MAS8306: Environmental Extremes

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Semester 2, 2017/18

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Timetable and Administrative arrangements

- Lectures are in Herschel TR2 on Mondays at 10am and again at 3pm.
- Occasionally, some lecture time will be replaced with tutorial / reading / self-study / feedback / computer practical time. I will notify you in advance when this is due to happen.
- Office hours: Mondays 4pm, Thursdays 4pm.

	Assessment	Weighting	Date/Deadline	
	Homework 1		4pm, Thu 22 Feb	
Extremes	Homework 2	10% total	4pm, Thu 15 Mar	
(LF)	Homework 3		4pm, Thu 10 May	
	Mid-semester test	10%	10–11, Mon 16 Apr	
	Exam (half of MAS8306)	30%	May/June	
	Homeworks	10%	See JQS	
Smoothing	Mid-semester test	10%	See JQS	
(JQS)	Exam (half of MAS8306)	30%	May/June	
		100%		

Other stuff

- Notes (with gaps) will be handed out in lectures you should fill in the gaps during lectures.
- A summarised version of the notes will be used in lectures as slides.
 - Listen and learn
 - Write down
 - Announcements
- These notes and slides will be posted on the course website after each section is finished, along with any other course material – such as problems sheets, model solutions to assignment questions, supplementary handouts etc.

My personal webpage – and hence the course webpage – can be found via the "Staff information" link on the School's webpage, or directly via:

http://www.mas.ncl.ac.uk/~nlf8

Please check your University email account regularly, as course announcements will often be made via email.

- MAS369: 1995–2000 Dr. Mark Dixon now the multi–millionaire founder of sports betting company ATASS
- MAS369: resurrected in 2002 for one year only Dave Walshaw (see OHP slides...)
- Course: Reading module for Stage 3 MMath/MMathStat students (and select BSc students!)
- New Stage 4 2011: material in MAS369 out-of-date with current research – now a new, more advanced "topic" in MAS8306

Aims of this course

- To expose you to an area of active research in the School
- To expose you to a very hands—on, applied area of Statistics
- To give you a firm grounding in the basics of techniques for analysing environmental data...
- ... but also to bring you bang up-to-date with current research ideas
- Quite a niche area of research, but along the way we will have to get to grips with some more generic statistical tools
- Assignment 3: part A open-ended data response; part B – based on a recently-published paper in the field of extremes

A word on pre-requisite knowledge

- Statistical "Theory": I will not assume any knowledge past 2nd year Statistics courses (MAS2302 and MAS2317)
- Statistical "Practice": Some basic Statistical Modelling techniques and MCMC techniques will be used, but will be fully demonstrated if they go beyond MAS3320/MAS3321
- We will make use of some techniques from these courses (e.g. maximum likelihood, simple Bayesian inference, likelihood ratio tests) – these will be quickly reviewed, as-and-when they make an appearance, but you may want to consult your old notes for further details

Let's start with some (non–mathematical) background and motivation...

Chapter 1

Background and motivation

Finally, there is almost a **global consensus** amongst scientists that our planet's climate is changing.

Evidence for climatic change has been collected from a variety of sources, some of which can be used to reconstruct the earth's changing climates over **tens of thousands of years**.

Reasonable complete global records of the earth's surface temperature since the mid–1800's indicate a **positive trend** in the average annual temperature, and maximum annual temperature, most noticeable at the earth's poles.

1.1 Introduction



1.1 Introduction



Glaciers are considered the **most sensitive indicators** of climate change.

As the earth warms, glaciers retreat and ice sheets melt.

Over the last 30 years or so this has resulted in a gradual **increase in sea and ocean levels**.

1.1 Introduction



Retreat of Lyall Glacier, California

1.1 Introduction

Mountain Glacier Changes Since 1970



Consequences

- Irreversible changes to sea and ocean ecosystems
- Threat of flooding to low-lying inhabited areas of land
- Effect on the earth's weather systems for example:
 - Larger amount of warmer water in North Atlantic Ocean
 → Stronger, more frequent tropical storms/hurricanes (e.g. Katrina, Sandy)
 - More frequent tropical cyclones in the Indian Ocean/Pacific Ocean (e.g. Bangladesh, India, Malaysia)
 - Flooding in the U.K. 2012 being the second wettest year on record

The world's changing climate is also likely to give rise to an increase in the frequency of periods of intense **heat** and **drought**.

Though some parts of the world are familiar with the effects of extreme heat, we are beginning to see an increase in severe hot spells in more temperate latitudes – for example, the **2003 European heatwave** which resulted in thousands of deaths.

In drier parts of the world, this has resulted in an increase in devastating forest fires (New South Wales and Victoria), and in developing countries an increase in famine.



Some facts

- Category 5 Hurricane (Category 3 when it made landfall)
- Killed 1833 people
- Caused \$108 bn worth of damage
- Most damage/loss of life caused by storm surge
- Storm surge reached nearly 14 feet above sea level
- Lowest air pressure 902 mb
- Political controversy
- Billed as the "storm of the century"





















- Devastated parts of the Caribbean, Mid–Atlantic and New Jersey/New York
- Tenth hurricane of busy 2012 hurricane season
- Caused an estimated \$ 65.6 bn worth of damage
- Second costliest hurricane in US history (after Katrina)
- Killed 253 people
- Sea surge reached 10 feet

1.2 Examples: Hurricane ????, USA, 2018?



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The UK is no stranger to changing climate.

- 2012 was the second wettest year in the UK since records began
- 1998, 1999, 2000, 2002, 2008 and 2012 in the top ten wettest years
- Examples:
 - Flash-flooding in Glasgow (2002)
 - Flooding in **Boscastle** (2004)
 - Entire UK (2007, 2008, 2009, 2012) including severe flash–flooding in Newcastle in June 2012











1.2 Examples: The Great North Sea Flood, 1953



1.2 Examples: The Great North Sea Flood, 2025?



15/16 October 1987

- Killed 22 people in England/France
- Met Office criticism:
 - Recent cutbacks no weather ship in the Southwest Approaches
 - Weather presenter Michael Fish told the British public not to worry, and that there is no "hurricane on the way"

1.2 Examples: Tornadoes in Birmingham, 2005



1.2 Examples: Tornadoes in Birmingham, 2005



The world's changing climate is also likely to give rise to an increase in the frequency of periods of **intense heat** and **drought**.

- Not a new thing for some parts of the world!
- Hot spells becoming more frequent in other areas: central Europe, Northern USA,...
- Heatwaves in Europe 2003, 2006
- Increase in frequency of forest fires in parts of Europe, Canada and Australia

Statistical modelling of extreme weather has a very practical motivation: **reliability** —

— anything we build needs to have a good chance of surviving the weather/environment for the whole of its working life.

This has obvious implications for **civil engineers** and **planners**.

For example, in the context of some of the examples we have looked at so far, they need to know:

- How tall to build sea walls/flood defences for example
 - the levees surrounding New Orleans;
 - flood defences in New York that were breached during Superstorm Sandy;
 - river and sea defences in the U.K.;
- How strong to make buildings for example, in the U.K. the British Standards Institute specifies that new structures need to be strong enough to withstand the "Fifty year wind speed";
- How tall to build reservoir dams;
- How much fuel to stockpile.

This motivates the need to estimate what the:

- Highest tide;
- Heaviest rainfall;
- Strongest wind;
- most severe cold spell;

will be over some fixed period of future time.

The only sensible way to do this is to use **data** on the variable of interest (wind, rain etc.) and fit an appropriate **statistical model**.

The models themselves are motivated by **asymptotic theory**, and this will be our starting point in Chapter 2.

Before this, let's start at a very basic level, and think about why we need statistical models at all.

Wassaw Island is a barrier island off the southeast coast of Georgia, in the USA.

Any hurricanes about to make landfall on the mainland often hit such barrier islands first, substantially subduing the impending storm.

Sea surge data is collected at Wassaw Island every hour; the data shown below are the extracted **annual maxima** for the years 1955–2004.

8.5	8.9	9.1	8.9	8.4	9.7	9.1	9.6	8.7	9.3
9.6	9.3	8.7	9.0	8.8	8.9	8.9	12.2	7.8	7.7
8.3	8.1	7.3	6.8	6.7	7.3	7.6	8.2	8.6	9.8
9.5	7.4	7.3	10.2	10.3	10.4	8.8	9.7	10.0	10.8
11.1	12.7	11.5	11.8	12.6	13.0	10.5	10.5	10.0	9.4

1. Civil engineers are interested in various exceedance probabilities.

For example, suppose they need to know the probability that sea–surge will exceed 8.75, 11.25 and 14 feet. Use the data to estimate these probabilities.

Estimating these probabilities using relative frequencies gives:

Pr(sea-surge exceeds 8.75 feet) =



8.5	8.9	9.1	8.9	8.4	9.7	9.1	9.6	8.7	9.3
9.6	9.3	8.7	9.0	8.8	8.9	8.9	12.2	7.8	7.7
8.3	8.1	7.3	6.8	6.7	7.3	7.6	8.2	8.6	9.8
9.5	7.4	7.3	10.2	10.3	10.4	8.8	9.7	10.0	10.8
11.1	12.7	11.5	11.8	12.6	13.0	10.5	10.5	10.0	9.4

Estimating these probabilities using relative frequencies gives:

$$Pr(sea-surge exceeds 8.75 \text{ feet}) = \frac{33}{50} = 0.66$$

$$Pr(sea-surge exceeds 11.25 \text{ feet}) = \frac{6}{50} = 0.12$$

$$Pr(sea-surge exceeds 14 \text{ feet}) = \frac{0}{50} = 0.$$

Do you *really* think it's *impossible* for sea-surge to exceed 14 feet?

- 2. How high should state authorities build flood defences at the nearby city of Savannah if they want to protect the city against the sea–surge they would expect to see:
 - (i) Once every 10 years;
 - (ii) Once every hundred years?

In ascending numerical order, the data are:

6.7	6.8	7.3	7.3	7.3	7.4	7.6	7.7	7.8	8.1
8.2	8.3	8.4	8.5	8.6	8.7	8.7	8.8	8.8	8.9
8.9	8.9	8.9	9.0	9.1	9.1	9.3	9.3	9.4	9.5
9.6	9.6	9.7	9.7	9.8	10.0	10.0	10.2	10.3	10.4
10.5	10.5	10.8	11.1	11.5	11.8	12.2	12.6	12.7	13.0

Since we have annual data, an intuitive argument would be to find the value which has 10% of the data above it.

We have 50 observations, and 10% of these observations exceed 11.7999 \approx 11.8 feet.

For the level which is exceeded once every **hundred** years, we would need the value which has 1% of the data above it.

We don't have enough data – we only have 50 years of data, and we want the value that is exceeded once every *hundred* years! 1% of 50 = 1/2 an observation!