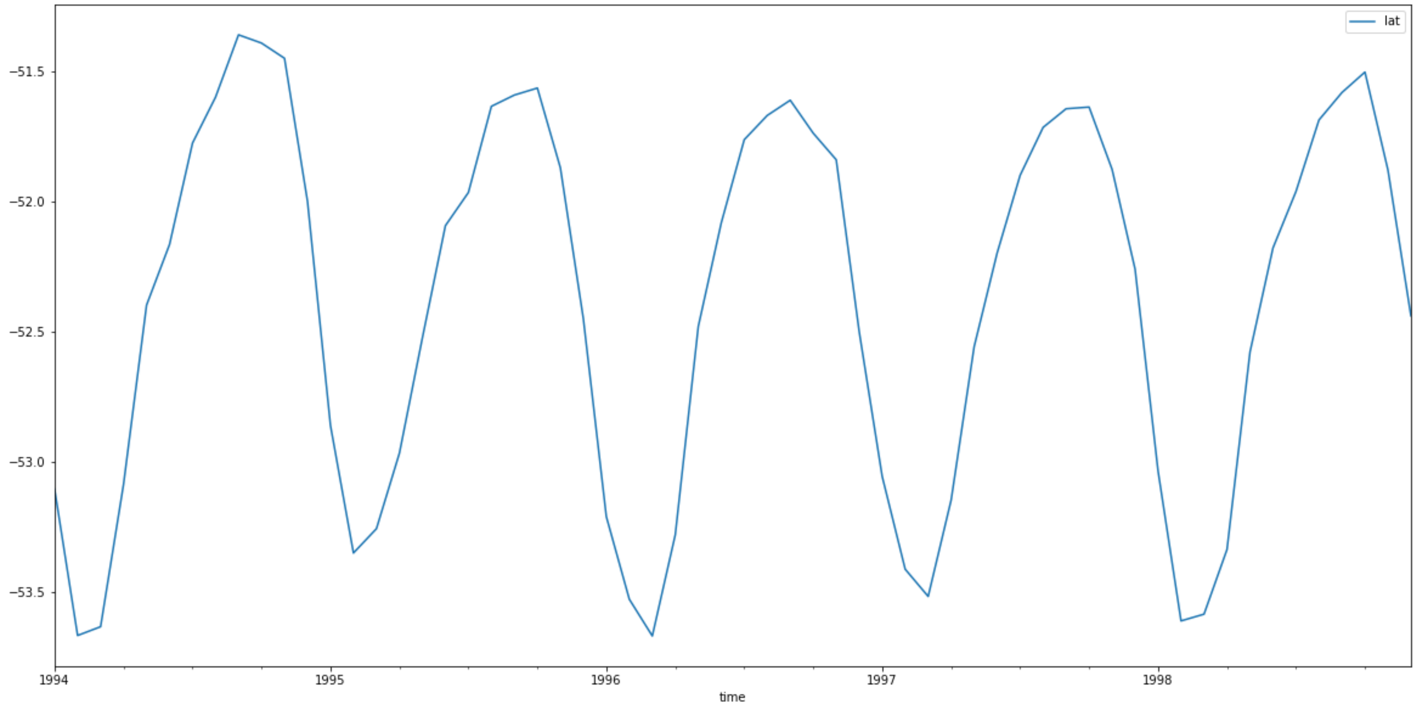




## 1997 Dip investigation

In [32]:

```
timeRange = np.arange(np.datetime64("1994-01",'M'), np.datetime64("1999-01", 'M'), np.time
breakDown = monthlyLatMMList[2]
timeRangeDF = breakDown[breakDown.index.isin(timeRange)]
timeRangeDF.plot(figsize=(20,10))
print("Single Lat mean value for 1994 to 1998")
plt.show()
```

```
Single Lat mean value for 1994 to 1998
```



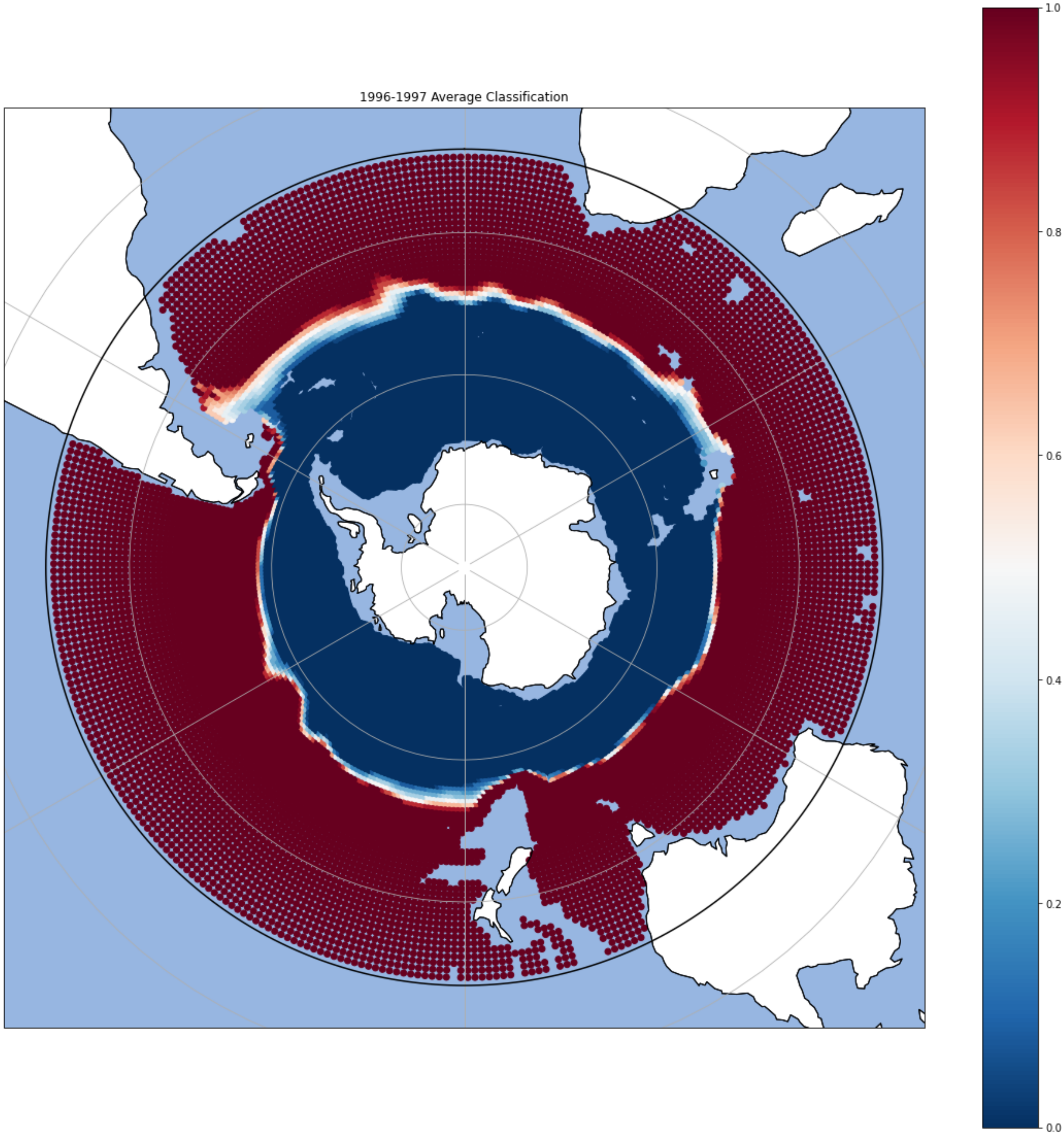

In [33]:

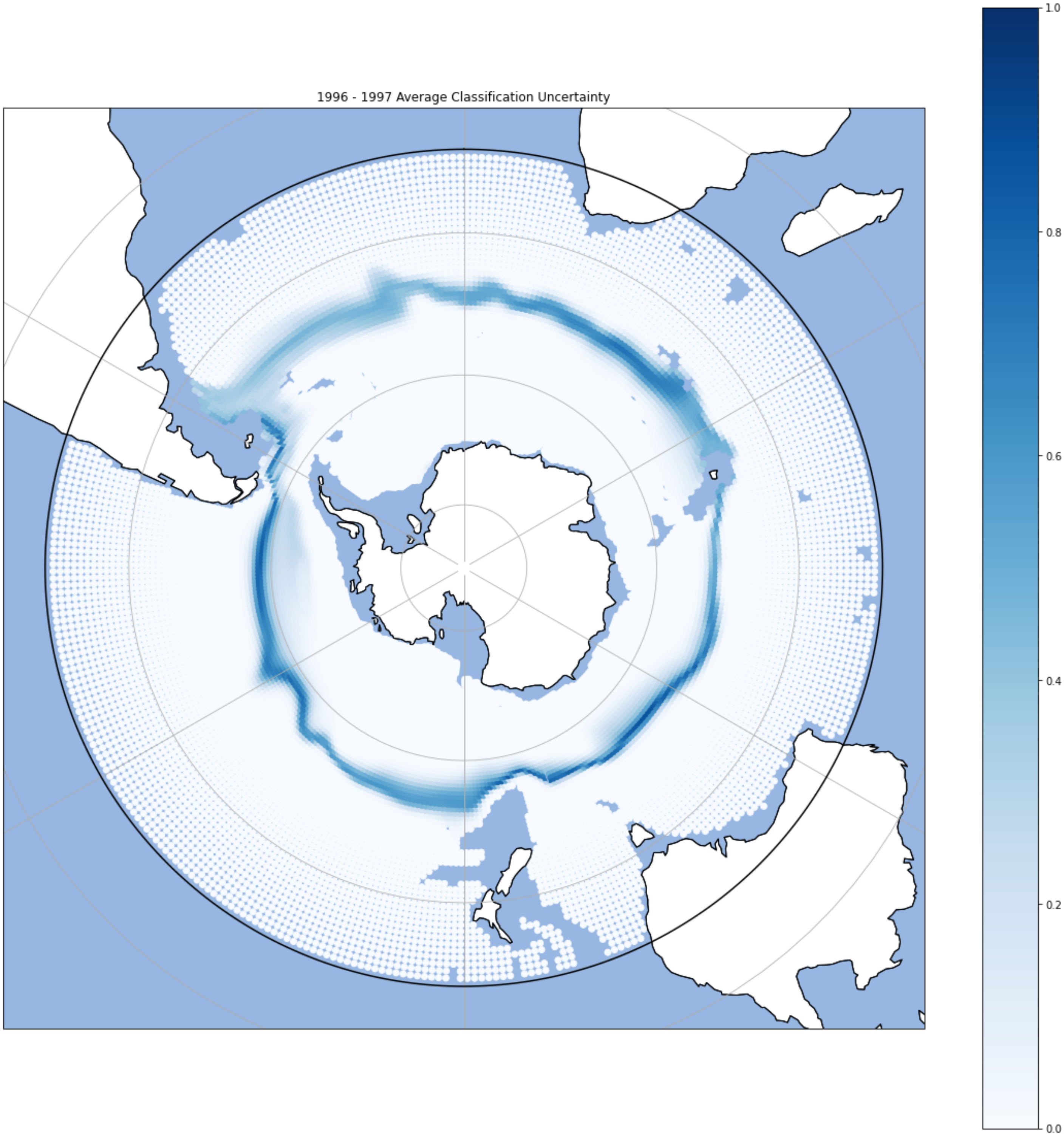
```
timeRangeClose = np.arange(np.datetime64("1996-01",'M'), np.datetime64("1998-01", 'M'), np
timeRangeCloseDF = sampleMetaDFL[sampleMetaDFL["time"].isin(timeRangeClose)]
avgGeoTimeRangeCloseDFG = timeRangeCloseDF.groupby(["lat", "lon"])
avgGeoTimeRangeCloseDF = avgGeoTimeRangeCloseDFG.mean(["lat", "lon"])
avgGeoTimeRangeCloseDF = avgGeoTimeRangeCloseDF.reset_index()
print("Average classification information calculated for 1996 - 1997, stored in avgGeoTime
```

```
Average classification information calculated for 1996 - 1997, stored in avgGeoTimeRangeCl
oseDF.
```

In [34]:

```
locationPlotGroupDFLab(avgGeoTimeRangeCloseDF, "1996-1997 Average Classification", (20,20)
locationPlotUncertaintyDF(avgGeoTimeRangeCloseDF, "1996 - 1997 Average Classification Unce
plt.show()
```


1996-1997 Average Classification
1.0
0.8
0.6
0.4
0.2
0.0




## Decadal investigation

In [35]:

```
decades = ["1980", "1990", "2000"]
decade80 = np.arange(np.datetime64("1980", 'M'), np.datetime64("1990", 'M'), np.timedelta(
decade90 = np.arange(np.datetime64("1990", 'M'), np.datetime64("2000", 'M'), np.timedelta(
decade00 = np.arange(np.datetime64("2000", 'M'), np.datetime64("2010", 'M'), np.timedelta(
decadeList = [decade80, decade90, decade00]
print("Decade lists created and stored in decade80, decade90 and decade00.")
```

```
Decade lists created and stored in decade80, decade90 and decade00.
```

In [36]:

```
sampleMetaDFDecList = [sampleMetaDFL[sampleMetaDFL["time"].isin(decade80)], sampleMetaDFL
print("Decade split performed and stored in sampleMetaDFDecList.")
```

Decade split performed and stored in sampleMetaDFDecList.

In [37]:

```
decDFIThreshList = []
decDFIThreshLatMList = []
decDFIThreshLatSList = []
threshold = 0.75

for i in range(len(decades)):
    decDF = sampleMetaDFDecList[i]
    decDFIThresh = decDF[decDF["classUncertainty"] > threshold]
    decDFIThreshList.append(decDFIThresh)

    decDFIThreshLonG = decDFIThresh.groupby("lon")
    decDFIThreshLatMList.append(decDFIThreshLonG.mean()[["lat"]])
    decDFIThreshLatSList.append(decDFIThreshLonG.std()[["lat"]])
print("Decadal class uncertainty latitude means calculted and stored in decDFIThreshLatMLi
```

Decadal class uncertainty latitude means calculted and stored in decDFIThreshLatMList. Sta
ndard deviations are stored in decDFIThreshLatSList.

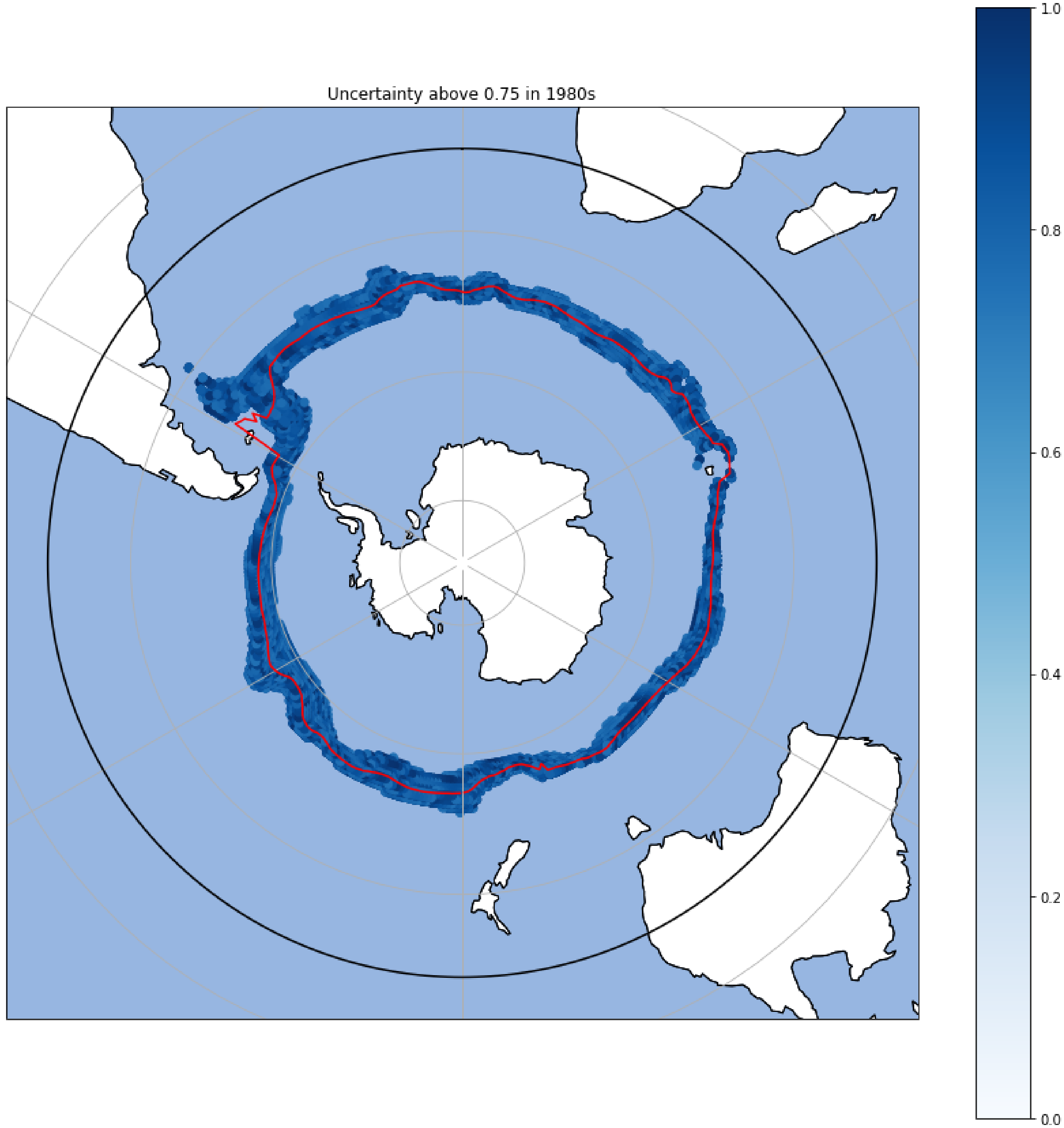
In [38]:

```
decDFIThreshLatMMListDecade = []
decDFIThreshLatMMListYearly = []
for i in range(len(decDFIThreshLatMList)):
    decDFIThreshLatMMListDecade.append(decDFIThreshLatMList[i]["lat"].mean()) #Decadal Mea

    yearlyLatMeans = monthlyLatMMList[2]
    decadeSet = yearlyLatMeans[yearlyLatMeans.index.isin(decadeList[i])]
    decDFIThreshLatMMListYearly.append(decadeSet["lat"].mean()) #Yearly Mean from previous

    print("For "+str(decades[i])+" the singular mean latitude for a threshold of "+str(thr
print("Decade singular mean latitude values calculated.")
```

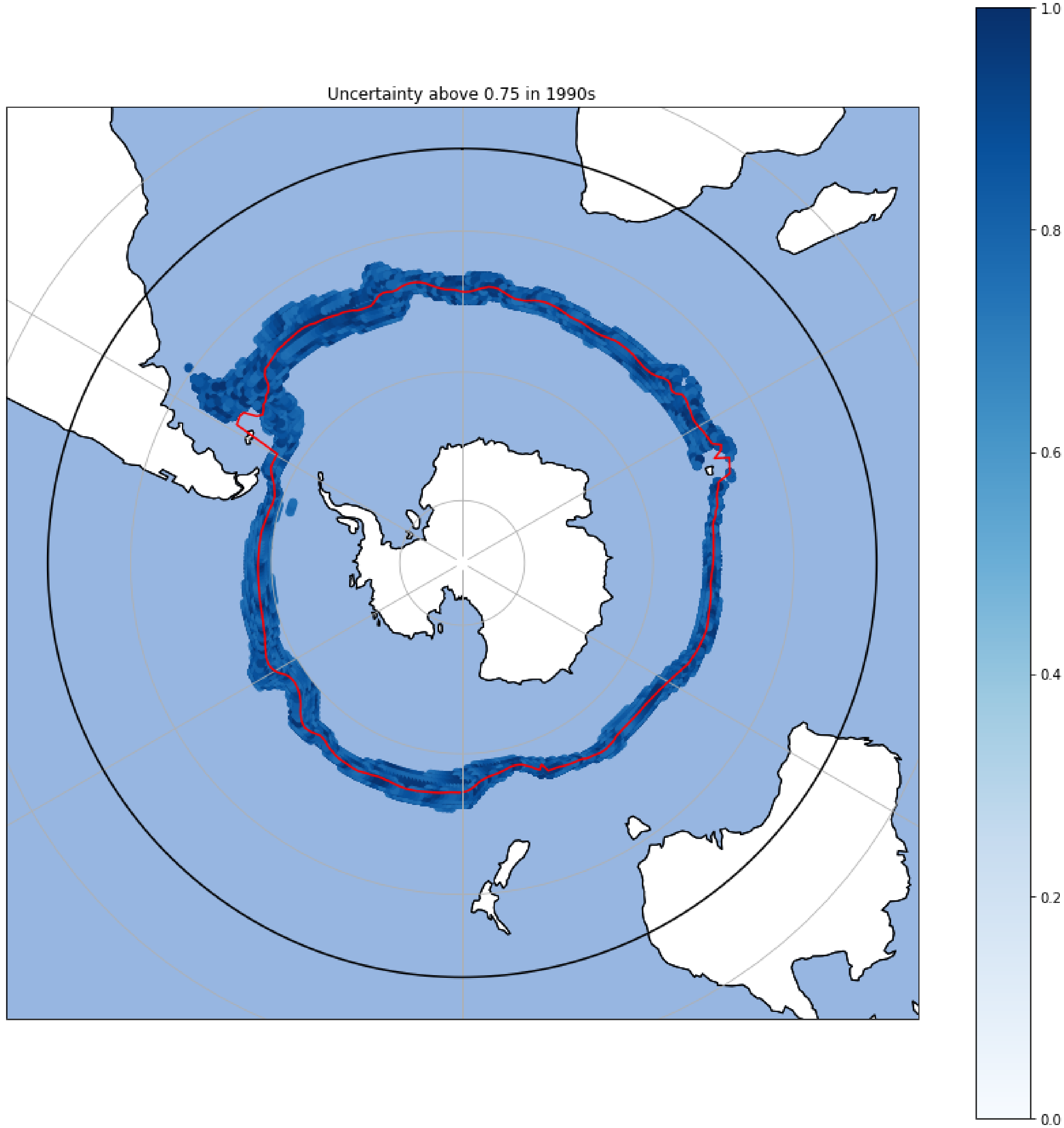
For 1980 the singular mean latitude for a threshold of 0.75 was -52.45 via decade and -52.
53 via yearly.
For 1990 the singular mean latitude for a threshold of 0.75 was -52.33 via decade and -52.
39 via yearly.
For 2000 the singular mean latitude for a threshold of 0.75 was -52.3 via decade and -52.3
1 via yearly.
Decade singular mean latitude values calculated.

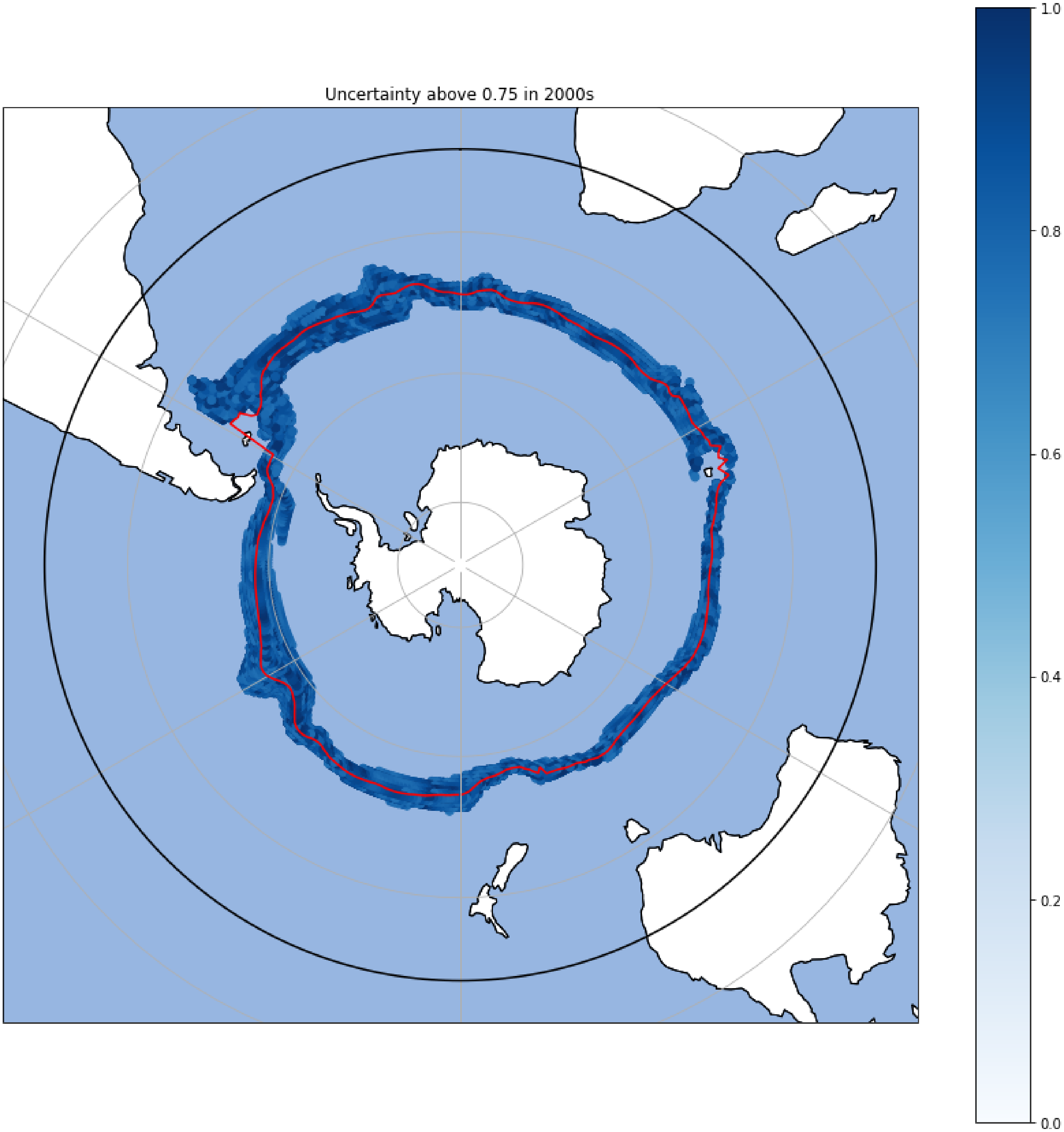
In [39]:

```
for i in range(len(decades)):
    locationPlotUncertaintyDF(decDFIThreshList[i], "Uncertainty above "+str(threshold)+" i
    plt.plot(decDFIThreshLatMList[i].index, decDFIThreshLatMList[i]["lat"], transform=ccrs

locationUncertaintyMean(decDFIThreshLatMList, decDFIThreshLatSList, threshold, (20,20), 4)
plt.show()
```

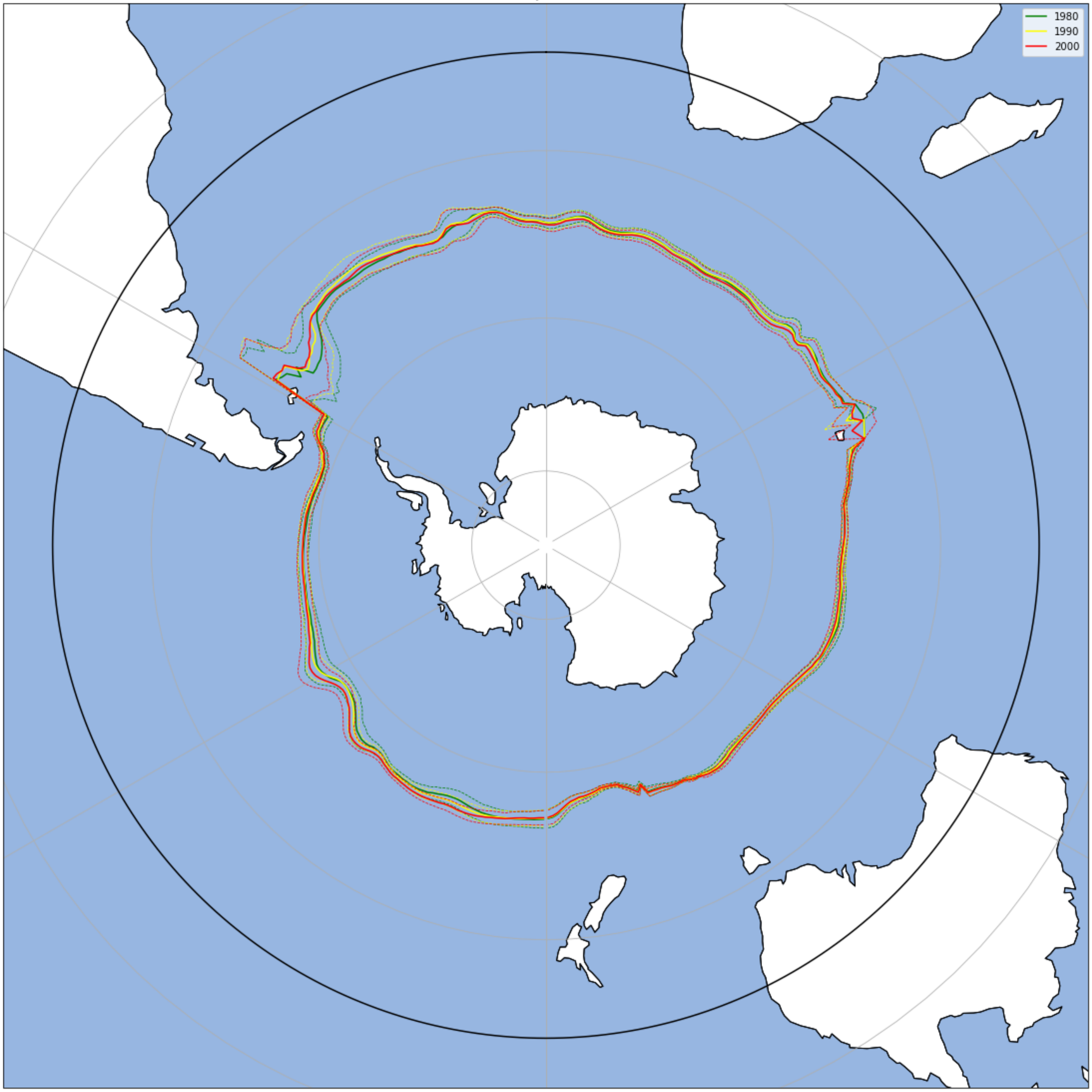


Uncertainty above 0.75 in 1980s
1.0
0.8
0.6
0.4
0.2
0.0


Uncertainty above 0.75 in 1990s
1.0
0.8
0.6
0.4
0.2
0.0


Uncertainty above 0.75 in 2000s
1.0
0.8
0.6
0.4
0.2
0.0

Classification Uncertainty above 0.75 Mean Latitude




## Exporting Monthly Latitude Means

In [40]:

```
exportName = modelName + "_LatMeans"
np.save(exportName, monthlyLatMMList)
print("Monthly Latitude means (monthlyLatMMList) exported to "+exportName+".")
```

```
Monthly Latitude means (monthlyLatMMList) exported to GMM_UK_2Class_R2_LatMeans.
```

In [41]:

```
importName = exportName+".npy"
monthlyLatMMListReload = np.load(importName)
print("Monthly Latitude means reloaded into monthlyLatMMListReload from "+importName+".")
```

```
Monthly Latitude means reloaded into monthlyLatMMListReload from GMM_UK_2Class_R2_LatMean
s.npy.
```

In [42]:
```
print("Reloaded monthly latitude means.")
monthlyLatMMList
```

```
Reloaded monthly latitude means.
```

Out[42]:
```
[                   lat
 time
 1980-01-01 -53.496106
 1980-02-01 -53.969822
 1980-03-01 -53.881028
 1980-04-01 -53.454682
 1980-05-01 -52.949074
 ...               ...
 2009-08-01 -52.119879
 2009-09-01 -52.051606
 2009-10-01 -52.044739
 2009-11-01 -52.202208
 2009-12-01 -52.779794

 [360 rows x 1 columns],
                   lat
 time
 1980-01-01 -53.295487
 1980-02-01 -53.848568
 1980-03-01 -53.741754
 1980-04-01 -53.288814
 1980-05-01 -52.848369
 ...               ...
 2009-08-01 -51.944610
 2009-09-01 -51.822196
 2009-10-01 -51.785042
 2009-11-01 -52.014766
 2009-12-01 -52.568497

 [360 rows x 1 columns],
                   lat
 time
 1980-01-01 -53.345058
 1980-02-01 -54.055194
 1980-03-01 -53.913183
 1980-04-01 -53.283171
 1980-05-01 -52.851608
 ...               ...
 2009-08-01 -51.837059
 2009-09-01 -51.691782
 2009-10-01 -51.632764
 2009-11-01 -51.950423
 2009-12-01 -52.410042

 [360 rows x 1 columns],
                   lat
 time
 1980-01-01 -53.436115
 1980-02-01 -54.497759
 1980-03-01 -54.237743
 1980-04-01 -53.584481
 1980-05-01 -53.109243
 ...               ...
 2009-08-01 -52.134495
 2009-09-01 -51.203775
 2009-10-01 -50.813929
 2009-11-01 -51.861067
 2009-12-01 -52.356784

 [360 rows x 1 columns]]
```

## End of Notebook