SAM Analysis

Designed to calculate and plot the SAM. Link to Data analysis.

Choices for data

In [1]:
```
#Experiment data for analysis
dataVariableId = 'psl'
dataSourceId = "UKESM1-0-LL"
experimentId = "historical"
tableId = "Amon"
approvedIds = ["r1i1p1f2", "r2i1p1f2", "r3i1p1f2"] #insert start of approved member_ids

#External data files
externalSAMFileName = "SAMIndex.txt"
GMModelNames = ["GMM_UK_2Class_R1", "GMM_UK_2Class_R2", "GMM_UK_2Class_R3"]#, "GMM_UK_2Cla

#Custom Variables
latSel = slice(-89.5,-29.5) #Selected latitude to be investigated
maskName = "OceanMaskVolcello"
```

Imports

In [2]:
```
import cartopy.crs as ccrs
import cartopy.feature as cfeature
import dask.dataframe as dd
import fsspec
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import xarray as xr
import zarr

from dask import delayed
from matplotlib.pyplot import cm
from scipy import signal
print("Imports complete")
```

```
Imports complete
```

Data loading

Loading the ESM Pressure data

In [3]:
```
df = pd.read_csv('https://storage.googleapis.com/cmip6/cmip6-zarr-consolidated-stores.csv'
dfFilt = df[df.variable_id.eq(dataVariableId) & df.source_id.eq(dataSourceId) & df.table_i

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]
```

```
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 ESM3 data sets opened")

for i in range(fileCount): #Formatting dates into np.datetime64 format
    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
print("Data sets successfully merged")

dfESMLat = fileSet.psl.sel(lat=latSel) #Selection of latitude
dfESMLat = dfESMLat.reset_coords(drop=True) #Removes lev if single value

globalStartDate = dfESMLat["time"][0].values
globalDateInc = dfESMLat["time"][1].values - globalStartDate
globalEndDateIn = dfESMLat["time"][-1].values
globalEndDateOut = globalEndDateIn + globalDateInc

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

print("UKESM data sucessfully loaded.")
```

```
3 UKESM1-0-LL data sets opened
Data sets successfully merged
UKESM data sucessfully loaded.
```

Loading the ocean mask

In [4]:

```
maskFile = xr.open_dataset(maskName)
oceanMask = maskFile.to_array()
print("Mask Loaded into oceanMask")
```

```
Mask Loaded into oceanMask
```

Unpacking ocean masks

In [5]:

```
#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.")
```

```
Ocean mask unpacked into geoRangeFilt.
```

Loading external SAM Index

In [6]:
```
externalSAMIndex = np.loadtxt("SAMIndex.txt", skiprows=1, max_rows=64)
externalSAMIndexYear = np.transpose(externalSAMIndex)[0]
externalSAMIndexSort = np.empty(shape=(0,2))
for i in range(len(externalSAMIndexYear)):
    for j in range(1,13):
        externalSAMIndexSort = np.append(externalSAMIndexSort, [[np.datetime64(str(int(ext
externalSAMIndexSort = np.transpose(externalSAMIndexSort)
print("External SAM index data in "+externalSAMFileName+" loaded into externalSAMIndexSort
```

```
External SAM index data in SAMIndex.txt loaded into externalSAMIndexSort.
```

Loading mean latitudes from GMM

In [7]:
```
thresholds = [0.25, 0.5, 0.75, 0.85]
LatMeanList = []
for i in GMModelNames:
    importName = i + "_LatMeans.npy"
    LatMeanList.append(np.load(importName))
print("GMM mean latitudes imported into LatMeanList.")
```

```
GMM mean latitudes imported into LatMeanList.
```

SAM pressure calculations

In [8]:
```
if True:
    normalisationData = dfESMLat.sel(time=slice('1971-01','2000-12'))
    normalisationDataP40 = normalisationData.sel(lat=-40, method="nearest")
    selLat40 = normalisationDataP40["lat"].values
    normalisationDataP65 = normalisationData.sel(lat=-65, method="nearest")
    selLat65 = normalisationDataP65["lat"].values

    normalisationDataP40MLon = normalisationDataP40.mean(["lon"], keep_attrs=True)
    normalisationDataP65MLon = normalisationDataP65.mean(["lon"], keep_attrs=True)
    normalisationDataP40MLonG = normalisationDataP40MLon.groupby("time.month")
    normalisationDataP65MLonG = normalisationDataP65MLon.groupby("time.month")
    P40m = normalisationDataP40MLonG.mean(["time"], keep_attrs=True).values
    P65m = normalisationDataP65MLonG.mean(["time"], keep_attrs=True).values

    normalisationDataP40G = normalisationDataP40.groupby("time.month")
    P40std = normalisationDataP40MLonG.std(["time"], keep_attrs=True).values #
    normalisationDataP65G = normalisationDataP65.groupby("time.month")
    P65std = normalisationDataP65MLonG.std(["time"], keep_attrs=True).values #
else:
    normalisationData = dfESMLat.sel(time=slice('1971-01','2000-12'))
    normalisationDataP40 = normalisationData.sel(lat=slice(-41,-39))
    normalisationDataP40M = normalisationDataP40.mean("lat", keep_attrs=True)
    normalisationDataP65 = normalisationData.sel(lat=slice(-66,-64))
    normalisationDataP65M = normalisationDataP65.mean("lat", keep_attrs=True)

    normalisationDataP40MLon = normalisationDataP40M.mean(["lon"], keep_attrs=True)
    normalisationDataP65MLon = normalisationDataP65M.mean(["lon"], keep_attrs=True)
    normalisationDataP40MLonG = normalisationDataP40MLon.groupby("time.month")
    normalisationDataP65MLonG = normalisationDataP65MLon.groupby("time.month")
    P40m = normalisationDataP40MLonG.mean(["time"], keep_attrs=True).values
    P65m = normalisationDataP65MLonG.mean(["time"], keep_attrs=True).values

    normalisationDataP40G = normalisationDataP40.groupby("time.month")
    P40std = normalisationDataP40G.std(["lat","lon","time"], keep_attrs=True).values
    normalisationDataP65G = normalisationDataP65.groupby("time.month")
    P65std = normalisationDataP65G.std(["lat","lon","time"], keep_attrs=True).values
print("Normalisation data calculated.")
```

```
Normalisation data calculated.
```

Calculation Functions

Functions:

- externalSAMSearch - returns externalSAMIndexSort between two dates.
- SAMCalculateRaw - returns a data array of the difference in pressures between lat -40 and lat -65 (tolerance ±1°) for an input data array, not normalised .
- SAMCalculateNorm - returns a data array of the difference in pressures between lat -40 and lat -65 (tolerance ±1°) for an input data array, normalised using second input data array.

In [9]:

```
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 externalSAMSearch(startDate, endDate):
    '''Performs np searching across externalSAMIndexSort for start-end date data, returns
    x, startIndex = np.where(externalSAMIndexSort == np.datetime64(startDate, 'M'))
    x, endIndex = np.where(externalSAMIndexSort == np.datetime64(endDate, 'M'))
    dateArray = externalSAMIndexSort[0][startIndex[0] : endIndex[0] + 1]
    dataArray = externalSAMIndexSort[1][startIndex[0] : endIndex[0] + 1]
    externalSAMSearch = np.append([dateArray], [dataArray], axis=0)
    return externalSAMSearch


def SAMCalculateNorm(dataArray, runId):
    '''Calculates the SAM index using P40m, P65m, P40std and P65std. Returns SAM index np
    timeArray = dataArray["time"].values
    startTimeY = timeArray[0].astype('datetime64[Y]').astype(int) + 1970
    endTimeY = timeArray[-1].astype('datetime64[Y]').astype(int) + 1970
    startTimeM = timeArray[0].astype('datetime64[M]').astype(int) % 12 + 1
    endTimeM = timeArray[-1].astype('datetime64[M]').astype(int) % 12 + 1

    P40 = dataArray.sel(lat=slice(-41, -39))
    P65 = dataArray.sel(lat=slice(-66, -64))

    P40zArray = np.empty(shape=0)
    P65zArray = np.empty(shape=0)
    if startTimeM > 1: #Part start year z transform
        P40YearPartS = P40.sel(time = str(startTimeY))
        P40YearPartS = P40YearPartS.mean(dim=["lat", "lon"])
        P40YearPartS = P40YearPartS.reset_coords(drop=True)
        P40zYearPartS = ((P40YearPartS-P40m[startTimeM-1:])/P40std[startTimeM-1:]).values
        P40zArray = np.append(P40zArray, P40zYearPartS)

        P65YearPartS = P65.sel(time = str(startTimeY))
        P65YearPartS = P65YearPartS.mean(dim=["lat", "lon"])
        P65YearPartS = P65YearPartS.reset_coords(drop=True)
        P65zYearPartS = ((P65YearPartS-P65m[startTimeM-1:])/P65std[startTimeM-1:]).values
        P65zArray = np.append(P65zArray, P65zYearPartS)
        startTimeY += 1

    P40zYearPartE = np.empty(0)
    P65zYearPartE = np.empty(0)
    if endTimeM < 12: #Part end year z transform
        P40YearPartE = P40.sel(time = str(endTimeY))
```

```
        P40YearPartE = P40YearPartE.mean(dim=["lat", "lon"])
        P40YearPartE = P40YearPartE.reset_coords(drop=True)
        P40zYearPartE = ((P40YearPartE-P40m[:endTimeM-12])/P40std[:endTimeM-12]).values

        P65YearPartE = P65.sel(time = str(endTimeY))
        P65YearPartE = P65YearPartE.mean(dim=["lat", "lon"])
        P65YearPartE = P65YearPartE.reset_coords(drop=True)
        P65zYearPartE = ((P65YearPartE-P65m[:endTimeM-12])/P65std[:endTimeM-12]).values
        endTimeY -= 1

    if startTimeY <= endTimeY: #Full year z transform
        for i in range(startTimeY, endTimeY + 1):
            P40Year = P40.sel(time = str(i))
            P40Year = P40Year.mean(dim=["lat", "lon"])
            P40Year = P40Year.reset_coords(drop=True)
            P40zYear = ((P40Year-P40m[runId])/P40std[runId]).values
            P40zArray = np.append(P40zArray, P40zYear)

            P65Year = P65.sel(time = str(i))
            P65Year = P65Year.mean(dim=["lat", "lon"])
            P65Year = P65Year.reset_coords(drop=True)
            P65zYear = ((P65Year-P65m[runId])/P65std[runId]).values
            P65zArray = np.append(P65zArray, P65zYear)

    P40zArray = np.append(P40zArray, P40zYearPartE) #Appends End year
    P65zArray = np.append(P65zArray, P65zYearPartE) #Appends End year

    SAMArray = P40zArray - P65zArray
    SAMArray = np.round(SAMArray, 2)

    try:
        intRunId = runId.values
    except:
        intRunId = runId

    indexName = "SAM_Index_"+str(intRunId)
    exportSAMData = {"time":timeArray, indexName:SAMArray}
    exportSAMDF = pd.DataFrame(exportSAMData, columns=["time",indexName])
    return exportSAMDF

print("Calculation functions defined")
```

```
Calculation functions defined
```

Plotting Functions

Functions:

- mapPlot - plots the Southern Ocean orthographic project of the input data set, with input title and figure number.
- timePlot - plots the SAM index in the input data array over time.
- timePlotStd - plots the SAM index for a 12 month period (starting January) with error bars.
- timePlotYear - plots the SAM index for a 12 month period (starting January) without error bars. Compatible with timePlotStd.
- timePlotDecade - plots the SAM index for an input data array over a decade period. Start date is dispalyed as 2001-01.

In [10]:

```
months = ["Jan","Feb","Mar","Apr","May","Jun","Jul","Aug","Sep","Oct","Nov","Dec"]
lineType = ["-.", "--", ":"]
timeAxis = np.arange(np.datetime64("1980-01"), np.datetime64("2010-01"), np.timedelta64(1,
```

```
def latMeanPlot(dataArray, labelIn, plotNo):
    plt.figure(plotNo, figsize=(20,10))
    plt.plot(timeAxis, dataArray, label=labelIn)
    plt.xlabel("Month")
    plt.ylabel("Mean Latitude")
    plt.legend()


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


def SAMLatPlot(plotNo):
    '''Plots SAM index latitudes on a map, requires selLat40 and selLat65'''
    plt.figure(plotNo, figsize=(7,7))
    ax = plt.axes(projection=ccrs.SouthPolarStereo())
    ax.add_feature(cfeature.OCEAN)
    ax.add_feature(cfeature.COASTLINE)
    ax.coastlines()
    ax.gridlines()
    plt.plot(np.arange(0,361,1),np.ones(361)*selLat40, transform=ccrs.PlateCarree(), colo
    plt.plot(np.arange(0,361,1),np.ones(361)*selLat65, transform=ccrs.PlateCarree(), colo
    plt.title("Selected latitudes for SAM index calculation")


def timePlot(dataArray, runId, label, title, plotNo):
    '''Displays SAM index over time for any given range.'''
    plt.figure(plotNo, figsize = (20,10))
    indexName = "SAM_Index_"+str(runId)
    plt.plot(dataArray["time"], dataArray[indexName],label = str(label))
    #plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.axhline(0, color="Black", lw=0.5)
    plt.legend(loc='upper right')
    plt.ylabel("SAM Index")
    plt.title(str(title))


def timePlotStd(dataSetMean, dataSetError, title, plotNo):
    '''Displays SAM index with standard deviations over a 12 month period.'''
    plt.figure(plotNo, figsize = (10,10))
    plt.errorbar(months, dataSetMean.values, yerr=dataSetError.values, label = dataSetMean
    plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.xlabel("Month")
    plt.ylabel("SAM Index")
    plt.title(str(title))


def timePlotYear(dataArray, title, plotNo):
    '''Displays SAM index for a 12 month period starting in January. Compatible with timeR
    plt.figure(plotNo, figsize = (10,10))
    plt.plot(months, dataArray.values, label = dataArray.name)
    plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.xlabel("Month")
    plt.ylabel("SAM Index")
    plt.title(str(title))
```

```
def timePlotDecade(dataArray, runId, label, title, plotNo):
    '''Displays SAM index over a decade.'''
    timeAxis = np.arange(np.datetime64("2001-01"), np.datetime64("2011-01"), np.timedelta6
    indexName = "SAM_Index_"+str(runId)
    plt.figure(plotNo, figsize = (20,10))
    plt.plot(timeAxis, dataArray[indexName], label = str(label))
    plt.axhline(0, color="Black", lw=0.5)
    plt.legend(bbox_to_anchor=(1.05, 1), loc='upper left')
    plt.ylabel("SAM Index")
    plt.xlabel("Time")
    plt.title(str(title))

print("Plotting functions defined")
```

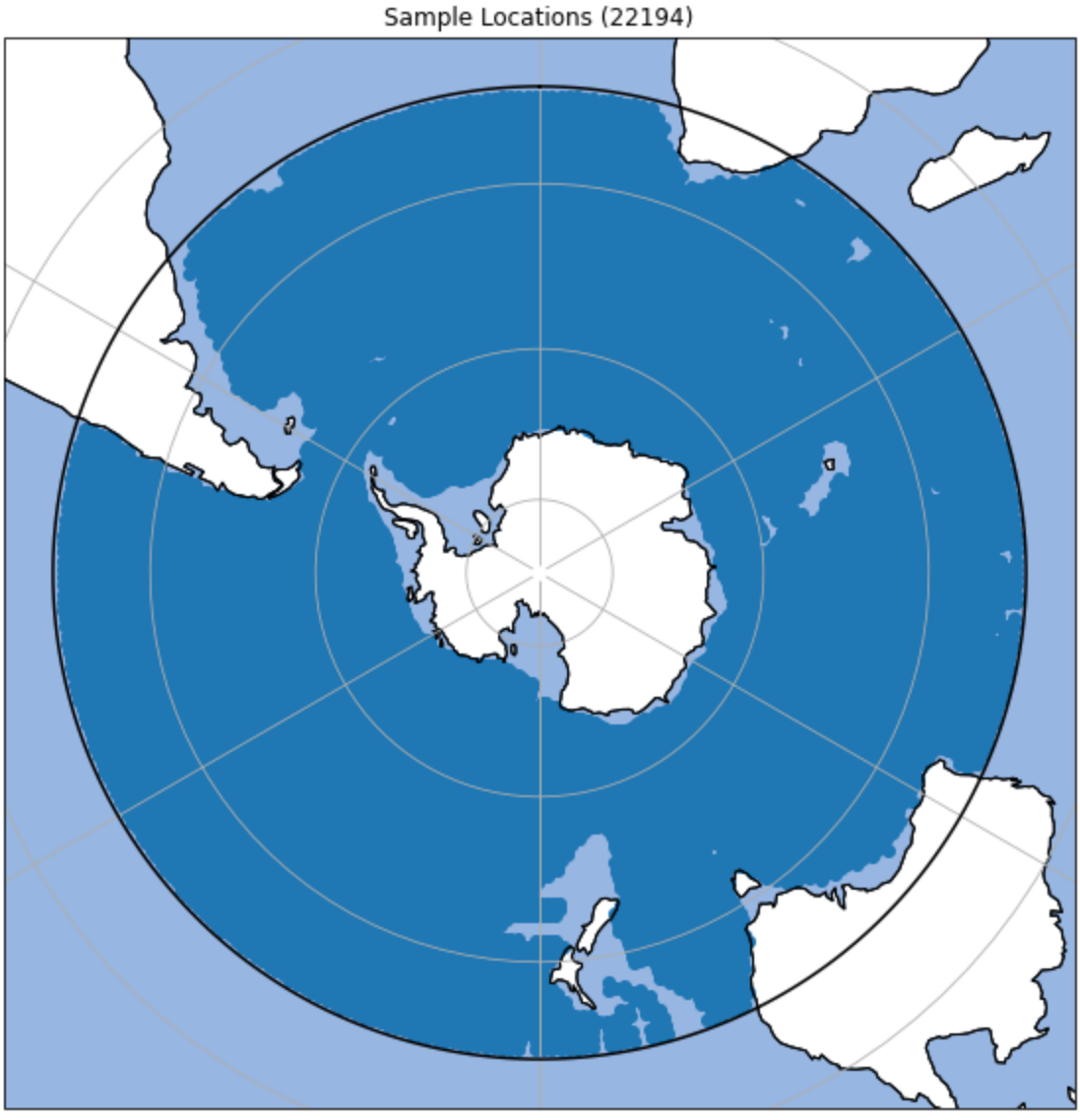
```
Plotting functions defined
```

Plotting the mask

In [11]:

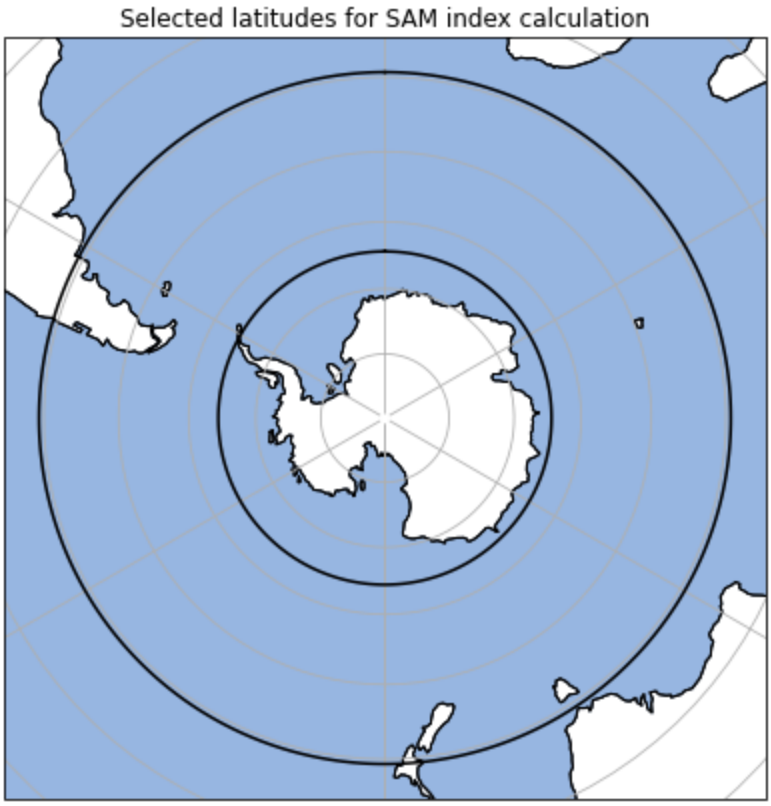
```
locationPlotXr(geoRangeFilt, (10,10), 1) #OceanMaskVolcello
print("Ocean Mask from Volcello Data")
plt.show()
```

```
Ocean Mask from Volcello Data
```



Latitudes Visualised

In [12]:
```
SAMLatPlot(1)
plt.show()
```



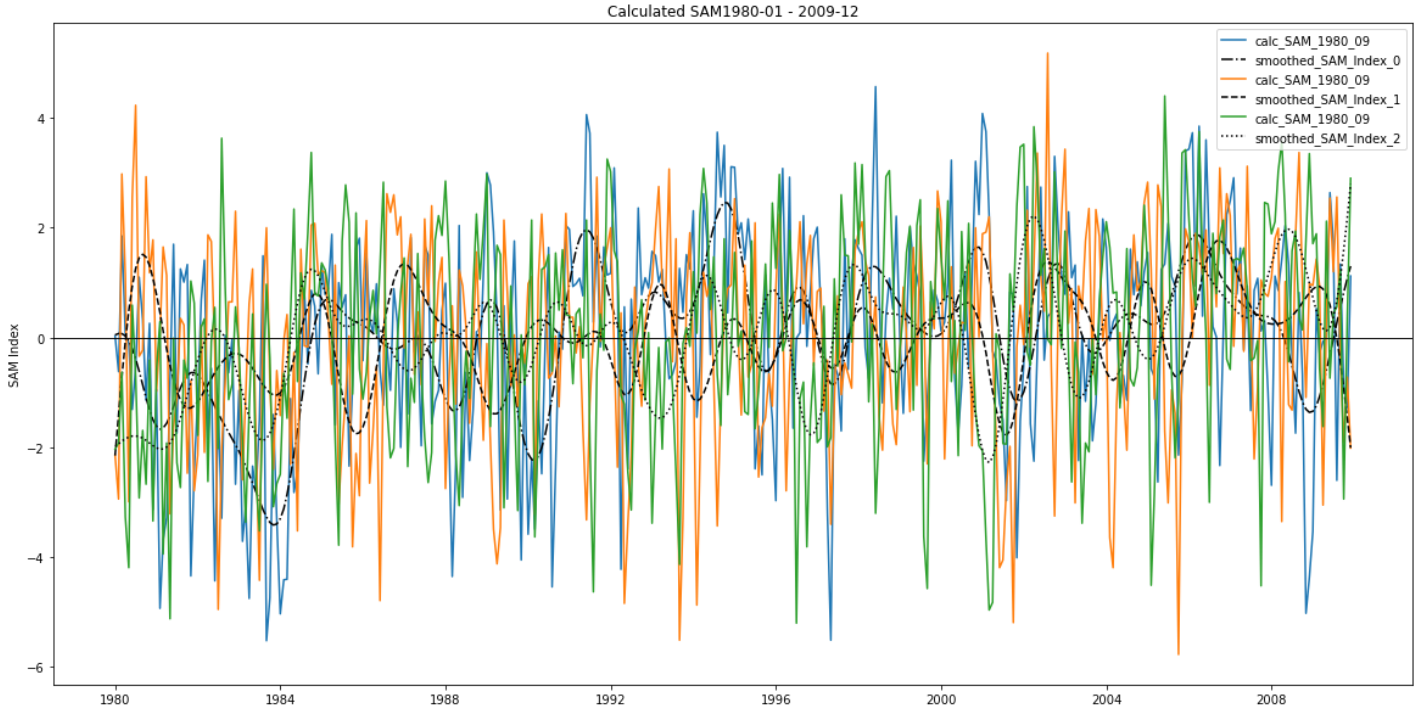
Data Analysis

SAM trend for 1980 - 2009

In [13]:
```
startDate, endDate = "1980-01","2009-12"
SAM1980_09DF = pd.DataFrame({'time' : dfESMLat.time.sel(time=slice(startDate, endDate)).va

for i in dfESMLat["RunId"]:
    SAM1980_09Part_data = dfESMLat.sel(time=slice(startDate, endDate), RunId=i)
    SAM1980_09Part = SAMCalculateNorm(SAM1980_09Part_data, i)
    SAM1980_09DF = SAM1980_09DF.merge(SAM1980_09Part, left_on="time", right_on="time")

print("External and internal SAM calculated for "+startDate+" - "+endDate+".")
```

```
External and internal SAM calculated for 1980-01 - 2009-12.
```

In [14]:
```
smooth18SAM1980_09Arr = np.empty(shape=(0,len(SAM1980_09DF["time"])))
for i in range(fileCount):
    indexName = "SAM_Index_"+str(i)
    smooth18SAM1980_09 = butter_lowpass(SAM1980_09DF[indexName], 18)
    smooth18SAM1980_09Arr = np.append(smooth18SAM1980_09Arr, [smooth18SAM1980_09], axis=0)

    timePlot(SAM1980_09DF, i, "calc_SAM_1980_09", "Calculated SAM"+startDate+" - "+endDate
    plt.plot(SAM1980_09DF["time"], smooth18SAM1980_09Arr[i%3], color="Black", ls=lineType
plt.axhline(0, color="Black", lw=0.5)
plt.legend()
plt.show()
```



SAM smoothing

In [15]:

```
startDate, endDate = "1980-01","2009-12"
extSAM1980_09 = externalSAMSearch(startDate, endDate)
print("External SAM calculated for "+startDate+" - "+endDate+".")
```

```
External SAM calculated for 1980-01 - 2009-12.
```

In [16]:

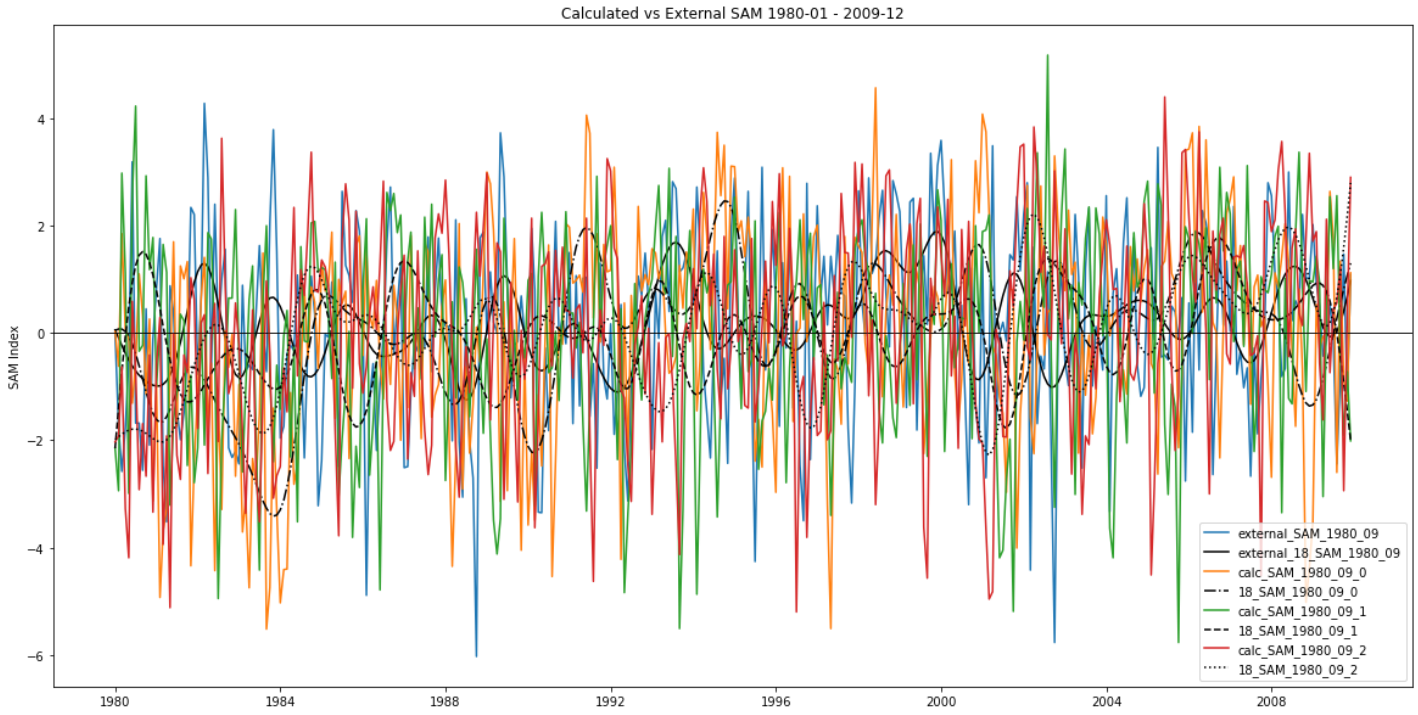
```
smooth18SAM1980_09Arr = np.empty(shape=(0,len(SAM1980_09DF["time"])))
smooth24SAM1980_09Arr = np.empty(shape=(0,len(SAM1980_09DF["time"])))
smooth120SAM1980_09Arr = np.empty(shape=(0,len(SAM1980_09DF["time"])))

smooth18extSAM1980_09 = butter_lowpass(extSAM1980_09[1], 18)
for i in range(fileCount):
    indexName = "SAM_Index_"+str(i)
    smooth18SAM1980_09 = butter_lowpass(SAM1980_09DF[indexName], 18)
    smooth18SAM1980_09Arr = np.append(smooth18SAM1980_09Arr, [smooth18SAM1980_09], axis=0)


smooth24extSAM1980_09 = butter_lowpass(extSAM1980_09[1], 24)
for i in range(fileCount):
    indexName = "SAM_Index_"+str(i)
    smooth24SAM1980_09 = butter_lowpass(SAM1980_09DF[indexName], 24)
    smooth24SAM1980_09Arr = np.append(smooth24SAM1980_09Arr, [smooth24SAM1980_09], axis=0)

smooth120extSAM1980_09 = butter_lowpass(extSAM1980_09[1], 120)
for i in range(fileCount):
    indexName = "SAM_Index_"+str(i)
    smooth120SAM1980_09 = butter_lowpass(SAM1980_09DF[indexName], 120)
    smooth120SAM1980_09Arr = np.append(smooth120SAM1980_09Arr, [smooth120SAM1980_09], axis

print("Smoothing calculated for SAM Index.")
```

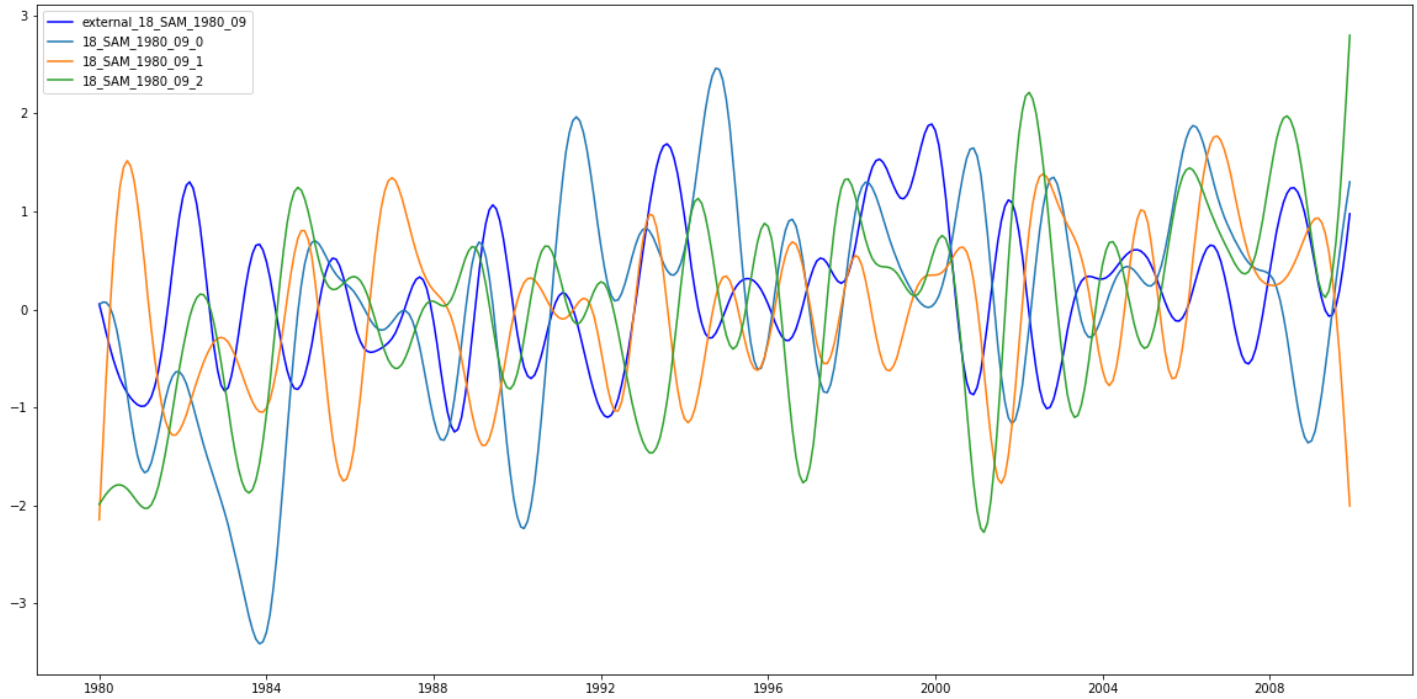
```
Smoothing calculated for SAM Index.
```

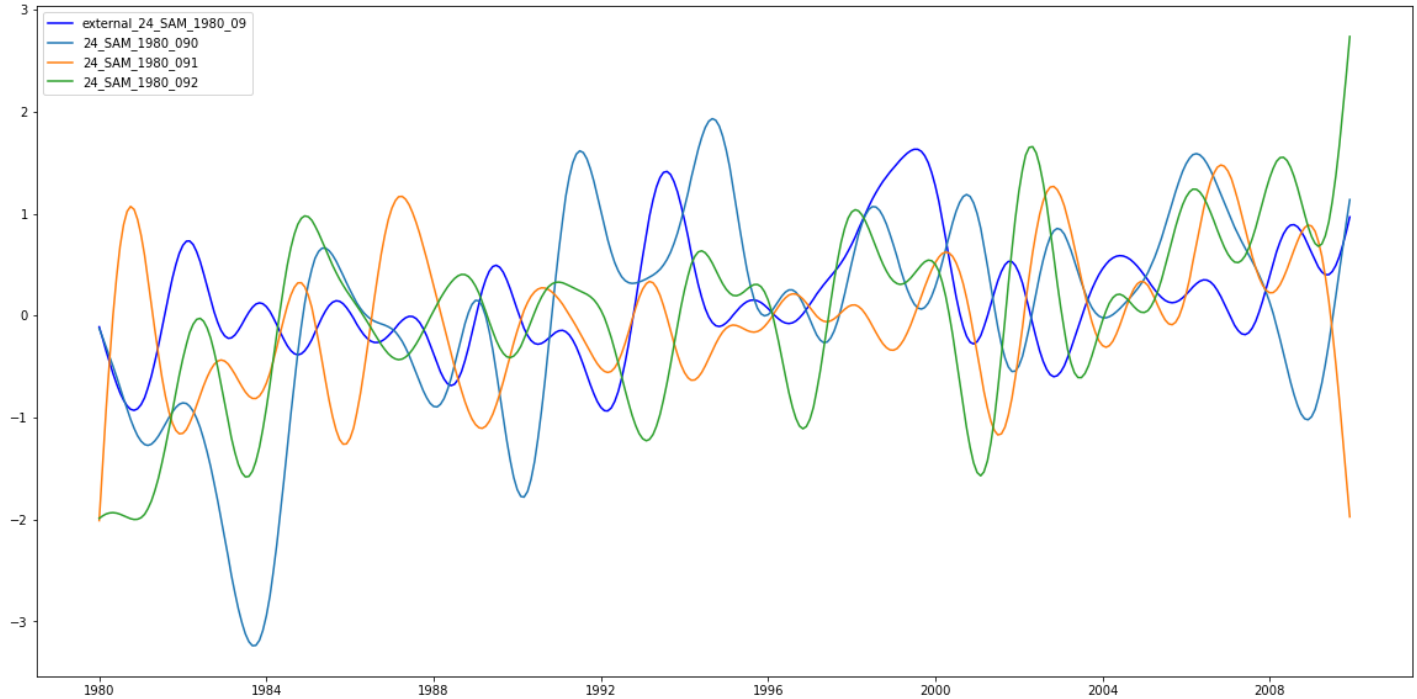
In [17]:

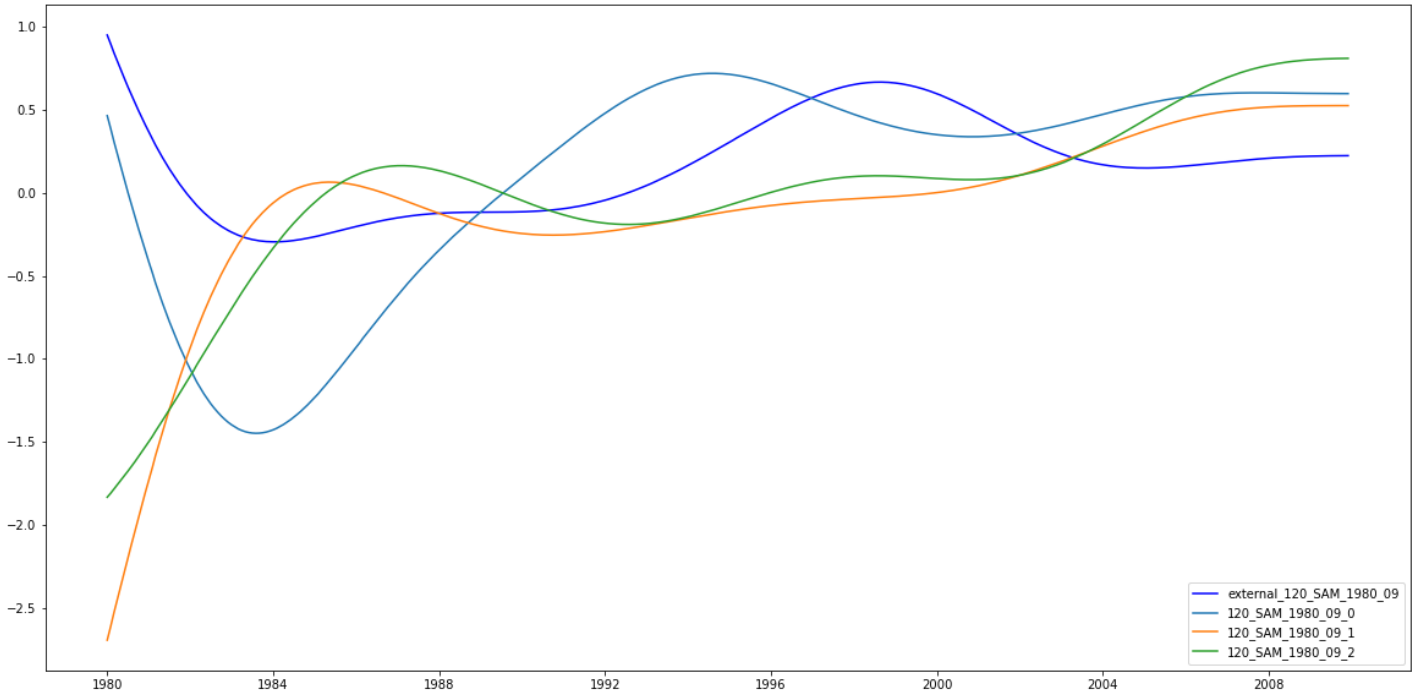
```
plt.figure(1, figsize=(20,10))
plt.plot(extSAM1980_09[0], extSAM1980_09[1], label="external_SAM_1980_09")
plt.plot(SAM1980_09DF["time"], smooth18extSAM1980_09, color="Black", label="external_18_SA
for i in range(fileCount):
```

```
    timePlot(SAM1980_09DF, i, "calc_SAM_1980_09_"+str(i), "Calculated vs External SAM "+st
    plt.plot(SAM1980_09DF["time"], smooth18SAM1980_09Arr[i], color="Black", ls=lineType[i%
plt.legend()

plt.figure(2, figsize=(20,10))
plt.plot(SAM1980_09DF["time"], smooth18extSAM1980_09, color="Blue", label="external_18_SAM
for i in range(fileCount):
    plt.plot(SAM1980_09DF["time"], smooth18SAM1980_09Arr[i], label="18_SAM_1980_09_"+str(i
plt.legend()


plt.figure(3, figsize=(20,10))
plt.plot(SAM1980_09DF["time"], smooth24extSAM1980_09, color="Blue", label="external_24_SAM
for i in range(fileCount):
    plt.plot(SAM1980_09DF["time"], smooth24SAM1980_09Arr[i], label="24_SAM_1980_09"+str(i)
plt.legend()

plt.figure(4, figsize=(20,10))
plt.plot(SAM1980_09DF["time"], smooth120extSAM1980_09, color="Blue", label="external_120_S
for i in range(fileCount):
    plt.plot(SAM1980_09DF["time"], smooth120SAM1980_09Arr[i], label="120_SAM_1980_09_"+str
plt.legend()

plt.show()
```




external_18_SAM_1980_09
18_SAM_1980_09_0
18_SAM_1980_09_1
18_SAM_1980_09_2
3
2
1
0
−1
−2
−3
1980
1984
1988
1992
1996
2000
2004
2008


external_24_SAM_1980_09
24_SAM_1980_090
24_SAM_1980_091
24_SAM_1980_092
3
2
1
0
−1
−2
−3
1980
1984
1988
1992
1996
2000
2004
2008



Mean Latitude Data

In [18]:

```
smoothLatArrLen = len(LatMeanList[0][0])
smooth18Lat1980_09Arr = np.empty(shape=(0, 4, smoothLatArrLen))
smooth24Lat1980_09Arr = np.empty(shape=(0, 4, smoothLatArrLen))
smooth50Lat1980_09Arr = np.empty(shape=(0, 4, smoothLatArrLen))

for i in range(len(GMModelNames)):
    currentLatMeans = LatMeanList[i]
    smooth18TempArr = np.empty(shape=(0,smoothLatArrLen))
    smooth24TempArr = np.empty(shape=(0,smoothLatArrLen))
    smooth50TempArr = np.empty(shape=(0,smoothLatArrLen))
    for j in range(len(thresholds)):
        currentLatMeanSingle = currentLatMeans[j].squeeze()
        smooth18TempArr = np.append(smooth18TempArr, [butter_lowpass(currentLatMeanSingle,
        smooth24TempArr = np.append(smooth24TempArr, [butter_lowpass(currentLatMeanSingle,
        smooth50TempArr = np.append(smooth50TempArr, [butter_lowpass(currentLatMeanSingle,

    smooth18Lat1980_09Arr = np.append(smooth18Lat1980_09Arr, [smooth18TempArr], axis=0)
    smooth24Lat1980_09Arr = np.append(smooth24Lat1980_09Arr, [smooth24TempArr], axis=0)
    smooth50Lat1980_09Arr = np.append(smooth50Lat1980_09Arr, [smooth50TempArr], axis=0)
print("Smoothing calculated for SAM Index.")
```

```
Smoothing calculated for SAM Index.
```

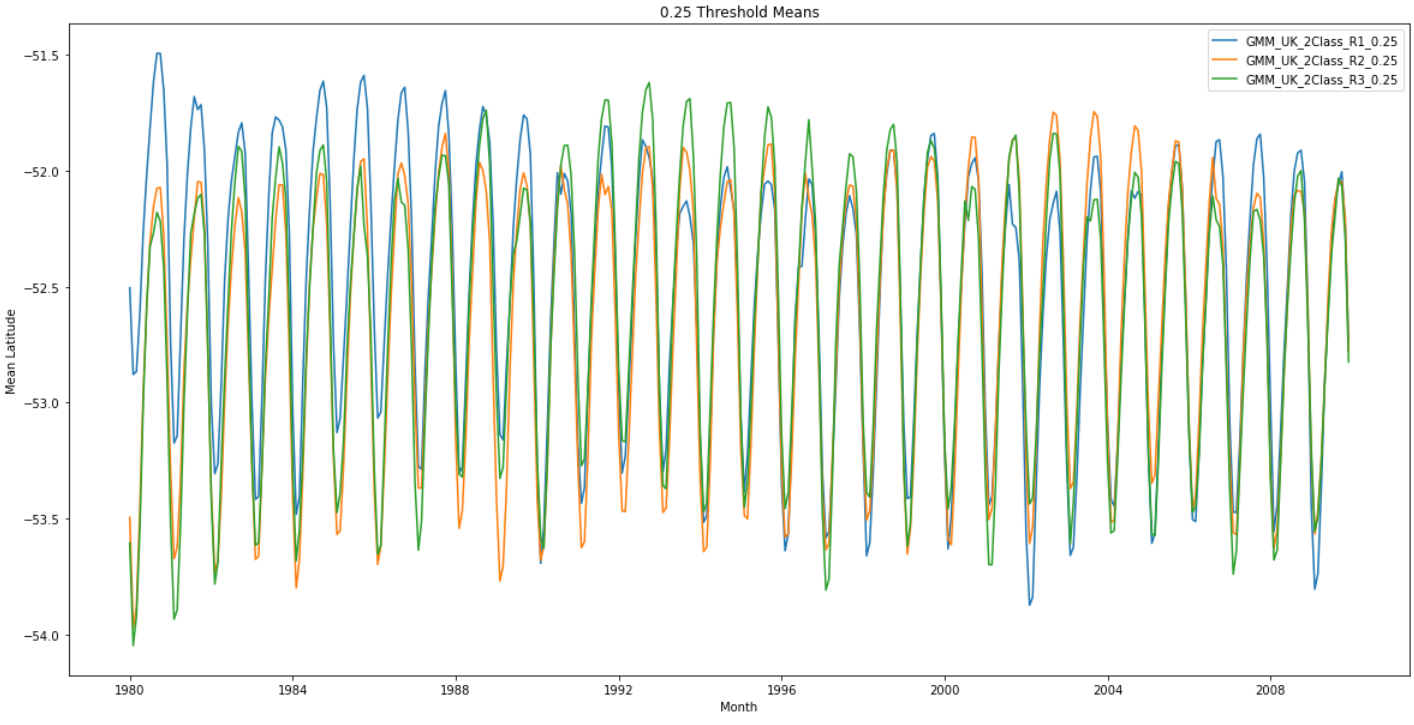
In [19]:

```
thresholdsLen = len(thresholds)
currSmooth18MeanArr = np.empty(shape=(0, smoothLatArrLen))
currSmooth24MeanArr = np.empty(shape=(0, smoothLatArrLen))
currSmooth50MeanArr = np.empty(shape=(0, smoothLatArrLen))

for i in range(thresholdsLen):
    currSmooth18Mean = np.mean(smooth18Lat1980_09Arr[:,i], axis=0)
    currSmooth24Mean = np.mean(smooth24Lat1980_09Arr[:,i], axis=0)
    currSmooth50Mean = np.mean(smooth50Lat1980_09Arr[:,i], axis=0)

    currSmooth18MeanArr = np.append(currSmooth18MeanArr, [currSmooth18Mean], axis=0)
    currSmooth24MeanArr = np.append(currSmooth24MeanArr, [currSmooth24Mean], axis=0)
    currSmooth50MeanArr = np.append(currSmooth50MeanArr, [currSmooth50Mean], axis=0)

print("Smoothing Averages calculated.")
```

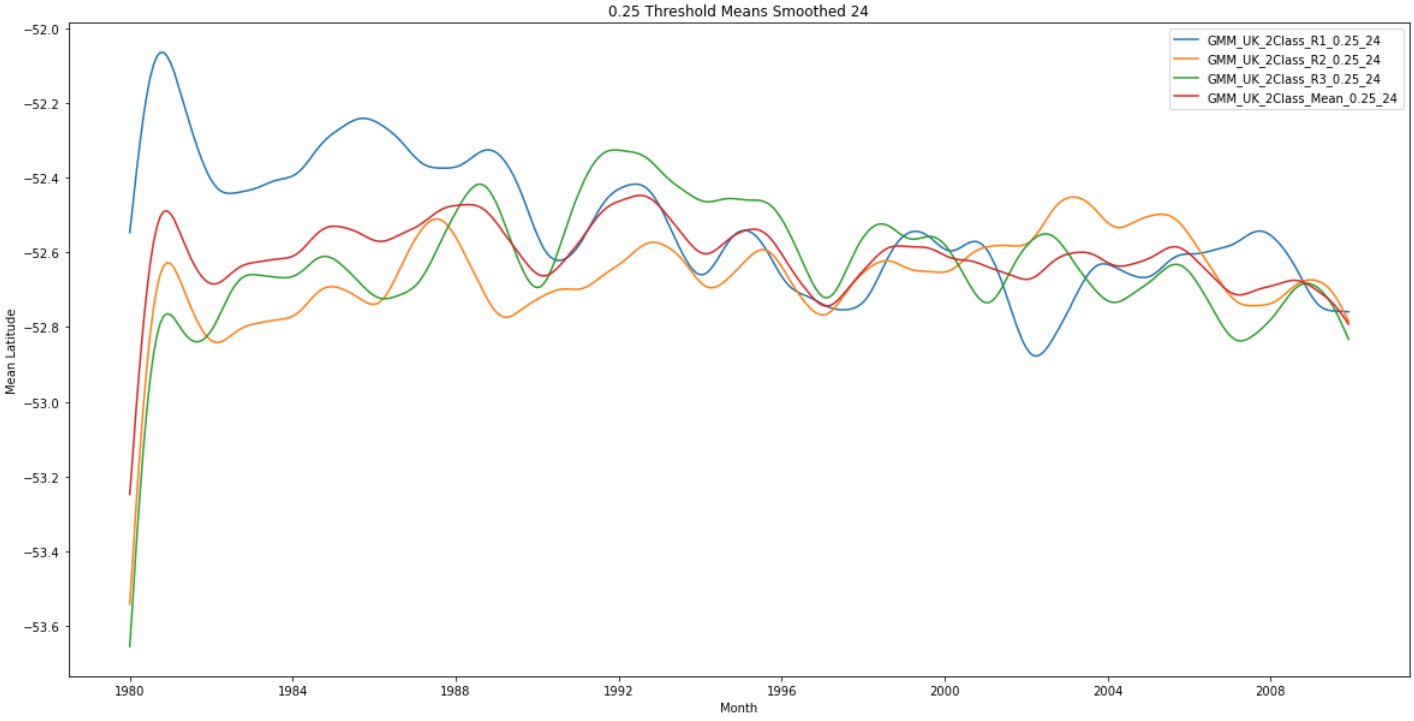
```
Smoothing Averages calculated.
```

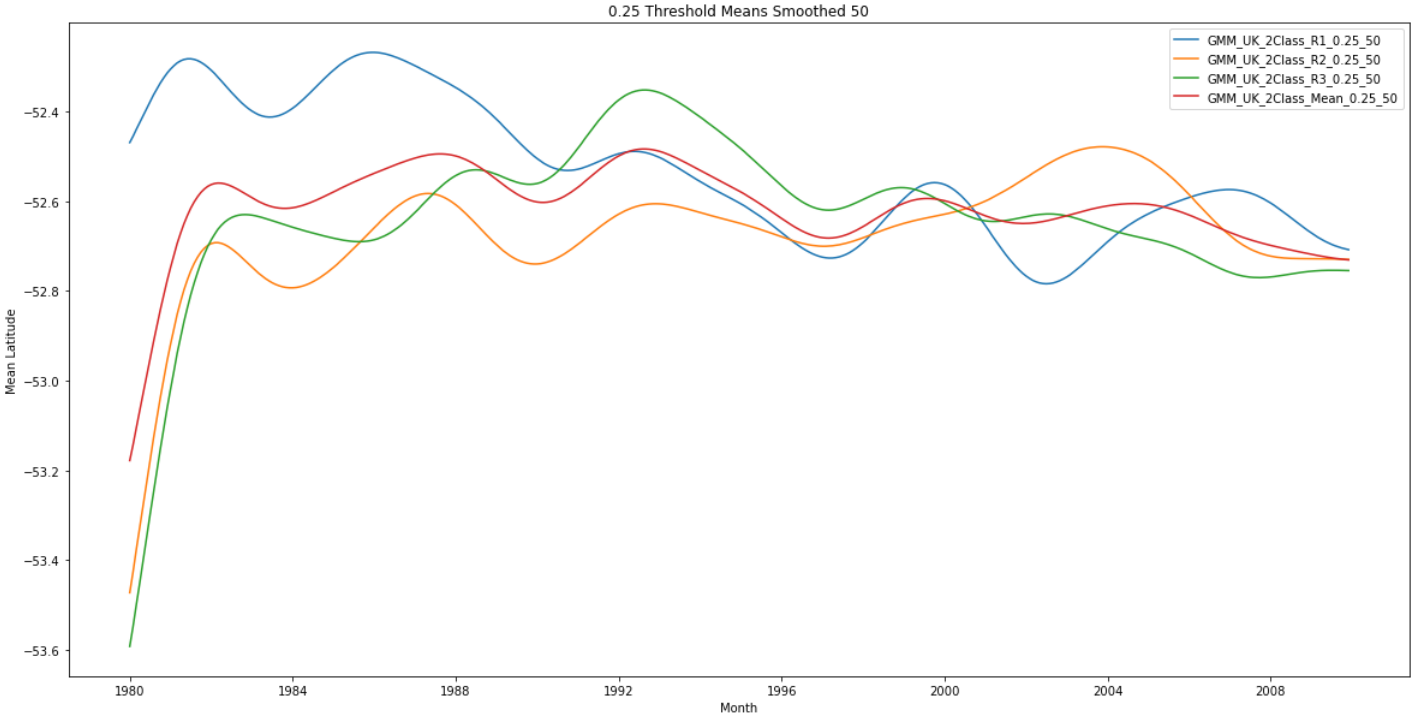
In [20]:

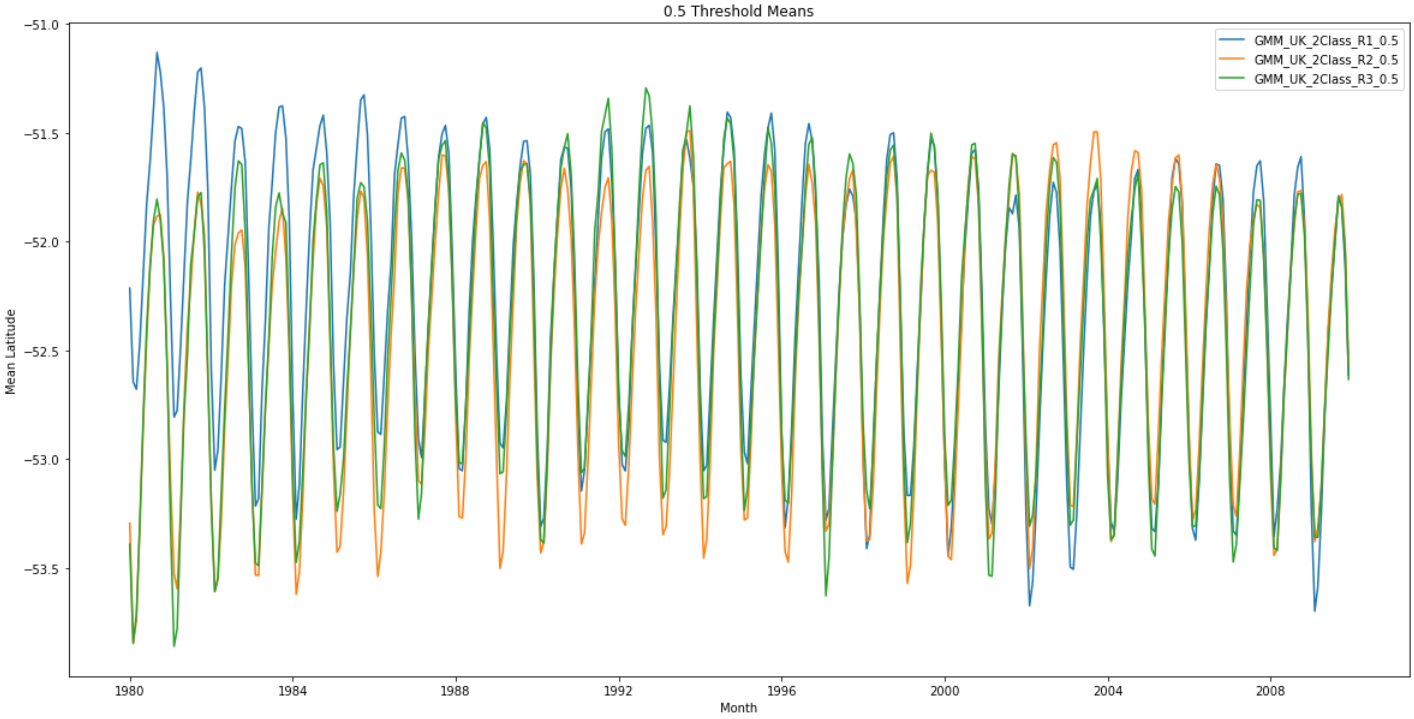
```
thresholdsLen = len(thresholds)
for i in range(len(GMModelNames)):
    currentLatMeans = LatMeanList[i]
    currentLatSmooth18 = smooth18Lat1980_09Arr[i]
    currentLatSmooth24 = smooth24Lat1980_09Arr[i]
    currentLatSmooth50 = smooth50Lat1980_09Arr[i]
    for j in range(thresholdsLen):
        latMeanPlot(currentLatMeans[j], str(GMModelNames[i])+"_"+str(thresholds[j]), j)
        latMeanPlot(currentLatSmooth18[j], str(GMModelNames[i])+"_"+str(thresholds[j])+"_1
        latMeanPlot(currentLatSmooth24[j], str(GMModelNames[i])+"_"+str(thresholds[j])+"_2
        latMeanPlot(currentLatSmooth50[j], str(GMModelNames[i])+"_"+str(thresholds[j])+"_5

for i in range(thresholdsLen):
    latMeanPlot(currSmooth18MeanArr[i], "GMM_UK_2Class_Mean_"+str(thresholds[i])+"_18", i+
    latMeanPlot(currSmooth24MeanArr[i], "GMM_UK_2Class_Mean_"+str(thresholds[i])+"_24", i+
    latMeanPlot(currSmooth50MeanArr[i], "GMM_UK_2Class_Mean_"+str(thresholds[i])+"_50", i+

for j in range(len(thresholds)):
    threshString = str(thresholds[j])
    plt.figure(j)
    plt.title(threshString+" Threshold Means")
    plt.figure(j+thresholdsLen)
    plt.title(threshString+" Threshold Means Smoothed 18")
    plt.figure(j+2*thresholdsLen)
    plt.title(threshString+" Threshold Means Smoothed 24")
    plt.figure(j+3*thresholdsLen)
    plt.title(threshString+" Threshold Means Smoothed 50")
plt.show()
```

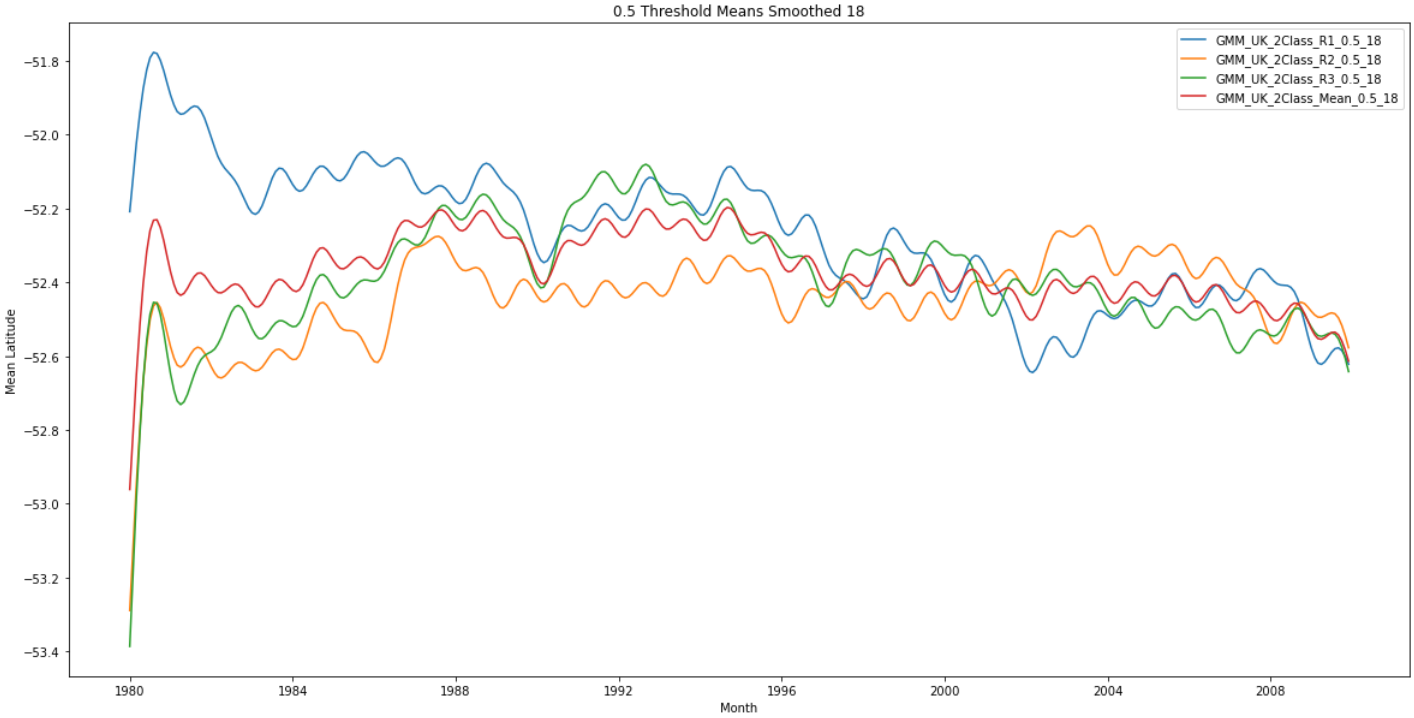


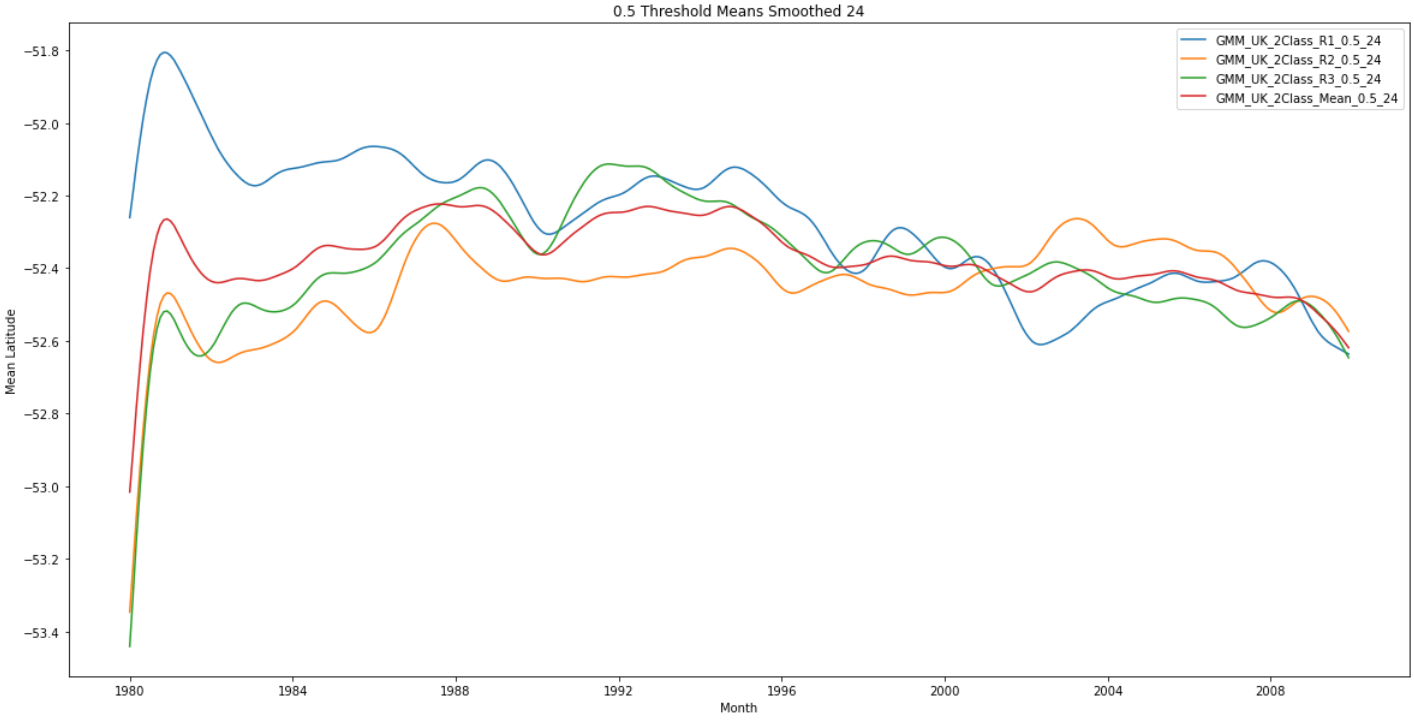

0.25 Threshold Means Smoothed 18
GMM_UK_2Class_R1_0.25_18
GMM_UK_2Class_R2_0.25_18
GMM_UK_2Class_R3_0.25_18
GMM_UK_2Class_Mean_0.25_18
Mean Latitude
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
−53.6
1980
1984
1988
1992
1996
2000
2004
2008
Month

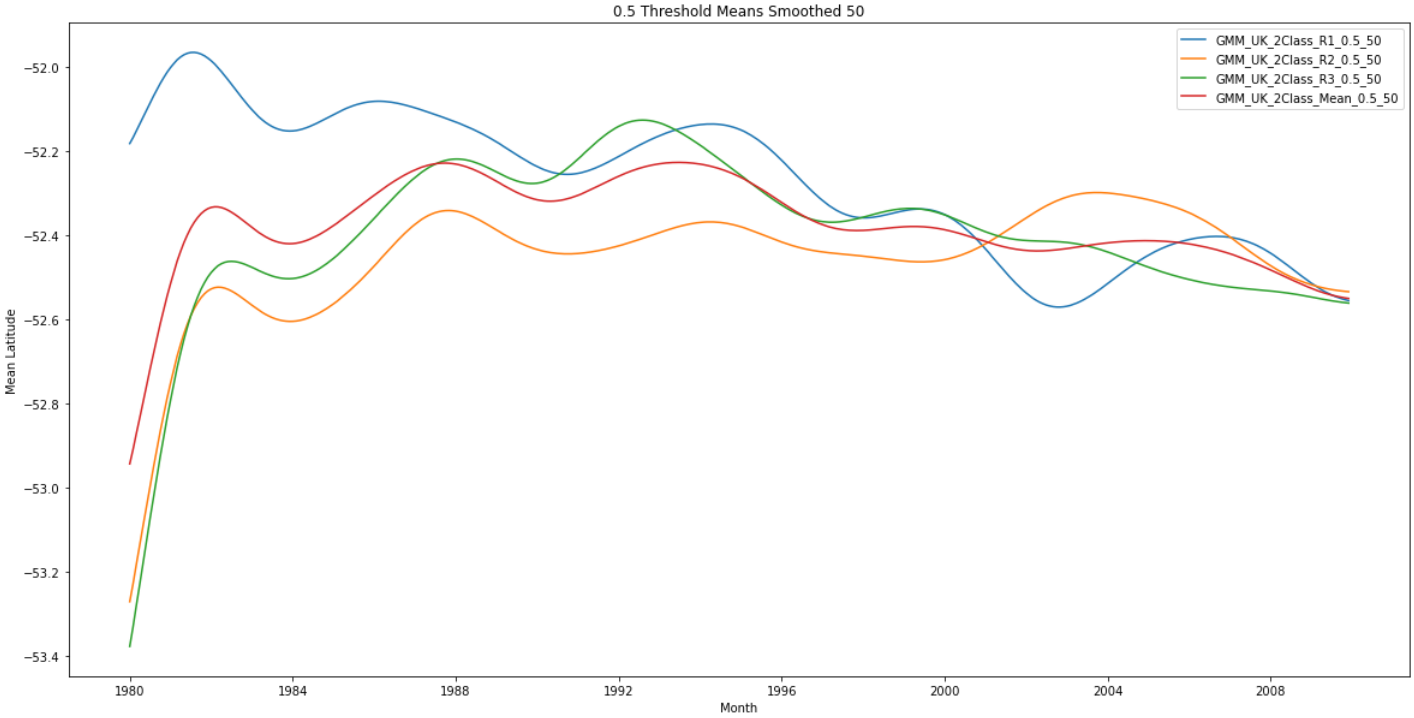

0.25 Threshold Means Smoothed 24
GMM_UK_2Class_R1_0.25_24
GMM_UK_2Class_R2_0.25_24
GMM_UK_2Class_R3_0.25_24
GMM_UK_2Class_Mean_0.25_24
Mean Latitude
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
−53.6
1980
1984
1988
1992
1996
2000
2004
2008
Month

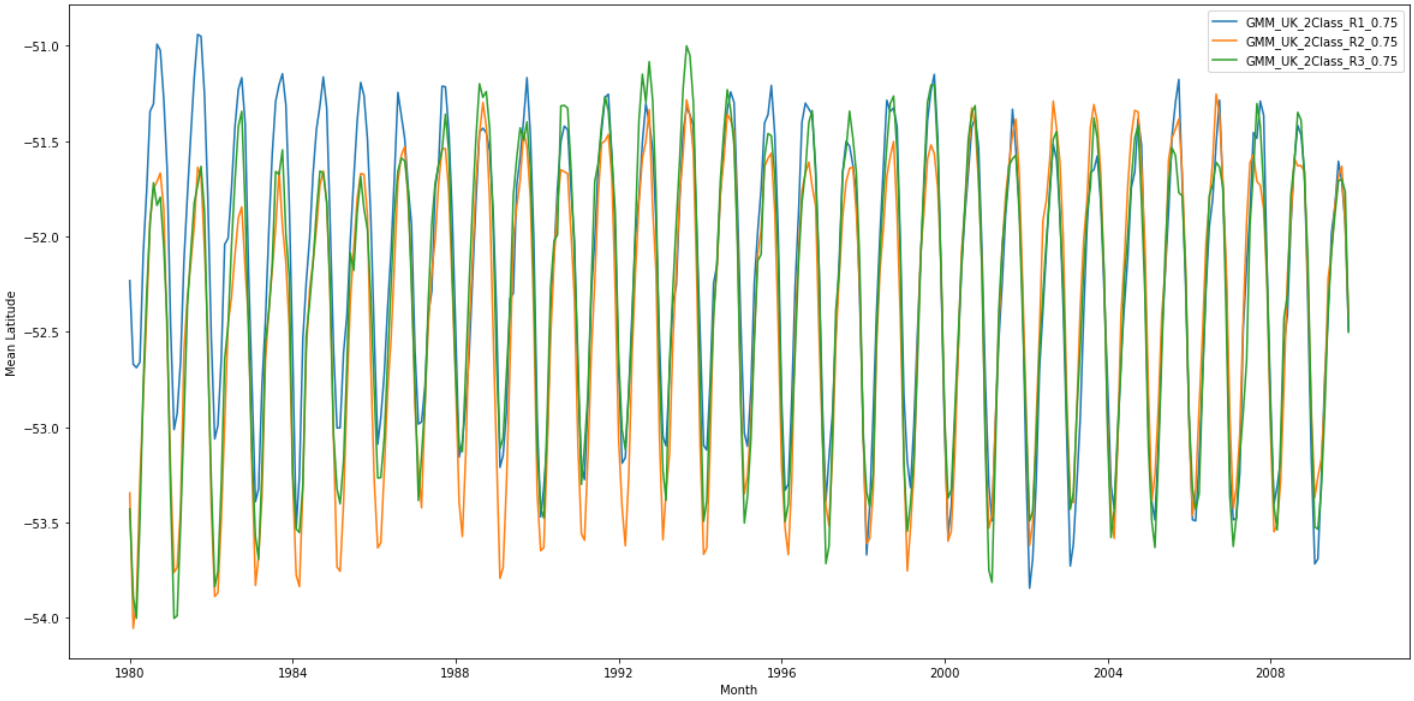

0.25 Threshold Means Smoothed 50
GMM_UK_2Class_R1_0.25_50
GMM_UK_2Class_R2_0.25_50
GMM_UK_2Class_R3_0.25_50
GMM_UK_2Class_Mean_0.25_50
Mean Latitude
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
−53.6
1980
1984
1988
1992
1996
2000
2004
2008
Month

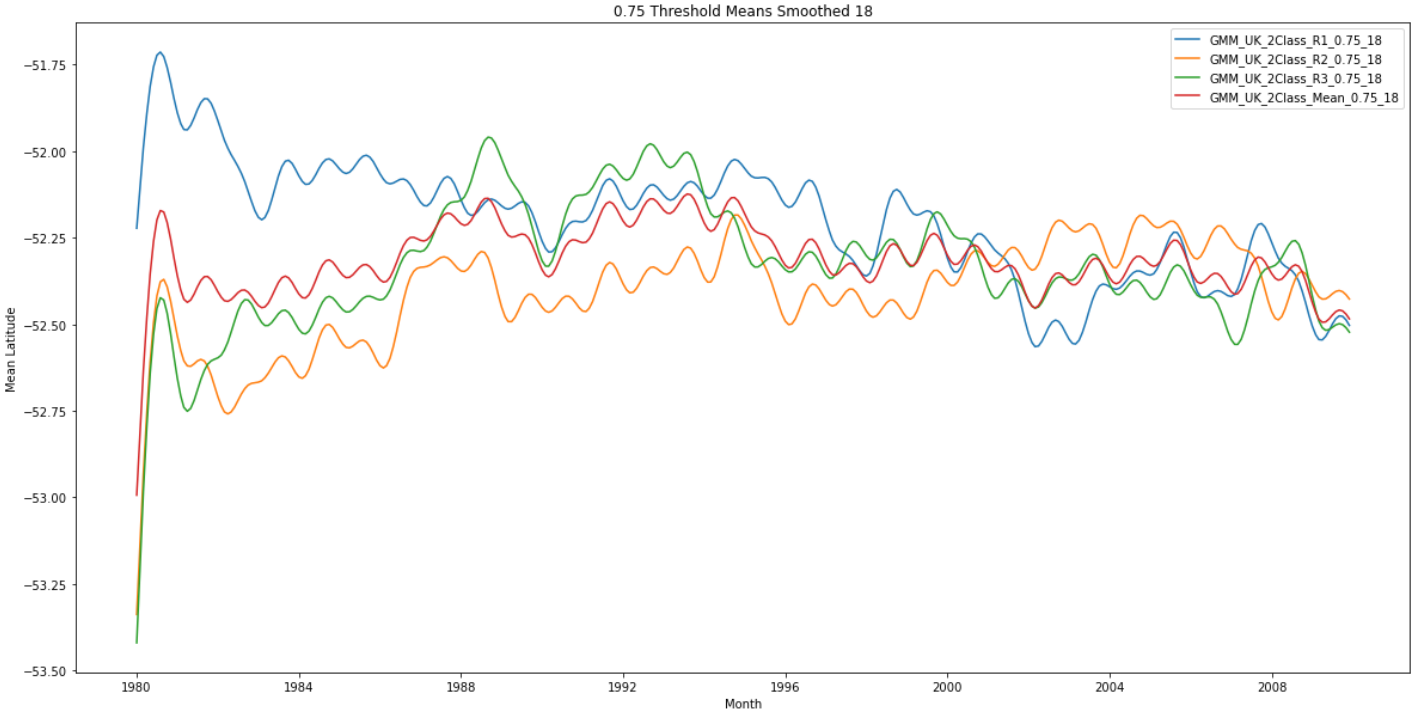

0.5 Threshold Means
GMM_UK_2Class_R1_0.5
GMM_UK_2Class_R2_0.5
GMM_UK_2Class_R3_0.5
Mean Latitude
−51.0
−51.5
−52.0
−52.5
−53.0
−53.5
1980
1984
1988
1992
1996
2000
2004
2008
Month

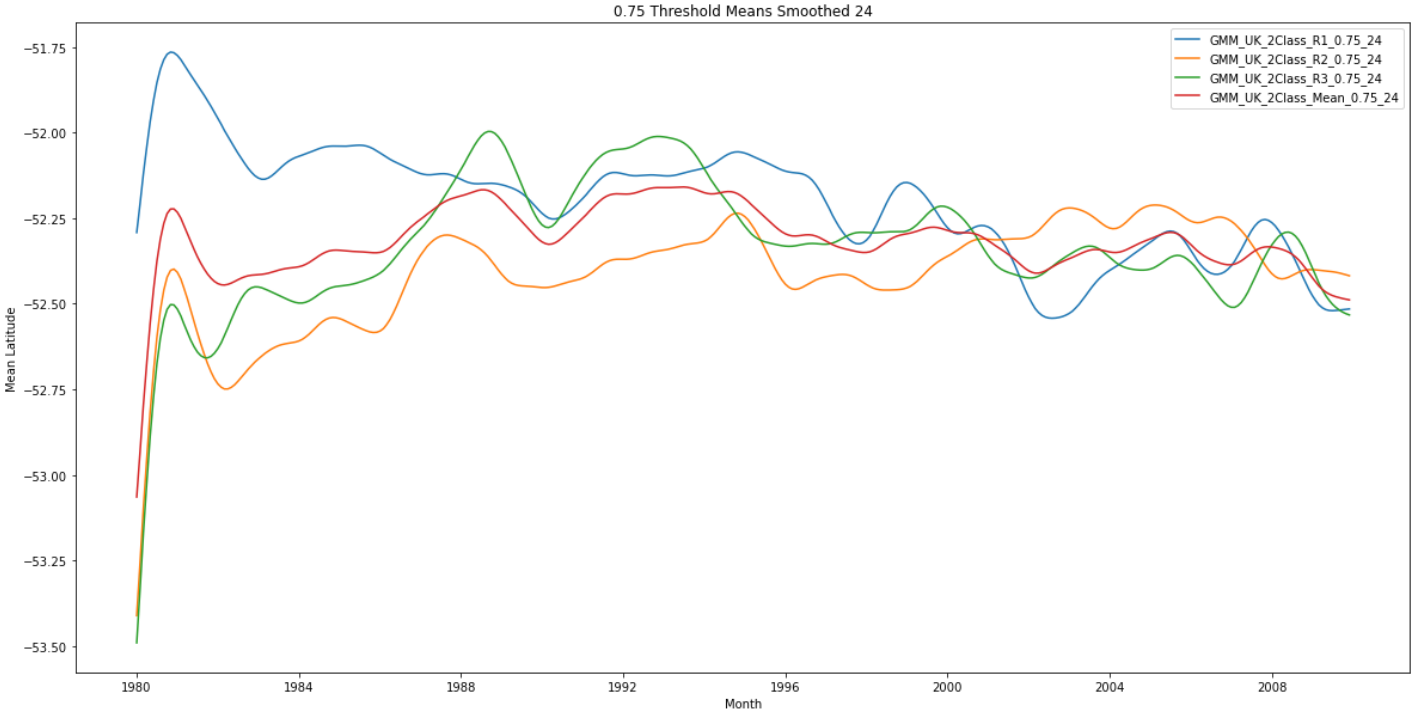

0.5 Threshold Means Smoothed 18
GMM_UK_2Class_R1_0.5_18
GMM_UK_2Class_R2_0.5_18
GMM_UK_2Class_R3_0.5_18
GMM_UK_2Class_Mean_0.5_18
Mean Latitude
−51.8
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
1980
1984
1988
1992
1996
2000
2004
2008
Month

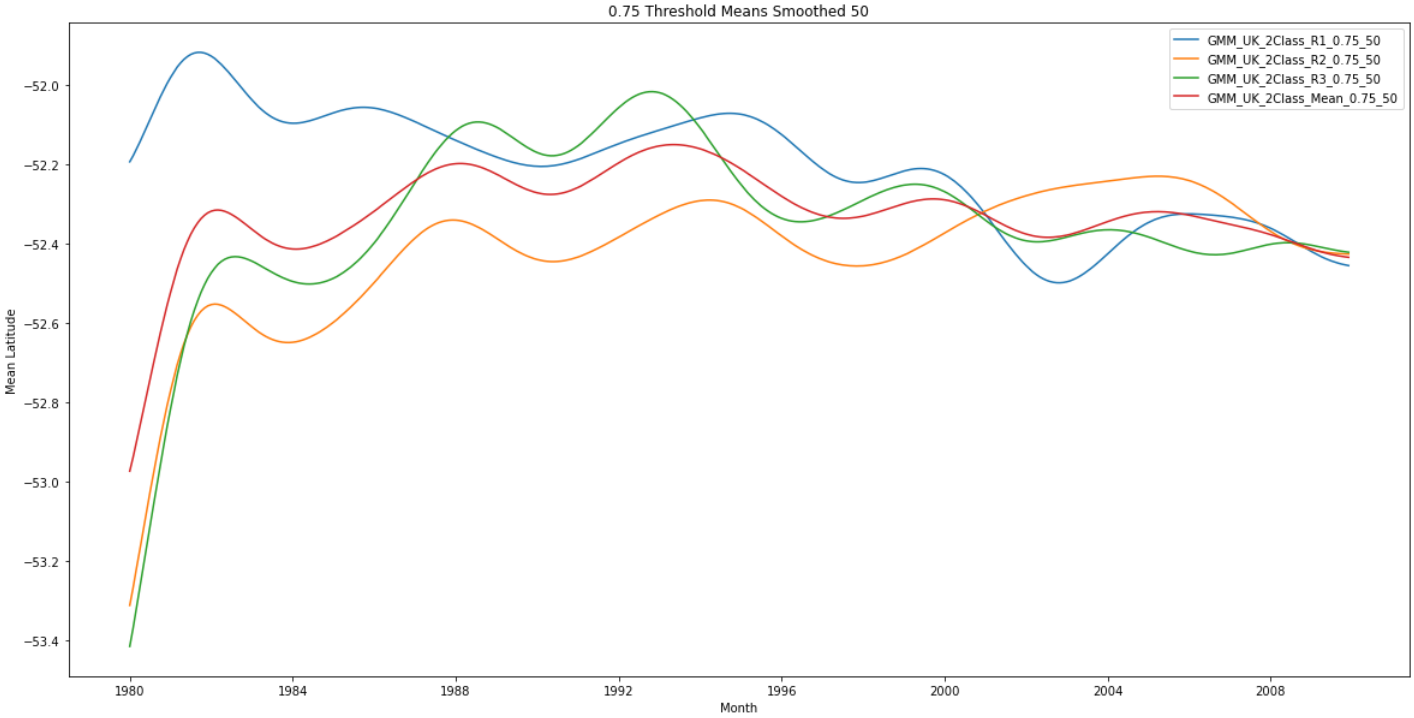

0.5 Threshold Means Smoothed 24
GMM_UK_2Class_R1_0.5_24
GMM_UK_2Class_R2_0.5_24
GMM_UK_2Class_R3_0.5_24
GMM_UK_2Class_Mean_0.5_24
Mean Latitude
−51.8
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
1980
1984
1988
1992
1996
2000
2004
2008
Month

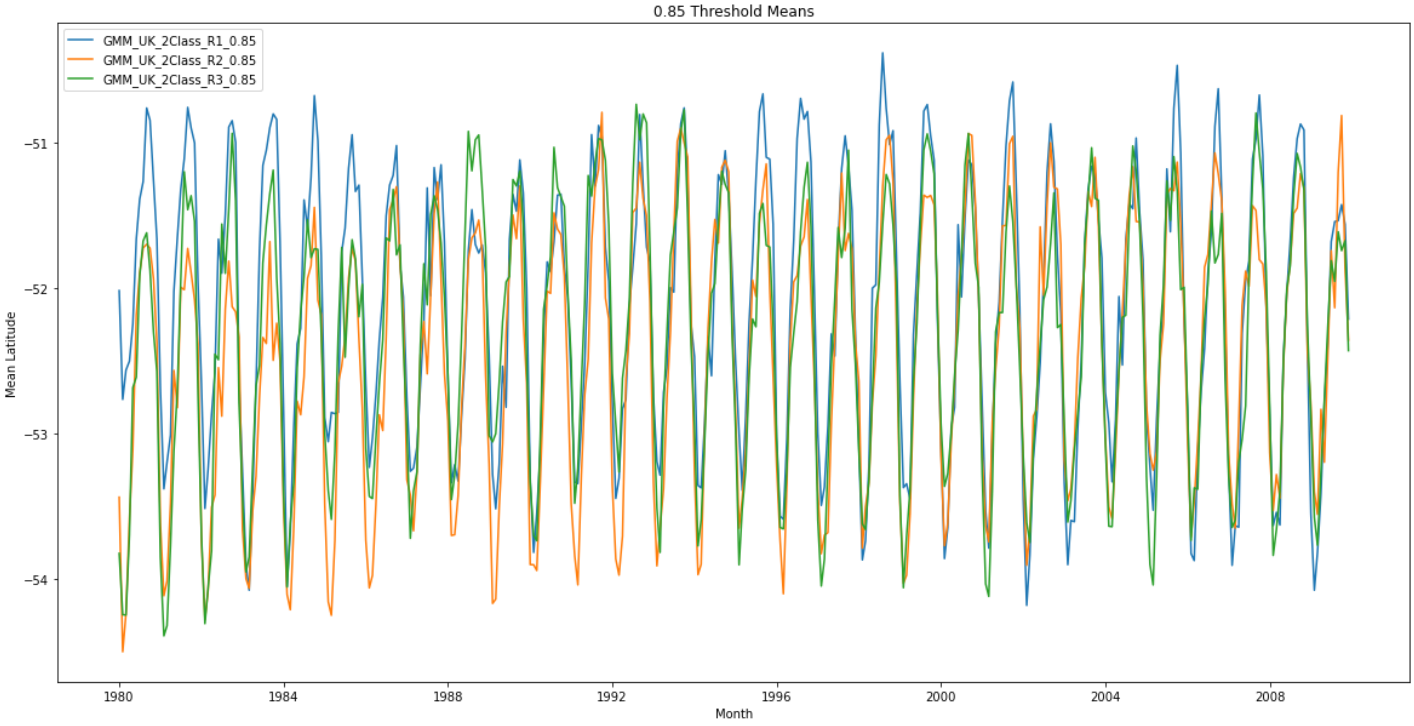

0.5 Threshold Means Smoothed 50
GMM_UK_2Class_R1_0.5_50
GMM_UK_2Class_R2_0.5_50
GMM_UK_2Class_R3_0.5_50
GMM_UK_2Class_Mean_0.5_50
Mean Latitude
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
1980
1984
1988
1992
1996
2000
2004
2008
Month

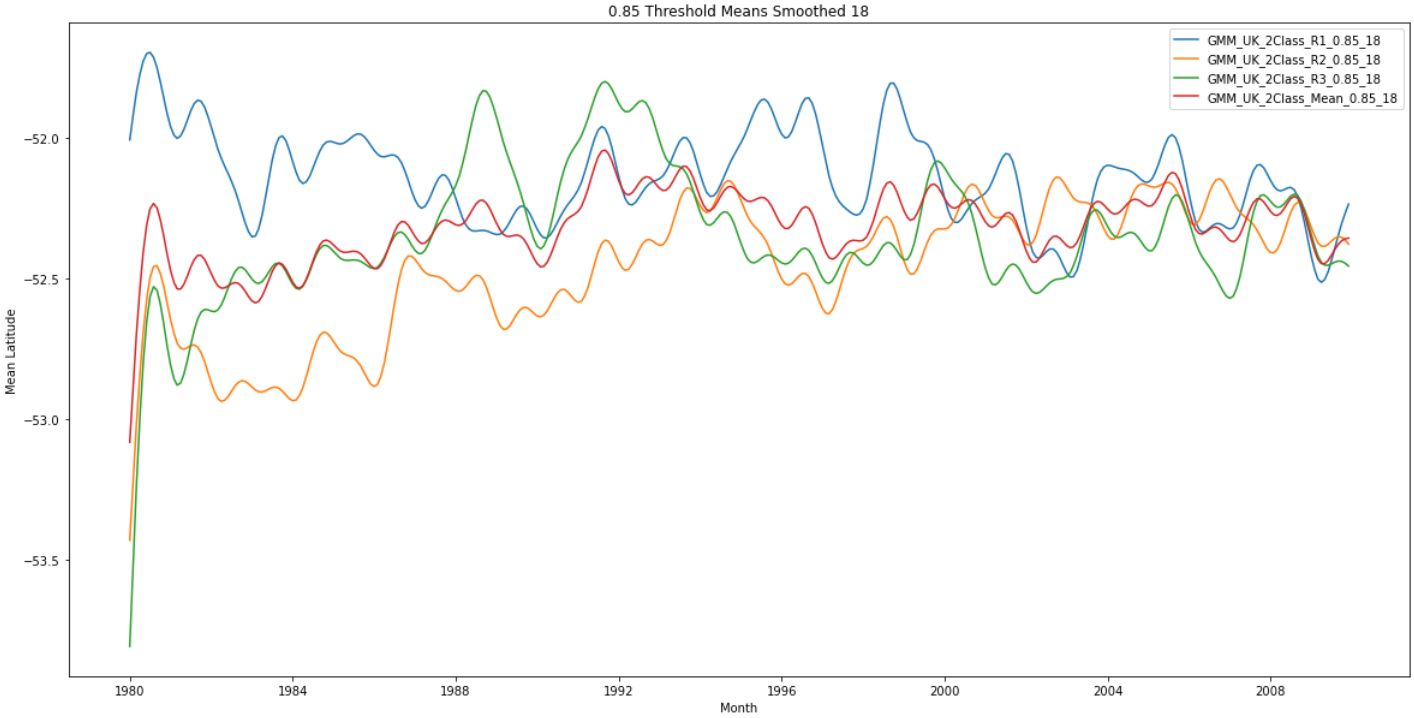

0.75 Threshold Means
GMM_UK_2Class_R1_0.75
GMM_UK_2Class_R2_0.75
GMM_UK_2Class_R3_0.75
Mean Latitude
−51.0
−51.5
−52.0
−52.5
−53.0
−53.5
−54.0
1980
1984
1988
1992
1996
2000
2004
2008
Month

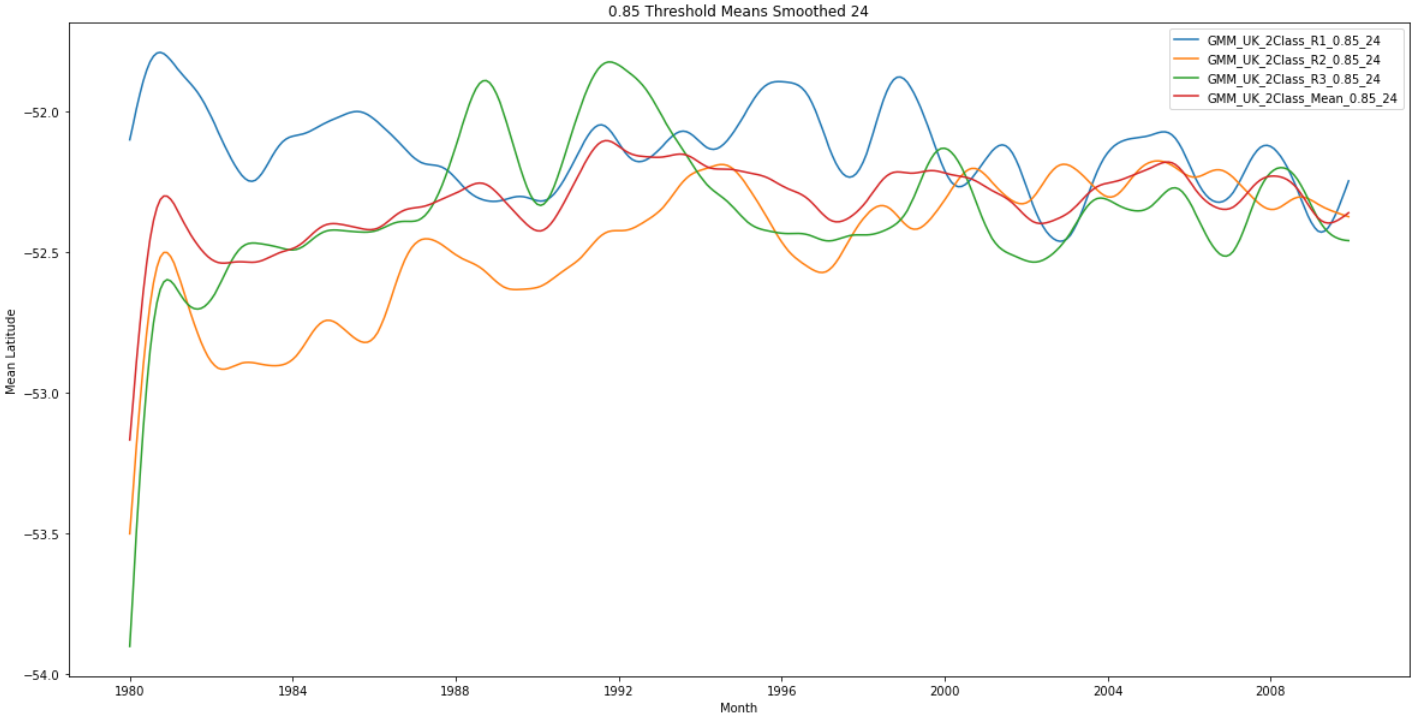

0.75 Threshold Means Smoothed 18
GMM_UK_2Class_R1_0.75_18
GMM_UK_2Class_R2_0.75_18
GMM_UK_2Class_R3_0.75_18
GMM_UK_2Class_Mean_0.75_18
Mean Latitude
−51.75
−52.00
−52.25
−52.50
−52.75
−53.00
−53.25
−53.50
1980
1984
1988
1992
1996
2000
2004
2008
Month

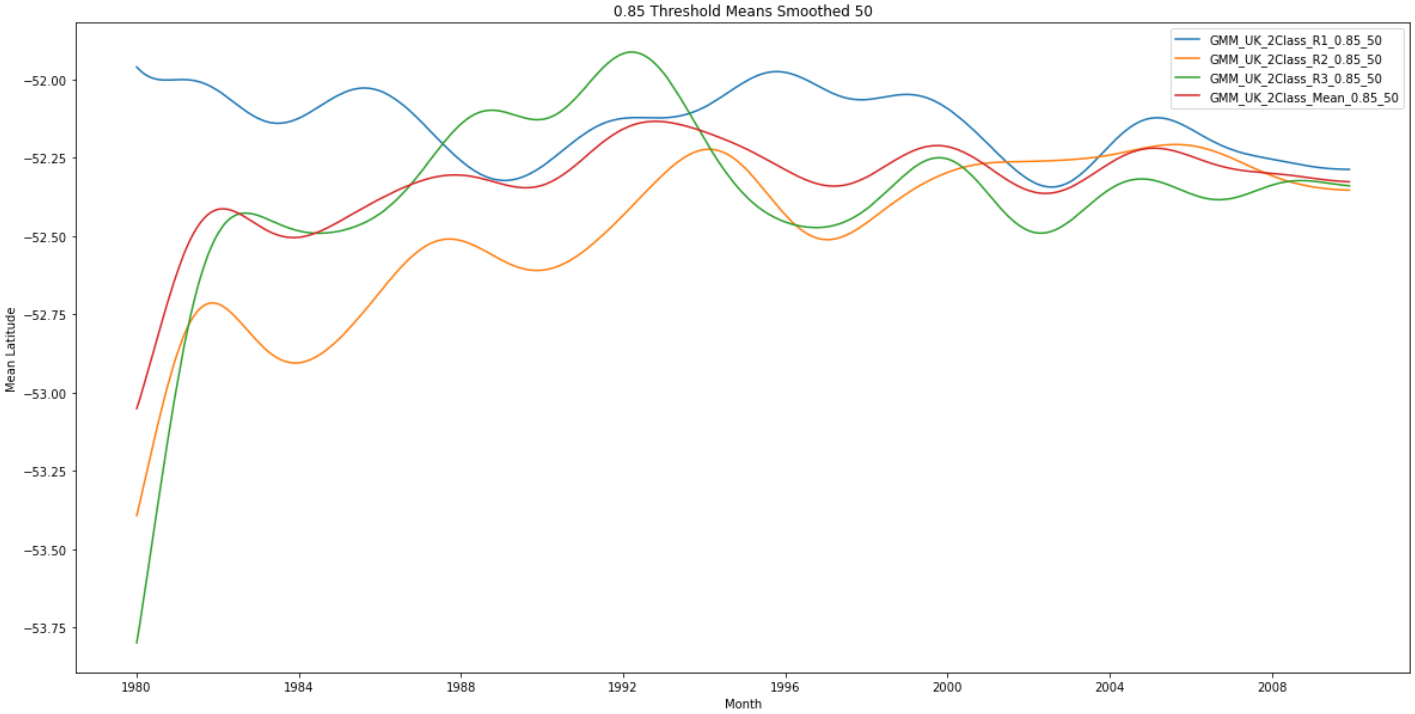

0.75 Threshold Means Smoothed 24
GMM_UK_2Class_R1_0.75_24
GMM_UK_2Class_R2_0.75_24
GMM_UK_2Class_R3_0.75_24
GMM_UK_2Class_Mean_0.75_24
Mean Latitude
−51.75
−52.00
−52.25
−52.50
−52.75
−53.00
−53.25
−53.50
1980
1984
1988
1992
1996
2000
2004
2008
Month


0.75 Threshold Means Smoothed 50
GMM_UK_2Class_R1_0.75_50
GMM_UK_2Class_R2_0.75_50
GMM_UK_2Class_R3_0.75_50
GMM_UK_2Class_Mean_0.75_50
Mean Latitude
−52.0
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
−53.4
1980
1984
1988
1992
1996
2000
2004
2008
Month


0.85 Threshold Means
GMM_UK_2Class_R1_0.85
GMM_UK_2Class_R2_0.85
GMM_UK_2Class_R3_0.85
Mean Latitude
−51
−52
−53
−54
1980
1984
1988
1992
1996
2000
2004
2008
Month


0.85 Threshold Means Smoothed 18
GMM_UK_2Class_R1_0.85_18
GMM_UK_2Class_R2_0.85_18
GMM_UK_2Class_R3_0.85_18
GMM_UK_2Class_Mean_0.85_18
Mean Latitude
−52.0
−52.5
−53.0
−53.5
1980
1984
1988
1992
1996
2000
2004
2008
Month


0.85 Threshold Means Smoothed 24
GMM_UK_2Class_R1_0.85_24
GMM_UK_2Class_R2_0.85_24
GMM_UK_2Class_R3_0.85_24
GMM_UK_2Class_Mean_0.85_24
Mean Latitude
−52.0
−52.5
−53.0
−53.5
−54.0
1980
1984
1988
1992
1996
2000
2004
2008
Month

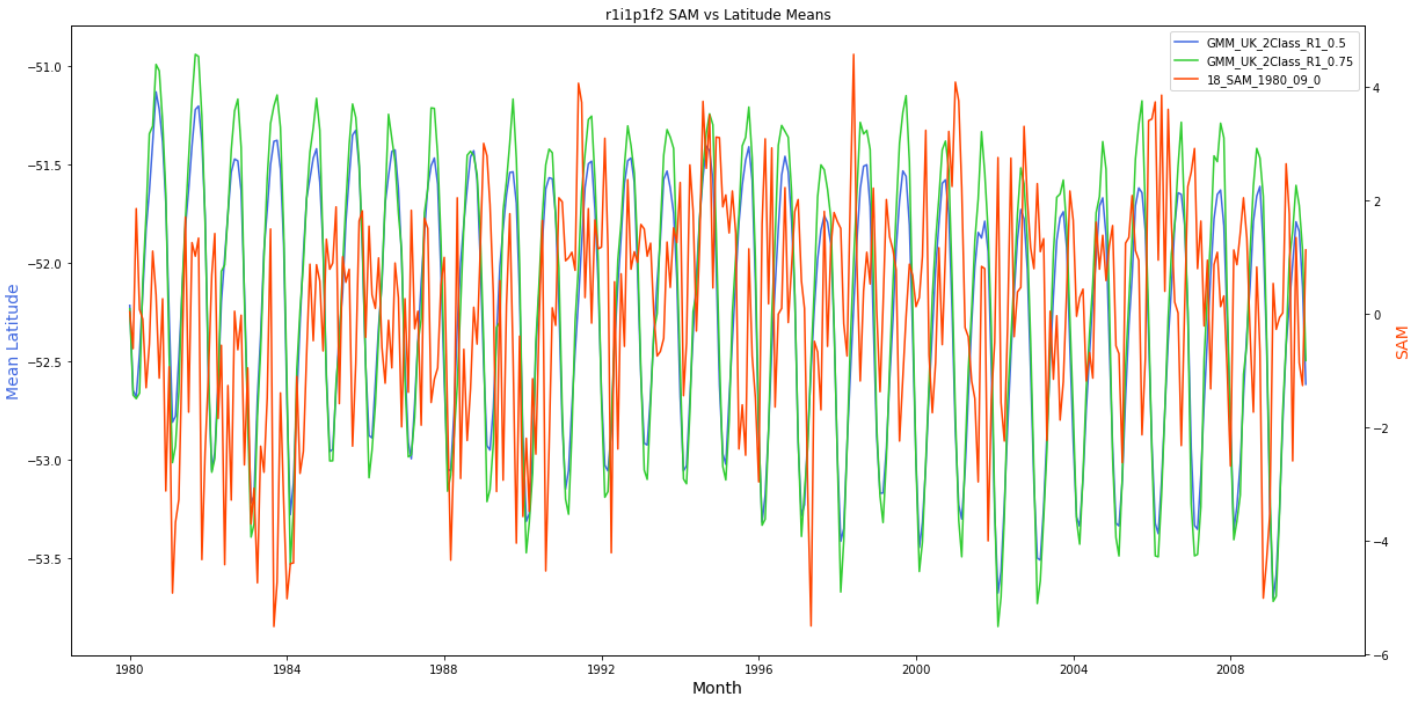


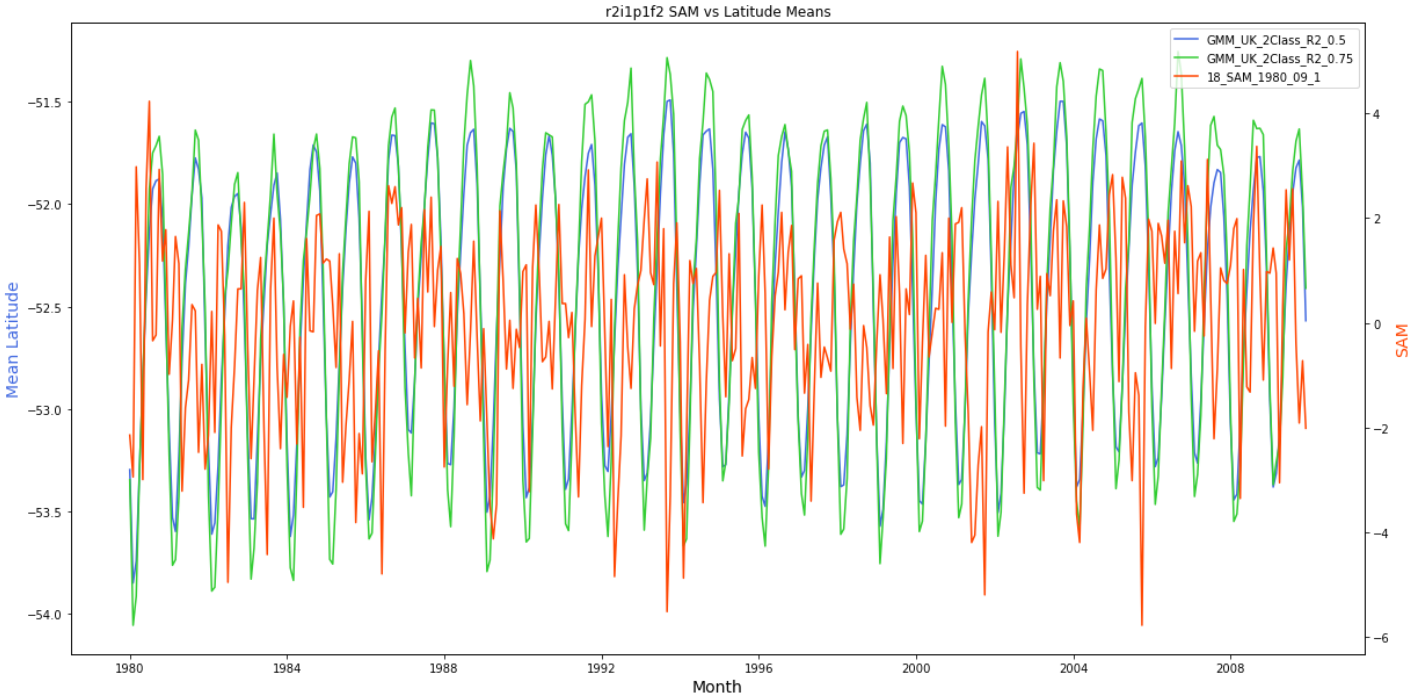
SAM vs Latitude Means

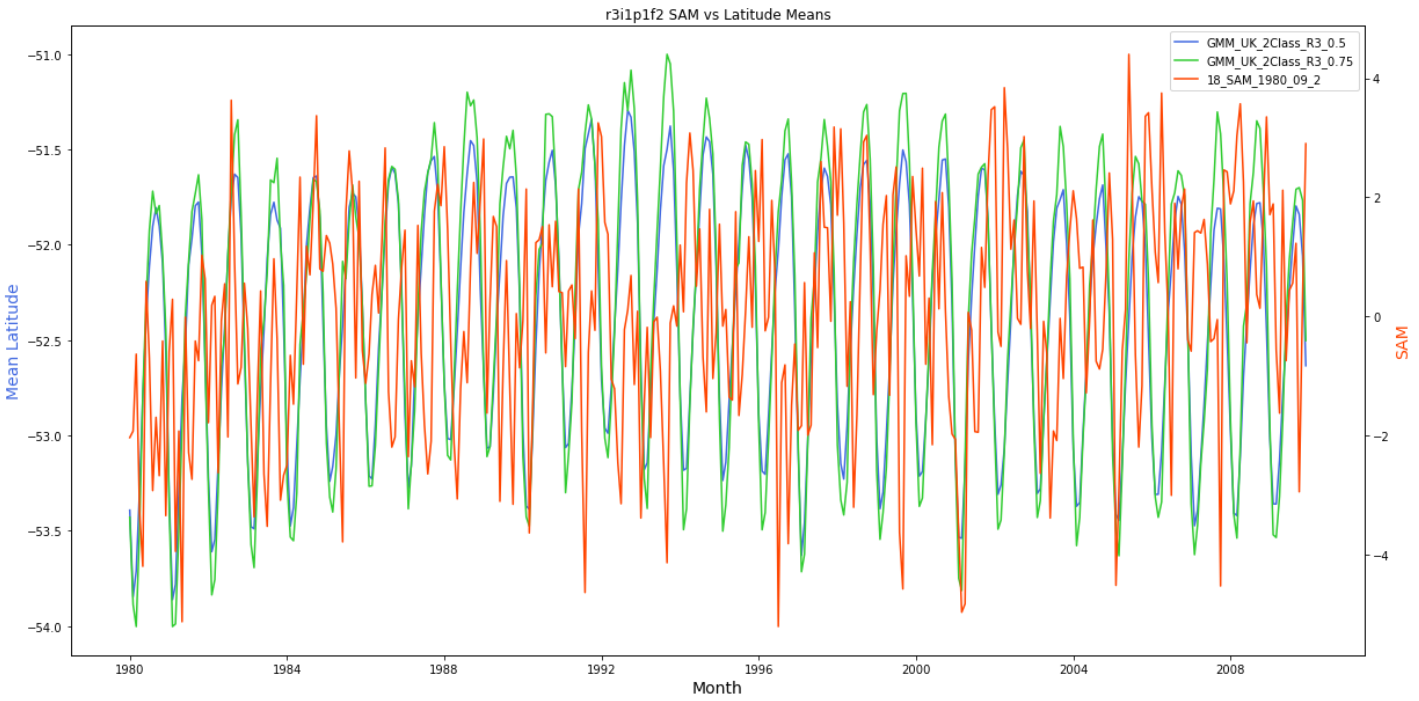
In [21]:

```
thresholdLook1 = 1
thresholdLook2 = 2
print("SAM vs Latitude Means")
for i in range(fileCount):
    fig,ax = plt.subplots()
    fig.set_figheight(10)
    fig.set_figwidth(20)
    ax.plot(timeAxis, LatMeanList[i][thresholdLook1], label=str(GMModelNames[i])+"_"+str(t
    ax.plot(timeAxis, LatMeanList[i][thresholdLook2], label=str(GMModelNames[i])+"_"+str(t
    ax.title.set_text(str(approvedIds[i]+" SAM vs Latitude Means"))

    indexName = "SAM_Index_"+str(i)
    ax2 =ax.twinx()
    ax2.plot(SAM1980_09DF["time"], SAM1980_09DF[indexName], label="18_SAM_1980_09_"+str(i)
    ax.set_xlabel("Month",fontsize=14)
    ax.set_ylabel("Mean Latitude",fontsize=14, color="RoyalBlue")
    ax2.set_ylabel("SAM",fontsize=14, color="OrangeRed")
    lines, labels = ax.get_legend_handles_labels()
    lines2, labels2 = ax2.get_legend_handles_labels()
    ax2.legend(lines + lines2, labels + labels2)
```

```
SAM vs Latitude Means
```


r1i1p1f2 SAM vs Latitude Means
GMM_UK_2Class_R1_0.5
GMM_UK_2Class_R1_0.75
18_SAM_1980_09_0
Mean Latitude
SAM
Month

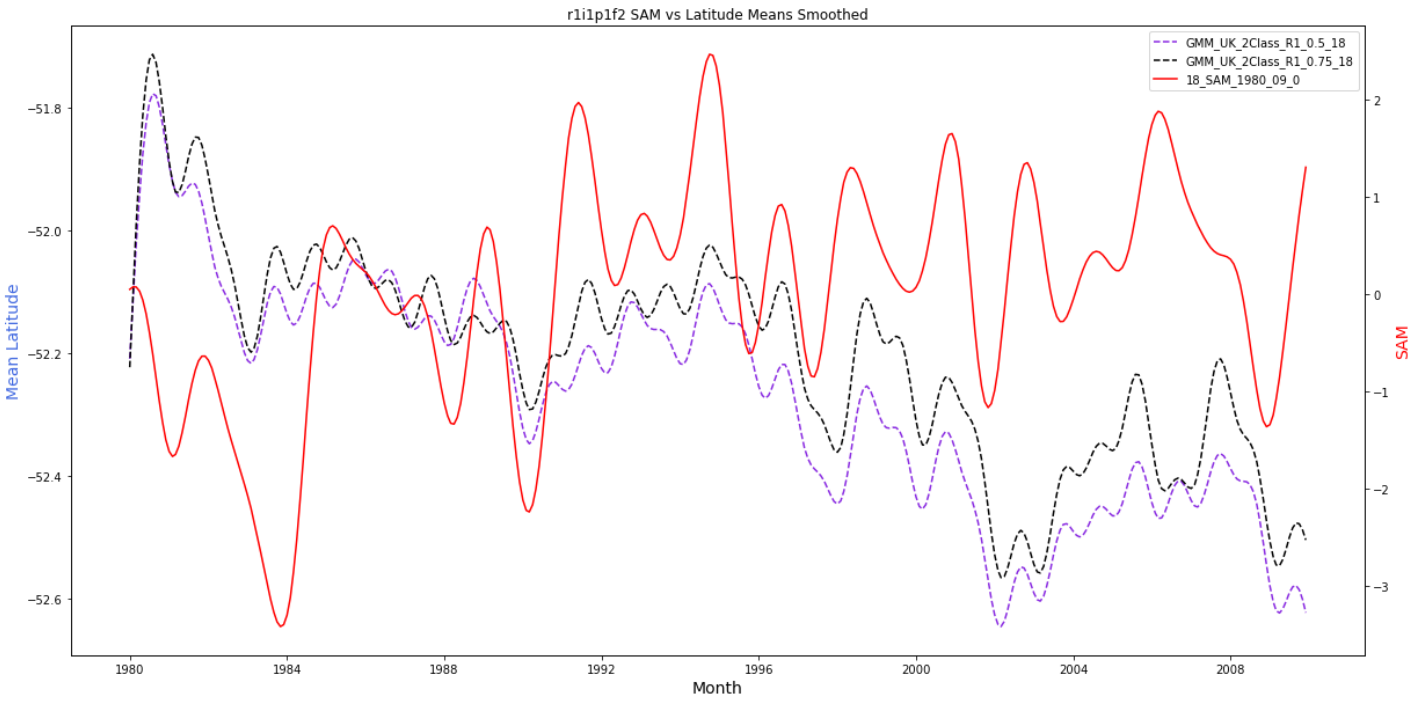

r2i1p1f2 SAM vs Latitude Means
GMM_UK_2Class_R2_0.5
GMM_UK_2Class_R2_0.75
18_SAM_1980_09_1
Mean Latitude
SAM
Month

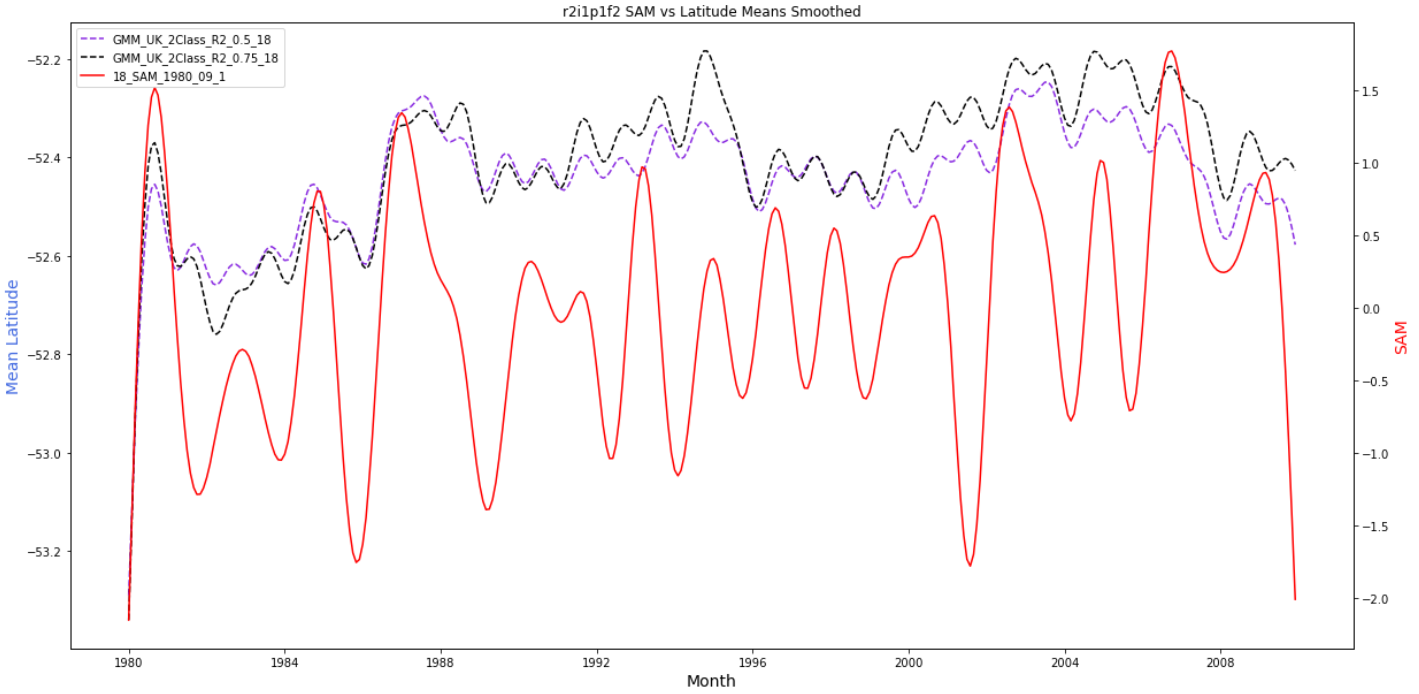


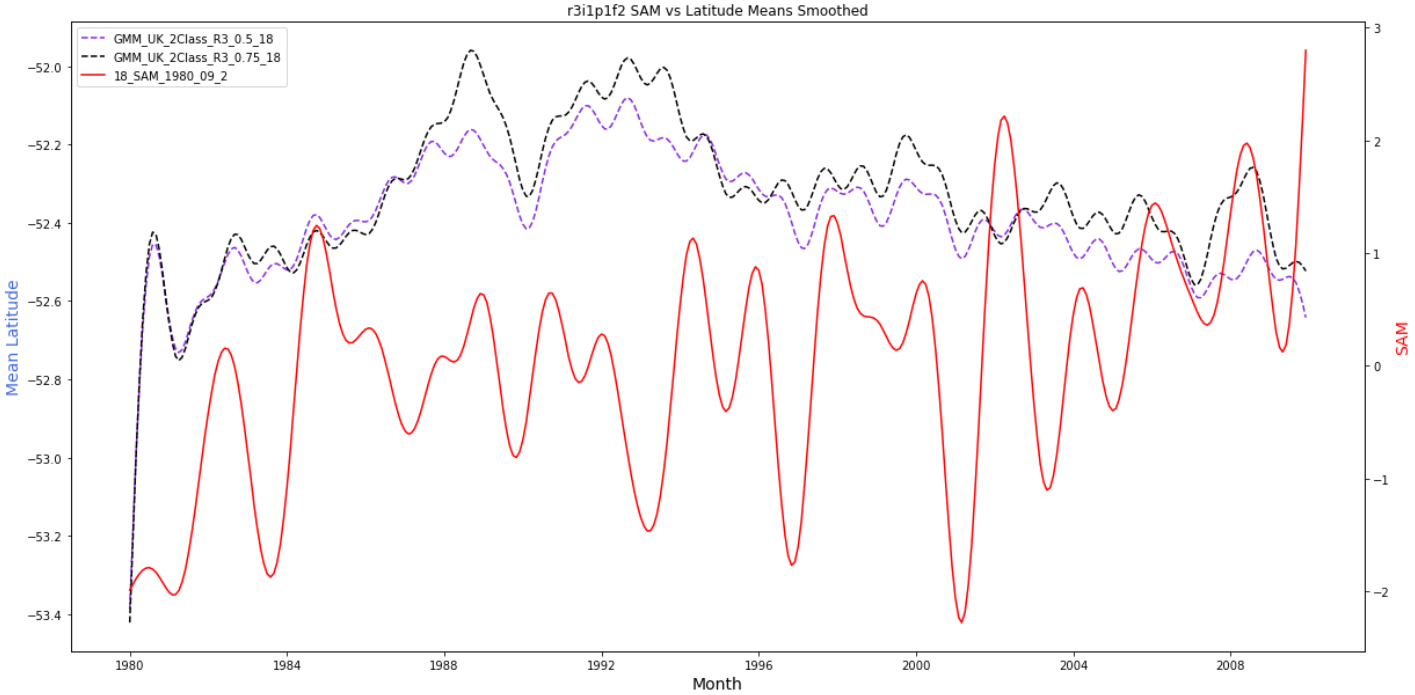
In [22]:

```
thresholdLook1 = 1
thresholdLook2 = 2
print("Smoothed SAM vs Latitude Means")
for i in range(fileCount):
    fig,ax = plt.subplots()
    fig.set_figheight(10)
    fig.set_figwidth(20)
    #ax.plot(timeAxis, LatMeanList[i][thresholdLook], label=str(GMModelNames[i])+"_"+str(t
    ax.plot(timeAxis, smooth18Lat1980_09Arr[i][thresholdLook1], label=str(GMModelNames[i])
    ax.plot(timeAxis, smooth18Lat1980_09Arr[i][thresholdLook2], label=str(GMModelNames[i])
    ax.title.set_text(str(approvedIds[i]+" SAM vs Latitude Means Smoothed"))

    ax2 =ax.twinx()
    ax2.plot(SAM1980_09DF["time"], smooth18SAM1980_09Arr[i], label="18_SAM_1980_09_"+str(i
    ax.set_xlabel("Month",fontsize=14)
    ax.set_ylabel("Mean Latitude",fontsize=14, color="RoyalBlue")
    ax2.set_ylabel("SAM",fontsize=14, color="Red")
    lines, labels = ax.get_legend_handles_labels()
    lines2, labels2 = ax2.get_legend_handles_labels()
    ax2.legend(lines + lines2, labels + labels2)

plt.show()
```

```
Smoothed SAM vs Latitude Means
```


r1i1p1f2 SAM vs Latitude Means Smoothed
GMM_UK_2Class_R1_0.5_18
GMM_UK_2Class_R1_0.75_18
18_SAM_1980_09_0
Mean Latitude
SAM
Month
−51.8
−52.0
−52.2
−52.4
−52.6
2
1
0
−1
−2
−3
1980
1984
1988
1992
1996
2000
2004
2008


r2i1p1f2 SAM vs Latitude Means Smoothed
GMM_UK_2Class_R2_0.5_18
GMM_UK_2Class_R2_0.75_18
18_SAM_1980_09_1
Mean Latitude
SAM
Month
−52.2
−52.4
−52.6
−52.8
−53.0
−53.2
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
1980
1984
1988
1992
1996
2000
2004
2008



End of Notebook