Researchers in Schools

Butterflies and Tornadoes:

Why are weather forecasts always wrong?

Pupil Name

Coursebook Designed by Dr TJ Thornes

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5 6 (Feedback)			
7 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Baseline Assignment: Problem set	Tutorial 2
Tutorial 2	The St Jude's Day Storm (reading)	Tutorial 3
Tutorial 3	Forecasting the Old Fashioned Way	Tutorial 4
Tutorial 4	Short Essay	Tutorial 5
Tutorial 5	Final Assignment: Long essay (draft)	Tutorial 6
Tutorial 6	Final Assignment: Long essay (final)	1 week after tutorial 6

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after the agreed date	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	All marks deducted – fail

Uni Pathways launch event

Welcome to Uni Pathways! We are delighted to be able to launch the Uni Pathways programme with you. We hope that you are ready to embark on your Uni Pathways journey and that you enjoy the video.
You will be asked to pause the video at times to complete some work in this workbook, so make sure you have a pen / pencil to hand when you start the video.

By the end of the video, you will have

- Learnt about what studying at university means
- Learnt about some of the skills that you will develop during Uni Pathways
- Heard from pupils who have participated in Uni Pathways or The Scholars Programme (which is the same programme!)
- Heard from current university students talking about what life is like at university

If you are in school your teacher will play the video. If you are at home and logged in to a session with your teacher, your teacher will play the video and show it to you. If you are participating independently your teacher will email you the link to the video or the video file. There are opportunities for you to answer some questions, and you will be told when to pause the video to answer them.

Introduction to Uni Pathways

1. Write down what you think a supra-activity is

_____
_____
_____

2. Independent learning is

_____
_____
_____

3. Write down in your own words what resilience means, and come up with a different example to the one mentioned in the PowerPoint.

_____
_____
_____
_____

4. Why do you think analysis and evaluation skills are useful in your academic career? _____
_____
_____
_____
_____
_____

5. Why do you think analysis and evaluation skills are useful in life in general? _____
_____
_____
_____
_____
_____

6. What are the different types of learning that university students do?

Pupils' experience of Uni Pathways

You will now watch some pupils talk about their experience of learning a PhD topic and producing a final assignment. Some may refer to The Scholars Programme rather than Uni Pathways. As you heard in the introduction PowerPoint, The Scholars Programme is a very similar programme to Uni Pathways. Listen carefully and then respond to the questions below. Be prepared to share some of your responses with your peers.

1. How did the pupils describe talking about writing a long essay for their final assignment?

2. Write down something that one of the pupils mentioned was particularly interesting in their course.

3. What were some challenges that the pupils met?

Virtual campus tours

You will now go on a virtual tour of some universities! Once you have seen some of the university campuses, respond to the questions below.
Note down something that you liked out of any of the campus tours you saw. It may be a particular building, space, city etc.

1. Were there any similarities between the different university campuses? If so, what are the similarities?

2. If you had to pick one of those universities to go and visit in person, which one would it be and why?

3. Note down some of the societies that you could join at different universities

Meet university students!
You are about to virtually meet or hear from some current university students.
If you are virtually meeting them, think about what questions you would like to ask the students, share your questions with a partner and note those questions down in the space below.

If you are not meeting them but watching some videos that they have made, use the space below to note down what else you would like to find out about university. You can then ask your teacher during Uni Pathways tutorials!

Reflection
Congratulations on completing the launch of the Uni Pathways programme. Before you go, take some time to reflect on what you have learnt by answering the following questions:

1. Are there any aspects of university style learning that you would look forward to? If so, what are they?

2. What challenges do you think students face when learning at university? How would you try to overcome these challenges?

3. What skills do you hope to develop during your Uni Pathways course?

4. What part of Uni Pathways seems the most challenging for you?

5. What are you most looking forward to about Uni Pathways?

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Course Rationale

How often have you trusted a weather forecast, only to find that it was wrong? Why is it that, for all our modern technologies, we still can't predict exactly where it will rain and when? Can the forecast ever be completely right?

In this course, you will learn about how forecasts of both weather and climate are made, what the limitations of these forecasts are and why they are never perfect. You will gain an understanding of Chaos Theory and how something as small as the flap of a butterfly's wings could lead to storms, flooding and other extreme weather. You will learn about the difference between weather and climate, and why the weather is becoming more extreme with climate change. You will also get the opportunity to make weather observations of your own, and judge for yourself whether the weather forecasts you have access to are up to scratch.

By taking part in this course, you will develop a range of important scientific skills, including how to apply scientific scrutiny to predictions and how to represent uncertainties in those predictions. You will be tested on your ability to check the accuracy of real forecasts against your own observations and to explain the shortfalls of forecasting. Ultimately, you will be able to explain the science of one of the most important, dangerous, and aweinspiring phenomena in the known universe: the world's weather.

The course aims to convey a sense of both the power and the limitations of science.

Uni Pathways Mark Scheme 2020 – science-based assignments

	Subject Knowledge	Critical Thinking	Written Communication
1st	The work shows a depth of knowledge and understanding of key concepts and scientific methods, through engaging with relevant sources. Knowledge is used to build and support highly effective scientific arguments and explanations .	Analyses key scientific evidence, arguments, and reasoning. Interprets meaning and makes connections. Identifies and critically evaluates key scientific arguments and evidence, deciding on their credibility, strength, and relative significance, drawing convincing conclusions.	The work has a coherent flow and is well structured. The writing style is appropriate; scientific language and key scientific terms are used accurately and effectively to support the arguments and explanations made. There are no, or very few, errors in spelling or grammar. Consistent referencing, appropriate paragraphing and use of correctly labelled tables and graphs matching the style taught in the course.
2:1	The work shows an understanding of key concepts and scientific methods, drawing on relevant sources. Knowledge is used to build and support effective scientific arguments and explanations .	Analyses relevant scientific evidence, arguments, and reasoning. Identifies and critically evaluates relevant scientific arguments and evidence, deciding on their credibility and strength, drawing reasonable conclusions. Shows some understanding of the relative value of evidence and arguments.	The work is well-structured. The writing style is appropriate; scientific language and key terms are used correctly. There are few errors in spelling or grammar. Mostly consistent referencing and use of tables and figures; matching the style taught in the course.
2:2	The work shows an understanding of key concepts and scientific methods, with no major misconceptions. Beginning to apply this knowledge to build and support effective scientific arguments and explanations .	Identifies and uses basic scientific evidence, arguments, and reasoning. Showing some understanding of the quality of scientific arguments and evidence. Not yet showing understanding of the relative value of evidence and arguments.	The work has some structure. The writing style can sometimes be informal; occasionally scientific language and key terms are not used when it would be appropriate to do so. There are some errors in grammar and spelling do not get in the way of communicating the content. Referencing has some consistency; matching the style taught in the course Limited use of tables and graphs.

3rd	Shows a developing understanding of key concepts and scientific methods, with some misconceptions. Does not yet apply this knowledge to build and support scientific arguments and explanations .	Beginning to analyse scientific evidence, arguments, and reasoning. Describes evidence and arguments, while not yet evaluating them.	The grammar, spelling, style, and structure of the work need improving in order to communicate ideas to the reader. Scientific language, key terms and references are not always used correctly. Limited, or no use of tables and graphs.

Baseline Assignment (problem-set): Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	Dr TJ Thornes
Title of Assignment	What Goes into a High-Quality Weather Forecast?

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

Subject knowledge	
	mark

Critical thinking	
	mark

Written communication	
	mark

Problem Set	
Comment	*mark*

Final Assignment (essay based): Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	Dr TJ Thornes
Title of Assignment	To What Extent can You Trust the Weather Forecast?

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Subject Vocabulary

Word	Definition	In a sentence
Accuracy	The extent to which something is true	The accuracy of the measurement was checked by looking up other measurements of the value

Chaos	A state in which a very small change in conditions very quickly grows to completely change the system	Chaos in the atmosphere means that a butterfly's wing-flap can set off a storm
Climate	The weather conditions that are usually experienced in a particular place	Scotland has a wet climate
Discretization	The process of splitting something large into smaller chunks that are easier to deal with	The blank page was discretized into a set of squares
Forecast	A statement about what is expected to happen in the future	It is forecast to be sunny tomorrow
Lead-time	How far into the future a forecast is looking	To forecast whether it will rain next weekend requires a lead-time of several days
Model	A way of representing something, often on a computer	I used a model of a star to predict how brightly it would shine
Parameter	A value for something that is fixed during an experiment	The number of hours in the day is a parameter that unfortunately I cannot change
Precision	How exact a number is	Max's measurement of the temperature was very precise because it had two decimal places
Resolution	The ability of equipment to distinguish small things clearly	My telescope has a very high resolution because it can distinguish rocks on the Moon.
System	A collection of particles that can interact with each other	The atmosphere is a system that is very difficult to understand
Weather	Conditions such as temperature, cloud or rain in the air at a particular time and place	The weather is wet today
Variable	A value that can change over time during an experiment	The temperature is a variable that tends to decrease overnight

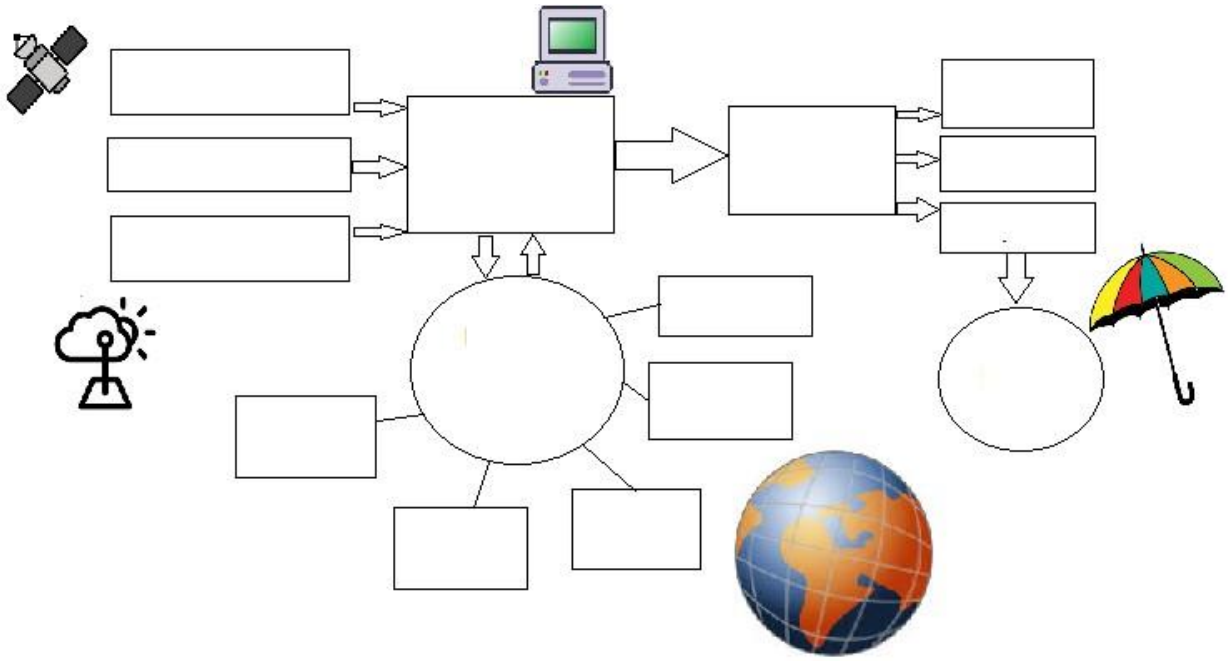
Tutorial 1 – Introduction to Weather and Climate

What is the Purpose of Tutorial 1?

At the end of this tutorial I will be able to…

- Understand the difference between 'weather' and 'climate'
- Describe how weather and climate forecasts are produced
- Use the key terms 'resolution', 'precision' and 'accuracy' in a forecasting context

Task 1: What are the key components of a weather forecast?



Task 2: Describing a weather forecast

Weather forecasts are produced using _____. These very powerful machines gather information from _____ observations in space, observations on the ground produced by a network of _____, and forecasts made previously. Computer _____ are run which split or _____ the Earth into a grid of squares, each representing a few square kilometres of the planet's surface. The higher the resolution of the forecast, the _____ the squares. For each square, the model calculates the state of the atmosphere using fundamental _____.

Things that are not _____ because they are too small are _____ using schemes, and the behaviour of the ocean, land surface and ice caps are often computed separately. The computer provides output to the forecast _____, forecasting up to a specified time in the future (such as one week) with specified forecast intervals (such as every ____). The forecast is then shared with the public on websites, television and radio or sent to weather-dependent companies.

You can use some of these words to fill in the blanks: satellite, telescope, physics, discretise, equations, dice, larger, maths, ideas, resolved, supercomputers, centre, station, points, scientists, year, larger, smaller, hour, second, week, approximated, models, guessed, ignored, weather stations, chemistry, seen

Task 3: Weather or Climate?

A: "The forecast is for snow on Saturday." Is this sentence about **weather** or **climate**?

B: "Last week, it was very wet – I recorded a month's worth of rainfall with my rain gauge!" Is this sentence about **weather** or **climate**?

C: "It's almost always hot in California." Is this sentence about **weather** or **climate**?

D: "I do hope that it's sunny on my birthday. It would make it much more fun." Is this sentence about **weather** or **climate**?

E: "The Ice caps are melting year on year: at this rate, there won't be any ice left!" Is this sentence about **weather** or **climate**?

F: "In the UK, there's often a lot more rain in autumn than in spring." Is this sentence about **weather** or **climate**?

G: "A huge tornado has struck, causing a lot of damage." Is this sentence about **weather** or **climate**?

The key difference between 'weather' and 'climate' is……

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Task 4: Discussion - How do we Measure the Weather?

My notes

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Baseline Homework Assignment: What goes into a High Quality Weather Forecast?

1. Carry out research to answer the question, 'What makes a high-quality weather forecast?' Your answer should be roughly 250 words long and include reference to these key words and phrases:
    a. Computer models
    b. Observations
    c. Resolution and complexity [5 marks]

2. Using internet searches or the article in Appendix 2, explain, in one sentence for each, what you think is meant by the following terms in the context of weather or climate forecasting:
    a. 'Hindcast'
    b. Lead-time [2 marks]

3. Amy, Ben and Cary are measuring the weather conditions on their street. They each have a different thermometer and rain gauge. The table shows their measurements of maximum temperature and total rainfall for one day.

Name	Temperature (°C)	Rainfall (mm)
Amy	10.77	2.20
Ben	16.9	0.8
Cary	17	1

    a. Whose measurements are the *most precise*?

b. Whose measurements do you think are the *least accurate*, and why?
c. What do you think could have caused these measurements to be inaccurate? [3 marks]

Success Criteria: Your answers to these questions will be assessed on the extent to which you demonstrate an understanding of key forecasting concepts and on your ability to synthesise information you have learnt to answer the questions. You will need to use fluent English and accurate scientific terminology throughout your answers.

Tutorial 2 – Limitations of Computer Models

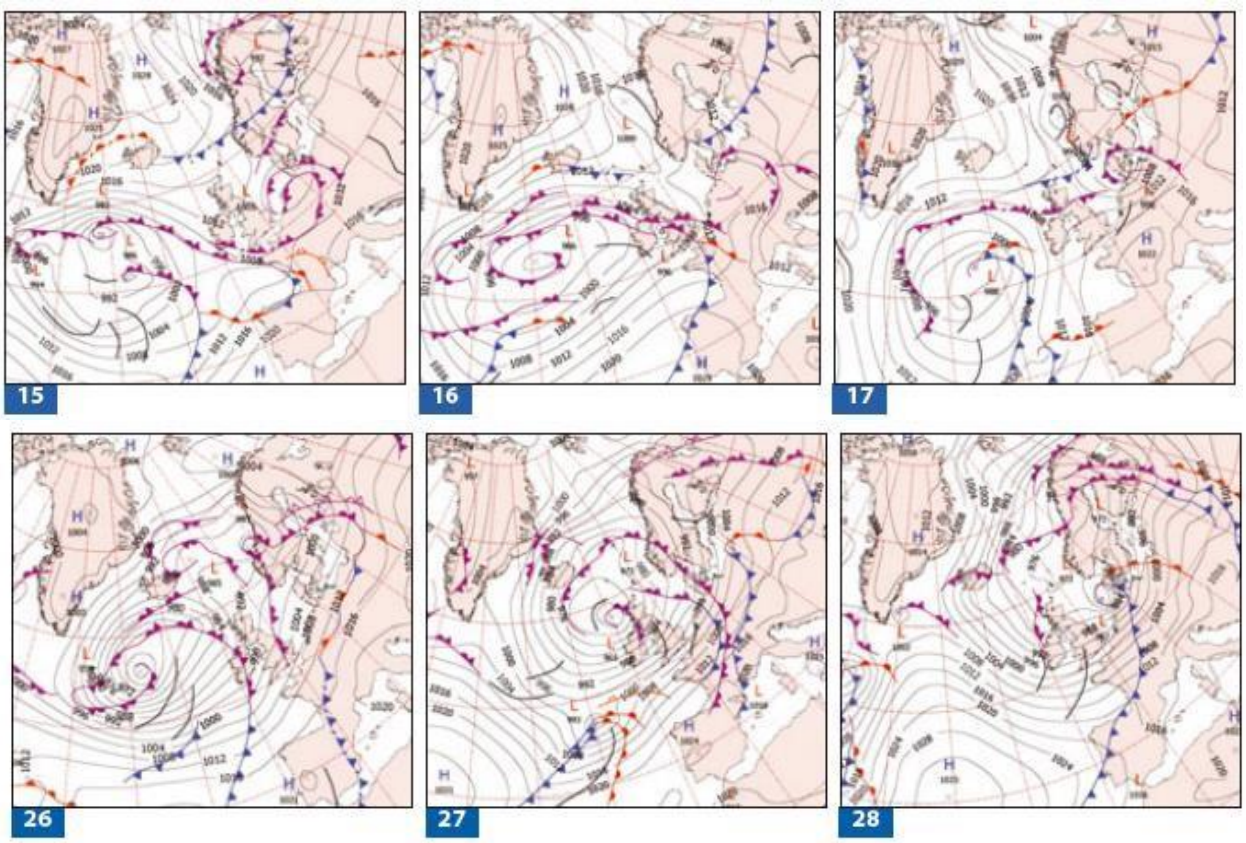
What is the Purpose of Tutorial 2?

At the end of this tutorial, I will be able to…

- Recall some case studies of when forecasts can go very wrong!
- Describe the key limitations of computer modelling
- Recognise the role of uncertainty and probabilities in forecasts

Task 1: Discussion – Is a Hurricane Coming?

Which of these do you think shows the development of a storm? These are all sea-level pressure charts for different days in October 2013 at 12.00 GMT



Discussion: do you think storms develop when the air pressure is low, normal or high?.....

This is because.....

.....

.....

.....

Why is it difficult to forecast when a storm will develop?

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Task 2: Assigning Probabilities

A ensemble of 50 different forecasts is created at midnight, each with slightly different initial conditions, to forecast the weather for the day ahead. Complete the table.

Time	No. members forecasting		Probability of	
	Rain	Sunshine	Rain	Sunshine

06:00	2	30	2/50 = 4%	30/50 = 60%
09:00	4	8		
12:00	36	1		
15:00	50	0		
18:00	24	24		

It is most likely to rain at what time? …… It is most

likely to be sunny at what time? ……..

Is it guaranteed to be raining or sunny at any time?

……

……

Homework Assignment: The St Jude's Day Storm.

Read the article 'St Jude's Day Storm' in Appendix 3 and write a few sentences on why you think the storm was important, and whether you think the Met Office forecast for this storm was good.

Success Criteria: Your paragraph will be assessed on your ability to summarise relevant information from the article and to draw an evidence-based conclusion.

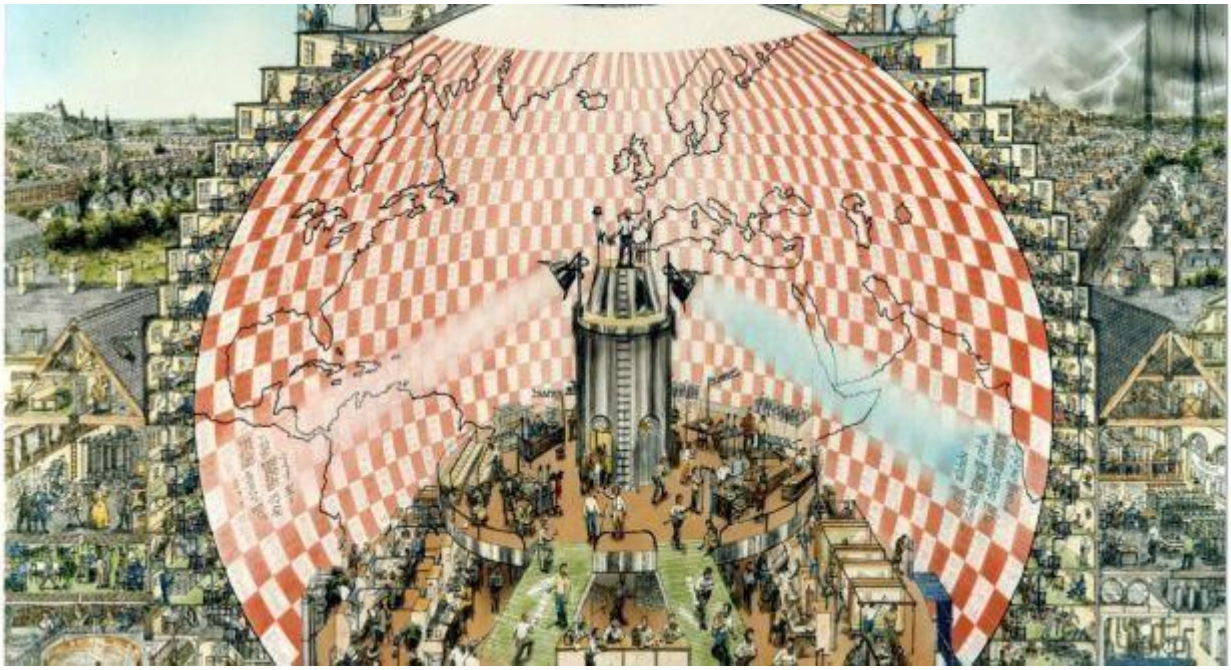
Tutorial 3 – Chaos!

What is the Purpose of Tutorial 3?

At the end of this tutorial, I will be able to…

- Understand the meaning of 'chaos' and 'The Butterfly Effect
- Know the outline of the history of weather forecasting
- Recall that forecast quality decays *exponentially* with lead time

Task 1: Discussion – What do you think this is?



Answer ……

Task 2: Resolution vs Complexity

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Ultra-speedy weather model!
Costs:
Resolution          Complexity
100km: 2 GFlops     Simple: 1 GFlop
10km: 64 GFlops     Moderate: 100 GFlops
1km:  512 GFlops    Ultra-high: 0.5 TFlops

Add these costs together to get the total.

You can also add more ensemble members!
Double the total cost for each one added.
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My supercomputer has a maximum capacity of 4 Gigaflops. That means 4 billion 'floating point operations' (calculations) per second! With what resolution and complexity can I run the ultra-speedy weather model?

If I upgrade to a £100 million brand new machine with a capacity of 1 Teraflop (1 thousand billion operations per second), what combinations of resolution, complexity and ensemble size could I run?

You could use a maximum resolution of ..... with complexity .....

Or you could use a maximum complexity of ..... with resolution ..... Or you could run a maximum of ..... ensemble members, with resolution ..... and complexity .....

What capacity would I need my supercomputer to have in order to run 50 ensemble members at 1 km resolution with ultra-high complexity?

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Task 3: Which Statements are True?

A: Chaos means that the whole atmosphere is completely random.

B: Chaos means that a small change now can lead to a big change in the future

C: Chaos means that the atmosphere is ultimately unpredictable

D: Chaos is captured accurately in computer models

E: Exponential growth or decay always means something getting bigger or smaller really fast

F: Exponential growth or decay means something will keep getting bigger or smaller indefinitely

G: The quality of weather forecasts decays exponentially with lead-time

H: The quality of climate forecasts decays exponentially with lead-time

Task 4: Discussion – Do you think we can ever have a perfect weather forecast?

My notes .....

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Homework Assignment: Forecasting the Old-fashioned Way

Imagine we are trying to produce a modern-day weather forecast using Richardson's idea, with a room full of people carrying out calculations. Answer the following questions:

1. If a state-of-the-art computer has a capacity of 1000 TFlops, how many calculations per second is that? [1 mark]

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2. How long do you think it would take for a person to carry out a simple calculation, such as adding two small numbers together? [1 mark]

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3. At this rate, how many people would it take to match the supercomputer's output? [1 mark]

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4. How good do you think the resolution and complexity was of early weather forecasts, before supercomputers were invented, compared to today? Why? [2 marks]

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5. Do you think the method that Richardson proposed (making lots of calculations) was taken up before supercomputers? What other method do you think might have been used to predict the weather? [2 marks]

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Success Criteria: Your answers will be assessed on your ability to utilise the information discussed in the tutorial to solve the problems. You will need to demonstrate the capacity to use accurate scientific terminology and good maths and English throughout.

Tutorial 4 – Changing Climates

What is the Purpose of Tutorial 4?

At the end of this tutorial, I will be able to…

- Understand how weather forecast models can be applied to predict the future climate
- Discuss why climate forecasts are difficult to verify
- Understand the observational evidence that the climate is changing

Task 1: Discussion – How can we hope to predict the climate decades ahead?

My notes……

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Task 2: Climate Change Timeline

How did climate change come to be known about? Fill in the blanks.

	Jean-Baptiste Fourier predicted the warming effect of gasses in the atmosphere
1863	John Tyndall coined the term 'greenhouse gas' for water vapour in the atmosphere
	The warming effect of carbon dioxide produced by burning fossil fuels was predicted, but considered of small consequence
1940s	
	First warnings that humanity was conducting a 'largescale geophysical experiment' by releasing greenhouse gasses; Keeling began measuring atmospheric CO2 concentration
1979	First 'world climate conference' identified climate change as a major issue, following scientific studies
1985	Major conference warned of unprecedented warming in the next century if emissions weren't stopped
1987	
1990	IPCC warned that Earth had warmed 0.5°C in 100 years
1992	
1996	After a four-year plateau, global emissions began to rise
	Kyoto Protocol: Legally-binding emissions cuts agreed
2001	New US President George Bush refused to ratify the Kyoto protocol, fearing it would harm the US economy
2005	
2007	*The Great Global Warming Swindle* documentary argued that climate change was made up
2009	
2011	Fukushima nuclear disaster caused a drop in nuclear generation, increasing fossil fuel burning and emissions

	Atmospheric CO2 concentration passed 400ppm for the first time in a million years
	Paris Agreement: nations finally agreed to produce stringent targets for greenhouse gas emissions reduction
2020	Increasingly natural disasters such as Australian wild fires were blamed on climate change, whilst emissions were stabilised only by a global pandemic

Task 3: Trace the Chain of Events

Trace the impact of climate change through the sequence of events. You can move up, down, sideways or diagonally from square to square.

START HERE

A: People use more electricity and fossil-fuel transport	B: Oceans start to warm up by absorbing heat from the air	C: Warmer atmosphere and ocean leads to more storms and floods	D: Sea levels rise as arctic ice melts
E: Carbon dioxide concentration in the atmosphere increases	F: More fuel is burnt in power stations and engines	G: Global average temperatures start to increase	H: Cities flood and forests die because of changed conditions
I: More carbon dioxide is emitted	J: More heat gets trapped by the atmosphere	K: More carbon gets emitted from forests and permafrost	L: Earth warms so much that plant and animal species die out

END HERE

At around what year do you think that E occurred? .....

At around what year do you think that B occurred? .....

When did C occur? .....

When will D occur? .....

Has L occurred yet? .....

Task 4: Discussion – Why are Climate Forecasts Difficult?

First note down some ideas in the space below.

My ideas…
Other people said…

Task 5: Impacts of Climate Change

Write down five impacts of climate change. Are they positive or negative – or both?

Impact	Positive or Negative?
e.g. Ice sheets melt	Negative – habitats destroyed, animals die Positive – new land opened up

Do you think climate change is a good thing overall?

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How can we reduce the negative impacts of climate change? Give three ways.

1.
2.
3.

Homework Assignment: Short essay

'We can't even predict the weather next week – scientists can't possibly claim to be able to predict the climate in 50 years time!'

Write a short essay (about 250 words or 1 side A4) on why you agree or disagree with this statement.

Success Criteria:

You will need to demonstrate an understanding of:

- The difference between weather and climate
- Limitations of both weather and climate forecasts
- How forecasts of weather and climate are made

You should be able to:

- Produce an evidence-based argument for or against the statement

- Identify key misunderstandings that may commonly arise regarding forecasting

Tutorial 5 – Can we make forecasts better?

What is the Purpose of Tutorial 5?

At the end of this tutorial, I will be able to:

- Discuss how weather and climate forecasts could be made more accurate
- Understand how forecast quality is evaluated by comparison to observations
- Justify an argument for or against the statement 'I can trust the weather forecast'

Task 1: Discussion – How could forecasts be made more accurate?

My notes……

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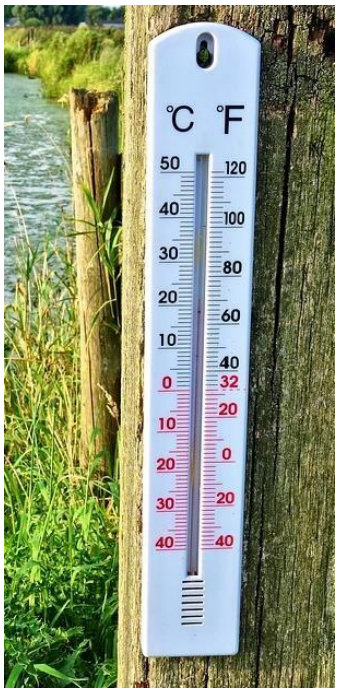
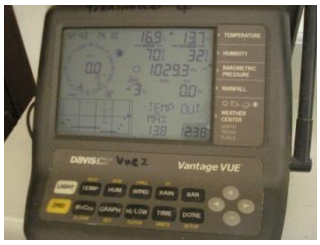
Task 2: Types of Weather Apparatus

Label each of these with its name and what it's used for





Task 3: Which is the Better Forecast?

Compare the different forecasts with the observations and familiarise yourself with the strengths and weaknesses. Which do you think is the best forecast?

15:00 GMT

Variable	Forecast 1	Forecast 2	Observation
Likelihood of rain	30%	No	No rain
Wind speed (mph)	12	10	8
Temperature (°C)	17	17	18
Cloud cover (%)	100	50	70

18:00 GMT

Variable	Forecast 1	Forecast 2	Observation
Likelihood of rain	80%	Yes	Heavy rain: 3mm
Wind speed (mph)	22	20	23
Temperature (°C)	14	14	15
Cloud cover (%)	100	100	100

21:00 GMT

Variable	Forecast 1	Forecast 2	Observation
Likelihood of rain	70%	Yes	No rain

Wind speed (mph)	17	20	17
Temperature (°C)	10	9	10
Cloud cover (%)	100	50	50

Think about the accuracy of each forecast, the precision of each forecast and possible limitations of the measuring equipment.

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Final Homework Assignment: Can I Trust the Weather Forecast?

This is the main assignment of the course, and is designed to test your understanding of everything we've covered as well as giving you the opportunity to do some hands-on science.

Your task is to write a 2000 word essay exploring the accuracy of weather forecasts for where you live. You will need to apply what you have learnt about weather forecasting to real-world forecasts and observations to complete the assignment.

Your essay should address the following questions (in any order):

1. Are there disagreements between forecasts obtained from different sources?
2. Are any of these forecasts certain? Why, or why not?
3. What is the climate where you live?
4. How well do the forecasts agree with your observations of the weather?
5. Is it possible to use these observations to identify changes in the climate?
6. Why are weather and climate forecasts always limited in accuracy?
7. How could these forecasts be made more accurate in the future?

To answer question 4, you will need to create a weather diary for a short period of time, at least five days. For each day, write down the weather forecast for that day in the morning or on the night before, and take observations in the morning and evening to compare with the forecast for that day. If you miss an observation, don't worry; you can leave one or two gaps but try to keep these to a minimum. What you observe – temperature, cloudiness, rain – is entirely up to you, and your observations can either be by eye or using equipment such as a thermometer. You could consider including graphs or pictures in your essay.

You can choose which weather forecast you compare your observations to (or even use more than one!), as long as it applies to the place where you're observing. It could be a television or radio forecast, or online; you should explore different possibilities when answering question 1. If you like you can make your own 'persistence' forecast for one of the forecasts; this is where you assume that the weather tomorrow will be the same as it was today.

Please include references to any forecasts that you use, and books, websites etc. that you draw material from. Don't forget to address the central question of the essay in your conclusions: to what extent do *you* trust weather forecasts?

Success Criteria:

You will need to demonstrate an understanding of:

- How weather forecasts and observations are made
- Chaos and the 'Butterfly Effect' in the atmosphere
- The limitations that chaos places on forecasts
- How weather forecasts demonstrate and represent uncertainty.

You should be able to:

- Demonstrate advanced knowledge and understanding of the key concepts
- Apply scientific scrutiny to weather forecasts
- Present an evidence-based argument
- Explain why weather forecasts are sometimes wrong and never perfect.

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on your final assignment
- To respond to the feedback from your Uni Pathways teacher
- To write targets for improvement on your final assignment

Final assignment feedback from your Uni Pathways Teacher

(Remember to look at the mark scheme to help you understand what you have done well so far, and how you can do even better in your final assignment)

Here are three things that my Uni Pathways Teacher thought I did well in my draft assignment

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Here are three things that my Uni Pathways Teacher thinks that I could do to get a higher mark in my final assignment
• • •

Tasks from my Uni Pathways Teacher to do during the feedback tutorial to help me improve
• • •
My response:

Actions I will take to improve my final assignment after this tutorial…
•   •   •

Hand in date for my final assignment:	

Tutorial 7 – Final tutorial

What is the Purpose of Tutorial 7?

- To receive feedback and a grade on your final assignment.
- To reflect on the programme including what you enjoyed and what was challenging.
- To ask any questions you may have about university.

Final assignment feedback from my Uni Pathways Teacher

Final mark:	University style grade:

Feedback: Here are three things that my Uni Pathways teacher thought I did well in my final assignment
•   •   •

Here are three things that my Uni Pathways teacher thinks I should remember for when I am doing this kind of study in the future
•   •   •

University

What questions do you still have about University after taking part in Uni Pathways?
•   •   •

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
•   •   •

What did you find challenging about the programme?	How did you overcome these challenges?
•	•
•	•
•	•

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].

2. **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

   a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

   E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

   b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

   E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

   c. **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

   E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2: Additional Reading Material

From observations to forecasts – Part 9: what is decadal forecasting?

Collins M, Fricker T & Hermonson L (2011) in *Weather* 66:160-164
https://doi.org/10.1002/wea.794

Introduction

Towards the end of 2010 the United Kingdom was gripped by an early winter spell of cold and snow that caused Christmas travel chaos, burst pipes and cancelled rubbish collections. The thought in many minds at the time was *is this part of a pattern of cold winters that might continue for many years?* Is this perhaps a question that decadal forecasting might be able to answer? This article is an attempt to explain what decadal forecasting is and describe the science behind its rise in prominence. We also aim to expose some of the scientific and technical challenges, including those that have already been tackled with success and those that remain for the future.

Decadal forecasts should not be confused with weather forecasts. It is not possible to predict the precise details of weather any more than a week or so in advance, so forecasting weather a decade ahead is impossible. Advances in seasonal forecasting mean that, for some parts of the world, it is possible to be accurate (deterministic) about the chance of, for example, a drought or flood in the coming season, particularly where rain bands such as the Intertropical Convergence Zones are strongly affected by phenomena such as El Niño. But decadal forecasting is not about extending the deterministic aspects of those forecasts many seasons ahead in the future.

Like many seasonal forecasts, decadal forecasts are inherently probabilistic in nature. The aim is to predict, for example, the probability that it may be warmer or colder, drier or wetter over the coming decade (or parts of it) relative to the decade-long average temperature or precipitation. It may be possible to produce probabilities for seasonal averages within a specified period of many years, or even give probabilities of runs of cold or warm or wet or dry seasons. In general, though, the signals are subtle and all we can really hope for is to assess how the probabilities are changed with respect to some climatological probability.

Sources of decadal predictability

Early work in decadal forecasting has focused on identifying sources of potential prediction skill on decadal time-scales. Broadly speaking we can characterise the potential for predictability as coming from two different types of source: that arising from low-frequency natural variability in the climate system, and that from externally-forced climate change (e.g. Meehl *et al.*, 2009). The former may be thought of as predictability from initial conditions similar to that with which we are familiar in weather and seasonal forecasting. The latter is a form of boundary-condition predictability or of estimating quantitatively the climate response from a radiative forcing. Edward Lorenz described these as predictability of the first and second kind respectively (**Lorenz, 1975**).

Boundary-condition predictability on decadal time scales arises principally from the warming from greenhouse gases, offset by the cooling from aerosol particles, and from the influence of other anthropogenic factors which produce a radiative forcing (e.g. land-use change).

Forced signals generally produce trends that persist over decades and are global or very large scale. Inertia in the physical, biological and political systems means that, once underway, it is hard to alter these trends and hence they can be exploited as prediction tools. Even quite different scenarios of future greenhouse gas emissions with different assumptions about energy generation and geopolitics produce very similar levels of global warming for 20–30 years ahead. It is thus useful to think of the difference between a long ‐term climate *projection* being strongly dependent on the global‐emission pathway and a near‐term climate *prediction* that is quasi‐independent of that pathway.

Long‐term forced trends can however be disturbed by short‐term radiative forcing events, with the most common being those associated with explosive volcanic eruptions which inject large quantities of aerosol particles into the stratosphere. These lead to temporary global cooling whose signal may persist for many years. Recent examples are the eruptions of Mt Agung (1963), El Chichón (1982) and Pinatubo (1991). (The recent Icelandic volcanic eruption of Eyjafjallajökull did not produce a significant enough stratospheric injection of aerosols to affect global temperatures.) Although volcanic eruptions are not predictable many months in advance, once they have happened they may be exploited for seasonal ‐decadal prediction (**Collins, 2004**). Their influence is generally global/hemispheric but they might also impact on atmospheric circulation patterns that can cause predictable regional climate variations. For example, there is a tendency for warmer‐than‐average winter conditions in northwest Europe following a large volcanic eruption because of an impact on the North Atlantic Oscillation (NAO) (**Robock and Mao, 1992**).

Initial ‐condition predictability on decadal time ‐scales might arise from a number of phenomena. The ocean can store excess heat that it gets from the atmosphere and give that heat back to the atmosphere many years later. **Frankignoul and Hasselmann (1977)** proposed a simple model of atmosphere‐ocean interaction that produces a red ‐noise sea surface temperature (SST) spectra with only white‐noise fluctuations in surface fluxes into the ocean from random atmospheric disturbances (Figures **1**(a) and **1**(b)). That is, the ocean can produce low ‐frequency fluctuations in SST even without an excess of low ‐frequency atmospheric forcing – such as when shallow summer mixed layers isolate deeper heat‐content anomalies which then re‐emerge the next year or even many years into the future (Figures **1**(c) and **1**(d)).

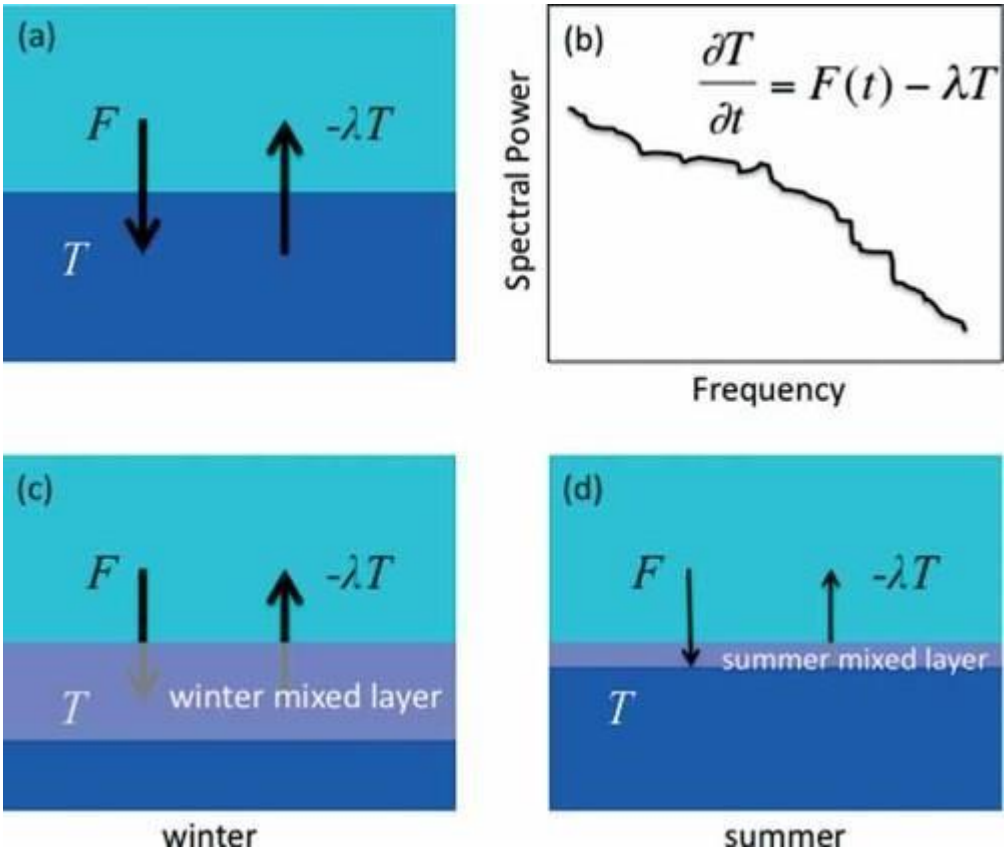

Figure 1

Schematic figures highlighting how atmosphere-ocean interactions may lead to long time-scale variability and hence to decadal predictability. In (a) random atmospheric fluctuations associated with, for example, weather events produce surface fluxes (F) that transfer heat from the atmosphere to the ocean, changing the sea surface temperatures (SSTs, T). SST anomalies are damped with a simple linear term –lT. With white-noise flux forcing, a red-noise SST spectra is produced (b) leading to long time-scale SST anomalies. Low-frequency SST fluctuations are produced with only uniformly random atmospheric fluctuations. In (c) the winter mixed layer is deep when the surface winds are strong, more storms are evident and the surface fluxes are greater because of a greater atmosphere-ocean temperature contrast. Anomalous heat can penetrate deep into the ocean. In summer (d), the mixed layer shoals and can trap anomalous heat below it. This heat can re-emerge the following winter and lead to long time-scale predictability.

Atmosphere–ocean heat exchange is a component of the mechanisms for mooted decadal 'modes of variability' such as the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO). The latter is associated with the slow overturning cell in the ocean known as the Atlantic Meridional Overturning Circulation (MOC or AMOC). This transports heat polewards and changes in the strength of the MOC can cause large-scale changes in climate in the Atlantic basin – a stronger MOC transports more tropical warmth polewards producing higher SSTs and reduced sea-ice in the north Atlantic and Arctic oceans. More speculative phenomena include the decadal modulation of El Niño events via changes in background conditions in the tropical Pacific, either internally-generated or via remote interactions (**Timmermann *et al.*, 2007**).

Many of the phenomena identified so far as candidates for initial-condition decadal predictability are associated with the ocean or the interaction of the ocean circulation and the atmosphere. The potential for phenomena associated with purely land processes or atmospheric circulation have not been fully explored. These components of the climate system lack the ability to store significant amounts of heat but the land may have long time-scales associated with vegetation cover and water storage. Current initial-condition

predictability for land areas relies on the translation of ocean signals to those land areas and on climate models to represent those processes reliably.

The potential for initial-condition decadal predictability has been identified using a number of techniques. Modes of decadal variability have been identified in observations but are compromised by the short period of records in comparison with the time-scales of the modes.

The principal tools for identifying potential predictability have been complex climate models. The physical processes responsible for decadal modes of variability have been investigated in a number of studies and provide the theoretical underpinning for studying possible skill. 'Diagnostic' potential predictability studies rely on statistical techniques to analyse the behaviour of long unforced coupled atmosphere-ocean climate models to identify regions and time-scales for potential skill (e.g. **Boer, 2000**). The predictability is estimated purely from the statistics of the free-running model simulations. Other more 'prognostic' approaches use ensembles of climate-model simulations in which small perturbations are made to the initial conditions (Figure **2**), sometimes called perfect -predictability or perfect-ensemble studies because they allow the measurement of skill presuming that both the ocean and atmospheric initial conditions could be specified without any error and that the climate model is consistent with those initial conditions (e.g. **Collins, 2002**). Both diagnostic and prognostic techniques only really tell us about the potential for predictability in the model-world however. This has led to the development of experimental decadal-prediction systems.

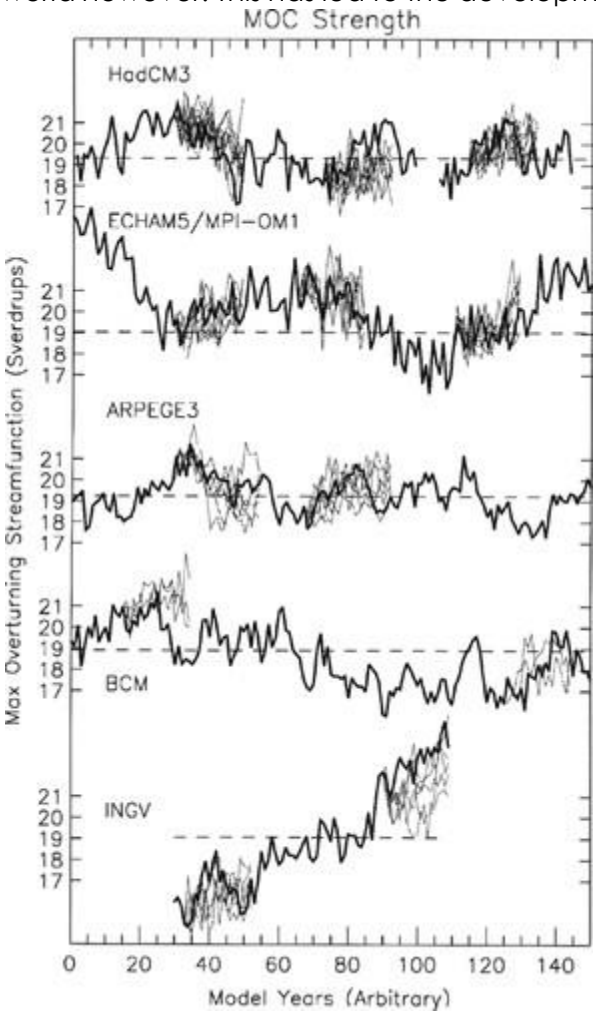

Figure 2

*Examples of perfect ensemble predictability experiments (from **Collins et al., 2006**). The black solid lines show the evolution of the strength of the Atlantic Meridional Circulation (MOC) in free-running coupled-model simulations using five different models. The grey lines show ensemble experiments initiated using the same model but with very small variations to initial conditions. The rate at which the spread in the ensemble grows is a measure of how*

potentially predictable the MOC is in that model. Different models show different levels of potential predictability depending on when the experiment is started in the natural MOC cycle. The INGV model has a strong drift away from its initial state and highlights an extreme example of the bias and drift that can plague decadal prediction systems. (Crown Copyright.)

Decadal prediction systems

A decadal prediction system is similar to a weather forecasting system. The first stage is to collect as many observations as possible. These are then assimilated into a model to make an analysis – the best estimate of the state of the climate system at any time in the past. Assimilation attempts to ensure that the prediction is started from a balanced state, for example that the winds are in balance with the temperature gradients. Several such initial states, all consistent with the incomplete observations, may be used to make multiple predictions so that the uncertainty associated with incomplete observational coverage may be sampled.

A standard weather forecast uses surface and atmospheric observations in its assimilation. Since the predictability of the atmosphere is limited, decadal prediction includes observations from other components of the Earth system to get longer predictability. As highlighted above, probably the biggest source of initial condition predictability is in the ocean and all current decadal prediction systems try to take advantage of this.
Compared to well developed atmospheric assimilation systems, oceanic assimilation presents a number of challenges. For example, oceanic currents may be confined to connected basins and unable to circle the planet. Also the density of seawater, the gradients of which determine most of the flow, is a non linear function of temperature, salinity and pressure. Possibly the biggest problem is the lack of continuous observations below the ocean surface. Whereas *in situ* atmospheric observations have been made routinely for many decades and are augmented by near global satellite measurements, continuous sub surface ocean observations have only really been made since the middle of the twentieth century and only recently has near global coverage been possible for temperature and salinity using autonomous floats.

For weather forecasts the actual value of the observation is used in the atmospheric assimilation. This means the forecast model starts as close as possible to the actual atmospheric state – this is commonly known as full field assimilation. However, as the model is an approximation of the real world, it soon starts drifting towards its preferred state. The difference between a long average of the observed state and a long average of the model state is often called the model bias or error. Drift and bias are less of a problem in weather forecasting compared with decadal prediction where, because of the longer time scales involved, they can become larger than the predictable signal.

In order to reduce the problems of drift, some decadal prediction systems have used anomaly assimilation in place of full field assimilation (**Smith *et al.*, 2007**). A climatology period is chosen and the observations are expressed as anomalies from that period. This observed anomaly is then added to the model climatology and used for the prediction. The prediction is presented as the anomaly from the chosen period and calculated by removing the model climatology from the predicted value. If the anomalies are small, the model is always close to its preferred state and this reduces drift.

Inevitably, both full field and anomaly assimilation have bias and drift in their predictions, though it is of course much smaller in the latter system. This can be dealt with using simple bias correction, which is a post processing technique developed for seasonal prediction. By using a large number of past predictions that can be verified, the average error (or bias) is calculated as a function of the prediction lead time. Then, when a prediction is made, this

average error is subtracted from the prediction to, hopefully, give a better prediction. This method can occasionally backfire and make the prediction worse (e.g. when biases evolve in a non-linear way), but the idea is that on average the predictions should get better.

Testing and evaluating decadal-prediction systems

Evaluation of the performance of the decadal-prediction system is essential. This may be in order to diagnose inadequacies in the system, or to enable comparison with competing prediction systems, or to judge the value of the predictions to some user or policy-maker. A common way of testing a decadal prediction system is to use a so-called 'perfect model' or 'identical twin' approach. Pseudo-observations are sampled according to the present observational network from one model integration. These pseudo-observations are then assimilated into the prediction system to try to predict the subsequent evolution of the sampled model integration. By repeating this for many different model states, a picture of the prediction system&'s potential skill can be built up. We can use the same model to produce the pseudo-observations and potential predictability experiments, or different models. In the same way, the impact of new or different observational types may be assessed.

In the case of real observations, we cannot afford to wait for 30 years to see how good a set of predictions is, so decadal-prediction systems are usually evaluated using hindcasts: retrospective forecasts that can be compared to past observations. The idea is that if the model can reproduce past events in a series of hindcasts, we can have some confidence in its ability to predict the future.

Evaluation using hindcasts presents several issues. First, it is difficult to get enough hindcasts to obtain statistically-significant results. The time window for hindcasts is rather limited, since the historical record of ocean observations required for initialisation goes back only as far as the mid-twentieth century. The effective sample size is further reduced by the lack of independence between hindcasts launched in consecutive years. Also, the quality of ocean observations has improved over time, so more recent hindcasts have a more accurate initialisation and should in theory perform better than older hindcasts, meaning that the sample of hindcasts is not homogeneous. Another problem is that, although the prediction system is only given data from before the hindcast start date, information about the climate during the subsequent period may have been used implicitly in building the prediction model to make it realistic. There is a risk that prediction systems that perform well in hindcast mode may not perform as well in a future, changed, climate.

Hindcast information may be analysed using any number of methods routinely used in the verification of weather forecasts – skill scores, reliability diagrams, ROC curves etc. (**Joliffe and Stephenson, 2003**) – but care must be taken. As noted above, there are fundamental differences between decadal-climate prediction and a weather forecast. Although a typical climate model produces output at sub-daily time intervals, we do not expect this to directly correspond to actual daily observations. Some kind of temporal averaging must be performed to obtain the forecast probability distribution, but it is not obvious what time-averaging period should be used. Climate processes occur on many different time-scales, and one goal of the evaluation should be to discover which of these the prediction system can, and cannot, reproduce.

A further aspect of the evaluation problem is distinguishing between skill arising from initial-condition predictability and that arising from boundary-condition predictability. In weather forecasting, predicting baseline climatology is not considered to contribute to skill at all, but clearly there is utility in predicting how the baseline will change due to external factors. The ability to predict internal variability arises from assimilation of observations, so there is also a wish to assess the value added by the expensive assimilation procedure. An obvious way to

do this is to compare hindcasts initialised with observations to parallel, uninitialised, hindcasts, but other methods such as the statistical decomposition of the error variance have also been explored.

It is now just possible to perform genuine forecast verification on two of the earliest major decadal-prediction studies (Figure **3**, **Smith *et al.*, 2007**; **Keenlyside *et al.*, 2008**). Such studies indicate skill in predicting global mean temperatures a decade ahead, except in the case of large interannual variability associated, for example, with future explosive volcanic eruptions or large El Niño events. Regional predictions can also be skillful. A recent ground-breaking study has highlighted the potential for multi-year predictions of Atlantic hurricane frequency (Figure **4** – Smith *et al.*, 2010). It is thought that the region which is predictable may change from forecast to forecast as regional predictability has been seen in perfect-model studies to be dependent on the particular climate state at the time (**Hermanson and Sutton, 2010**).

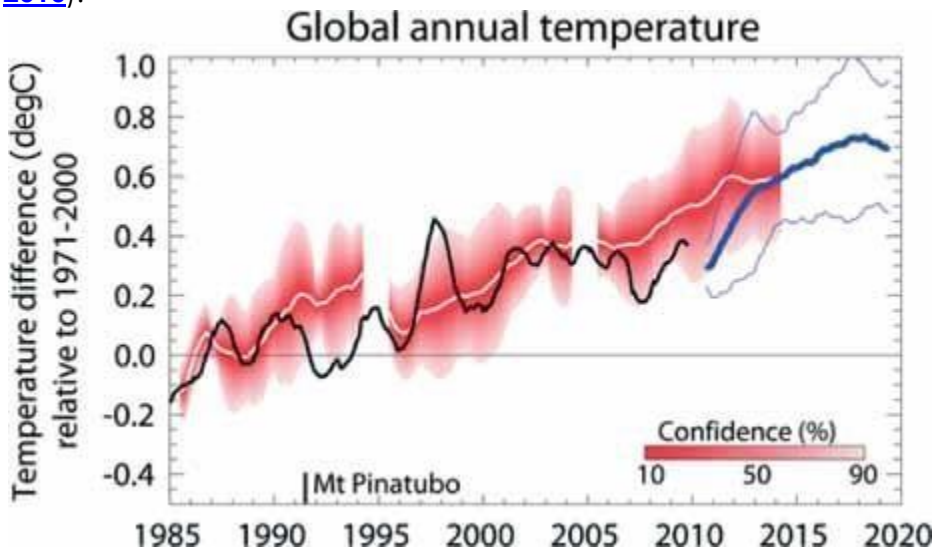

Figure 3

*Output from an experimental decadal-prediction system (DePreSys – **Smith et al., 2007**). The black line shows a time-series of observed global, annual mean surface air temperature. The white lines surrounded by red shading indicate hindcasts of this variable from 1985, 1995 and 2005 (mean and confidence). The DePreSys system predicts the global mean temperature well, except for events such as the cooling following the eruption of Pinatubo and the warming associated with the 1997/1998 El Niño event. Such interannual variability cannot be forecast on decadal time-scales. The blue lines indicate the mean and uncertainty bounds from a forecast initialised in 2010. (Crown Copyright.)*

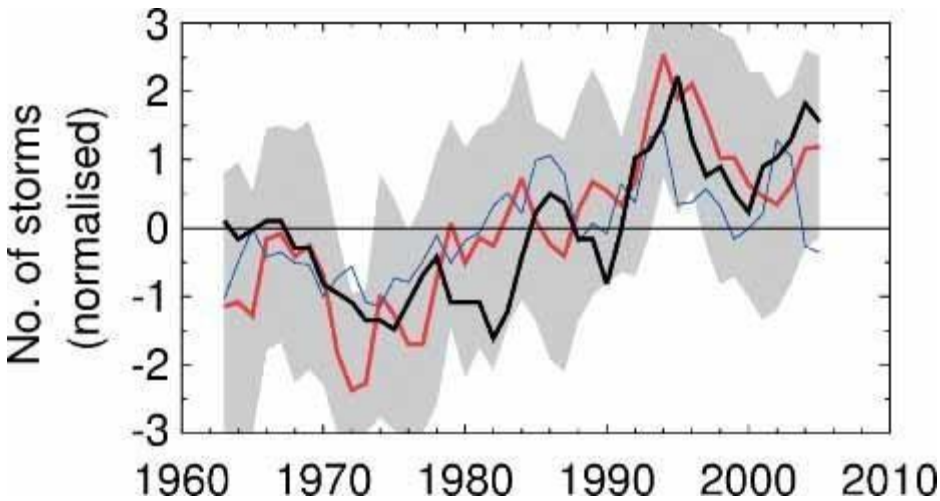

Figure 4

Hindcasts of five-year rolling mean Atlantic hurricane frequency normalised to account for model biases by removing the mean and dividing by the standard deviation. The black curve comes from observations, the red curve from the DePreSys decadal-prediction system and the blue curve from a set of DePreSys experiments with no assimilation of observed data. The grey shading represents the hindcast uncertainty for the red predictions. (Crown Copyright.)

Future advances and challenges

Despite much progress, decadal prediction is still in its infancy. Much has been learnt but much is still to be done.

Improving ocean assimilation is key to improving decadal predictions, especially when it comes to making these on a regional basis. It is also important to continue taking frequent ocean sub-surface observations so as to improve ocean models and provide initial states for the predictions. Since 2003, thousands of drifting and diving buoys making observations of the top 2000 metres have been deployed across all oceans of the world in a network called the ARGO array. They have revolutionised our knowledge of the ocean and will lead to improved decadal predictions. Also important is the RAPID array, which is made up of fixed moorings in the Atlantic along the 26°N latitude. It measures the meridional overturning transport in the ocean (MOC), which could turn out to be very useful.

In terms of the existing decadal-prediction systems, new and improved coupled-climate models, new and improved data-assimilation systems and more frequent, high-quality, observations should all lead to improvements in prediction skill. Particular challenges here are in coupled atmosphere-ocean assimilation and initialisation and in fully exploiting new observational platforms such as ARGO and RAPID. To make further progress, decadal prediction must start to use sources of predictability other than the ocean. One promising candidate is the cryosphere, primarily sea ice and snow cover. Another candidate is the stratosphere, which has a quasi-biennial oscillation that is thought to be predictable. Adding these to the atmosphere and ocean observations, or improving their representation and assimilation, maximises the chance of capturing a predictable signal.

Perhaps one of the biggest challenges is still in improving the climate models that form the basis of decadal-prediction systems. Much effort is expended in improving models, and recent work at the Met Office Hadley Centre, for example, has focussed effort in improving those processes which are key to initial-condition seasonal and decadal prediction such as El Niño and global teleconnections. As climate models become more complex, the effort to maintain and update them increases. It is difficult to know how to focus this effort in order to maximise decadal-prediction skill. One promising area has been termed 'seamless prediction' which attempts to improve models and predictions by using information from predictions on different time-scales from weather forecasting to climate-change projection (**Palmer *et al.*, 2008**). An alternative approach is to use statistical techniques to combine information from inadequate models and assimilation systems and incomplete observations to optimise prediction skill.

A significant activity that is currently underway is the international coordination of near-term decadal-prediction hindcast experiments as part of the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP5). This will allow the comparison of prediction skill from many different prediction systems, many of which have only recently been developed. The rise of decadal-prediction science has led to it having a dedicated chapter in the forthcoming Intergovernmental Panel on Climate Change report (IPCC) that is currently being written. International collaboration, as ever, should produce more rapid progress than could be obtained by one country alone.

It has certainly been an exciting time for the science of decadal prediction. But how long will it be before we see regular operational predictions which are routinely used by governments, NGOs, businesses and individuals in planning for the future? Because decadal predictions are so different from other weather and seasonal predictions, involving trends, subtle signals and extensive use of probabilities, research is required to enable the use of the new prediction products. This research is currently being undertaken by the EQUIP project (**http://www.equip.leeds.ac.uk/**) which brings together multiple UK partners with a focus on the end- -to end problem.

So, are we expecting to see a run of cold winters in the United Kingdom with associated snow, ice and the chaos of the latter part of 2010? It is perhaps premature for decadal prediction to provide a robust answer to this question. But work is underway to see if such a question can be answered.

Acknowledgements

We thank Julian Mayes for first suggesting this article for *Weather*. Nick Dunstone, Holger Pohlmann and Doug Smith provided valuable comments on the draft. TF is supported by the NERC EQUIP Project and LH by the NERC RAPID Valor project.

Appendix 3: The St Jude's Day Storm

This article was published by the Met Office on their website in 2013 (http://www.metoffice.gov.uk/about-us/who/how/case-studies/st-judes-day-storm-oct-2013 accessed 25/07/2017)

'St Jude's Day' storm - October 2013

We forecast that a severe storm would affect southern England in late October 2013.

On Monday 28 October 2013 a severe storm, which the media named the 'St Jude's Day' storm, travelled across southern England. The timing of the storm meant that trees were still in full leaf and vulnerable to strong winds. The path of the storm was also significant - strong gusts of 70 to 80 mph are rare in southern England, making these areas more vulnerable to the impacts of severe weather. Falling trees were the main cause of disruption, contributing to transport disruption and power outages. Tragically, four people died as a result of falling trees. Our trusted forecasts enabled contingency planners, emergency responders and the general public prepare for and limit the impacts of the storm.

What we forecast - timeline

Thursday 24 October
We issued warnings for the risk of potentially damaging winds across southern parts of England five days ahead of the storm - the earliest possible warning on our five-day National Severe Weather Warning service.

Friday 25 October
The amber warning area was extended across southern England on Friday 25 October.

Saturday 26 and Sunday 27 October
The areas we identified as most at risk changed very little in the run-up to the storm on Monday.

Monday 28 October
The storm arrived in line with our forecasts in terms of timing, wind speeds (we talked of 60 to 70 mph inland, and potential for over 80 mph), and the areas most likely to be affected by the strongest winds.

We highlighted a broad area for the amber warning to convey the risk of damaging winds depending on potentially relatively small variations in the storm track. In the event, the storm closely followed the most likely forecast track, meaning some areas on the northern edge of the amber area avoided the strongest winds.

Working with partners

We began communicating the potential for severe weather more than a week ahead, giving increasing detail as it became available. In the run up to the storm, Met Office advisors took part in 90 teleconferences with local resilience groups around the UK to keep them up to date with the latest information so they could plan for likely impacts. Here are just some of the people we worked with to help the UK prepare:

- Utility companies.
- Government agencies.
- Transport agencies and companies (road, rail, air and sea).
- Media partners, to help ensure safety messages were received by the public.
- Emergency responders such as the police, ambulance, fire and coastguard services.

We communicated warnings using social media, our apps and our website including:

- News releases shared across all platforms.
- Graphic explaining what to do during severe wind.
- Regular updates via Twitter on the latest storm track.
- Sharing videos explaining likely track of storm with Yahoo, BBC, Sky News, Channel 5, Mirror Online, Daily Mail Online and Express.

Met Office twitter and YouTube sites had a 10 percent increase in followers and subscribers over a three-day period, while our videos had over half a million views. Many more people visited our website with a peak of 2,510,603 visits and 1,768,424 new visitors on 27 October.

How did our forecasts help?

Our trusted, authoritative warnings enabled many people, including contingency planners, emergency responders and the general public, prepare for and take action to avoid the impacts of the storm, for example:

- People opted to work from home to avoid travelling in adverse conditions.
- Local councils cleared drains of leaves the day before and had staff on standby throughout the night and clearing up during the morning of the storm.
- Train services were cancelled to avoid the danger of trees on the lines. Extra buses were able to get passengers to their destinations.
- Insurers received fewer claims as people protected their property against the wind.

Impacts - what happened?

- Hundreds of trees were blown over.
- Four people died as a result of falling trees.
- More than 660,000 homes were left without power.
- Gusts of up to 99 mph were recorded on the Isle of Wight.
- Heavy rain caused some localised flooding with the highest rainfall of 53.6 mm recorded in Cardiff.
- Widespread transport disruption to road and rail with cancelled or delayed trains and flights.

Comparisons to other storms

The storm is a notch down in terms of the strength of the winds in comparison to the Great Storm of 1987 or the Burns Day Storm of 1990. You don't have to go far back to find a more powerful storm than this - for example, we saw winds of over 100 mph in Edinburgh when Winter storms, early January 2012.

To find a storm of similar strength in southern parts of the UK, and at a similar time of year, you'd have to go back to the Strong Winds - 27 October 2002 over much of the south of the UK.

Working together

We're grateful to all our partners in the media, government and agencies for helping us get our trusted warnings out to the public and those who keep them safe.

Our accurate forecasts received widespread praise. Here's a selection of some of the comments:

Prime Minister, David Cameron, speaking about the response to the storm said: "I got together with the different agencies to make sure that everything that could be prepared was being prepared. The emergency services, as ever, do a brilliant job. These are difficult things to handle because you don't know for certain how strong the storm will be. | think the Met Office provided good information and updated it regularly. That really is the advice to people: things will get back to normal but make sure you consult the relevant websites before you travel"

London Mayor, Boris Johnson thanked utility companies for helping to restore power, gas and water as soon as possible and the Met Office, "who gave accurate and useful predictions of what was to come".

Transport Minister, Robert Goodwill, praised the efforts of workers who have tried to minimise disruption: "We knew this was coming, the Met Office got this absolutely right and of course this couldn't have happened at a worse time. the early hours of Monday morning are the most difficult time. It isn't as if we weren't aware this was going to happen and people have been out all night ensuring what can be done, is being done."

Minister for the Cabinet Office and Paymaster General, Mr Francis Maude: "The primary responsibility for emergency planning sits with local responders. The Cabinet Office works with other Departments, devolved Administrations and emergency responders to enhance the country's ability to prepare for, respond to and recover from emergencies. The whole House will want to thank the emergency services, local authorities and the Met Office, who did a brilliant job working together to prepare effectively for and respond to the effects of Monday's storm."

Steve Barnes, Policy Manager, Civil Contingencies Secretariat Cabinet Office
"Thank you to yourself, the advisers and forecasters for all your work in this event. Everyone here and at No10 thought it was spot-on and a really good call."

Mark Taglietti, Head of ICT Service Delivery & Vendor Management, University College London Hospitals: "| used the forecast that was widely communicated in the press last week and over the weekend to pro-actively engage a range of managed services providers to conduct pre-storm assessments and remedial activities across some of these locations in preparation for potential flooding. This resulted in a range of short term mitigation activities and the provision of local accommodation for our 'core ICT engineers' on Sunday night into Monday morning. | am extremely pleased to advise that the level of warning provided, its accuracy, and subsequent activity across the NHS Trust lmost certainly mitigated against service disruption. Therefore thank you and all at the Met Office for providing the information in a timely manner and enabling a critical NHS Foundation Trust to assure network and service availability to our values customers, i.e. nurses, administrators, consultants and patients etc."

What makes our accurate forecasts possible?

Without our warnings, the threat to public safety and damage to the UK economy and infrastructure would have been a lot worse. New ways of collecting, measuring and interpreting data have helped us to correctly predict the timing and severity of the 'St Jude's Day' storm.

Increased observational coverage of the atmosphere over the ocean to the south and west of the UK has improved by increasing the quality and quantity of observations from ships, aircraft, buoys, radar and satellites. Developments in our science over many years, investment in our supercomputer and continually refining the computer models used in forecasting further increase the accuracy and reliability of our forecasts.

In summary, advances in science, technology, communication and platforms, and working with partners all contribute to being able to make forecasts that were previously impossible.

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