Wind Turbine Load Extrapolation

Unceirtainty quantification in wind turbine load extrapolation

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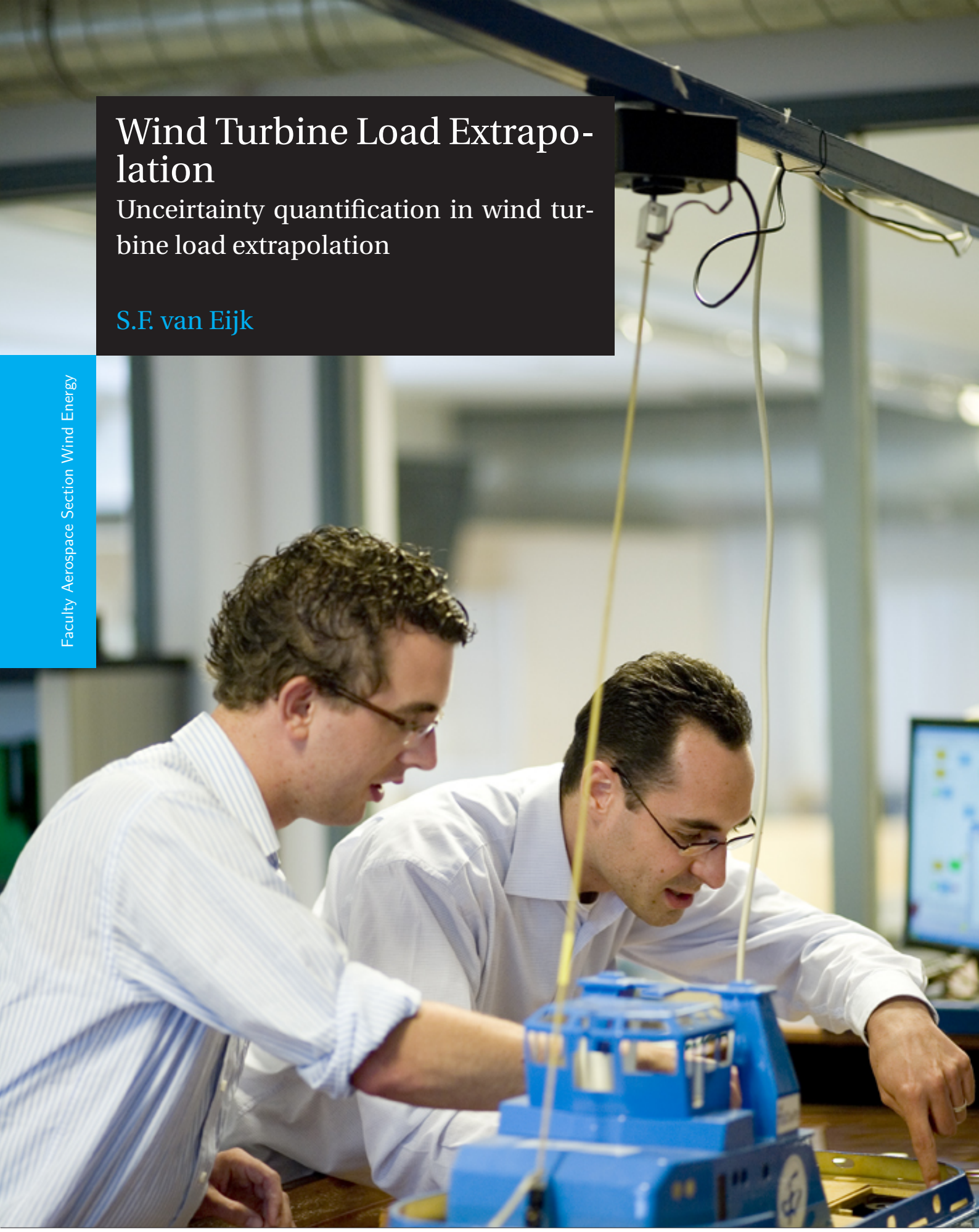

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Challenge the future

WIND TURBINE LOAD EXTRAPOLATION

UNCEIRTAINTY QUANTIFICATION IN WIND TURBINE LOAD EXTRAPOLATION

by

S.F. van Eijk

in partial fulfillment of the requirements for the degree of

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This thesis is confidential and cannot be made public until December 31, 2013.

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PREFACE

Preface...

S.F. van Eijk
Delft, January 2013

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INTRODUCTION

This document is intended to be both an example of the TU Delft LaTeX template for reports and theses, as well as a short introduction to its use. It is not intended to be a general introduction to LaTeX itself,[1] and we will assume the reader to be familiar with the basics of creating and compiling documents.

Instructions on how to use this template under Windows and Linux, and which LaTeX packages are required, can be found in `README.txt`.

1.1. DOCUMENT STRUCTURE

Since a report, and especially a thesis, might be a substantial document, it is convenient to break it up into smaller pieces. In this template we therefore give every chapter its own file. The chapters (and appendices) are gathered together in `report.tex`, which is the master file describing the overall structure of the document. `report.tex` starts with the line

```
\documentclass{tudelft-report}
```

which loads the TU Delft report template. The template is based on the LaTeX `book` document class and stored in `tudelft-report.cls`. The document class accepts several comma-separated options. The default language is English, but this can be changed to Dutch (*e.g.*, for bachelor theses) by specifying the `dutch` option:

```
\documentclass[dutch]{tudelft-report}
```

Furthermore, hyperlinks are shown in blue, which is convenient when reader the report on a computer, but can be expensive when printing. They can be turned black with the `print` option. This will also turn the headers black instead of cyan.

If the document becomes large, it is easy to miss warnings about the layout in the LaTeX output. In order to locate problem areas, add the `draft` option to the `\documentclass` line. This will display a vertical bar in the margins next to the paragraphs that require attention. Finally, the `nativefonts` option can be used to override the automatic font selection (see below).

This template has the option to automatically generate a cover page with the `\makecover` command. See the next section for a detailed description.

The contents of the report are included between the `\begin{document}` and `\end{document}` commands, and split into three parts by

1. `\frontmatter`, which uses Roman numerals for the page numbers and is used for the title page and the table of contents;

2. `\mainmatter`, which uses Arabic numerals for the page numbers and is the style for the chapters;

3. `\appendix`, which uses letters for the chapter numbers, starting with 'A'.

[1] We recommend http://en.wikibooks.org/wiki/LaTeX as a reference and a starting point for new users.

The title page is defined in a separate file, *e.g.*, `title.tex`, and included verbatim with `\input{title}`.[2] Additionally, it is possible to include a preface, containing, for example, the acknowledgements. An example can be found in `preface.tex`. The table of contents is generated automatically with the `\tableofcontents` command. Chapters are included after `\mainmatter` and appendices after `\appendix`. For example, `\input{chapter-1}` includes `chapter-1.tex`, which contains this introduction.

The bibliography, finally, is generated automatically with

```
\bibliography{report}
```

from `report.bib`. Although it is possible to manage the bibliography by hand, we recommend using EndNote (available from Blackboard) or JabRef (available from http://jabref.sourceforge.net/). The bibliography style is specified in `tudelft-report.bst`, which is a modified version of `apsrev4-1.bst` (from REVTeX) designed to also display the titles of referenced articles. The template will automatically generate clickable hyperlinks if a URL or DOI (digital object identifier) is present for the reference. As an example, we cite the paper by Nobel Prize winner Andre Geim and his pet hamster [1]. If you need to use a different style, change

```
\bibliographystyle{tudelft-report}
```

at the end of `tudelft-report.cls` to, *e.g.*,

```
\bibliographystyle{apacite}
```

for the APA style.

1.2. COVER AND TITLE PAGE

This template will automatically generate a cover page if you issue the `\makecover` command. However, before generating the cover, you need to provide the information to put on it. This can be done with the following commands:

- `\title[Optional Subtitle]{Title}`
  This command is used to provide the title and optional subtitle of the document. The title and subtitle are printed inside the black box on the front cover, while the title is also printed on the spine. If you use a title page (see below), this information will be used there as well.
- `\author{J. Random Author}`
  This command specifies the author. It is printed in cyan below the title on the front cover (and, possibly, on the title page).
- `\affiliation{Technische Universiteit Delft}`
  The affiliation is the text printed vertically inside the blue box on the front cover. It can be the affiliation, such as the university or department name, or be used for the document type (*e.g.*, Master's thesis).
- `\coverimage{cover.jpg}`
  With this command you can specify the filename of the cover image. The image is stretched until it fills the full width of the front cover (including the spine if a back cover is present).
- `\covertext{Cover Text}`
  If a back cover is present, the cover text is printed in the blue box on the back. Internally, this box is created using the LaTeX `minipage` environment, so it supports line breaks.

The `\makecover` command also accepts several options for customizing the layout of the cover. The most important of these is `back`. Supplying this option will generate a back cover as well as a front, including the spine. Since this requires a page size slightly larger than twice A4 (to make room for the spine), and LaTeX does not support different page sizes within the same document, it is wise to create a separate file for the cover. `cover.tex` contains an example. The recommended page size for the full cover can be set with

```
\geometry{papersize={1226bp,851bp}}
```

[2] Note that it is not necessary to specify the file extension.

after the document class and before `\begin{document}`.

The other options `\makecover` accepts are

- `nospine`
  If a back cover is generated, the title will also be printed in a black box on the spine. However, for smaller documents the spine might not be wide enough. Specifying this option disables printing the title on the spine.
- `frontbottom`
  By default the black box on the front is situated above the blue box. Specifying this option will place the black box below the blue one.
- `spinewidth`
  If a back cover is present, this option can be used to set the width of the spine. The default is `spinewidth=1cm`.
- `frontboxwidth`, `frontboxheight`, `backboxwidth`, `backboxheight`
  As their names suggest, these options are used to set the width and height of the front (black) and back (blue) boxes. The default widths and heights are `4.375in` and `2.1875in`, respectively.
- `x`, `y`
  The blue and black boxes touch each other in a corner. The location of this corner can be set with these options. It is defined with respect to the top left corner of the front cover. The default values are `x=0.8125in` and `y=3in`.
- `margin`
  This option sets the margin between the borders of the boxes and their text. The default value is `12pt`.

For a thesis it is desirable to have a title page within the document, containing information like the thesis committee members. To give you greater flexibility over the layout of this page, it is not generated by a command like `\makecover`, but instead described in the file `title.tex`. Modify this file according to your needs. The example text is in English, but Dutch translations are provided in the comments. Note that for a thesis, the title page is subject to requirements which differ by faculty. Make sure to check these requirements before printing.

1.3. CHAPTERS

Each chapter has its own file. For example, the LaTeX source of this chapter can be found in `chapter-1.tex`. A chapter starts with the command

```
\chapter{Chapter title}
```

This starts a new page, prints the chapter number and title and adds a link in the table of contents. If the title is very long, it may be desirable to use a shorter version in the page headers and the table of contents. This can be achieved by specifying the short title in brackets:

```
\chapter[Short title]{Very long title with many words which could not possibly
fit on one line}
```

Unnumbered chapters, such as the preface, can be created with `\chapter*{Chapter title}`. Such a chapter will not show up in the table of contents or in the page header. To create a table of contents entry anyway, add

```
\addcontentsline{toc}{chapter}{Chapter title}
```

after the `\chapter` command. To print the chapter title in the page header, add

```
\setheader{Chapter title}
```

Chapters are subdivided into sections, subsections, subsubsections, and, optionally, paragraphs and subparagraphs. All can have a title, but only sections and subsections are numbered. As with chapters, the numbering can be turned off by using `\section*{...}` instead of `\section{...}`, and similarly for the subsection.

1.4. \SECTION{...}

1.4.1. \SUBSECTION{...}

\SUBSUBSECTION{...}

\paragraph{...} Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

1.5. FONTS AND COLORS

The fonts used by this template depend on which version of LaTeX you use. Regular LaTeX, *i.e.*, if you compile your document with with `latex`, `pslatex` or `pdflatex`, will use Utopia for text, Fourier for math and Latin Modern for sans-serif and monospaced text. However, if you want to adhere to the TU Delft house style, you will need to use XeLaTeX, as it supports TrueType and OpenType fonts. Compiling with `xelatex` will use Bookman Old Style for titles, Tahoma for text, Courier New for monospace and Cambria for math. If you want to use XeLaTeX, but do not want to use the TU Delft house style fonts, you can add the `nativefonts` option to the document class. This will still use Bookman Old Style and Tahoma on the cover, but not for the body of the document. If you need to use these fonts for certain sections in the main text, they are available via `\tudrmfamily` and `\tudsffamily`, respectively.

The corporate colors of the TU Delft are cyan, black and white, available, respectively, via `\color{tudelft-cyan}`, `\color{tudelft-black}` (which differs slightly from the default `black`) and `\color{tudelft-white}`. Apart from these three, the house style defines the basic colors

- tudelft-sea-green,
- tudelft-green,
- tudelft-dark-blue,
- tudelft-purple,
- tudelft-turquoise and
- tudelft-sky-blue,

as well as the accent colors

- tudelft-lavendel,
- tudelft-orange,
- tudelft-warm-purple,
- tudelft-fuchsia,
- tudelft-bright-green and
- tudelft-yellow.

2

EXTRAPOLATION

Why is extrapolation relevant for wind energy?

The extrapolation technique is used in the IEC 61400-1 for onshore- [2] and in IEC 61400-3 [3] for offshore wind turbine design.

relevance: Extrapolation of 50 years test usaly dictates the load values. -) A lot of unceirtainty in calculations

A

FUNCTION GUMBELUNC.MAT

```
%% GumbelUnc
% Quantifictaion of Gumbel extrapolation unceirtainty
%% Parameters
% # |N| = Available data points
% # |r| = Fits per |N|
% # |CI| = Confidence Interval of extrapolated values: |68| , |95| or
% |99.7| %
% # |normalise| = normalises the axis with: |'on'| , |'xon'| , |'yon'| or
% |'off'|
% # Optional: |mu| = mu of the Sample Gumbel |(default = 10)|
% # Optional: |beta| = beta of the Sample Gumbel |(default = 4)|
%% Syntax
% |[Returnlvlplot] = GumbelUnc(N,r,CI,normalise,mu,beta)|
%
% |[Returnlvlplot,musigma] = GumbelUnc(N,r,CI,normalise,mu,beta)|
%
% |[Returnlvlplot,musigma,SampleGumbel] =
% GumbelUnc(N,r,CI,normalise,mu,beta)|
%% Description
% *|GumbelUnc(N,r,CI,normalise,mu,beta)|* quantifies in a
% normalised way the uncertainty of extrapolation from 2 towards |N|
% available data points. It plots the return level plot and saves under
% GumbelUnc. Both axis can be normalised with |normalise|. Furthermore the
% sample Gumbel can be adjusted entering for |mu| and |beta|.
%%
% *|[Returnlvlplot] = GumbelUnc(N,r,CI,normalise,mu,beta)|* gives same
% output as |GumbelUnc(N,r,CI,normalise,mu,beta)|
%%
% *|[Returnlvlplot,musigma] = GumbelUnc(N,r,CI,normalise,mu,beta)|* stores
% the mu and sigmas of |N| normal distributions in the workspace in |musigma|
%%
% *|[Returnlvlplot,musigma,SampleGumbel] =
% GumbelUnc(N,r,CI,normalise,mu,beta)|*
% Gives a figure of the Gumbel from which N samples are drawn for |r| times
% per N. Negative values of the Sample Gumbel or a Sample Gumbel that is
% elevated too high may distort return level plot outcomes.

%% Function
function [Returnlvlplot,musigma,SampleGumbel] = ...
    GumbelUnc(N,r,CI,normalise,mu,beta)

%some in- and output checks
if nargout > 3
    error('GumbelUnc:Too many outputs, give a maximum of 3 outputs');
end


if nargin > 6
    error('GumbelUnc: Too many inputs, give maximum of 6 inputs');
```

```
elseif nargin < 4
    error('GumbelUnc: Too fieuw inputs, give a minimum of 4 inputs');
end

switch nargin
    case 4
        mu = 10;
        beta = 4;
    case 5
        error('Specify both mu and beta for sample Gumbel');
end

if mu > N;
    error('mu cannot be greater than N.')
end

if CI == 68;
    Nsigma = 1;
elseif CI == 95;
    Nsigma = 2;
elseif CI == 99.7;
    Nsigma = 3;
else
    error('Confidence Interval (CI) must be equal to 68%, 95% or 99.7% without ...
        percent sign.')
end

%%
% Construction Sample Gumbel
%
% The confidence interval from which is Sampled is between
% 0.1% and 99.9%.
%confidence interval
Rb = mu - (beta * log(-log(0.999)));
Lb = mu - (beta * log(-log(0.001)));

%creating values that are drawn (X) acording to the Sample Gumbel (f)
X = linspace(Lb,Rb,N);
f = gevpdf(X,0,beta,mu);

%some warnings for Sample Gumbel to prevent distortion in return level plot
if f(N)/max(f) > 0.05;
    warning('Sample Gumbel does not represent extreme values well because of limited ...
        use of probabilities. Change mu, beta, Duration0 or V.')
end

if f(find(X ≥ 0,1))/max(f) ≥ 0.05
    warning('Sample Gumbel does not represent extreme values well because of ...
        significant negative values probabilities.')
end

%%
% Unceirtanty of extrapolation toward |N|
%
% Here de data is generated using |polyfit| as fitting tool. Due to the
% logaritmic axis a linear relation exists. The |r| fitted lineair graphs
% are extrapolated towards |FN| which is the |N| th |X| value. A normal
% distribution of these values is fitted and described by mu and sigma.
% both are stored in the parameter |Normal|. |N| mu's and sigma's are
% iteratively stored in |Allmusigma|.

FN = -log(-log(N/(1+N)));   %the probability of the extremest value

Allmusigma = zeros(N,2);
for i = 2:N;                %minimal of 2 datapoints for fit
   betamu = zeros(r,2);
   Q = zeros(r,1);
   for j = 1:r;             %r extreme value points
       x = sort(X(discretesample(f,i)));        %Sort values
       P = -log(-log((1:i)/(1+i)));             %Plot positions
       betamu(j,:) = polyfit(P,x,1);            %Param. of lineair graph
```

```
        Q(j,:) = betamu(j,2) + (betamu(j,1)*FN); %All extrapolated values
    end
   Normal = fitdist(Q,'Normal');                 %Fit a Normal distribution
   Allmusigma(i,:)= [Normal.mu Normal.sigma];    %Store the mu and sigma's
end

%%
% Plot normal distributions

%normalisation towards Xtrue
Xtrue = ones(N,1)*(mu+(beta*FN));

NormaliseN = ((1:N)./N)*100;
NormaliseXmu = ((Allmusigma(:,1) - Xtrue)./Xtrue)*100;
NormaliseXup = (((Allmusigma(:,1)+(Nsigma*Allmusigma(:,2)))...
    - Xtrue)./Xtrue)*100;
NormaliseXdown = (((Allmusigma(:,1)-(Nsigma*Allmusigma(:,2)))...
    - Xtrue)./Xtrue)*100;

%Sample Gumbel that represents the data
SampleGumbel = figure;
plot(X,f,'k')
xlabel('$X$','Interpreter','LaTeX')
ylabel('$f$','Interpreter','LaTeX')
title({'Sample Gumbel'},'Interpreter','LaTeX')

set(gcf, 'Color', 'none')
set(gcf, 'Units', 'centimeters')
set(gcf, 'OuterPosition', [5, 5, 11.7, 9.5])

%manage output arguments
switch nargout
    case 0
        close figure 1
    case 1
        close figure 1
    case 2
        close figure 1
end

%check axis for normalisation
normalis1 ='off';
normalis0 ='on';
normalis2 ='yon';
normalis3 ='xon';

if strcmp(normalis0,normalise)==1;
    Returnlvlplot = figure;
    hold on
    plot(NormaliseN(2:N),NormaliseXmu(2:N),'k')
    plot(NormaliseN(2:N),NormaliseXup(2:N),'k')
    plot(NormaliseN(2:N),NormaliseXdown(2:N),'k')
    plot(NormaliseN,zeros(N,1),'--k')
    xlabel('$N_{normalised}¬[\%]$','Interpreter','LaTeX')
    ylabel('$X_{normalised}¬[\%]$','Interpreter','LaTeX')
    legend({'$\mu$',['$\mu+' num2str(Nsigma) '\sigma$'],...
        ['$\mu-' num2str(Nsigma) '\sigma$'],'Expected $\mu$'},...
        'Interpreter','LaTeX')
    title([ num2str(CI) '\% Confedence Interval of Gumbel extrapolation from 2 ...
        toward¬' num2str(N) '¬data points'],...
        'Interpreter','LaTeX')
    annotation('textbox',[0.5,0.23,0.31,0.15],'String',...
        {'Information Sample Gumbel:',['$N_{sample}≠¬$' num2str(N-1)],...
        ['$\beta_{sample}=¬$' num2str(beta)],['$\mu_{sample}≠¬$' num2str(mu)]},...
        'VerticalAlignment','middle','HorizontalAlignment','center',...
        'FitBoxToText','on','LineWidth',0.1,'Interpreter','LaTeX')
    hold off

elseif strcmp(normalis1,normalise)==1;
    Returnlvlplot = figure;
    hold on
```

```
188     plot(2:N,Allmusigma(2:N,1),'k')
189     plot(2:N,Allmusigma(2:N,1)+(Nsigma*Allmusigma(2:N,2)),'k')
190     plot(2:N,Allmusigma(2:N,1)-(Nsigma*Allmusigma(2:N,2)),'k')
191     plot(1:N,Xtrue,'--k')
192     xlabel('$N¬[-]$','Interpreter','LaTeX')
193     ylabel('$X¬[F]$','Interpreter','LaTeX')
194     legend({'$\mu$',['$\mu+' num2str(Nsigma) '\sigma$'],...
195         ['$\mu-' num2str(Nsigma) '\sigma$'],'Expected $\mu$'},...
196         'Interpreter','LaTeX')
197     title([ num2str(CI) '\% Confedence Interval of Gumbel extrapolation from 2 ...
        toward¬' num2str(N) '¬data points'],...
198         'Interpreter','LaTeX')
199     annotation('textbox',[0.5,0.23,0.31,0.15],...
200         'String',{'Information Sample Gumbel:',...
201         ['$N_{sample}≠¬$' num2str(N-1)],...
202         ['$\beta_{sample}=¬$' num2str(beta)],...
203         ['$\mu_{sample}≠¬$' num2str(mu)]},...
204         'VerticalAlignment','middle','HorizontalAlignment','center',...
205         'FitBoxToText',...
206         'on','LineWidth',0.1,'Interpreter','LaTeX')
207     hold off
208 
209 elseif strcmp(normalis2,normalise)==1;
210     Returnlvlplot = figure;
211     hold on
212     plot(2:N,NormaliseXmu(2:N),'k')
213     plot(2:N,NormaliseXup(2:N),'k')
214     plot(2:N,NormaliseXdown(2:N),'k')
215     plot(1:N,zeros(N,1),'--k')
216     xlabel('$N¬[-]$','Interpreter','LaTeX')
217     ylabel('$X_{normalised}¬[\%]$','Interpreter','LaTeX')
218     legend({'$\mu$',['$\mu+' num2str(Nsigma) '\sigma$'],...
219         ['$\mu-' num2str(Nsigma) '\sigma$'],'Expected $\mu$'},...
220         'Interpreter','LaTeX')
221     title([ num2str(CI) '\% Confedence Interval of Gumbel extrapolation from 2 ...
        toward¬' num2str(N) '¬data points'],...
222         'Interpreter','LaTeX')
223     annotation('textbox',[0.5,0.23,0.31,0.15],'String',...
224         {'Information Sample Gumbel:',['$N_{sample}≠¬$' num2str(N-1)],...
225         ['$\beta_{sample}=¬$' num2str(beta)],['$\mu_{sample}≠¬$' num2str(mu)]},...
226         'VerticalAlignment','middle','HorizontalAlignment','center',...
227         'FitBoxToText','on','LineWidth',0.1,'Interpreter','LaTeX')
228     hold off
229 
230 elseif strcmp(normalis3,normalise)==1;
231     Returnlvlplot = figure;
232     hold on
233     plot(NormaliseN(2:N),Allmusigma(2:N,1),'k')
234     plot(NormaliseN(2:N),Allmusigma(2:N,1)+(Nsigma*Allmusigma(2:N,2)),'k')
235     plot(NormaliseN(2:N),Allmusigma(2:N,1)-(Nsigma*Allmusigma(2:N,2)),'k')
236     plot(NormaliseN,Xtrue,'--k')
237     xlabel('$N_{normalised}¬[\%]$','Interpreter','LaTeX')
238     ylabel('$X¬[F]$','Interpreter','LaTeX')
239     legend({'$\mu$',['$\mu+' num2str(Nsigma) '\sigma$'],...
240         ['$\mu-' num2str(Nsigma) '\sigma$'],'Expected $\mu$'},...
241         'Interpreter','LaTeX')
242     title([ num2str(CI) '\% Confedence Interval of Gumbel extrapolation from 2 ...
        toward¬' num2str(N) '¬data points'],...
243         'Interpreter','LaTeX')
244     annotation('textbox',[0.5,0.23,0.31,0.15],'String',...
245         {'Information Sample Gumbel:',['$N_{sample}≠¬$' num2str(N-1)],...
246         ['$\beta_{sample}=¬$' num2str(beta)],['$\mu_{sample}≠¬$' num2str(mu)]},...
247         'VerticalAlignment','middle','HorizontalAlignment','center',...
248         'FitBoxToText','on','LineWidth',0.1,'Interpreter','LaTeX')
249     hold off
250 end
251 
252 %manage output arguments
253 musigma = Allmusigma;
254 
255 switch nargout
```

```
256     case 0
257         clear musigma
258     case 1
259         clear musigma
260 end
261 
262 set(gcf, 'Color', 'none')
263 set(gcf, 'Units', 'centimeters')
264 set(gcf, 'OuterPosition', [5, 5, 11.7, 9.5])
265 
266 end
267 
268 %% Note
269 % This function uses *discretesample.m* and thus before use this must
270 % be present in the same directory
```

BIBLIOGRAPHY

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[3] B. I. S. O. Store, *International Standard,* (2007).