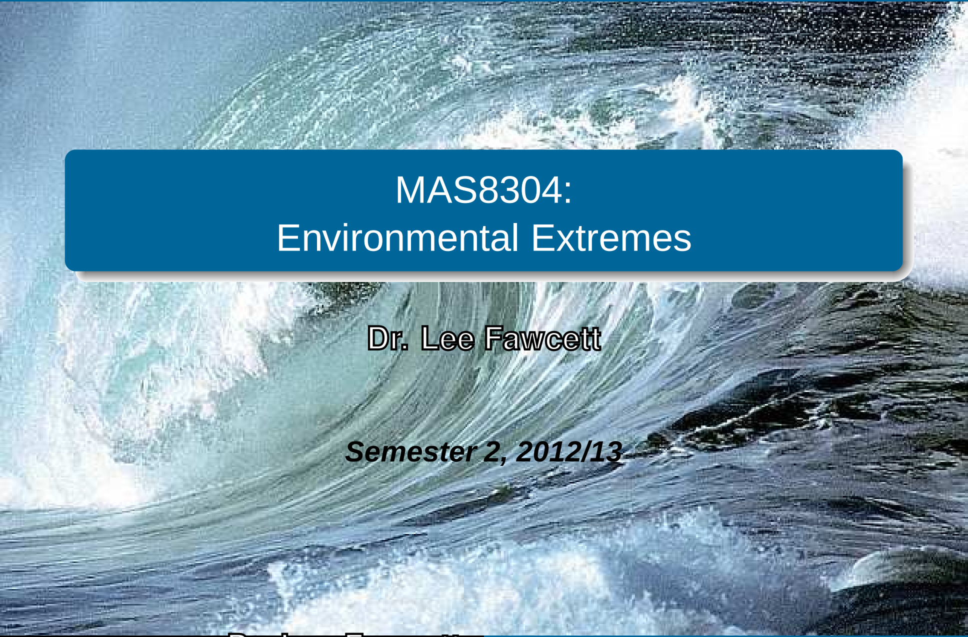
MAS8304: Environmental Extremes



Dr. Lee Fawcett

Semester 2, 2012/13

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Timetable and Administrative arrangements

- **Lectures** are in Herschel TR2 on **Mondays at 12 noon** and **Thursdays at 4pm**.
- **Tutorial time** will be given in some lectures. I will notify you in advance if a lecture/part of a lecture is to be replaced with tutorial/reading/self–study time – these slots will be optional.
- **Computer practicals**: **Tuesdays at 1pm** (Herschel PC blue zone). These will happen in teaching weeks 3, 6 and 9, and will help you with the assignments and project.
- **Office hours**: **Mondays 11**, **Thursdays 10**.

Assessment and deadlines

	Assessment	Weighting	Date/Deadline
Extremes (LF)	Homework 1	2.5%	4pm, Mon 25 Feb
	Homework 2	2.5%	4pm, Mon 11 Mar
	Mid–semester test	5%	12–1, Mon 15 Apr
	Individual project	5%	4pm, Mon 6 May
	Exam (half of MAS8304)	35%	May/June
Queues (PJA)	Homeworks	5%	See PJA
	Mid–semester test	5%	See PJA
	Project	5%	See PJA
	Exam (half of MAS8304)	35%	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.

Other stuff

- The course website can be found via the “Additional teaching 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.

History of this course

- 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!)
- MAS369 out–of–date with current research – now a new, more advanced “topic” in MAS8304

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 níche area of research, but along the way we will have to get to grips with some more generic statistical tools
- **Independent project**: will be based on a recently–published article in the field

A word on pre–requisite knowledge

- I will not assume any knowledge past 2nd year Statistics courses (**MAS2302**, **MAS2305**)
- We will make use of some techniques from these courses (e.g. **maximum likelihood**, **the delta method**, **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
- Some basic **Statistical Modelling** techniques will be used, but will be fully demonstrated if they go beyond MAS2302/2305.

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

Chapter 1

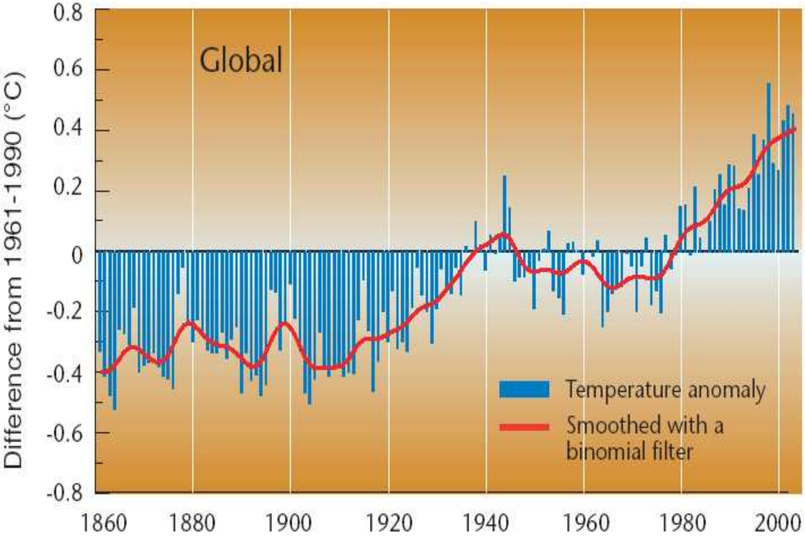
Background and motivation

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

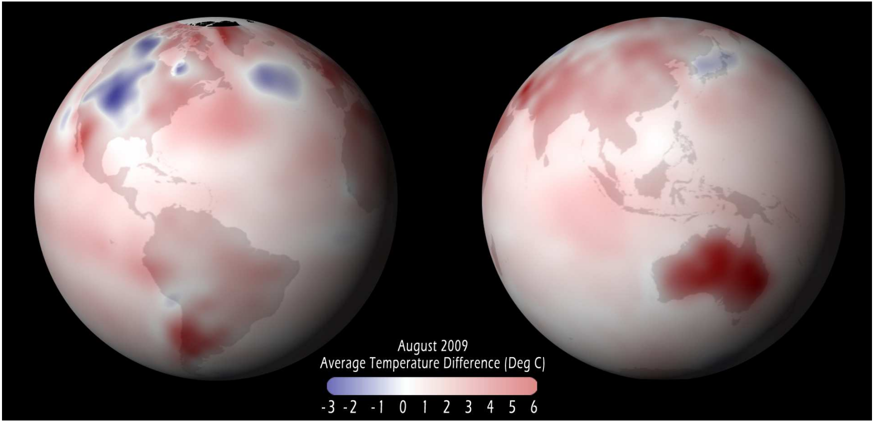
Evidence for climatic change has been collected from a variety of sources, some of which can be used to reconstruct the earth's changing climates over **tens of thousands of years**.

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



1.1 Introduction

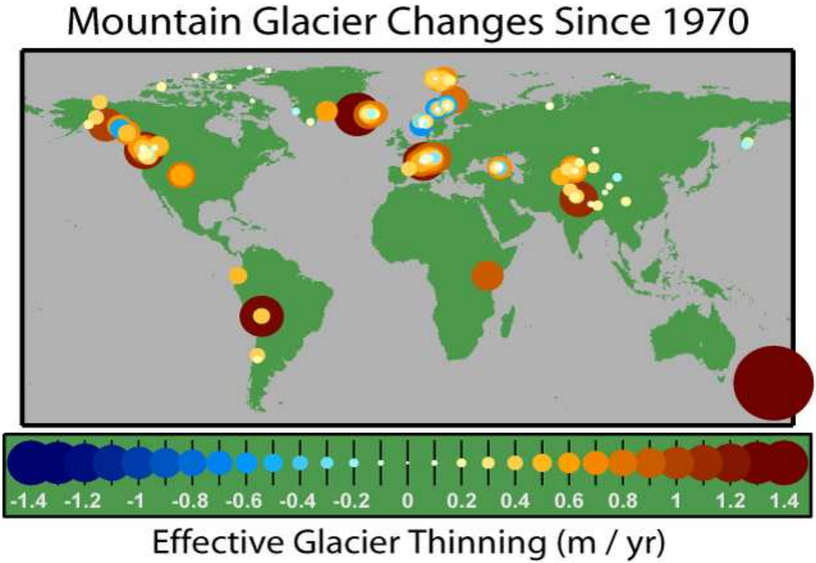
Glaciers are considered the **most sensitive indicators** of climate change.

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


Mountain Glacier Changes Since 1970
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Effective Glacier Thinning (m / yr)

Consequences

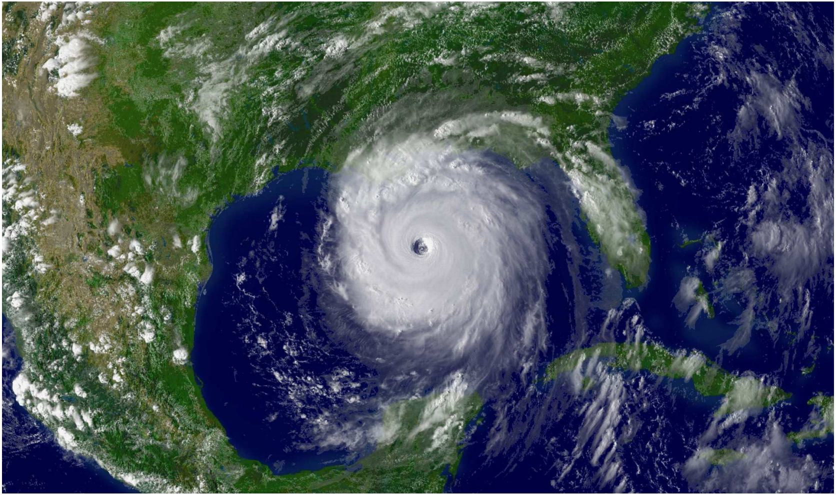
- Irreversible changes to **sea** and **ocean ecosystems**
- Threat of **flooding** to low–lying inhabited areas of land
- Effect on the earth's **weather systems** – for example:
  - Larger amount of warmer water in North Atlantic Ocean $\longrightarrow$ Stronger, more frequent tropical storms/hurricanes (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 counties an increase in famine.

1.2 Examples: Hurricane Katrina



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**"

1.2 Examples: Hurricane Katrina


www.KatrinaDestruction.com

1.2 Examples: Hurricane Katrina

1.2 Examples: Hurricane Katrina

1.2 Examples: Hurricane Sandy

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1.2 Examples: Hurricane Sandy

- 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, 2013?

1.2 Examples: Extreme weather in the UK

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: Flooding in Newcastle, June 2012

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1.2 Examples: The Great North Sea Flood, 1953

1.2 Examples: The Great North Sea Flood, 2025?

1.2 Examples: The Great Storm of 1987

- 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

1.2 Examples: Heatwaves and drought

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:
- **Heatwaves** in Europe 2003, 2006
- Increase in frequency of **forest fires** in parts of Europe, Canada and Australia

1.3 Why statistical modelling?

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**.

1.3 Why statistical modelling?

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.

1.3 Why statistical modelling?

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.

1.4 Simple example: sea surges at Wassaw Island

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.

Solution

Estimating these probabilities using relative frequencies gives:

$$\text{Pr(sea–surge exceeds 8.75 feet)} \quad =$$

Solution

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**

Solution

Estimating these probabilities using relative frequencies gives:

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

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

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

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?

Solution (1/2)

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.

Solution (2/2)

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!

Further comments

We have no chance of producing any sort of estimate that goes beyond the timeframe of our collected data – however, it is **vitally important** for engineers that we do estimate such quantities!

We are trying to estimate events more extreme than have ever occurred before – an impossible task?

Not *impossible*... To extrapolate beyond the range of our observed data, we need a **statistical model** that we can assume is valid for our observed extremes *and beyond*.

This is where **extreme value theory** comes in!