Table of Contents


```
clearvars;close all;clc;
addpath('./functions');
```

Question 1

hub height of the DTU 10 MW wind turbine is 119 m

```
zHub = 119;
```

Question 2

Interpolate the wind speed data at hub height

```
T = readtable('NORA10_5674N_0501E.txt',"NumHeaderLines" ,3);

time = datetime(T.YEAR,T.M,T.D,T.H,zeros(size(T.H)),zeros(size(T.H)));


oldU = [T.W10,T.W50,T.W80,T.W100,T.W150];
oldZ_U = [10 50 80 100 150];

oldDir = [T.D10,T.D100,T.D150];
oldZ_Dir = [10 100 150];

newZ = sort([10 50 80 100 zHub 150]);

[~,indZ]=min(abs(newZ-zHub));


% t = datetime(T.YEAR,T.M,T.D,T.H);
N = size(oldU,1);
dt = 3;
t = [0:N-1].*dt;

% let's use pchip interpolation (only work in 1D) (safe and often better than
% linear)
```

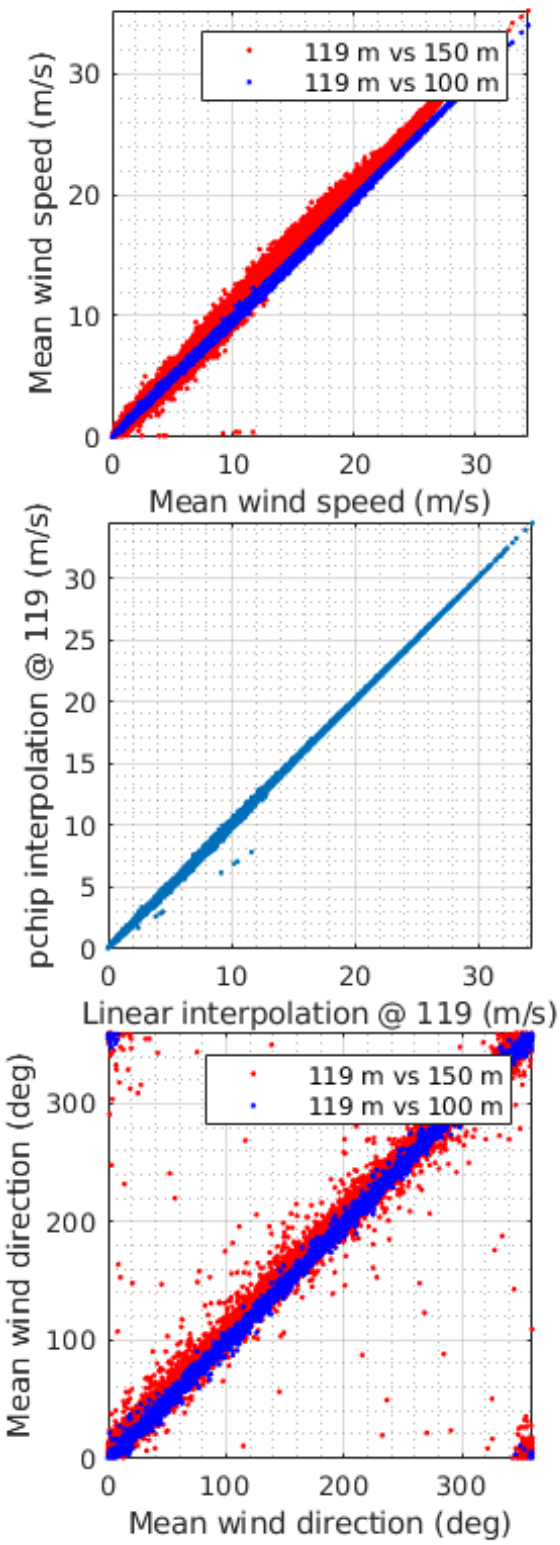
```
newU = zeros(numel(newZ),N);
% For comparison, let's use linear interpolation (safe but not always good
% enough)
newU_linear= zeros(numel(newZ),N);
tic
for ii=1:N
    newU(:,ii) = interp1(oldZ_U,oldU(ii,:),newZ,'pchip');
    newU_linear(:,ii) = interp1(oldZ_U,oldU(ii,:),newZ,'linear');
end
toc


% Interpolate the mean wind direction

newDir= zeros(numel(newZ),N);
tic
for ii=1:N

    oldVx = cosd(oldDir(ii,:));
    oldVy = sind(oldDir(ii,:));

    newVx = interp1(oldZ_Dir,oldVx,newZ,'pchip');
    newVy = interp1(oldZ_Dir,oldVy,newZ,'pchip');

    newDir(:,ii)=atan2d(newVy,newVx);

end
toc
newDir(newDir<0)= newDir(newDir<0) + 360; % no negative wind direction by
 convention
```

```
Elapsed time is 4.389490 seconds.
Elapsed time is 3.828390 seconds.
```

Visualize the interpolation results

```
clf;close all;
figure('position',[165    42   560   879])
tiledlayout(3,1,'TileSpacing','tight')
nexttile
plot(newU(indZ,:),newU(indZ+1,:),'r.')
hold on
plot(newU(indZ,:),newU(indZ-1,:),'b.')
axis equal
axis tight
grid on
grid minor
xlabel('Mean wind speed (m/s)')
ylabel('Mean wind speed (m/s)')
legend(' 119 m vs 150 m ',' 119 m vs 100 m ')

nexttile
plot(newU(indZ,:),newU_linear(indZ,:),'.')
```

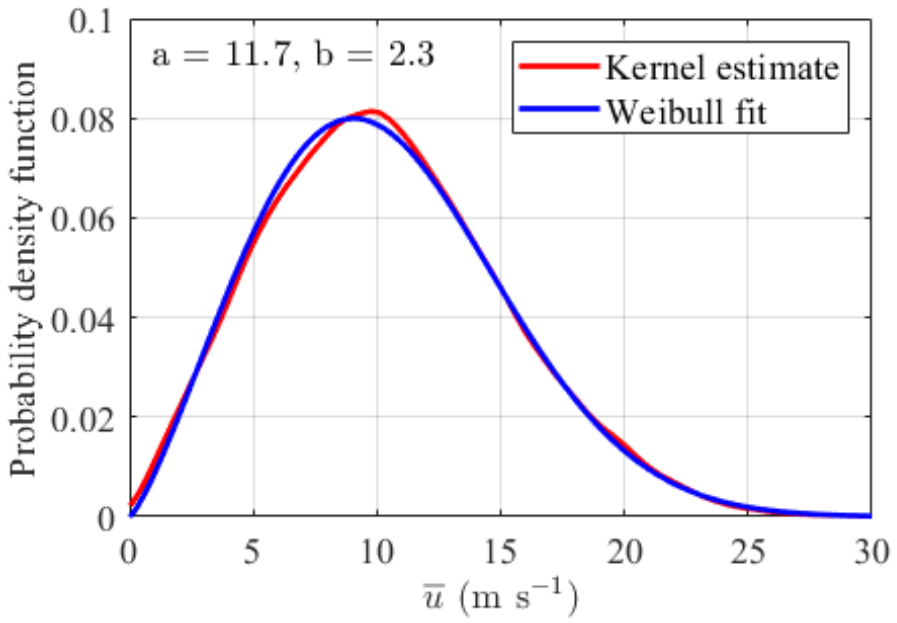
```
axis equal
axis tight
grid on
grid minor
xlabel('Linear interpolation @ 119 (m/s)')
ylabel('pchip interpolation @ 119 (m/s)')


nexttile
plot(newDir(indZ,:),newDir(indZ+1,:),'r.')
hold on
plot(newDir(indZ,:),newDir(indZ-1,:),'b.')
axis equal
axis tight
grid on
grid minor
xlabel('Mean wind direction (deg)')
ylabel('Mean wind direction (deg)')
legend(' 119 m vs 150 m ',' 119 m vs 100 m ')
set(gcf,'color','w')
```

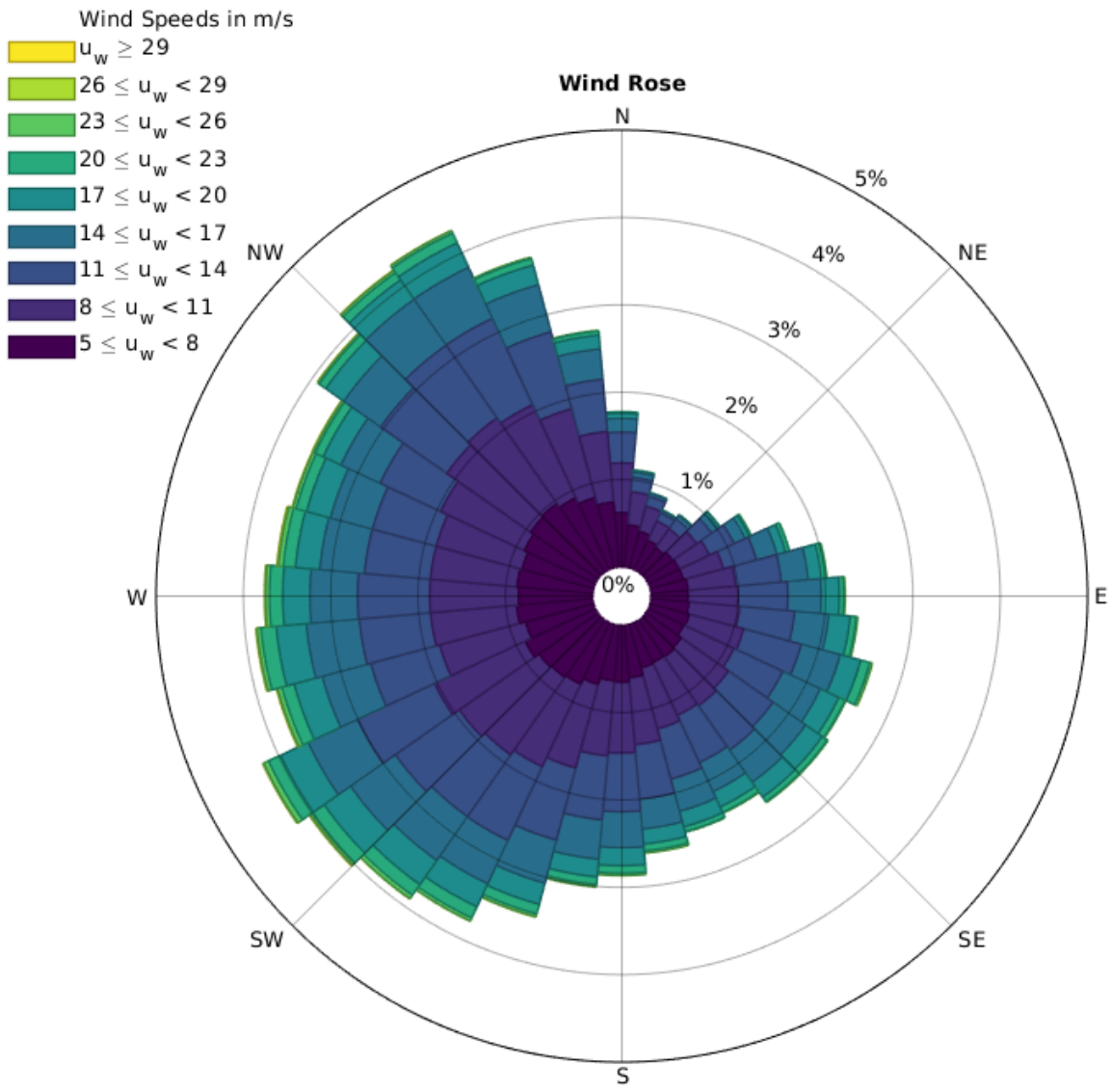

119 m vs 150 m
119 m vs 100 m
Mean wind speed (m/s)
Mean wind speed (m/s)
pchip interpolation @ 119 (m/s)
Linear interpolation @ 119 (m/s)
119 m vs 150 m
119 m vs 100 m
Mean wind direction (deg)
Mean wind direction (deg)

Question 3:

Plot the wind speed and wind direction histograms, the fitted two-parameter Weibull distribution for the wind speeds, and a wind rose for the overall data set.

```
newU(newU==0) = nan;
newU = inpaint_nans(newU,4);

figure('position',[811   516   476   321])
[h1,parmHat1,kernelData] = plotWindDistribution(newU(indZ,:)','r');
xlim([0 30])
grid on
set(findall(gcf,'-property','FontSize'),'FontSize',14,'FontName','Times')
% exportgraphics(gcf,['./figures/weibull_fit.pdf'],'ContentType','vector')



indSpeed = find(newU(indZ,:)>5); %   We only want wind speed above  5 m/s

f = wind_rose(90-newDir(indZ,indSpeed),newU(indZ,indSpeed), 'nDirections',...
    36, 'labels',
 {'N', 'NE', 'E', 'SE', 'S', 'SW', 'W', 'NW'}, 'cMap', 'viridis', ...
    'vWinds', 5:3:30);
set(f,'position',[151   113   732   764])
```



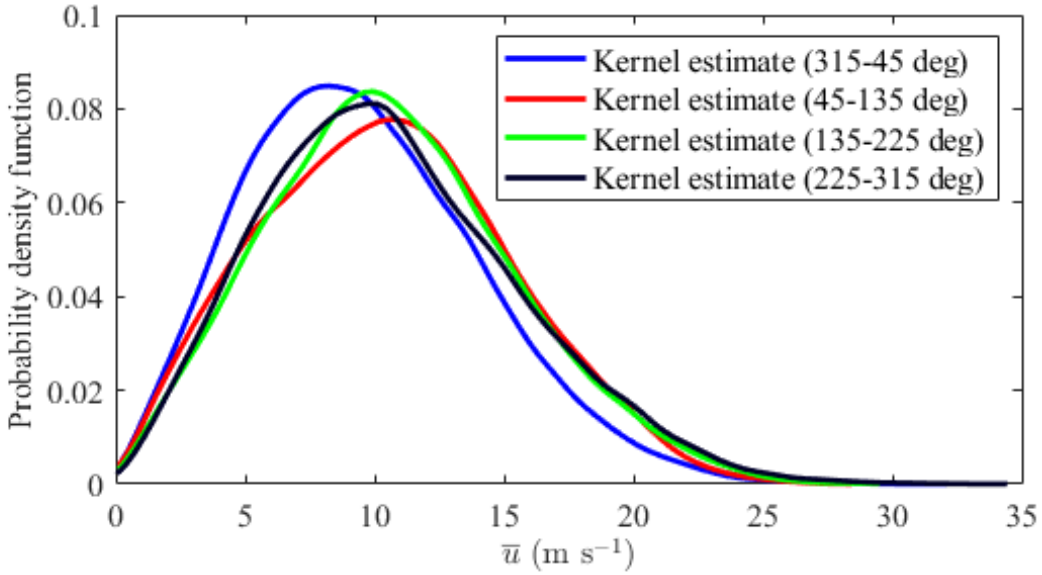


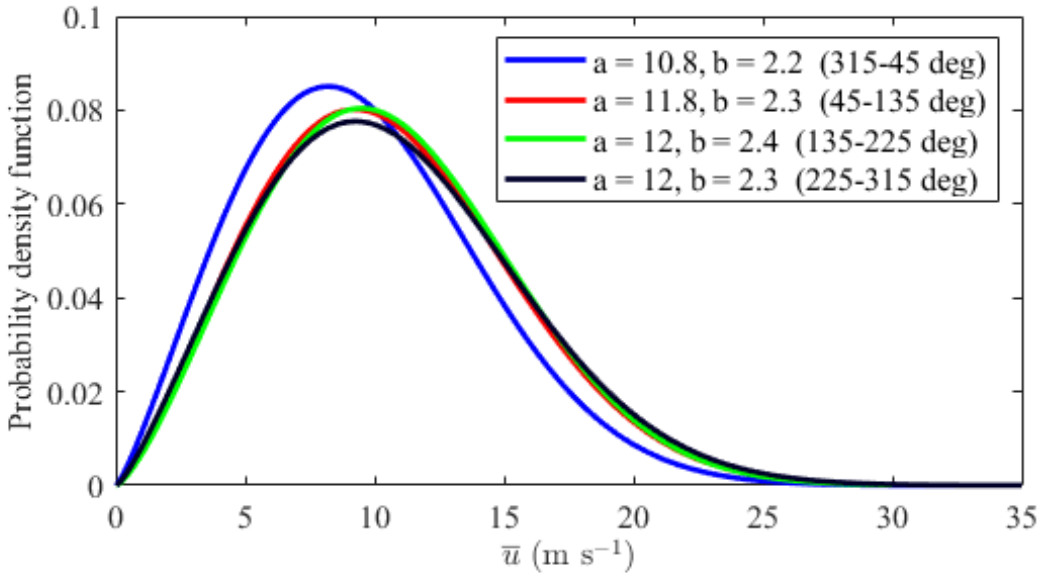
Question 4: susbectors

For the overall period, plot now 4 different Weibull distributions for the 4 different wind direction ranges 315 deg-45 deg (northerlies), 45 deg-135 deg (easterlies), 135 deg-225 deg (southerlies) and 225 deg-315 deg (westerlies). Can you see significant differences, and if yes can you try to interpret them

```
clear ind
sector = {'315-45 deg','45-135 deg','135-225 deg','225-315 deg'};
ind{1} = find(newDir(indZ,:)>=315 | newDir(indZ,:)<45);
ind{2} = find(newDir(indZ,:)>=45 & newDir(indZ,:)<135);
ind{3} = find(newDir(indZ,:)>=135 & newDir(indZ,:)<225);
```

```
ind{4} = find(newDir(indZ,:)>=225 & newDir(indZ,:)<315);

% With kernel estimate (similar to the histogram approach)
COLOR = distinguishable_colors(numel(ind));
figure('position',[407   240   568   637])
tiledlayout(2,1,"TileSpacing","tight")
nexttile
clear h1 leg
for ii=1:numel(ind)
    U= newU(indZ,ind{ii});
    u = linspace(min(U),max(U),100);
    pd1 = fitdist(U(:),'kernel');
    Y1 = pdf(pd1,u);
    h1(ii) = plot(u,Y1,'color',COLOR(ii,:),'linewidth',2);
    hold on
    leg{ii} = ['Kernel estimate (', sector{ii},')'];
end
xlabel('$\overline{u}$ (m s$^{-1}$)','interpreter','latex');
ylabel('Probability density function');
legend(h1,leg{:})
set(gcf,'color','w')
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')

% With Weibul fit
nexttile
clear h1
for ii=1:numel(ind)
    U= newU(indZ,ind{ii});
    parmHat1 = wblfit(U(:));
    y = wblpdf(0:0.1:ceil(max(U)),parmHat1(1),parmHat1(2));
    h1(ii) = plot(0:0.1:ceil(max(U)),y,'color',COLOR(ii,:),'linewidth',2);
    hold on
    fitlabel = ['a = ',num2str(round(parmHat1(1)*10)/10),', b = ',...
        num2str(round(parmHat1(2)*10)/10)];
    leg{ii} = [fitlabel,'  (',sector{ii},')'];

end

xlabel('$\overline{u}$ (m s$^{-1}$)','interpreter','latex');
ylabel('Probability density function');
legend(h1,leg{:})
set(gcf,'color','w')
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')
```



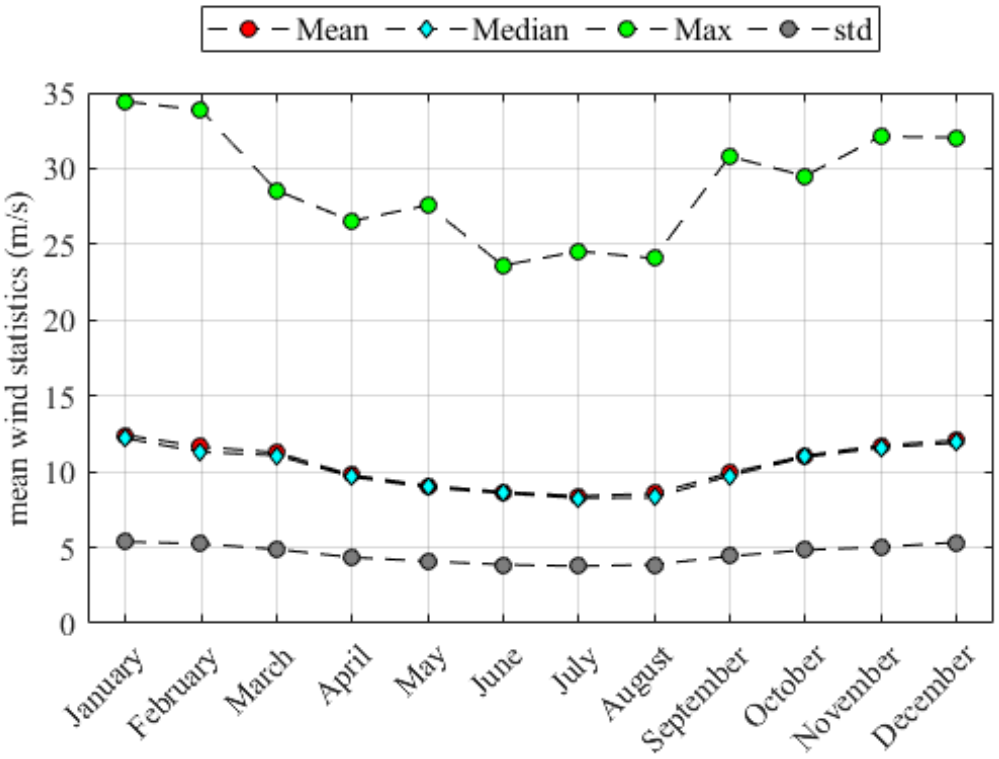


Question 5:

Compute on amonthly basis the mean, median, maximum, and standard deviation of the wind speed at nacelle level for each month of the year. Also determine those values on an annual basis. Can you see any trends over the investigated period?

```
clear monthlyStat
for ii=1:12
    ind = find(month(time)==ii);
    monthlyStat.meanU(ii) = mean(newU(indZ,ind));
    monthlyStat.medianU(ii) = median(newU(indZ,ind));
    monthlyStat.maxU(ii) = max(newU(indZ,ind));
```

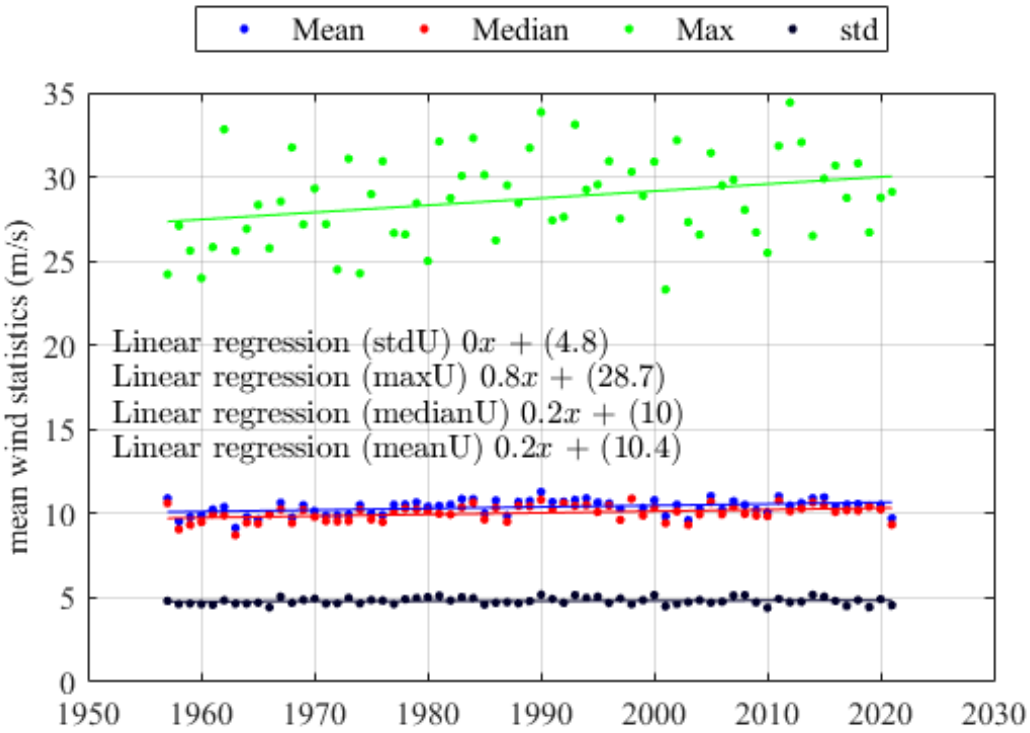
```
    monthlyStat.stdU(ii) = std(newU(indZ,ind));
    monthlyStat.x(ii) = categorical(month(time(ind(1)),'name'));
end

figure('position',[407   240   568   400])
plot(monthlyStat.x,monthlyStat.meanU,'ko--','markerfacecolor','r')
hold on
p=plot(monthlyStat.x,monthlyStat.medianU,'kd--','markerfacecolor','c','markersize',5)
plot(monthlyStat.x,monthlyStat.maxU,'ko--','markerfacecolor','g')
plot(monthlyStat.x,monthlyStat.stdU,'ko--','markerfacecolor',[1 1 1]*0.5)
grid on

ylim([0 35])
set(gcf,'color','w')
ylabel('mean wind statistics (m/s)')
legend('Mean','Median','Max','std','location','northoutside','orientation','horizontal')
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')


p =

  Line with properties:

            Color: [0 0 0]
        LineStyle: '--'
        LineWidth: 0.5000
           Marker: 'diamond'
       MarkerSize: 5
    MarkerFaceColor: [0 1 1]
            XData: [January    February    March    April    May    …    ]
            YData: [12.2063 11.2950 11.0830 9.6557 8.9546 8.5726 8.2546 … ]

  Use GET to show all properties
```



Yearly wind speed statistics without sliding window

```
clear yearlyStat
tyear=unique(year(time));
Nyear = numel(tyear);


for ii=1:Nyear
    ind = find(year(time)==tyear(ii));
    if ~isempty(ind)
        yearlyStat.meanU(ii) = mean(newU(indZ,ind));
        yearlyStat.medianU(ii) = median(newU(indZ,ind));
        yearlyStat.maxU(ii) = max(newU(indZ,ind));
        yearlyStat.stdU(ii) = std(newU(indZ,ind));
        yearlyStat.x(ii) = tyear(ii);
    end
end

COLOR = distinguishable_colors(4);

figure('position',[407   240   568   400])
plot(yearlyStat.x,yearlyStat.meanU,'.','color',COLOR(1,:),'markersize',10)
hold on
p=plot(yearlyStat.x,yearlyStat.medianU,'.','color',COLOR(2,:),'markersize',10);
```

```
plot(yearlyStat.x,yearlyStat.maxU,'.','color',COLOR(3,:),'markersize',10)
plot(yearlyStat.x,yearlyStat.stdU,'.','color',COLOR(4,:),'markersize',10)
grid on

f= fields(yearlyStat);
for ii=1:4
    [p,S,mu] = polyfit(tyear,yearlyStat.(f{ii}),1);
    [y] = polyval(p,tyear,S,mu);
    plot(tyear,y,'color',COLOR(ii,:));

    label(['Linear regression (',f{ii},') ',num2str(round(p(1)*10)/10),...
        '$x$ + ','(',num2str(round(10*p(2))/10),')'],0.03,0.3+0.06*ii);
end

ylim([0 35])
set(gcf,'color','w')
ylabel('mean wind statistics (m/s)')
legend('Mean','Median','Max','std','location','northoutside','orientation','horizontal')
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')
```

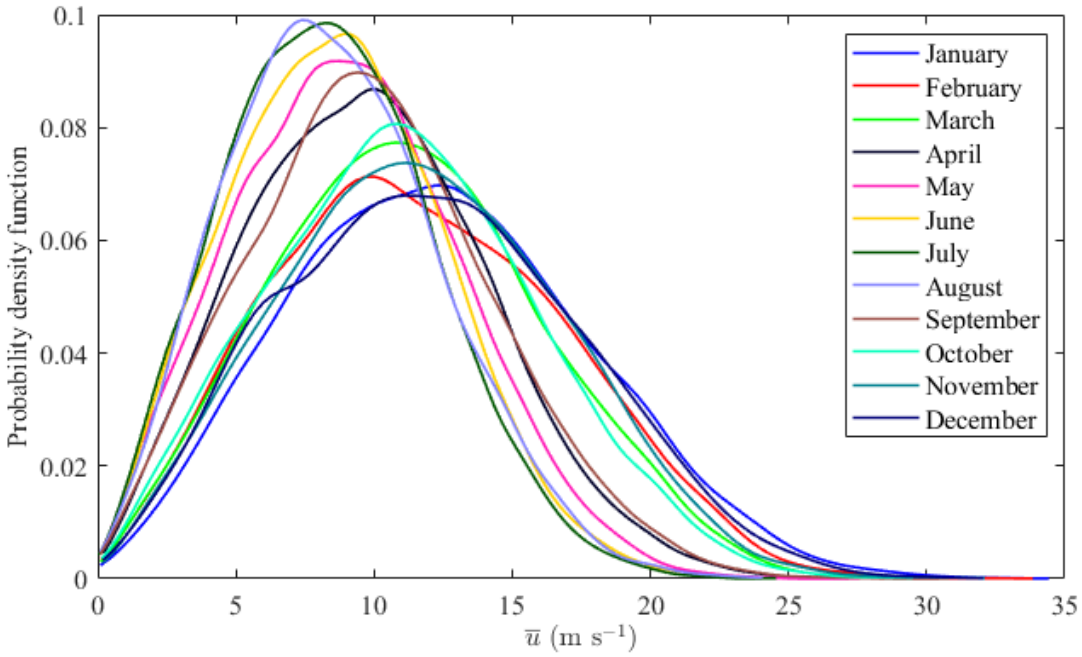


Question 6

For each month also make a histogram of the wind speed at nacelle level.

```
clf; close all;
COLOR = viridis(12);
figure('position',[402    46   723   868])
```

```
tiledlayout(2,1,"TileSpacing","tight")
nexttile
COLOR = distinguishable_colors(12);
clear leg
for ii=1:12
    ind = find(month(time)==ii);
    U = (newU(indZ,ind));
    u = linspace(min(U),max(U),100);
    pd1 = fitdist(U(:),'kernel');
    Y1 = pdf(pd1,u);
    plot(u,Y1,'color',COLOR(ii,:),'linewidth',1.2);
    hold on
    leg{ii} = char(month(time(ind(1)),'name'));
end
legend(leg{:});
xlabel('$\overline{u}$ (m s$^{-1}$)','interpreter','latex');
ylabel('Probability density function');
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')
set(gcf,'color','w');
```

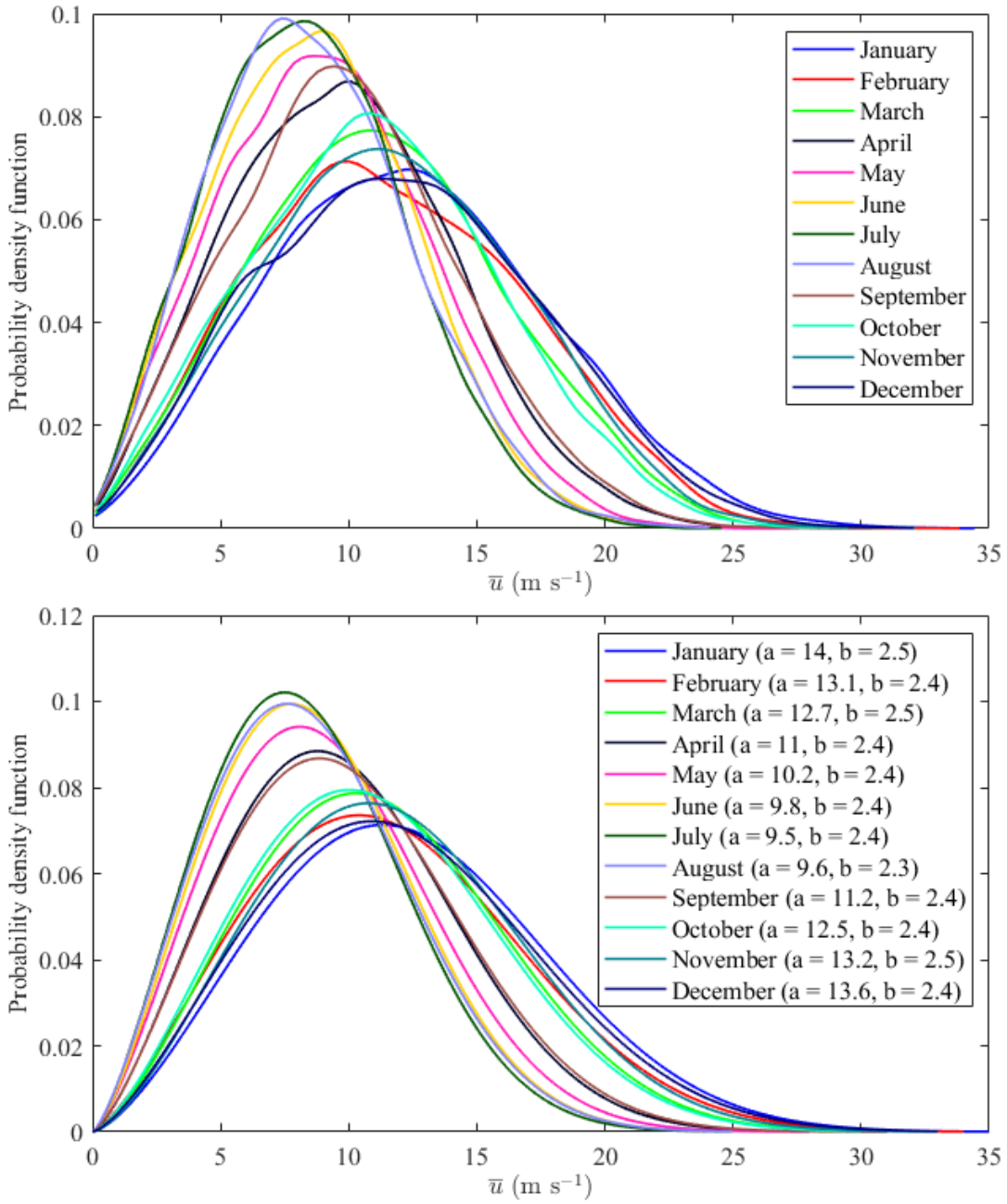


Question 7

Fit a two-parameter Weibull distribution to the above histograms and list the distribution parameters for each month

```
nexttile
COLOR = distinguishable_colors(12);
```

```
clear leg
for ii=1:12
    ind = find(month(time)==ii);
    U = (newU(indZ,ind));
    u = linspace(min(U),max(U),100);
    pd1 = fitdist(U(:),'kernel');
    Y1 = pdf(pd1,u);
    parmHat1 = wblfit(U(:));
    y = wblpdf(0:0.1:ceil(max(U)),parmHat1(1),parmHat1(2));
    plot(0:0.1:ceil(max(U)),y,'color',COLOR(ii,:),'linewidth',1.2);
    hold on
    leg{ii} = [char(month(time(ind(1)),'name')),...
        ' (a = ',num2str(round(parmHat1(1)*10)/10),...
        ', b = ',num2str(round(parmHat1(2)*10)/10),')'];
end
legend(leg{:});
xlabel('$\overline{u}$ (m s$^{-1}$)','interpreter','latex');
ylabel('Probability density function');
set(findall(gcf,'-property','FontSize'),'FontSize',12,'FontName','Times')
set(gcf,'color','w');
```

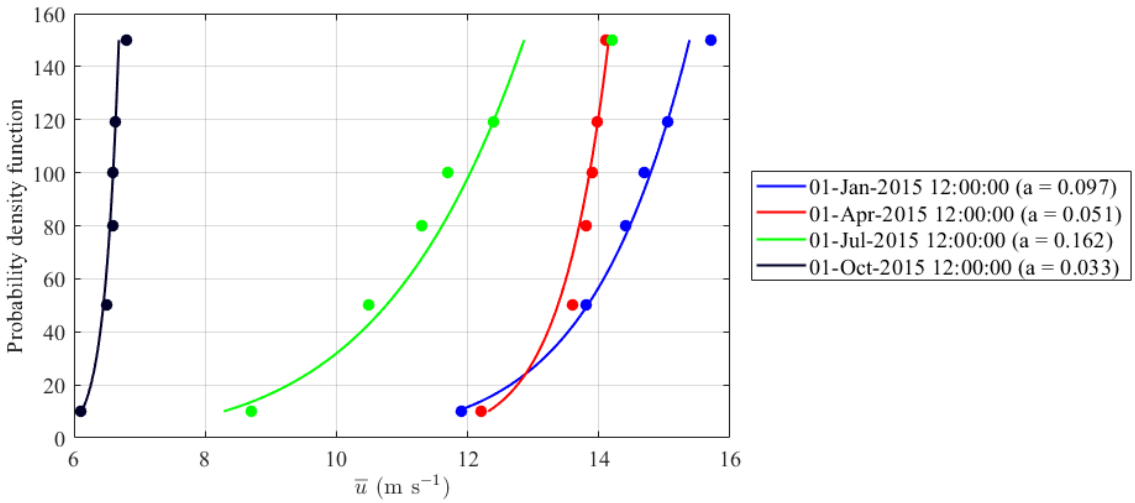


Question 8

Choose 4 (or more) wind situations picked mid-day a day in January, April, July, and October. Investigate the wind profile by estimating the shear exponent* and the wind veer. Discuss your findings

```
targetDate = [datetime(2015,01,01,12,0,0),datetime(2015,04,01,12,0,0),...
```

```
    datetime(2015,07,01,12,0,0),datetime(2015,10,01,12,0,0)];


COLOR = distinguishable_colors(4);

myFun = @(alpha,zr)  zr.^alpha;
guess = 0.1;
z1 = linspace(min(newZ),max(newZ),100);

options = optimoptions('lsqcurvefit','Display','off');
clf;close all
clear p leg a
figure('position',[197         504        1000         426])

for ii=1:numel(targetDate)
    [~,ind]=min(abs(time-targetDate(ii)));

    zr = newZ./newZ(indZ);
    ur = newU(:,ind)./newU(indZ,ind);
    a(ii) = lsqcurvefit(myFun,guess,zr(:),ur(:),-1,1,options);

    plot(newU(:,ind),newZ,'.','color',COLOR(ii,:),'markersize',25);
    hold on
    p(ii) = plot(myFun(a(ii),z1./
newZ(indZ)).*newU(indZ,ind),z1,'color',COLOR(ii,:),'linewidth',1.5);
    leg{ii} = [datestr(time(ind)), ' (a =
 ',num2str(round(a(ii)*1000)/1000),')'];
end
ylim([0 160])
legend(p,leg{:},'location','eastoutside');
xlabel('$\overline{u}$ (m s$^{-1}$)','interpreter','latex');
ylabel('Probability density function');
set(findall(gcf,'-property','FontSize'),'FontSize',14,'FontName','Times')
grid on
set(gcf,'color','w');
```



Question 9

For the same situations as above, check the temperature difference between sea surface level and for example 100 m above sea level. Do you see any relation to the findings on the wind shear exponent?

```
clc

myTable = readtable('NORA10_T_5674N_0501E.txt',"NumHeaderLines" ,2);
dT = myTable.T100-myTable.SST; % temperature difference

time2 = datetime(myTable.YEAR,myTable.M,myTable.D,myTable.H,0,0);


for ii=1:numel(a),
    [~,ind]=min(abs(time2-targetDate(ii)));
    if dT(ind)>0
    fprintf([datestr(time2(ind)),...
        ' --- a = %1.2f and dT = %1.2f (air warmer than sea, stable regime (?)
 \n'],...
        [a(ii),dT(ind)])
    else
fprintf([datestr(time2(ind)),...
        ' --- a = %1.2f and dT = %1.2f (air colder than sea, unstable regime
 (?) \n'],...
        [a(ii),dT(ind)])
    end

end
```

```
01-Jan-2015 12:00:00 --- a = 0.10 and dT = 0.30 (air warmer than sea, stable
 regime (?)
01-Apr-2015 12:00:00 --- a = 0.05 and dT = -3.00 (air colder than sea,
 unstable regime (?)
01-Jul-2015 12:00:00 --- a = 0.16 and dT = 1.40 (air warmer than sea, stable
 regime (?)
01-Oct-2015 12:00:00 --- a = 0.03 and dT = -2.40 (air colder than sea,
 unstable regime (?)
```

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