Project 1

Downscaling

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## 1 Introduction

These are the packages that will be used in this project.

using Dates  
using MultivariateStats  
using Plots  
using NCDatasets  
using StatsBase  
using Unitful  
using NetCDF  
using DataFrames  
using IJulia

We have imported hourly temperature data from the ERA5 reanalysis dataset, which encompasses temperature of air at 2m above the surface of land, from 1980 to 2020.

The precipitation data from Texas serves as a predictand with 16365 daily data values from January 1, 1979 to October 21, 2023. Through preprocessing, only daily data from 1980 to 2020 will be considered in our testing and training data.

precip\_tx = NCDataset("data/raw/precip\_tx.nc")  
precip\_time = precip\_tx["time"][:]  
precip\_lon = precip\_tx["lon"][:]  
precip\_lat = precip\_tx["lat"][:]  
precip = precip\_tx["precip"][:, :, :]

24×24×16365 Array{Union{Missing, Float32}, 3}:  
[:, :, 1] =  
 1.37582 1.57975 1.45262 … 0.0 0.0202463 0.0  
 1.20963 1.85082 2.28766 0.0308067 0.0602374 0.114836  
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 1.5909 1.33469 1.65327 0.0664271 0.389667 0.678864  
 1.43704 1.75647 2.29071 0.0964478 0.24362 1.0564  
 1.23506 1.71966 1.24682 … 0.29584 0.192309 0.594209  
 1.34688 2.06668 1.14913 0.50683 0.345075 0.153464  
 1.45706 2.27098 0.724487 1.06509 0.576138 0.0801041  
 5.20069 3.71962 0.181735 1.43136 0.706655 0.133022  
 2.88819 0.759342 0.163341 2.08092 1.4474 0.53837  
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 1.43436 0.139224 0.290842 missing missing missing  
 3.18961 2.13086 2.59861 missing missing missing  
 5.19326 5.16296 4.65167 missing missing missing  
 5.3778 4.47193 6.19447 missing missing missing  
 2.81836 8.9879 5.9169 … missing missing missing  
 1.80613 8.12168 2.24706 missing missing missing  
 6.17247 15.1932 14.4421 missing missing missing  
 15.3935 12.0708 20.1535 missing missing missing  
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precip = replace(precip, missing => NaN)  
precip[isnan.(precip)] .= NaN

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precip = precip .\* 1u"mm"  
precip\_lat = reverse(precip\_lat)  
precip = reverse(precip; dims=2)

24×24×16365 Array{Quantity{Float64, 𝐋, Unitful.FreeUnits{(mm,), 𝐋, nothing}}, 3}:  
[:, :, 1] =  
 0.0 mm 0.0202463 mm 0.0 mm … 1.57975 mm 1.37582 mm  
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 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm

Below generates a heatmap of the first day of our precipitation data in Texas.

heatmap(  
precip\_lon,  
precip\_lat,  
precip[:, :, 366]';  
xlabel="Longitude",  
ylabel="Latitude",  
title="Precipitation on $(precip\_time[366])"  
)

Below generates a heatmap of the last day of our precipitation data in Texas.

heatmap(  
precip\_lon,  
precip\_lat,  
precip[:, :, 15341]';  
xlabel="Longitude",  
ylabel="Latitude",  
title="Precipitation on $(precip\_time[15341])"  
)

We will divide our daily data in training and testing data, the former from 1980 to 2009, the latter from 2010 to 2020.

precip\_train = precip[:, :, 366:11323]  
precip\_test = precip[:, :, 11324:15341]

24×24×4018 Array{Quantity{Float64, 𝐋, Unitful.FreeUnits{(mm,), 𝐋, nothing}}, 3}:  
[:, :, 1] =  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.737155 mm 1.25108 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.683543 mm 1.34457 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.357297 mm 0.548465 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0484054 mm 0.398182 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0450338 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0311482 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm … 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
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 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.230749 mm  
 NaN mm NaN mm NaN mm NaN mm … 0.212686 mm 3.56092 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.455371 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
  
[:, :, 2] =  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
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 NaN mm NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm 0.0 mm  
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 NaN mm NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm 0.0 mm  
  
[:, :, 3] =  
 0.0591173 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm  
 0.0398183 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0392539 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm  
 0.0372318 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.103347 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.312466 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.468261 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm … 0.0 mm 0.145941 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.171049 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.0323264 mm 0.0564729 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.597011 mm 2.3467 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.245914 mm 0.389802 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm … 1.4663 mm 1.38762 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 1.79308 mm 1.13261 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 1.42096 mm 0.377946 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 2.89917 mm 2.21083 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 2.13806 mm 0.890985 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm … 1.65857 mm 0.495807 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.131071 mm 0.0577657 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0 mm  
  
;;; …   
  
[:, :, 4016] =  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.0477955 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.119863 mm 0.0455003 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 0.401172 mm 0.796996 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm … 1.52083 mm 2.25361 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 3.45653 mm 2.94061 mm  
 0.0 mm 0.0 mm 0.0 mm 0.0 mm 4.00622 mm 5.56214 mm  
 0.0 mm 0.0741697 mm 0.144369 mm 0.0 mm 3.36176 mm 4.76516 mm  
 0.30115 mm 0.616208 mm 0.21298 mm 0.0 mm 7.93134 mm 3.37715 mm  
 NaN mm NaN mm NaN mm NaN mm … 1.65429 mm 3.56267 mm  
 NaN mm NaN mm NaN mm NaN mm 1.27439 mm 2.27779 mm  
 NaN mm NaN mm NaN mm NaN mm 1.44041 mm 1.19195 mm  
 NaN mm NaN mm NaN mm NaN mm 1.45074 mm 2.11218 mm  
 NaN mm NaN mm NaN mm NaN mm 2.06649 mm 2.5608 mm  
 NaN mm NaN mm NaN mm NaN mm … 2.19545 mm 2.45329 mm  
 NaN mm NaN mm NaN mm NaN mm 14.9819 mm 9.12608 mm  
 NaN mm NaN mm NaN mm NaN mm 5.69264 mm 8.77505 mm  
 NaN mm NaN mm NaN mm NaN mm 0.319118 mm 0.791221 mm  
 NaN mm NaN mm NaN mm NaN mm 0.0 mm 0.0593512 mm  
 NaN mm NaN mm NaN mm NaN mm … 9.8264 mm 0.533203 mm  
 NaN mm NaN mm NaN mm NaN mm 33.6242 mm 0.821212 mm  
 NaN mm NaN mm NaN mm NaN mm 18.3737 mm 2.72226 mm  
 NaN mm NaN mm NaN mm NaN mm 11.281 mm 2.21517 mm  
  
[:, :, 4017] =  
 0.0 mm 0.0 mm 0.0 mm … 0.202297 mm 0.0370915 mm  
 0.0 mm 0.0 mm 0.0 mm 0.188817 mm 0.165833 mm  
 0.0 mm 0.0 mm 0.0 mm 0.396195 mm 1.24755 mm  
 0.0 mm 0.0 mm 0.0 mm 3.14623 mm 2.01133 mm  
 0.0 mm 0.0 mm 0.0 mm 5.43779 mm 4.1886 mm  
 0.0 mm 0.0 mm 0.0 mm … 14.4429 mm 8.45235 mm  
 0.0 mm 0.0 mm 0.0 mm 23.6285 mm 11.666 mm  
 0.10504 mm 0.273542 mm 0.0 mm 23.4767 mm 19.2731 mm  
 0.099015 mm 0.77644 mm 0.651323 mm 24.8665 mm 20.2429 mm  
 0.237783 mm 0.361714 mm 0.31161 mm 29.6727 mm 24.3044 mm  
 NaN mm NaN mm NaN mm … 29.9843 mm 22.6502 mm  
 NaN mm NaN mm NaN mm 23.3782 mm 19.8635 mm  
 NaN mm NaN mm NaN mm 16.9999 mm 19.211 mm  
 NaN mm NaN mm NaN mm 13.7751 mm 15.3863 mm  
 NaN mm NaN mm NaN mm 14.0525 mm 16.3776 mm  
 NaN mm NaN mm NaN mm … 12.6517 mm 15.3066 mm  
 NaN mm NaN mm NaN mm 11.8776 mm 20.5023 mm  
 NaN mm NaN mm NaN mm 11.5352 mm 21.6087 mm  
 NaN mm NaN mm NaN mm 20.2197 mm 13.4096 mm  
 NaN mm NaN mm NaN mm 11.3124 mm 9.68808 mm  
 NaN mm NaN mm NaN mm … 17.4192 mm 8.72952 mm  
 NaN mm NaN mm NaN mm 45.769 mm 7.1502 mm  
 NaN mm NaN mm NaN mm 28.4755 mm 6.26385 mm  
 NaN mm NaN mm NaN mm 17.1595 mm 4.42172 mm  
  
[:, :, 4018] =  
 2.8943 mm 4.28216 mm 9.56883 mm … 0.0 mm 0.0 mm  
 6.17869 mm 10.5928 mm 11.3078 mm 0.0 mm 0.0 mm  
 4.19719 mm 9.33642 mm 8.28378 mm 0.0 mm 0.0 mm  
 2.9599 mm 3.68912 mm 3.67904 mm 0.0 mm 0.0 mm  
 1.67837 mm 2.60111 mm 2.76474 mm 0.0 mm 0.0 mm  
 0.0 mm 0.577809 mm 1.76789 mm … 0.0 mm 0.0 mm  
 0.173758 mm 2.86261 mm 3.15937 mm 0.0 mm 0.0 mm  
 0.165058 mm 2.67939 mm 3.44498 mm 0.0 mm 0.0 mm  
 1.28164 mm 3.46535 mm 2.35935 mm 0.359488 mm 0.057642 mm  
 5.90772 mm 7.22955 mm 10.1741 mm 0.0 mm 0.0 mm  
 NaN mm NaN mm NaN mm … 0.556832 mm 0.0 mm  
 NaN mm NaN mm NaN mm 4.15889 mm 0.302957 mm  
 NaN mm NaN mm NaN mm 8.4346 mm 2.5942 mm  
 NaN mm NaN mm NaN mm 8.8601 mm 6.17807 mm  
 NaN mm NaN mm NaN mm 5.42405 mm 7.28522 mm  
 NaN mm NaN mm NaN mm … 3.64344 mm 6.69638 mm  
 NaN mm NaN mm NaN mm 4.39767 mm 10.9094 mm  
 NaN mm NaN mm NaN mm 7.66618 mm 8.03027 mm  
 NaN mm NaN mm NaN mm 11.0269 mm 4.45515 mm  
 NaN mm NaN mm NaN mm 16.2241 mm 6.78132 mm  
 NaN mm NaN mm NaN mm … 21.1198 mm 10.5038 mm  
 NaN mm NaN mm NaN mm 24.4384 mm 16.6078 mm  
 NaN mm NaN mm NaN mm 25.9856 mm 18.9122 mm  
 NaN mm NaN mm NaN mm 35.302 mm 23.6042 mm

The two code blocks below aims to collect all of the temperature data into one dictionary repository.

using NCDatasets  
base\_path = "data/raw/"  
files = ["2m\_temperature\_1980.nc", "2m\_temperature\_1981.nc", "2m\_temperature\_1982.nc", "2m\_temperature\_1983.nc", "2m\_temperature\_1984.nc", "2m\_temperature\_1985.nc", "2m\_temperature\_1986.nc", "2m\_temperature\_1987.nc", "2m\_temperature\_1988.nc", "2m\_temperature\_1989.nc", "2m\_temperature\_1990.nc", "2m\_temperature\_1991.nc", "2m\_temperature\_1992.nc", "2m\_temperature\_1993.nc", "2m\_temperature\_1994.nc", "2m\_temperature\_1995.nc", "2m\_temperature\_1996.nc", "2m\_temperature\_1997.nc", "2m\_temperature\_1998.nc", "2m\_temperature\_1999.nc", "2m\_temperature\_2000.nc", "2m\_temperature\_2001.nc", "2m\_temperature\_2002.nc","2m\_temperature\_2003.nc","2m\_temperature\_2004.nc","2m\_temperature\_2005.nc","2m\_temperature\_2006.nc","2m\_temperature\_2007.nc","2m\_temperature\_2008.nc","2m\_temperature\_2009.nc","2m\_temperature\_2010.nc","2m\_temperature\_2011.nc","2m\_temperature\_2012.nc","2m\_temperature\_2013.nc","2m\_temperature\_2014.nc","2m\_temperature\_2015.nc","2m\_temperature\_2016.nc","2m\_temperature\_2017.nc","2m\_temperature\_2018.nc","2m\_temperature\_2019.nc","2m\_temperature\_2020.nc"]  
temp\_dict = Dict{String, Any}()  
time\_dict = Dict{String, Any}()  
lon\_dict = Dict{String, Any}()  
lat\_dict = Dict{String, Any}()  
for file in files  
 file\_path = joinpath(base\_path, file)  
 year\_str = split(file, "\_")[3]  
 temp\_ds = NCDataset(file\_path)  
 temp\_dict[year\_str] = temp\_ds[:t2m][:, :, :]  
 time\_dict[year\_str] = temp\_ds["time"][:]  
 lon\_dict[year\_str] = temp\_ds["longitude"][:]  
 lat\_dict[year\_str] = temp\_ds["latitude"][:]  
 close(temp\_ds)  
end

using CDSAPI  
using NCDatasets  
using StatsBase: shuffle  
base\_path = "data/raw"  
files = ["2m\_temperature\_1980.nc", "2m\_temperature\_1981.nc", "2m\_temperature\_1982.nc", "2m\_temperature\_1983.nc", "2m\_temperature\_1984.nc", "2m\_temperature\_1985.nc", "2m\_temperature\_1986.nc", "2m\_temperature\_1987.nc", "2m\_temperature\_1988.nc", "2m\_temperature\_1989.nc", "2m\_temperature\_1990.nc", "2m\_temperature\_1991.nc", "2m\_temperature\_1992.nc", "2m\_temperature\_1993.nc", "2m\_temperature\_1994.nc", "2m\_temperature\_1995.nc", "2m\_temperature\_1996.nc", "2m\_temperature\_1997.nc", "2m\_temperature\_1998.nc", "2m\_temperature\_1999.nc", "2m\_temperature\_2000.nc", "2m\_temperature\_2001.nc", "2m\_temperature\_2002.nc","2m\_temperature\_2003.nc","2m\_temperature\_2004.nc","2m\_temperature\_2005.nc","2m\_temperature\_2006.nc","2m\_temperature\_2007.nc","2m\_temperature\_2008.nc","2m\_temperature\_2009.nc","2m\_temperature\_2010.nc","2m\_temperature\_2011.nc","2m\_temperature\_2012.nc","2m\_temperature\_2013.nc","2m\_temperature\_2014.nc","2m\_temperature\_2015.nc","2m\_temperature\_2016.nc","2m\_temperature\_2017.nc","2m\_temperature\_2018.nc","2m\_temperature\_2019.nc","2m\_temperature\_2020.nc"]  
file\_paths = [joinpath(base\_path, file) for file in files]  
data\_dict = Dict{Symbol, Any}()  
for file\_path in file\_paths  
 dataset = NCDataset(file\_path)  
 variable\_data = dataset["t2m"][:]  
 push!(data\_dict, Symbol(file\_path) => variable\_data)  
 close(dataset)  
end

We will be training and testing the temperature data on the same date frame.

temp\_train\_years = Symbol.(1980:2010)  
temp\_test\_years = Symbol.(2011:2020)  
temp\_train = Dict(year => data\_dict[year] for year in temp\_train\_years if haskey(data\_dict, year))  
temp\_test = Dict(year => data\_dict[year] for year in temp\_test\_years if haskey(data\_dict, year))

Dict{Any, Any}()

n\_lon, n\_lat, n\_t = size(data\_dict)  
temp\_mat\_train = preprocess(temp\_train, temp\_train)  
temp\_mat\_test = preprocess(temp\_test, temp\_train)

pca\_model = fit(PCA, temp\_mat\_train; maxoutdim=25, pratio=0.999);  
p1 = plot(  
principalvars(pca\_model) / var(pca\_model);  
xlabel="# of PCs",  
ylabel="Fraction of Variance Explained",  
label=false,  
title="Variance Explained"  
)  
p2 = plot(  
cumsum(principalvars(pca\_model)) / var(pca\_model);  
xlabel="# of PCs",  
ylabel="Fraction of Variance Explained",  
label=false,  
title="Cumulative Variance Explained Plot"  
)  
plot(p1, p2; layout=(1, 2), size=(800, 400))

Scatter plot

scatter(  
 temp\_mat\_train  
 precip\_train;  
 label=false,  
 xlabel="Temperature (deg K)",  
 ylabel="Precipitation",  
 legend=:topleft  
)

function knn(X::AbstractMatrix, X\_i::AbstractVector, K::Int)::Tuple{Int,AbstractVector}  
dist = [euclidean\_distance(X\_i, X[j, :]) for j in 1:size(X, 1)]  
idx = nsmallest(dist, K)  
w = 1 ./ dist[idx]  
w ./= sum(w)