Statistical Modeling of the Red Sea Chlorophyll Concentration and Application to the ERSEM Ecological Model

Thesis by

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The thesis of Your Full Name is approved by the examination committee

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Motivation

1.1 Importance of phytoplankton

Phytoplankton are unicellular, photosynthetic algae that live in the upper layers of bodies of water (ocean, lakes, rivers or ponds). There a three main types of phytoplankton species: diatom (5-200m), dinoflagellates (5-200m) and cyanobacteria (¡5m). Diatoms and dinoflagellates are found in nutrient rich environments and multiply rapidly when conditions are favorable. On the other hand, cyanobacteria are capable of surviving in very oligotrophic (nutrient poor) environments like the Red Sea. In the oceans, phytoplankton live in the surface layer where there is enough sunlight for photosynthesis.

Phytoplankton plays a fundamental role for the ocean ecology as it is at the basis of the marine food web. Zooplankton graze phytoplankton which are consumed by larger species. Higher concentrations of phytoplankton will therefore result in larger stock of predator fishes. High phytoplankton concentration also impact their environment by creating dead zone when they die and are decomposed by bacteria. Due to the rapid growth of phytoplankton, it responds very well to changes in its environment, making it a key parameter to monitor the water quality.

Due to phytoplankton place at the bottom of the marine food chain, it is a key factor for fisheries and the marine ecology. Productive fishing zones like the regions in the Arabian seas, Californian coast, north-west African coast and Chilean coast are explained by the upwelling of cold nutrient rich water favourable to phytoplankton, which in turn feeds higher trophic levels. On the other hand, during the El-Nino phenomenon creates less favourable conditions for phytoplankton in the Eastern Pacific, resulting in a dramatic reduction of fish catches of fisheries in the western coast of South America.

Phytoplankton also plays the role of a biological CO2 pump and strongly impact the Earth climate. During photosynthesis, phytoplankton captures carbon and releases oxygen. A part of this organic material stays in the food web, either transmitted to higher trophic level, or degraded by bacteria. Another part however sinks to the bottom of the ocean and sediments. Research is currently done to evaluate the way this biological pump works and how it affects climate.

1.2 Measuring Chlorophyll Concentration

Chlorophyll is a molecule that is food in algae, phytoplankton and plants that is critical for photosynthesis. Phytoplankton is a poor absorber of green light, and is responsible for the coloration of plants. When phytoplankton are present in high concentrations they change the water also takes a detectable green coloration (it can also take a red or blue coloration depending on the type of phytoplankton dominating). This offers a way to estimate the chlorophyll concentration of the water, which is a good proxy for phytoplankton concentration.

In-situ measurements of chlorophyll are however expensive and have limited temporal and spatial coverage. In-situ measurement of chlorophyll concentration can be

gathered through scientific cruises, buoy stations or gliders (unmanned submarines). These methods are expensive to deploy and therefore the coverage is limited. Political issues, like in the Red Sea, can also be a practical barrier to in-situ measurements.

Satellite measurements of chlorophyll provide excellent proxies for phytoplankton concentrations with a good temporal and spatial coverage. The SeaWIFS, MODIS and MERIS missions have provided an uninterrupted coverage of the world since 1997. High-resolution maps of daily chlorophyll concentration are freely accessible to the scientific community. Despite some limitations, in particular of missing data due to cloud coverage and sunglint, or problematic values in coastal areas, remotely-sensed chlorophyll concentration are used intensively by the scientific community. In regions, like in the Red Sea, where little in-situ measurements are available, it is often the most important data source.

1.3 Primary productivity in the Red Sea

Typical tropical seas (TTS), like the Red Sea, are characterized by a highly stratified structure, where warm nutrient-depleted surface water is separated by cold nutrient-rich by a steep gradient of temperature zone called pycnocline. The pycnocline acts as barrier that prevents nutrients to reach the surface water. As a result, TTS are oligotrophic and have low chlorophyll concentrations. Until recently, marine biologists have thought that TTS had therefore a very low productivity. However, recent investigations have contested this idea, that different upwelling mechanisms exist that bring new nutrients to the surface water.

Despite being an oligotrophic and challenging environments for marine life, the Red Sea presents a surprisingly rich and diverse ecosystem. Most of it lives in the very developed coral reef system. The source of nutrient for sustaining such a developed

ecosystem is not well understood yet, but the interaction with the open sea through the mesoscale eddies is believed to play an important role.

Remotely-sensed chlorophyll data show an important seasonality of the Red Sea primary productivity, that has been linked to winter deep mixing, and the inversion of the wind direction in the southern Red Sea, enhancing intrusion of nutrient rich Gulf of Aden water. Despite this strong seasonality, there is a large interannual variability caused by the unpredictable occurrence of large phytoplanktonic blooms. Diverse causes have been hypothesized for these blooms such as wind-induced mixing, eddies or dust storms carrying nutrients.

Although the Red Sea environment is relatively preserved, it is under increasing pressure due to human activities. An abrupt increase of temperature has occurred in the last decade that threatens the fragile coral reef system. Moreover, the increasing urbanization and fishing activity contribute to the fragilization of this unique ecosystem.

1.4 Chlorophyll Concentration Prediction

Models can be useful to identify causes behind the chlorophyll patterns we observe in the Red Sea. Many hypotheses have be made about the drivers of chlorophyll concentration in this regions, but some of them have not been yet investigated through models. The role played by the exchange of water with the Gulf of Aden and winter overturning in the northern Red Sea have been successfully modeled with circulation and ecological models. However, the interaction between the open sea and coral reefs and the role of sand storms has not been investigated yet. Models, can also be helpful in discovering new dynamics affecting the chlorophyll concentration. In particular, the interaction between the productivity level of the different regions of the Red Sea

has not been studied yet.

Model predictions for chlorophyll concentration can also have practical applications. Phytoplankton blooms can be harmful to humans and marine life and are closely monitored in many regions of the world. In the Red Sea, where tourism and aquaculture are developing it is likely to become a concern too. Phytoplankton is also directly, and indirectly through zooplankton, the cause of microfouling that affects desalination plants. Anticipating a phytoplanktonic bloom might therefore be helpful in taking preventive actions. Finally, due to their short life-cycle, phytoplankton concentration reacts quickly to changes the environment, making it a key variable in water quality monitoring.

1.5 Modeling Chlorophyll Concentration

Ecological ordinary differential equation (ODE) deterministic models are a popular way to model marine ecology. Such models can be as simple as the nutrient-phytoplankton-zooplankton (NPZ) model that only has three variables representing two trophic level, or as complex as the European regional seas ecosystem model (ERSEM) that has dozens of variables and represent many ecological, biological and chemical interactions. Such a model has been couple to the MITgcm circulation model used to simulate the Red Sea ecology. However the complexity of these models makes them difficult to deploy and interpret their results.

On the other hand, data-driven statistical models are relatively easier to apply. They are relevant when the phenomenon producing the data is very complex or poorly known. They have been applied to predict chlorophyll concentration, mostly in small regions that have complex dynamics. Some statistical models, such as linear regression, GAM or tree regression have the advantage of being easy to interpret, and can

be used to understand the dynamics driving the chlorophyll concentration.

Phenomena such as propagation and diffusion play a key role in the chlorophyll spatial concentration, but are difficult to represent without spatial modeling. There is also a difference in the chlorophyll patterns of different regions of the Red Sea, in particular between the nutrient rich southern Red Sea and the oligotrophic northern Red Sea, and between the open ocean and the coastal waters. There is however no clear cut division between regions with different pattern, making it difficult to divide the Red Sea into regions. Finally the different regions of the Red Sea are believed to interact. A model is therefore needed to account for the spatial and temporal interaction of the chlorophyll.

Classical geostatistics is the most widely used spatial statistical models. It models spatial data as the realization of a two dimensional Gaussian process, of which one can estimate the parameters. Geostatistics can be easily extended to spatio-temporal datasets. Many flexible ways of constructing space-time covariance functions for these models have been proposed recently. Space-time geostatistics has been applied to many environment studies, but not to chlorophyll data yet.

Chapter 2

Objectives

The goal of the dissertation is to show that statistical predictive models can be used to help efficiently forecasting chlorophyll concentration in the Red Sea. Statistical methods can be more robust and computationally efficient when the underlying dynamics are very complex and observations are limited. The study of chlorophyll concentration is such a case. The dissertation will compare the 8-days prediction skill of increasingly sophisticated predictive models to the highly sophisticated ecological model ERSEM. We will explore the possibilities of combining statistical and deterministic models to improve the chlorophyll forecasts.

Efficient statistical models may be used as alternatives to the much more complex deterministic models in other seas. They can help researchers to gain insight into the dynamics of the phytoplankton. They can also help coastal communities to mitigate the effects of harmful phytoplankton blooms on public health and their economy. Moreover this study will help confirming hypothesizes that have been made about the interaction of Red Sea phytoplankton with the regional and global circulation.

Chapter 3

Editings

3.1 Language and Length

The dissertation or thesis must be written in English. There is no specific requirement for the page length of a dissertation or thesis. Work closely with your Thesis Advisor to plan, outline, write, and revise the text of the document. Writing a thesis or dissertation is an iterative process of written revisions.

3.2 Table of Contents

As a page heading, use "TABLE OF CONTENTS" all in capital letters, centered on the page. The format of the table should conform to the pagination guidelines and accurately reflect the outline and organization of the manuscript. List the sections/chapters of the body of the dissertation or thesis; also list preliminary sections starting with the signature approvals page and supplementary sections such as References and Appendices. The table of contents may be single-spaced.

3.3 Proofreading and Editing

All manuscripts should be proofread before being submitted to the Thesis Advisor. The consistency and accuracy of the spelling, punctuation, capitalization, abbreviations, and word divisions are primarily the responsibility of the dissertation or thesis writer, who should consult a dictionary and a manual of style for correct usage. Students need to adopt a consistent style throughout the dissertation or thesis. Students are especially urged to use the "spell-check" feature of the computer software being used and to proofread the manuscript carefully, or to enlist the help of a friend or professional proofreader. The Thesis Advisor will return to the student for correction and resubmission any dissertation or thesis that has not been carefully proofread. Students should also allow at least two weeks for proofreading before the final presentation/examination is scheduled.

Similarly, the dissertation or thesis writer is fully responsible for editing the style and grammar of the manuscript and for seeking support and assistance when necessary.

3.4 Reproduction

The following guidelines should be adhered to:

- Print the final copies of your manuscript on high-quality archival bond paper, minimum 20-pound weight, and 8.5 by 11 inches in size.
- All textual material should be double-spaced, but long quotations and footnotes may be single-spaced and indented. Follow the style manual chosen by your Thesis Advisor or department because these guidelines vary.

- The typeface, including headers, page numbers, and footnotes - must be produced with the same font or typeface throughout the document. Exceptions are made only for tables and figures. Suggestions: TIMES NEW ROMAN 12; ARIAL 12; BOOKMAN 12; GARAMOND 12; CAMBRIA 12.

3.5 Footnotes and Endnotes

Footnotes may be single-spaced in a 10-point size but must be in the same font as the rest of the text. Footnotes should be numbered with superscripted Arabic numbers. Numbering must be continuous throughout the document. Users of LaTeX may use CMR 12 font or any font that meets the above specifications. The print should be letter quality with dark black characters that are consistently clear and dense.

3.6 Justification

Left-aligned, ragged right margins are preferred. Use justified margins only if the computer does this well, i.e., does not separate punctuation from characters or leave large gaps in the text.

3.7 Margin

- Left margin - 1.5 inches
- Right margin - 1 inch
- Top and bottom - 1 inch

Exact margins are absolutely essential so that the thesis can be digitized in its entirety for interlibrary loan. The same width margins must apply to all pages,

including those containing graphs, tables, and other illustrative materials.

3.8 Pagination

All pages except the title page must be numbered at least 0.75" from the top of the page. Begin the numbering with Arabic numbers on the top of the page following the title page. Use continuous Arabic numbers beginning with the signature approvals page (page 2) and continue with every sheet that follows, whether it is text, figures, explanation for figures or photos, tables, maps, appendices, etc., numbering pages to the end. Page numbers must be within the margins at the top of each page.

Each chapter must be numbered separately, using consecutive Roman numerals to distinguish the individual chapters throughout the dissertation or thesis. Chapters within the text begin on new pages. There should be no page breaks between sections or before tables or figures, unless they occur naturally.

Paginate the parts of the dissertation or thesis in the order as shown in table 3.1:

3.9 Equations, Formulas, Sub/Superscripts

All equations and formulas should be typeset. When a computer or word processor cannot make a symbol, insertions by hand are acceptable. All subscripts and superscripts must be large enough to be clearly read.

Table 3.1: Parts Pagination [**?**]

S. No.	**Page Style/Type**	**Page Numbering**
1.	Title Page	(not numbered)
2.	Signature Approvals Page	2
3.	Copyright Page (if applicable)	3
4.	Abstract	4
5.	Acknowledgments (Optional)	5
6.	Table of Contents	6
7.	List of Abbreviations	7
8.	List of Symbols (Optional)	8
9.	List of Illustrations	9
10.	List of Tables	10
11.	Main text of thesis, including any Introduction or Summary.	
12.	Material to follow text, such as references, appendices, and fold-in maps. However, such material may be included at the end of each chapter, making each chapter a complete and self-contained paper, nonetheless with pagination in sequence with the remainder of the thesis.	

3.10 Charts, Graphs, Tables, Photographs, and Oversized Maps

Illustrations must be of equally high quality in the "final" copies submitted to the Offices of the Provost, Associate Provost of Graduate Affairs and to the library. For the digital copy of your work submitted to the library, illustrations must be inserted as an image at the appropriate place within the thesis or dissertation.

Please keep in mind:

- Labels or symbols rather than colors should identify lines on a graph.
- Shaded areas—such as countries on a map—will have better contrast if cross-hatching is used instead of color.
- Photographs should be professional-quality black and white or color. Most photographs will reproduce acceptably on positive microfilm or microfiche but will lack clarity on photocopies made from the microfilm. If color copies are necessary, all final copies of the dissertation or thesis should include the color photographs.
- Charts, graphs, and maps that are larger than the standard 8.5" x 11" page size may be used in your manuscripts. They should be carefully folded into the manuscript or rolled up and placed in a mailing tube.

3.11 Plagiarism Checking

All students are required to have their manuscripts checked by Skills Lab personnel using the 'Turn It In' plagiarism software. The resulting originality reports will be submitted to the office of the Associate Provost of Graduate Affairs for review and

approval. Copies of the approved reports will be forwarded to the Graduate Program Coordinators and to the library. This is a mandatory part of the graduation process.

3.12 Use of Copyrighted Material

As the author of the dissertation or thesis manuscript, you will be asked to certify that any previously copyrighted material used in your work, beyond "fair use," is with written permission of the copyright owner, and that KAUST will not be held responsible for any damages which may arise from copyright violations. When depositing your work in the KAUST digital archive, you will be required to warrant that you have obtained all necessary rights. (Please see 'sample permission letter' on page 19 of [**?**]).

In most cases no problem will arise if your evaluation of the circumstances suggests the use is fair. Your evaluation should weigh four factors:

- Purpose and character: Because your use is for non-profit educational purposes, this is a factor favoring fair use. But if you are to derive payment from use of the dissertation or thesis, this would weigh against fair use.

- Nature of copyrighted work: Is the work fact based, published, or out-of-print? These factors weigh in favor of fair use.

- Amount used: Using a small portion of a whole work would weigh toward fairness.

- Market effect: A use is more likely to be fair if it does not harm the potential market for or value of the copyrighted work. But if it does, this could weigh more heavily against fair use than the other factors.

Consider each of these factors, but all of them do not have to be favorable to make your use a fair one. When the factors in the aggregate weigh toward fairness, your use is better justified. When the factors tip the scales in the other direction, your need to obtain permission from the copyright holder increases. Don't worry that the answer isn't crystal clear. Just decide whether the factors weigh enough toward fairness so that you are comfortable not seeking permission.

KAUST Library offers links to more information on copyright and permissions on their theses and dissertations webpages at http://libguides.kaust.edu.sa/theses.

3.13 Use of Published Material

Published articles of which the candidate is author or joint author may be included as part of the dissertation or thesis, with due regard to copyright regulations (see previous section). For the "original copy" of the manuscript, such printed pages must follow the same requirements as outlined in this guide, maintaining margins, type size (at least 12 point), page number sequencing, etc.

3.14 Some Common Errors

- Unnumbered pages, especially those containing figures or captions to figures.
- Names of authors spelled differently in the text and in the bibliography; reference numbers or dates in the text that do not agree with the bibliography.
- Inconsistent presentation of bibliographic information.
- Incorrect punctuation of abbreviations. The Latin abbreviation for "and others" contains only one period "et al." The abbreviations "i.e." and "e.g." are

punctuated with two periods and set off by commas from the sentences in which they appear, unless a specific style manual required by your advisor or department suggests otherwise, as some do.

- Inconsistent hyphenation of compound words.
- Inconsistent capitalization of proper nouns used as adjectives.
- Reversed punctuation of quotations. Periods and commas always precede final quotation marks, even if the quotation consists of a single letter unless your text follows the quotation in the sentence.

3.15 Some Common Formatting Errors

- The page size should be 8.5 x 11 inches (regular US letter size)
- Incorrectly sized margins - the left margin should be 1.5" inches and all other margins 1 inch.
- All pages should be numbered consecutively (except for the title page) and the numbers should be correctly placed on the page - at least 0.75 inches from the top of the page.
- Pages should be ordered properly, with the title page first, followed by the signature approvals, copyright, and then the abstract pages. Check for missing pages.
- The abstract should be 350 words or less.
- The title page should include the correct date - the date should be the month and year you will receive the degree, for example December 2011.

- The correct number of copies should be submitted.

- You must have permission to use previously published material.

Chapter 4

Miscellaneous

4.1 Instructions for Permission Letters

- Include your return address, telephone number and email address, and date the top of the letter.
- Confirm the exact name and address of the addressee. Call the person to confirm the copyright ownership.
- State clearly the name of your university and your thesis title.
- Describe precisely the proposed use of the copyrighted material. If necessary or appropriate attach a copy of the quotations, diagrams, pictures, and other materials. If the proposed use is extensive, such as the general use of an archival or manuscript collection, describe it in broad and sweeping terms. Your objectives are to eliminate any ambiguities and to be sure the permission encompasses the full scope of your needs.
- The sample signature form at the end of the sample letter is appropriate when an individual grants the permission. When a company, such as a publishing house, is granting permission, use the following signature form.

4.2 Some important checks

- Appendices can be referred/cited as Appendix B.
- Equations can be referred using 'eqref' command.
- Bibliography can have different types of references such as conference proceedings [**?**], journal articles [**?**], books [**?**], miscellaneous references including web links etc. [**?**], and theses/dissertations [**?**] among others.

Chapter 5

Creating the List of Abbreviations and List of Symbols

5.1 Introduction

The most versatile package to create the List of Abbreviations (LoA) and List of Symbols (LoS) is currently the `glossaries` package. With the `glossaries` package, one can create those and even more lists all in the same document. Every list is sorted alphabetically and can even have the page numbers where the entries appear (if that's desired) just like an "Index of terms" list.

In the following there is a description on how to use the `glossaries` package. The material is taken from the documentation of the package and some other examples that can be found online.

5.2 How to use the `glossaries` package

The `glossaries` package works more or less like the `Makeindex`. In fact one needs to use the `makeindex` command to actually create the lists (see §5.4). The main difference is that when creating an index, one only has to define the index terms in

the text, using an \index{*term*} command. On the other hand, in order to create the LoA and LoS one needs to define those entries and use a \gls{*term*} or similar command to reference them in the text.

The definition of those entries must be in the preamble right after the definition of all the lists and the \makeglossaries command. It is probably a good idea to have them in a separate file, which you include (as is done in the example Thesis.tex with the \include{Lists} command).

The general format for entries is

\newglossaryentry{*label*}{*definition*}

The first argument (*label*) is a label that *uniquely* identifies this entry. The second argument (*definition*) is a comma-separated list of key=*value* pairs. For example

```
\newglossaryentry{datacomp}{name=data compression, description=
the  process of encoding information using less bits than the
original representation uses}
```

In this example there are two keys, namely the name and the description. The key name has the value "data compression" and the key description has the value "the process... uses". The glossaries package understands that a key value ends when it encounters a comma and treats the next word as a key. The value of the key name is what will appear in the text when referenced by a \gls{datacomp} command. The value of the key description is what will appear in the default Glossary (or any other) list.

5.2.1 Glossary entries

Some more examples of glossary or symbols entries are given below.

```
\newglossaryentry{elite}{name={\'e}lite, description=select
group or class, sort=elite}
```

In this example notice the use of {\'e} notation to produce the accented letter é. Because `makeindex` will not know how to sort this alphabetically (`makeindex` is hardcoded for english), it is a good idea to use the key `sort` to specify how we want this entry to be sorted. In this example the entry "élite" will be treated as if it were "elite".

```
\newglossaryentry{pi}{name={\ensuremath{\pi}}, sort=pi,
description={ratio of circumference of circle to its diameter}}
```

In this example the entry is π. Notice the `\ensuremath{}` command which makes sure that the term `\pi` is indeed in math mode (if it isn't then it prepends and appends the $ sign) so that LaTeX doesn't throw an error. Also notice that the curly brackets enclosing the `description` value are not mandatory here but they *should* be used if the description value contains a comma. Otherwise the `glossaries` package will understand that the comma denotes the end of the value and treat the following word as a key.

```
\newglossaryentry{ohm}{name=ohm, symbol={\ensuremath{\Omega}},
description=unit of electrical resistance}
```

This example defines an entry for both the Glossary list (due to the key `name`) and the LoS (due to the key `symbol`).

5.2.2 Abbreviation (Acronym) entries

Acronym entries can be defined using \newglossaryentry command but there is also a handy shortcut, namely the \newacronym command. For example

```
\newglossaryentry{led}{name=LED, description={light-emitting
diode}, first{light-emitting diode (LED)}
```

is equivalent to the much shorter

```
\newacronym{led}{LED}{light-emitting diode}
```

Note that the first time the entry led is found, the glossaries package will print the description followed by the acronym in parentheses i.e. "light-emitting diode (LED)" (this is actually what the key first is for in the \newglossaryentry command).

Also calling \acrlong{led} will produce "Light-Emitting Diode" (i.e. the *long* version of the entry —the description) while \acrshort{led} will produce "LED" (i.e. the *short* version of the entry —the acronym).

5.2.3 Symbols entries

Entries for the List of Symbols follow the exactly same rule as the glossary entries, with the addition of type=symbols in the definition part of the entry. For example

```
\newglossaryentry{pi}{type=symbols, name={\ensuremath{\pi}},
description={ratio of circumference of circle to its diameter},
sort=pi}
```

If the key type is omitted, the main glossary (i.e. the Glossary) is assumed.

5.3 Referencing the entries in the text

In order to reference the entry in the text one just has to write \gls{*label*}. For example for the glossary entry `datacomp` defined in §5.2, one just has to write \gls{datacomp} which will produce the value of the key `name`, i.e. "data compression". Note that

- \Gls{datacomp} will produce "Data compression" (i.e. the first is capital),
- \GLS{datacomp} will produce "DATA COMPRESSION" (i.e. all capital),
- \glspl{datacomp} will produce "Data compressions" (i.e. plural),
- \Glspl{datacomp} will produce "Data compressions" and
- \GLSpl{datacomp} will produce "DATA COMPRESSIONS".

The plural form is formed by just appending an "s". If the plural form of an entry is different, one just has to define it in the definition part using the key `plural`. For example

```
\newglossaryentry{bus}{name=data bus, description=a subsystem
that transfers data between computer components, plural=buses}
```

There are quite a few more keys in the documentation of the package that allow even more flexibility.

5.4 Printing the lists

The following piece of code is already in the `Thesis.tex` file. Here is an explanation of what each line does, in case something need to be modified.

```
1 \printglossary[type=\acronymtype,style=long, title=List of
2                 Abbreviations, toctitle=List of Abbreviations,
3                 nonumberlist=true]
4
5 \printglossary[type=symbols,style=long]
6
7 \printglossary[style=altlist, toctitle=Glossary, nonumberlist=true]
```

Lines 1-2 should appear where you want the List of Abbreviations to appear. They will print the entries and show them in the document's Table of Contents (ToC). Notice that I had to change the default title "List of Acronyms" to "List of Abbreviations" for both the chapter title and the ToC entry.

Line 4 should appear where you want the List of Symbols to appear. It will print the symbols entries and show them in the document's ToC.

Lines 6-8 should appear if you would like to have a Glossary (optional). They will print the Glossary entries and show an entry "Glossary" in the document's ToC. The `nonumberlist=true` suppresses the page numbers in the list.

In order to actually see the lists in your document, you need to run LaTeX once and then run the following commands in the command line (they can also be found in the preamble of the `Thesis.tex` as comments):

```
makeindex -s Thesis.ist -t Thesis.alg -o Thesis.acr Thesis.acn
makeindex -s Thesis.ist -t Thesis.slg -o Thesis.syi Thesis.sbl
makeindex -s Thesis.ist -t Thesis.glg -o Thesis.gls Thesis.glo
```

If your main input file is not `Thesis.tex`, then replace all the occurences of `Thesis` with that filename. Then run LaTeX once again.

Sometimes (depending on the entries) this procedure has to be repeated once more.

5.5 Test section

In this section there is some text,used to show how the `glossaries` package. See the source file of this chapter and of the Introduction for the exact usage.

5.5.1 General information

Our network uses Active Directory (AD). By using AD with Microsoft (MS) bases clients that have been installed using a response file from Compact Disc (CD), we can expect a high level of standardization.

5.5.2 Some Greek symbols

If you multiply a rational with π you always get an irrational result, because π itself is irrational. As a matter of fact, so are φ and λ, too.

Chapter 6

Concluding Remarks

6.1 Summary

The author must provide an overall summary and discussion of the significance of the work. If the dissertation or thesis consists of relatively independent chapters, a unifying summary should be included at the end or beginning of the dissertation or thesis. Such a summary will be significantly more expansive than the abstract.

6.2 Bibliography (or References or Works Cited)

As a page heading, use "BIBLIOGRAPHY" (or "REFERENCES" or "WORKS CITED") all in capital letters centered on the page. Always start a new page. Bibliographies may be single-spaced within each entry but must include 24 points of space between entries. It is recommended that you follow the standard citation format used by a major journal in your academic field and that the style be consistent throughout the dissertation or thesis.

6.3 References

The precise form of a bibliography or reference section can conform to the style current in the thesis or dissertation writer's discipline, but this form must be employed consistently throughout the thesis. All material already published must be reformatted into the guidelines specified here and pagination and bibliographic style should be consistent with the remainder of the document. For MS Word users, the EndNote citation management software can be utilized as a referencing tool. It is available for download by KAUST students via the KAUST Library website.

A variety of helpful guides to bibliographic style in various fields are available from KAUST Library, including:

- The ACS Style Guide: Effective Communication of Scientific Information. Anne M. Coghill and Lorrin R. Garson, editors. 3rd ed. Washington, D.C.: American Chemical Society, 2006.
- The Chicago Manual of Style. 16th ed. Chicago, IL: University of Chicago Press, 2010.
- A Manual for Writers of Research Papers, Theses, and Dissertations. Kate L. Turabian. 7th ed. / Chicago, IL: University of Chicago Press, 2007.
- MLA Style Manual and Guide to Scholarly Publishing. 3rd ed. New York: Modern Language Association of America, 2008.
- Scientific Style and Format: The CSE Manual for Authors, Editors, and Publishers. 7th ed. Council of Science Editors, 2006.
- United States Government Printing Office Style Manual. 30th ed. Washington, D.C.: U.S.G.P.O., 2008. (Also online: http://www.gpoaccess.gov/stylemanual/

browse.html)

- In addition, many technical journals publish appropriate style rules.
- For more resources on scholarly writing, visit the Library's theses and dissertations webpages at http://libguides.kaust.edu.sa/theses.

6.4 Submission of Thesis

As soon as you have received approval of your thesis or dissertation, you must submit the full final approved document to the KAUST digital archive in the library. You may not submit a draft or partial document. Please follow these submission instructions:

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6.5 Future Research Work

The work presented in this thesis can be extended in the following directions.

List of your planned future work goes here.

APPENDICES

A Appendix A Title

Detailed experimental procedures, data tables, computer programs, etc. may be placed in appendices. This may be particularly appropriate if the dissertation or thesis includes several published papers.

B Appendix B Title

Your content goes here.

C Papers Submitted and Under Preparation

• Author 1 Name, Author 2 Name, and Author 3 Name, "Article Title", *Submitted to Conference/Journal Name*, further attributes.

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