Ice Flows Game

Education Resource Pack

http://www.iceflowsgame.com

UNIVERSITY OF EXETER

Geographical Association

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

First published Dec. 2018

Written by Alan Parkinson, Consultant to the Geographical Association, and Dr. Anne Le Brocq, Senior Lecturer, University of Exeter.

Version 1.3 (Dec. 2018)

This resource pack was created in partnership with the Geographical Association.

The game "Ice Flows" was developed by Dr. Anne Le Brocq at the University of Exeter in collaboration with Inhouse Visuals and Questionable Quality.

Funding was provided by the Natural Environment Research Council (NERC) through a research grant led by the British Antarctic Survey.

Videos

Thanks to Twila Moon, Kenny Matsuoka, Sainan Sun, Olga Sergienko, Andres Rivera, Hartmut Hellmer and Christel Hansen for voicing the penguins in the explainer videos.

Images

Acknowledgement to Hugo Ahlenius, UNEP/GRID-Arendal for several images and maps from http://grida.no
NASA
NERC
British Antarctic Survey
Geographical Association
Mark Brandon – used under CC license
Alan Parkinson
University of Exeter

Education Resource Pack Contents

Introduction	**p. 4**
Introduction to the Cryosphere	**p. 7**
Ice Sheets and Shelves	**p. 11**
Playing the Game	**p. 18**
Sea Level Change	**p. 23**
Return to the Cryosphere	**p. 26**
Curriculum resources	**p. 30**
Specification links: GCSE and 'A' level	**p. 59**
Glossary	**p. 65**
Additional reading and resources	**p. 67**

Introduction

Welcome to the Ice Flows Game Education Resource Pack for Teachers

"Ice Flows" is a game built on a simplified representation of the behaviour of the Antarctic Ice Sheet: how the ice flows and how the speed of flow responds to changes in the environment. The two key drivers of change to impact on this flowing ice sheet are changes to **snowfall** and **ocean temperature**. The game allows players to impose their own climatic changes to control the resulting thickness and extent of the ice sheet, in order to guide penguins to fish they can eat. If the players get it 'wrong', the penguin may meet its doom in the jaws of a Leopard Seal. The game was launched in August 2016, as an app and also a website version.

Watch video 4 "The Game"

Aim

The aim of developing the game was to promote understanding of the complexity of an ice sheet system and how it responds to climate change, by enabling players to carry out their own ice sheet model experiments, much like the scientists working on the scientific research that underpins the way the game works.

Why did we make a game?

A game helps not only to visualise the system, but also to provide an immersive environment for the players to fully understand the behaviour of the ice environments and how it responds dynamically to changes in the environment, over a long period of time.

Where is the game based?

The game has a number of levels, which demonstrate the ways in which different parts of the Antarctic will respond to climate change. The game is based on the behaviour of ice flowing into the Filchner-Ronne Ice Shelf. It is a complex of two ice shelves, which are separated by Berkner Island. The western part of ice shelf – the Ronne Ice Shelf - is named after American Edith Ronne, one of the first women to stay in Antarctica over the winter, wife of Norwegian explorer Finn Ronne. The eastern part – the Filchner Ice Shelf – is named after German explorer Wilhelm Filchner.

Who developed the game?

The game development was led by Dr. Anne Le Brocq, who is a Senior Lecturer in Physical Geography, at the College of Life and Environmental Sciences, University of Exeter. The game was developed in collaboration with games developers *Inhouse Visuals* and *Questionable Quality*, in association with the *British Antarctic Survey*, who are leading the research project which funded the game (see https://www.bas.ac.uk/project/fiss/ for more information).

What is in this pack?

This Education resource pack provides further information on the game, and the scientific principles underlying it. It provides ideas for how to use the game with secondary school students, to help introduce a number of key ideas relating to ice sheets, ice movement, landscape change, and the possible impacts of climate change as ice melts. Recent iceberg calving events, such as iceberg "A-68" which broke off the Larsen C ice shelf in the Antarctic, have put these important changes into the news, and similar issues are happening in Greenland.

The pack provides an enquiry sequence, which takes students through the key ideas behind the game, before playing the game itself and reflecting on some possible, probable and preferred futures for the icy regions of the world.

The pack is particularly suitable to **KS3 students**, due to the nature of the game, and the complexity of the thinking that is required about the ice sheets and the way that they are affected by changes in snow fall and sea temperatures. There are, however, overlaps with both **GCSE and 'A' level specifications**, and we have provided some thoughts on extending students' thinking in these areas. Similarly, upper KS2 pupils may find the game enjoyable, and want to learn more about the geography that underpins it.

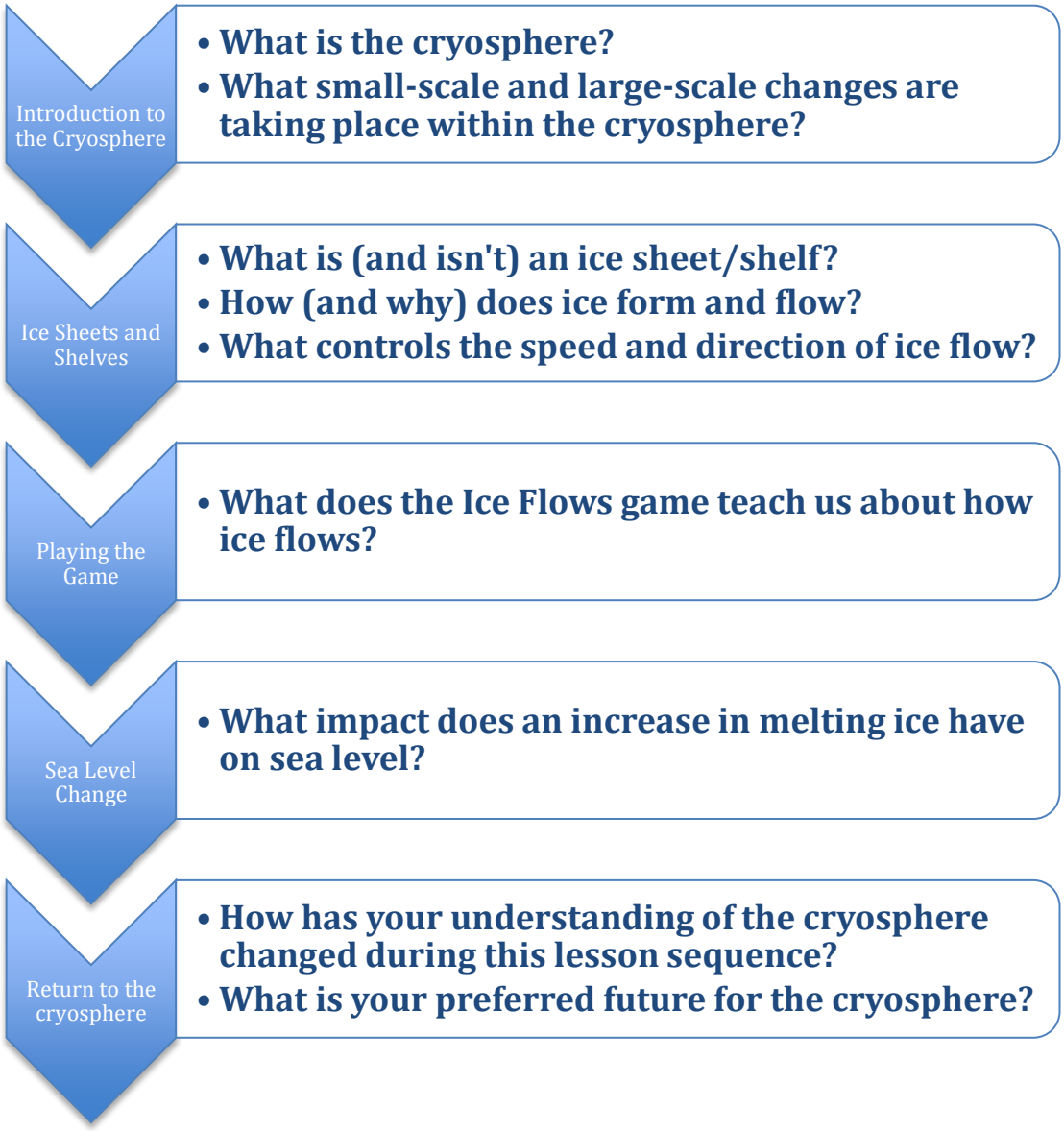
The pack also includes curriculum resources, specification maps for the key qualifications offered by the main awarding bodies, teacher and student resource sheets, and some ideas for using the game for homework and outside the classroom.

At various stages as you work through the pack, you can use the Iceberg of Understanding sheet to record and assess how 'deep' your knowledge, and that of the students is. We hope that you learn by playing the game, and that your students understand the role that 'game based learning' can play in introducing difficult concepts in geography (and other subjects).

Our curriculum resources are included in a section towards the end of the resource. You will also find **questions** which could be used with students to help them develop their understanding of the environment within which the game takes place. These are marked by these inquisitive young penguins, who are all keen to know what the students have to say.

Learning pathway

The resource materials follow the workflow below, beginning by thinking about what ice sheets are and how they work, and ending with how changes in ice sheets can impact on our lives.



The following pages provide information on these sections.

Section 1: Introduction to the Cryosphere

Introduction to the Cryosphere

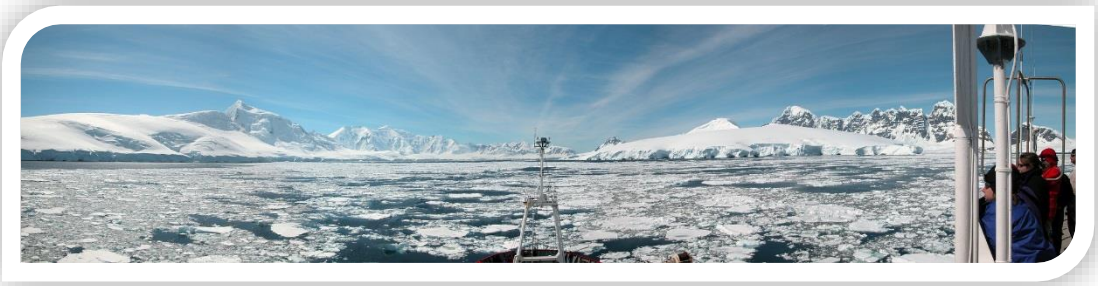
- Introduction

This section of the education resource pack is aimed at teachers and will introduce you to the environment within which the Ice Flows game takes place. Example questions for the students are provided in this section, and the curriculum resources section provides activity sheets for the students.

The environment in which the game takes place, known as the **cryosphere,** is of vital importance to the planet in terms of climate change, sea level, resource availability and hazards. In this resource we will concentrate on a particular part of the **cryosphere**: **ice sheets**. Changes to the amount of ice held in **ice sheets** are important as rapid, large-scale, retreat will have an impact on global sea level over short (decadal) and long term (millennial) timescales.

The game is set in the Antarctic Ice Sheet, in particular in a region called the Weddell Sea Embayment. The Weddell Sea Embayment includes the Filchner-Ronne Ice Shelf, a large mass of floating ice more than 1000 m thick and over 800 km across, but also includes the grounded parts of the ice sheet which feed into the ice shelf. The ice feeding into the ice shelf contains ice equivalent to ~13 m of potential global sea level rise. The Ice Flows game will teach you about how the ice in this region responds to changes in the environment around it.

Before we start though, do you know what the cryosphere is?



"Going into the Neuymayer Channel from th" (CC BY-NC-SA 2.0) by Mark Brandon

Introduction to the Cryosphere

• What is the cryosphere?

The Cryosphere is one of several large-scale systems that operate on the earth and interact with each other. There are six of these spheres – how many of them do you think you can name?

The six spheres are:

1. **The atmosphere**
2. **The biosphere**
3. **The cryosphere (our favourite)**
4. **The pedosphere**
5. **The lithosphere**
6. **The hydrosphere**

The spheres, and the processes which occur within them, overlap and interact with each other.

Use the 'Which Sphere am I?' sheets to find out more, and practice your knowledge

The cryosphere is a term used to describe those components of the Earth system that contain a substantial fraction of water in its frozen state, and the areas where they are found.

The cryosphere is made up of a number of components, which exist both on land and oceans:

- **snow**
- **river and lake ice**
- **glaciers**
- **sea ice**
- **ice shelves**
- **ice sheets and ice caps**
- **frozen ground (including permafrost)**

Introduction to the Cryosphere

- What small-scale and large-scale changes are taking place within the cryosphere?

Each component of the **cryosphere** has a different lifespan – some may be relatively short, but others may be millions of years old. The **cryosphere** is sensitive to temperature change and is a natural indicator of climate variability.

In the short term (e.g. seasonally) snow patches may last over the winter and melt the next summer. **Sea ice** (frozen sea water) reaches is greatest area in the winter and then decreases in area over the summer.

On a decadal scale, however, we have observed decreasing **sea ice** extent and thickness in the Arctic (comparing the same season), and **glaciers** have lost both ice mass and length globally. This is mainly due to increased air temperatures resulting from increased greenhouse gases in the atmosphere. Smaller glaciers are a problem for some areas which gain a large part of their drinking water from meltwater, particularly in the summer months, or where rivers originate in ice sheets or ice caps. Large ice masses such as the Greenland **Ice Sheet** and the West Antarctic **Ice Sheet** (WAIS) have seen particularly large losses. It is thought these losses may be speeding up due to changes in the velocity of outlet **glaciers**, which take ice away from these source areas. These losses have been contributing to global sea level rise.

In the long term, in the last 20 000 years, over 20% of the earth's land surface has been exposed by shrinking **ice sheets** and **ice caps** in response to warmer global temperatures since the "Last Glacial Maximum".

Questions to answer

1. What is the cryosphere?
2. Why is the cryosphere important to people who live a long way from areas covered by ice?
3. How does the cryosphere change over:
   a) short time scales (seasonal)
   b) medium term (decadal)
   c) longer term (millennial)

How is the cryosphere changing?

See the **Stories of Changing Ice** activity sheet in the curriculum resources section. This asks students to research a particular recent change to Antarctica, and produce a short presentation of the effects in some format of your choice.
At the time of the calving of Larsen C, in July 2017 BBC News released an interview with Professor Helen Fricker from the Scripps Institute of Oceanography.
Listen to it here:
http://www.bbc.co.uk/news/av/science-environment-40444569/ice-shelves-need-to-calve-icebergs
It provides a good introduction to the significance of the cryosphere to other parts of the world, and the reasons why icebergs calve.

The next section goes into more detail about the nature of ice sheets which will help to understand and evaluate the implications of these stories.

We recommend that you use the 'Iceberg of Understanding' sheet to record how students' knowledge and understanding changes as they use the pack and play the game. How deep can you take their knowledge?

Section 2: Ice Sheets and Shelves

Ice Sheets and Shelves

- What is (and isn't) an ice sheet/shelf?

Photo by Plume: *https://morguefile.com/p/1035639*

Ice Sheets

Watch video 2 "Ice Sheets & Ice Streams" up to 2:31

An **ice sheet** is like a large **glacier**, but differs from a **glacier** in that it covers an entire landscape, on a large scale, whereas a **glacier** is usually confined to a mountain valley. An **ice sheet** tends to cover tens of thousands of square kilometres and can be several kilometres thick. **Ice sheets** cover large areas of Antarctica, and Greenland.

Ice sheets form on land, and, hence, are made from compacted snow, rather than from frozen sea-water (this is **sea ice**). The process of ice formation takes decades – see the next section for more on this.

Ice Streams

 Watch video 2 "Ice Sheets & Ice Streams" from 2:31

Ice streams are like giant rivers of ice. Like rivers, ice flow organises itself into tributaries and fast flowing main channels. The **ice streams** drain the majority of the ice from the **ice sheet**, and changes in their behaviour can have massive impacts on the whole **ice sheet**.

Ice Shelves

 Watch video 3 "Ice Shelves"

Ice shelves are formed when the ice at the edges of the **ice sheet** gets thin enough to float, forming floating extensions of the **ice sheet**. Because they are in contact with the ocean, **ice shelves** can melt considerably from below as well as above.
Much of Antarctica is fringed by **ice shelves**. The Ross and Filchner-Ronne ice shelves each have areas greater than the British Isles.

Icebergs

 Watch video 4 "Icebergs"

An **iceberg** is a floating mass of ice which has calved (broken off) a larger ice mass. Because the density of ice is lower than water, ice has a greater volume than the equivalent unfrozen water and so part of the **iceberg** floats above the water, though the majority of it is submerged below the surface of the ocean.

The largest iceberg ever recorded was Iceberg B-15, which broke off the Ross Ice Shelf in March 2000. It measured almost 300 kilometres long and 40 kilometres wide, with a surface area of 11,000 square kilometres.

Interesting aside:
What happens to the ice that breaks off?

This BBC article: http://www.bbc.co.uk/news/science-environment-40321674# talks about the iceberg that broke off Larsen 'C' in July 2017. It is thousands of square miles in extent and will take years to melt as it moves away from the ice shelf.

Could we make use of icebergs to help countries suffering water shortages?
Read this article here:
https://www.theguardian.com/environment/2017/may/05/could-towing-icebergs-to-hot-places-solve-the-worlds-water-shortage

Questions to ask

- What is the main difference between an ice sheet and sea ice?.
- What is different about an ice shelf compared to the rest of the ice sheet?
- What is the largest iceberg ever observed, and when was it formed?

Did you know?

There's a whole vocabulary of words for pieces of floating ice of different sizes, some from icebergs (e.g. bergy bits) and some from frozen sea water (e.g. frazil ice and pancake ice). But **remember** – icebergs are made of compacted snow, whereas sea ice is made of frozen sea water. A mixture of ice bergs and sea ice is called "ice mélange" - as mélange is French for "mixed".

Ice Sheets and Shelves

- How (and why) does ice form and flow?

Ice accumulation

As mentioned above, glaciers and ice sheets are made from compacted snow, ***not*** frozen sea water - this is sea ice. In order for ice to form, snow has to fall and remain unmelted through the summer to the following winter, where it is added to by another layer. And then another, if conditions allow. When snow lands on the ground, it traps air between the flakes, and has a very low density. The impact of further falling snow will knock out some of that air, and there will also be settling of the snow pack due to melting and this will remove some of the air from the bottom layers.

Each layer of snow that falls changes the lower layers of snow, taking them through a stage called **firn** or **nevé** to become ice. This will turn the snowflakes from their individual crystalline form towards granules. Glacier ice has very little air in it and will become a blue-ish colour as the air is removed. The most recent snow will be lighter in colour until the weight of fresh layers starts to compress it and change its structure from flakes to grains.

See the **Pinterest** board for some useful diagrams on ice formation which could be used with students to show them the process involved.

Glacier Ice: Image by Alan Parkinson

Ablation

The term ablation is used to describe the loss of ice from an ice mass. This can include melting due to positive air and ocean temperatures, but also includes the loss of mass through iceberg calving.

Mass balance

Ice masses are said to have a 'mass budget' or "mass balance" which balances out the ice that is being gained (accumulation) and lost (ablation), in the same way that a financial budget balances income and spending. If the budget is positive, the ice mass grows in size, if it is negative, the ice mass reduces in size.

Ice Flow

In general, a glacier gains mass in the interior and loses it at the edges. This causes a gradient in the ice surface which causes the ice to flow. The ice flows at a speed which balances out the inputs and outputs and maintains the ice sheet or glacier in an equilibrium state.

See the 'Ice Formation Activity' sheet for questions and tasks for students to use. Also see the 'Snow to Ice' activity sheet, which students should complete.

Ice Sheets and Shelves

• What controls the speed and direction of ice flow?

Although people sometimes talk about glaciers retreating, they never actually move (flow) backwards. They continue to move (flow) forwards, but if the rate of ablation is greater than the rate of accumulation, they will lose more ice from the **snout** or front than can be replenished and the *ice front location* retreats.

Ice flow is driven by gravity. The speed at which it flows is, therefore, largely due to the surface gradient of the ice, the steeper the gradient, the faster the ice flows. However, the flow speed can be affected by a number of other factors, which include:

- The temperature of the ice which affects the ice rheology or effectively how "runny" the ice is.
- Whether the ice is flowing over hard bedrock, or soft sediments that the ice can plough through
- The presence of water at the base of the ice, which can lubricate the ice base and reduce the frictional resistance.

When the ice grows big enough to reach the ocean, it can float to form **ice shelves**. **Ice shelves** are relatively flat, however, which suggests they would flow slowly. However, being afloat, ice shelves experience no friction under them, so they can potentially flow extremely rapidly without much of a surface gradient to drive the flow. Unless the ice shelf is constrained by an embayment (providing drag at the sides) or a high point off shore (a "pinning point") it is likely to break up quickly after it floats. To be viable, an **ice shelf** need to be in an embayment or have a stabilising pinning point.

These constrained ice shelves **buttress** (hold in place) the ice sheets behind them, and if they are weakened or removed, the rate of flow of the grounded ice towards the oceans will speed up. Several ice shelves have broken up on the Antarctic Peninsula, and should more ice shelves break up, this may lead to more ice loss from the land, which will directly impact on sea level rise.

(See video 3 "Ice Shelves" for more detail)

Interesting aside:
One of the nearest scientific bases to the Filcher-Ronne Ice Shelf is the UK's Halley Station, which was in the news itself in early 2017, when the entire station had to be moved because a rift was opening up in the Brunt Ice Shelf on which it is located. The station was closed down and left unmanned during the Summer 2017.

See a 360 degrees tour of the station here: https://halley360.antarcti.co/
Read about the station here: https://www.bas.ac.uk/polar-operations/sites-and-facilities/facility/halley/
Read about its successful relocation here: http://www.bbc.co.uk/news/science-environment-38841100
And the decision to close it during winter (summer 2017): https://www.bas.ac.uk/media-post/halley-research-station-antarctica-to-close-for-winter/
Or read more about the Halley automation project - highlighting the engineering side of working in Antarctica: https://www.bas.ac.uk/project/halley-automation/

Section 3: Playing the Game

Playing the Game

- What does the Ice Flows game teach us about how ice flows?

It's time to play the game!

You will need a copy of the game on a browser, or a mobile device. See the 'How to Get the Game' sheet for more details.

Use the 'Ice Flows Game – Playing the Game – Student Guide' sheet for printable guidance for students on how to play the game.

➢ Click to play in the browser: http://www.iceflowsgame.com/iceflowsgame.html
You will need to use Mozilla Firefox, Google Chrome, Safari or Microsoft Edge.

You can choose from four options, including the option to press PLAY straight away:

Music plays during the game, however, the music and sound can be muted if preferred e.g. when demonstrating the game to students.

➢ Click OPTIONS to mute the music and change the volume of the sounds that play during the game.

➢ Click **PICK A PENGUIN** to choose which character to play.

You will start with RONNE: a female Emperor penguin from Antarctica. As you play the game, you can earn points, to 'buy' other characters in the shop.

➢ Click ABOUT to find out more: http://www.iceflowsgame.com/#chars. Or check out the '**Meet the Characters**' resource sheet.

The final option, which you may want to use the first time you play the game, is a **TUTORIAL** option. This explains some of the concepts about ice sheets which we have introduced above.

The game is called **Ice Flows** because, of course it does. It flows due to gravity, and it flows slowly, but it flows. In order to make the game playable, the time scale is sped up. The speed of ice flow is such that one minute of game time represents many thousands of years.

You will see the ice moving from left to right across the screen. It starts on land and then moves out into and over the water. At the far right, ice blocks break off, and separate from the main ice mass. This process is known as iceberg **calving.** The ice forming on land is called a **terrestrial** ice sheet. If ice grows out over the water, it becomes an ice shelf. If the ice is thick enough to become grounded on the bedrock below, it will become a marine ice sheet, even if the bedrock is below sea level.

➢ Press **PLAY** to start the game if you're ready.

You must play the TRAINING levels to a satisfactory standard before you can unlock the main game levels, these are greyed out at this stage.

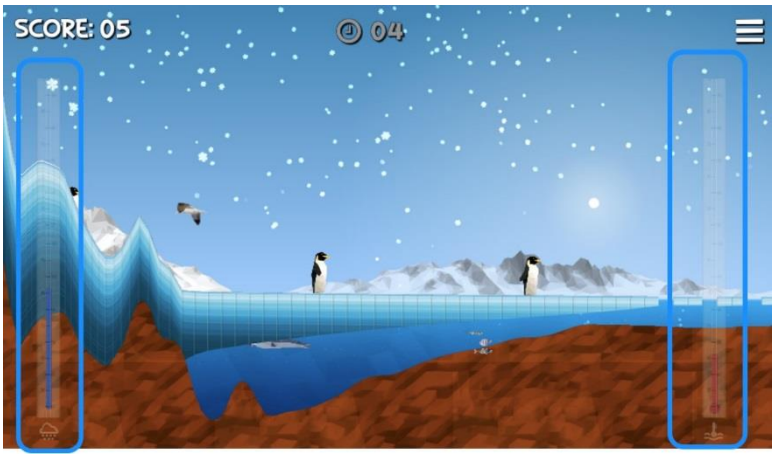
➢ Click on the TRAINING icon.

During the game, penguins will appear on the left of the screen, and travel with the ice towards the right-hand side. They are hoping to 'high-five' the Albatrosses as they go down, and in the second level onwards, dive down to eat the fish on the right. If the ice sheet is not the right size, this will not happen and the penguins will miss the albatross, and end up in the sea at the mercy of the waiting leopard seals.

You will be rewarded for accuracy, earning points and stars. This will also unlock new levels and gain credit, which can be used to 'buy' new characters to play in the game.

There are two variables to control the game:
The first level, **LET IT SNOW,** introduces the concept of "snowfall", where you can alter the thickness of the ice sheet by changing how much snow falls. A higher level will make the ice mass thicker over time. This is controlled with a slider on the left hand side of the screen.

The second level, **IN HOT WATER,** introduces the concept of changing the ocean temperature. Changing the ocean temperature alters the thickness of the ice shelves, and when they get to a critical thickness, results in gaps opening up as icebergs calve. This is controlled with a slider on the right hand side of the screen.



There will be a lag while the adjustments feed into the system. This reflects the way that the physical system works: changes will take some time to be reflected in the thickness of the ice mass. If the ice is in an **equilibrium state**, it means it isn't changing size, the snowfall and melting & calving are balancing each other.

The effect of warming water is discussed in video 5 "Climate Change".

Icebergs breaking off the ice opens up gaps in the ice - the penguins need to dive through these to get the fish for points, but if they dive at the wrong time, they will be attacked by the leopard seal called Erebus. Leopard seals are predators and will eat penguins if they can. Erebus is the name of an active volcano in Antarctica.

The game matches the processes that occur in the real world:

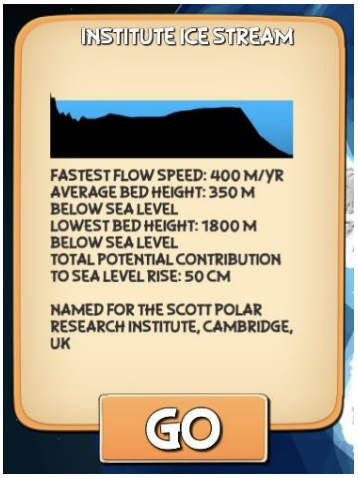
a) Snow accumulation in the interior is the process that builds the ice mass.
b) Ice is also lost through melting of the ice from beneath, where it is in contact with sea water.
c) Ice is lost from the edge of the ice shelves by iceberg calving to help maintain equilibrium

Also note that the shape of the **bedrock** beneath the ice will also have an impact on the way the ice responds to changing the snowfall and ocean temperature. If the bed slopes down inland, the ice will be more susceptible to retreat.

Once you have played through the TRAINING and achieved 6 stars in total, you can move on to play the main game levels. There are 8 levels, each of which takes place on a different **ice stream**.

➢ Click on the RONNE icon.

The first level, the **Foundation Ice Stream** is unlocked. To unlock further levels, you must gain 2 more stars for each level. Each level provides information on each ice stream.



How many levels can you unlock, and how many penguins can you buy?

A separate 'How to Play' Student Guide, which can be printed off as required, is provided in the Curriculum Resources section.

Also see the 'Ice Flows Explainer' sheet for an activity sheet, which asks students to experiment with the sliders and explore what happens.

These can be turned into a separate experiment, and an 'Experiment Form' has been provided for that activity too.

Playing the Game

• Questions for students

We have provided some questions that you could ask students while they are playing the game. These discussions can open up further thoughts about the scientific background to the action.

- The ice flow is sped up to make the game work. How fast do you think the ice is really flowing?
- Do you think that ice can flow in reverse?
- How thick do you think the ice shelf is in reality?
- How quickly does the ice grow in thickness when you make it snow more?
- Why is there a delay in the ice sheet growing in length?
- How quickly do gaps open up in the ice when you increase the sea temperature?
- Why do you think a warmer sea makes the ice thinner?
- Why do you think the particular characters were chosen?

Section 4: Sea Level Change

Sea Level Change

- What impact does increasing melting ice have on sea level?

Watch video 5 "Climate Change & Sea level" from 2:22

As ice melts, it changes from solid ice to liquid water. Melting ice from terrestrial **glaciers** and **ice sheets** goes into the world's oceans and has an impact on global sea level. Floating ice in **ice shelves** and **icebergs** has already displaced sea water so does not contribute directly to sea level rise when it melts. Loss of floating ice may, however, contribute indirectly through the loss of "buttressing" provided by the floating ice, holding up the ice flowing into it.

When we talk about **sea level change** in this context, we are talking about global average sea level rise, or **eustatic** sea level change. Because the land also changes as a result of the loss of ice (e.g. it rebounds because the weight of ice is not pressing down on it), the effect of this **eustatic** sea level change is not experienced equally around the world, this is known as **relative** sea level change.

The water around the polar Antarctic ice sheet is cold, but in places it is warm in comparison to the ice itself and the water melted from the **ice sheet** and **ice shelves**. This water, called "Circumpolar Deep Water", can be driven closer to the **ice sheet** by changing wind patterns, where it can cause melting of **ice shelves** and, hence, cause **ice sheets** to reduce in size. A changing climate may cause more of this warm water to come into contact with the ice and cause **ice sheets** to retreat.

See the 'What is the temperature in the Antarctic' sheet for information on Antarctic air and sea temperatures

Understanding this link between changing weather patterns, ocean circulation and retreating **ice sheets** was the motivating factor for the research work which underpinned the creation of the game. This work was featured in an interactive video by 'The Guardian'. You may wish to watch this before considering the questions that follow: https://www.youtube.com/watch?v=qsgXAJxFx0A

What is the potential sea level rise?
Marine West Antarctic Ice Sheet: ~3 metres
Weddell Sea sector: ~13 metres
East Antarctic Ice Sheet: ~54 metres
Whole Antarctic Ice Sheet: ~58 metres
Antarctica & Greenland combined: ~65 metres

These are absolute numbers, the amount that they will contribute over time is still very uncertain. We wouldn't expect these kinds of sea level rise values for many hundreds or thousands of years. A scientific paper[1] published in 2016 gave the worst case scenario as 1 metre of global eustatic sea level change from the Antarctic Ice Sheet by 2100.

How can we visualise the impact of sea level rise?
We will use an interactive mapping website called Firetree Flood map, produced by Alex Tingle, to visualise possible sea level rise, and how it might affect areas of the world's coastlines.

There are some limitations associated with the way that sea level rise is represented in the map, e.g. eustatic not relative sea level; not allowing for the likely use of sea defences to prevent inundations, and the more local variations that would occur as sea level rose significantly, but it is useful to identify low-lying areas at potential risk of future flooding.

See the 'Sea Level Rise Activity Sheet', which students should complete.

[1] DeConto, R. M., & Pollard, D. (2016). Contribution of Antarctica to past and future sea-level rise. Nature, 531(7596), 591.

Questions to ask

1. How much could the Antarctic Ice Sheet raise sea level by?
2. Does a melting ice shelf increase sea level?
3. What is the size of the Filchner-Ronne and Ross ice shelves?
4. Which other major ice shelves are there in Antarctica?
5. What are the possible implications of ice sheet changes for the UK?
6. What are the possible implications of ice sheet changes for coastlines around the world?

While students are completing this activity, you should discuss the accuracy of tools like the Firetree map. Ask students to think about what the issues might be before sharing some of them:

- the maps ignore the existence of sea defence and flood management which would reduce the extent that is shown on the map as being inundated
- some areas which are apparently 'safe' would be badly affected by other inundations which would sever communications and badly affect the local economy

Section 5: Return to the Cryosphere

Return to the Cryosphere

- How has your understanding of the cryosphere changed during this lesson sequence?

We have seen that changes in the cryosphere can have a significant impact on communities around the world through changing sea levels. We now return to the cryosphere to think about how our understanding has changed through playing the game.

Questions to ask yourself (!) as well as the students:

- **What did you know about the cryosphere at the start of this pack, and before you played the Ice Flows game?**
- **What do you know now?**
- **Complete the Iceberg of Understanding sheet at this point**

Return to the Cryosphere

• What is your preferred future for the cryosphere?

The cryosphere is changing in response to changes taking place in global systems, which interact with the processes that have created it over previous millennia. The cryosphere is affected by changes in air temperature, ocean temperature, and in the amount of snowfall.

The future is something that geographers are interested in more than most subjects. The future for Antarctica, Greenland and other ice-covered areas is uncertain. Climatic warming will lead to increased melting but might also lead to increased snowfall – warmer air can hold more moisture, so precipitation over ice sheets may increase. However, it is unlikely to be enough to offset the melting.

Smaller ice masses are already significantly retreating. Some mountain glaciers have shrunk in size, and the cities which depend on them for their drinking water are getting worried. You may be able to find some news stories of cities such as La Paz in Bolivia.

Was the calving event of ice berg A-68 from Larsen 'C', reported in July 2017, the sign of a disintegration of large ice masses in Antarctica, or a natural part of ice shelf life cycle?

There are **three** different futures which geographers usually consider, and they are shown below: possible, probable and preferred.

When considering the future for the world's ice sheets, we need to think about the controls which were mentioned in the game: the amount of snowfall, and the sea temperature. What impact might changing patterns of climate have on these two variables?

- What is possible?
- What is more probable?
- What would be our preferred situation?

What changes would a reduced ice volume cause to the planet? How can we coordinate a global effort to raise awareness of the actions that we need to take?

Questions to pose to students

- **How could we reduce the rate of ice loss in the future? Is that possible?**
- **What could individuals do?**
- **What could nations do?**
- **What could the international community do?**

What is the future for the Filchner-Ronne Ice Shelf?
Students should choose one of the 'Future Choices' sheets and complete it with some information from their research.
There is a suggested list of further reading at the end of the resource.

Remember that Antarctica is governed by the rules of the Antarctic Treaty. This is administered by a group of signatories, which ensures that nobody can claim any part of Antarctica for their own and has to behave in such a way that they do not damage the continent.
https://www.bas.ac.uk/about/antarctica/the-antarctic-treaty/the-antarctic-treaty-1959/

Resources

4.1 Lesson/Session Plans **p. 31**

4.2 Lesson/Session Resources: **p. 34-58**

Lesson 1
Resources
- Iceberg of Understanding p. 34
- Which sphere am I? p. 35-36
- How Does Glacier Ice Form? p. 37
- Snow to Ice p. 39
- Stories of Changing Ice p. 40

Lesson 2
Resources
- Ice Flows: How to get the game p. 42
- Ice Flows: Playing the Game p. 43
- Ice Flows: Explainer p. 45
- Ice Flows: Experiment Form p. 46
- Student Feedback Sheet p. 47

Lesson 3
Resources
- What temperature is the Antarctic? p. 48
- Sea Level Rise Activity sheet p. 49

Lesson 4
Resources
- Frosty Futures p. 52

Additional Resources
- Meet the Characters p. 54
- Map(s) of Antarctica p. 57
- Blank World Base Map p. 58

Powerpoint Presentations
These can be downloaded from the Ice Flows Game website in powerpoint format

Lesson/Session Plans

Here are suggested outlines for 4 sessions to use to introduce the ideas behind the game, play the game and reflect on the future for Antarctica. Feel free to adapt them to your own school's circumstances.
The resources referred to are available in the **Curriculum resources** document.

Lesson 1

Introducing the game and the "Cryosphere"
See Powerpoint 1 for a structure for this lesson

You may want to show Kalle Ljung's dramatic film to students as they enter the room: https://vimeo.com/124858722

Play video 1 "The Game"

- Introduce the term **cryosphere** to students.
- Ask them what they think it might mean and break down the word for them.
- *Think of terms such as 'cryogenics' or think of other large scale environments ending in the word 'sphere'*
- Discuss elements of the cryosphere, and where they might be found.
- Use the Iceberg of Understanding, and fill it in at the start of the series of sessions.
- You could use an information race: challenge pairs of students to find the meaning of the terms and write them down: *half of the group could use the internet and half use a dictionary.*
- Map the location of the world's ice at the moment using a **blank world base map** and a suitable thematic map from an atlas, or the Cryosphere map from Grida.no (added to one of the slides or available as a separate download)
- Use the **Which sphere am I?** activity sheet to reinforce what each sphere does.
- Where is the ice found, and what influences these locations e.g. altitude, latitude.
- **Ice ID** – show images of different ice features, and use these to help students understand the difference between **glaciers, ice sheets and ice shelves.** These could be obtained from http://www.swisseduc.ch/glaciers/

- Show a map of Antarctica, and the different ice sheets and shelves, and locate the Filchner-Ronne ice shelf on the continent. This is one of the largest ice shelves, and the location for the game.

Play video 2 "Ice Sheets and Ice Streams"

- What is the ice in ice sheets like and how does ice form? Use the Snow to Ice activity to explore the process that causes ice to form on land.

 Play videos 3 & 4 “Ice Shelves” and “Icebergs”

Homework / pre-reading for next lesson:
Stories of Changing Ice activity – this could produce a starter for Lesson 3, with students presenting their findings if appropriate.

Lesson 2

Playing the game.
See Powerpoint 2 for a structure for this lesson

This requires an IT room to be booked, or availability of mobile devices for student to access, with the app installed. Use the browser version of the game.

- Demonstrate the game first of all, and demonstrate the two sliders which control the game variables, and the Tutorial aspects.

- There are two activity sheets for students to use when they are set loose on the game with some time to explore.
    - Playing the Game – Student Guide
    - Ice Sheet Model Experiment sheet – provides a framework for seeing how the different settings will impact on the ice shelf.

- Could also use the **Student Feedback** sheet to identify some appropriate changes that might be made, and reflect on what they learned from playing the game.

Lesson 3

Changing sea levels
See Powerpoint 3 for a structure for this lesson

- Complete the “What temperature is the Antarctic?” Activity sheet.

 Play video 5 “Climate Change and Sea level”

- Explain that the melting of ice on land contributes to sea level rise. Ice shelves don’t contribute directly, but indirectly.
  There is the option to carry out an experiment using ice cubes and water. See the video for how this would work. Ice that is already in the sea doesn’t raise the level when it melts.
- Complete the Flood.Firetree activity sheet to explore what may happen as sea levels rise.

This requires an IT room to be booked, or availability of mobile devices for student to access the website with the mapping.

- Use the activity sheet to explore the map and identify areas which would be at greatest potential risk from sea level rises.
- Could introduce the idea of futures here, which will be returned to in Lesson 4.

Lesson 4

Icy Futures

See Powerpoint 4 for a structure for this lesson

- Display National Geographic images to show – what the world would look like if all the ice melted http://www.nationalgeographic.com/magazine/2013/09/rising-seas-ice-melt-new-shoreline-maps/
- What would be the impacts of rising sea levels on the world, and on its cities?
- Discuss what was learned using the Firetree mapping tool.
- Introduce the idea of the 3 futures: possible, probable and preferred.
- Complete the research using some stories from newspapers and other websites which explore some possible future changes to ice sheets and shelves in Antarctica. Use the Stories of Changing Ice.
- What are the possible ways that ice might be protected from melting at increased rates?
- Think about the global efforts that might be required.

- **What has the game taught the students?**
- **Pair, share and feedback to the group.**

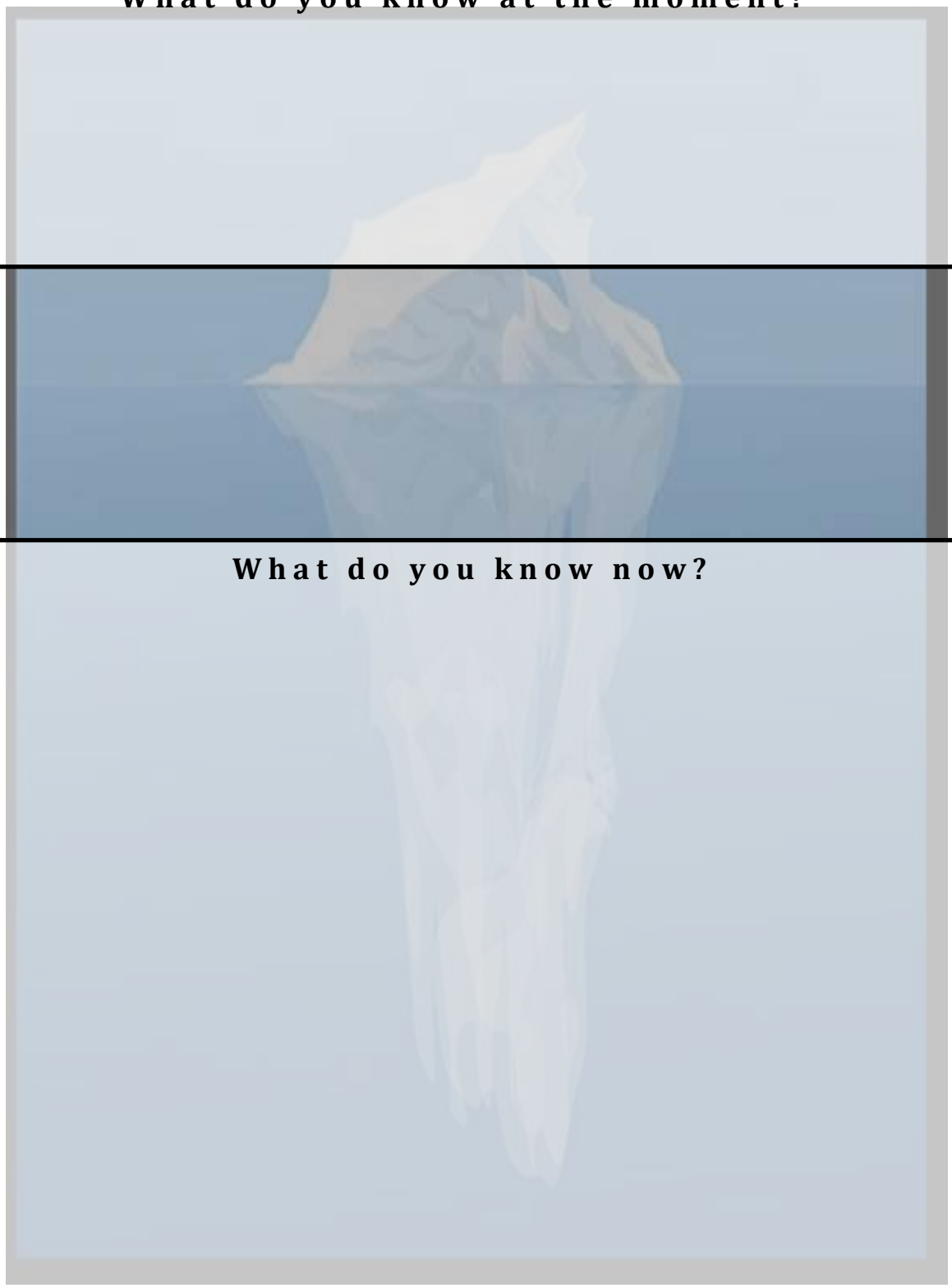
In the longer term:

- Encourage students to keep track of what is happening in Antarctica, and let you know if they spot stories relating to the continent and in particular the Filchner-Ronne Ice shelf system.
- What will happen to A-68 – the Larsen C iceberg - over the years to come?
- Watch https://www.youtube.com/watch?v=ua3WS8sPDL4 for a neat video of iceberg trajectories.

- Use the Iceberg of Understanding and fill it in at the end of the series of sessions. What have students learned about the importance of ice?

Iceberg of Understanding – how deep is your knowledge?

What do you know at the moment?



What do you know now?

Which Sphere am I?

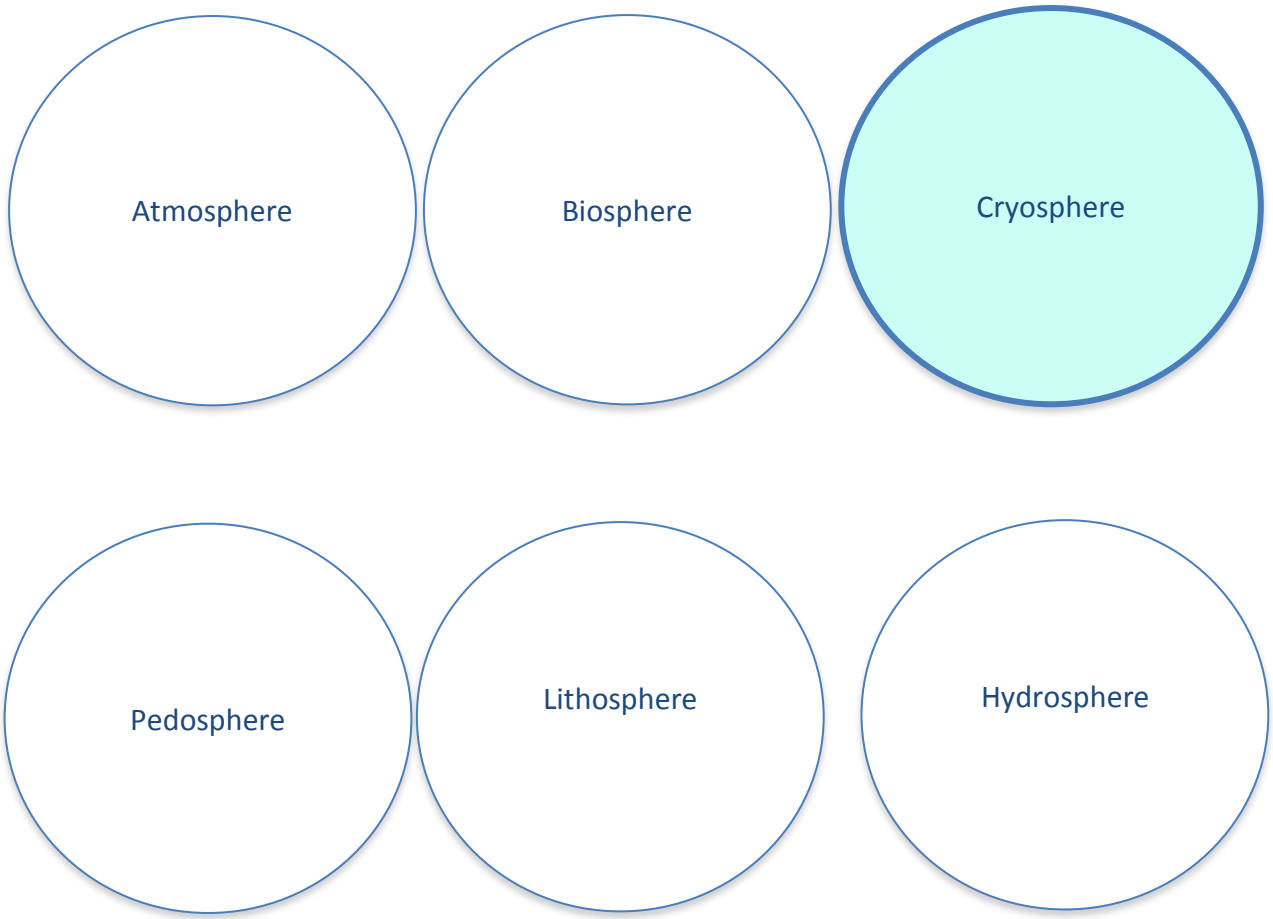
Match up the name of the sphere with the description by drawing a line between the two.

A	Atmosphere
B	Biosphere
C	Cryosphere
D	Pedosphere
E	Lithosphere
F	Hydrosphere

The living fabric of the Earth, including plants and animals, organised into ecosystems.	1
The soil layer that covers the skin of the earth, and where plants grow.	2
The layer of gas surrounding the earth, and where our weather is created.	3
The rocks of the earth's crust, formed into sections called tectonic plates.	4
The frozen parts of the Earth, covered in ice, or where ground is frozen into permafrost.	5
Liquid water in various forms, on the surface of the earth, and in the seas and oceans.	6

Which Sphere am I?

Which of these items match which sphere?
Write them inside the correct one.



River, Glacier, Rock, Elephant, Tree, Soil, Desert, Cloud, Volcano, Rainforest, Penguin, Ice Shelf, Raindrop, Snowflake, Pebble, Cauliflower, Puddle, Cactus, Insect, Animal Dung

Add in a few more of your own.

Are there any that could be in more than one sphere?

How Does Glacier Ice Form?

It starts to snow. The snowflakes fall and land on the ground and begin to accumulate as a layer of snow.

What factors will encourage this to happen?
What processes are involved in turning it into ice?

Discuss these questions for a few minutes with a partner, and then pair up with another pair to share your thinking.
Try to turn your ideas into a simple diagram, with text and arrows if necessary.

Conditions which encourage snow to accumulate:

- sheltered conditions in the lee of an obstacle to any wind, which allows accumulation
- places where wind might blow towards and drift e.g. against an obstruction, such as a landform
- where the ground is dry, rather than wet or waterlogged
- cold conditions, close to those which were responsible for the

In order for glacier ice to form, the snow has to stay there all year round for the next year's snow to land on top of it and begin the process of compressing the snow pack further, and removing more of the air.

Are there any places where snow lasts all year round in the UK?
Where would these places be?

Share some ideas about where these places might be.

Note that the temperature drops with height, and there may also be more snow in mountainous areas. Think about the route that the sun takes through the day, and the sheltered north facing sides of buildings.

Look at the characteristics of the ice that is found in glaciers.
Describe it…

"Close up of blue ice" (CC BY-NC-SA 2.0) by Mark Brandon

Through the year, it's possible that pollution might fall on the snow layer, and this will be sandwiched between the layers of snow to form layers.

There may also be **cryoconite** holes, where dark particles are heated to the point where they sink down into the ice creating small vertical holes.

Over time, the flakes of snow are compressed into plate-like crystals. These are able to slide over each other.

Glacier ice is known as a **polycrystalline solid**. This means that is made up of many individual crystals joined together to form an ice mass. The ice crystals are typically a few millimetres or centimetres in diameter.

Use the 'Snow to Ice' activity sheet to test your knowledge of the sequence involved.

Snow to Ice

Put these statements into the correct order to change from snow to ice.

The ice begins to deform under its own weight.

The lower layers are compressed into the consistency of thick porridge by the weight of overlying snow.

The snow doesn't melt, but lasts all through the year, and the following winter, another layer of snow falls on top of the first layer.

The top layers of the snow pack melt slightly and re-freeze

The deformation of the ice means that ice forms flat plate-like crystals which slide over each other.

It starts to snow, and snow flakes start to settle.

The snow has become névé or firn (German for 'old snow') and now has around 20% air held within it.

Stories of Changing Ice

What changes have there been in Antarctic ice sheets and shelves in recent years?

Research one of these stories in more detail, and produce a response to it, which can be presented to the rest of the group. Your teacher may provide more specific details on how long to spend on the task, and in which format to present your findings.

Larsen A, B and C
Throughout 2017, scientists watched the Larsen 'C' as a large rift spread across the ice shelf.
There had been earlier collapses of part of this ice sheet.

Larsen A collapsed during 1995
Larsen B collapsed during 2002
Larsen C calved a large iceberg named A-68 in July 2017, which may be a precursor to collapse: https://www.theguardian.com/world/2017/jul/12/giant-antarctic-iceberg-breaks-free-of-larsen-c-ice-shelf and https://www.bas.ac.uk/data/our-data/publication/larsen-c-ice-shelf/
As temperature warms, other ice shelves may be affected.

In 2017, there was drama for the Halley IV Research station too. This is located on the Brunt Ice shelf - it had to be moved as a result of a large crack which opened up in the ice shelf.
https://www.theguardian.com/world/2016/dec/07/british-antarctic-research-station-crack-ice

https://www.sciencealert.com/a-giant-ice-crack-is-forcing-the-evacuation-of-the-halley-antarctic-research-station

Did you know?
The largest iceberg ever was B-15, which calved from the Ross Ice Shelf in March 2000, and was larger than the island of Jamaica, with a surface area of over 11 000 square kilometres.

Impact of Antarctic Ice Sheets
http://www.independent.co.uk/environment/antarctic-larsen-ice-shelf-collapse-sea-levels-increase-three-metres-catastrophic-collapse-climate-a7839371.html

Features the Firetree mapping that we use in the resource.

"Iceberg and fractured sea ice" (CC BY-NC-SA 2.0) by Mark Brandon

How natural are these events?
Read this Guardian article from June 2017
https://www.theguardian.com/science/2017/jun/23/melting-and-cracking-is-antarctica-falling-apart-climate-change

Ice Flows: How to get the game

The Ice Flows game can be played on a range of devices or in several web browsers.
The game is **FREE** to obtain however you choose to play it.
The main game website is at http://www.iceflowsgame.com/

iOS – for Apple devices
Ice Flows Game
https://itunes.apple.com/gb/app/ice-flows/id1123467794?mt=8

Android – on Google Play Store
Ice Flows Game
https://play.google.com/store/apps/details?id=com.InhouseVisuals.IceFlows&hl=en_GB

The game will run on a number of browsers

- Google Chrome
- Mozilla Firefox
- Microsoft Edge
- Safari

The list of browsers does not include Internet Explorer, as the game requires a plugin called **OpenGL**, so you will need to install one of these other browsers on your school network if you choose the web-based access option.

Ice Flows: Playing the Game

Click to play in the browser: http://www.iceflowsgame.com/iceflowsgame.html
You will need to use Mozilla Firefox, Google Chrome, Safari or Microsoft Edge.

You will see this home screen:

The game is called **Ice Flows** because, of course it does! By playing the game you will understand more about the controls on how the ice flows.

The game is of course sped up, so that each one minute round represents thousands of years.

- Click **PICK A PENGUIN** to choose which character to play:

You will start with RONNE: a female Emperor penguin from Antarctica. As you play the game, you will earn points, to 'buy' other characters in the shop and 'upgrade' to different characters.

The first time you play, select the **TUTORIAL** option. This explains how ice sheets grow and shrink in response to changes in the environment.

Once the tutorial starts, you will see the ice moving from left to right across the screen. It starts high up, on land, and moves out over the water as an ice shelf. To the right of the ice sheet, blocks of ice break off, and separate from the main ice mass. This process is known as **CALVING** and produces **icebergs**.

- Press **PLAY** to start the game when you're ready.

The **TRAINING** screen shows the relative locations of the two areas, which combine to make the **Filchner-Ronne** ice shelf, where the game takes place.

During the game, penguins will appear on the left of the screen, and travel with the ice towards the right. Your job is to help them 'high five' the Albatrosses as they go, and reach the fish at the bottom of the ice by diving through the gap when an iceberg breaks off.

If the ice sheet is not at the right size, the penguins will end up in the sea at the mercy of the leopard seals which are waiting for them.

You will be rewarded for accurately controlling the size of the ice sheet, by moving two sliders up and down as required. These rewards will unlock new levels and gain credit, which can be used to 'buy' new characters.

There are two variables to control the game:

The first is to **LET IT SNOW** and alter the ice mass by changing how much snow falls. This will make the ice mass thicker. This is controlled with a slider on the left-hand side of the screen.

The second is **IN HOT WATER** and involves changing the sea temperature. This is controlled with a slider on the right-hand side of the screen.

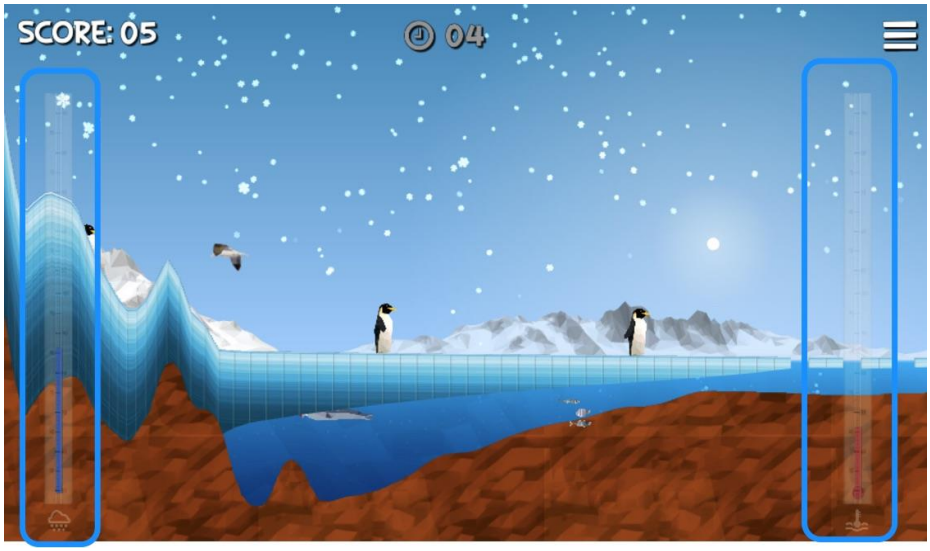
As the sea temperature warms, the ice will melt faster, and the ice shelf will be thinner. This will open up more gaps in the ice. The penguins need to dive through these to get the fish for stars, but if they dive at the wrong time, they will be attacked by the leopard seal.

Once you have worked through the TRAINING and unlocked the levels by getting 2 stars on each level, PLAY the real game levels themselves. There are 8 levels to play and unlock.

Best of luck – your penguins (and other creatures) are depending on you.

Once you've played the game through, fill in a **Feedback sheet.**

Ice Flows: Explainer



What happens if the left-hand slider is moved up?
Explain why this change happens

What happens if the right-hand slider is moved up?
Explain why this change happens

Experiment with different positions of the sliders to see how different combinations change the thickness of the ice. What are the best strategies for getting a high score?

Ice Flows: Experiment Form

Scientists Name:	
Date of Experiment:	
Game Level:	
Game Location:	

Insert a screenshot here to show the experiment in action

Results of experiment	
What did this tell you about the way that ice flows?	

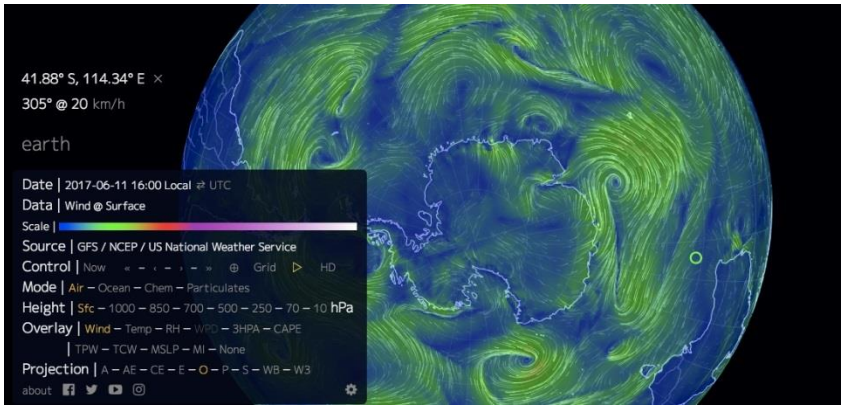
Student Feedback Sheet

Did you understand what you needed to do when playing the game?	
How useful was the Training section?	
How easy was the game to play?	
How well did you do? **What do you think were the best ways to succeed at the game?**	
What did you learn by playing the game?	
Did you have any ideas for improving the game?	
What was your preferred future for the Antarctic Ice sheets?	

What temperature is the Antarctic?

You can see the current sea temperatures and air temperatures in Antarctica, and indeed in other parts of the world, using Cameron Beccario's visualisation tool: Earth Null School

https://earth.nullschool.net/



Click the word **EARTH** to reveal a number of options for exploring the area where the game takes place. Rotate the globe and zoom in to any location to see it more closely.

What is the **air** temperature in and around Antarctica currently?

- Select **AIR** in the MODE, Sfc in the HEIGHT, TEMP in the OVERLAY to see the Air temperature at the surface.
- Click on any point to see the air temperature.

What is the **sea** temperature around Antarctica currently?

- Select **OCEAN** in the MODE, and **SST** in the OVERLAY section to see the Sea Surface Temperature.
- Click on any point to see the Sea Surface temperature.

Note: The sea surface temperature is very cold, but this does not tell us about the warm water that is lurking in the deeper parts of the ocean!

Further options can be seen here: https://earth.nullschool.net/about.html

Sea Level Rise Activity Sheet

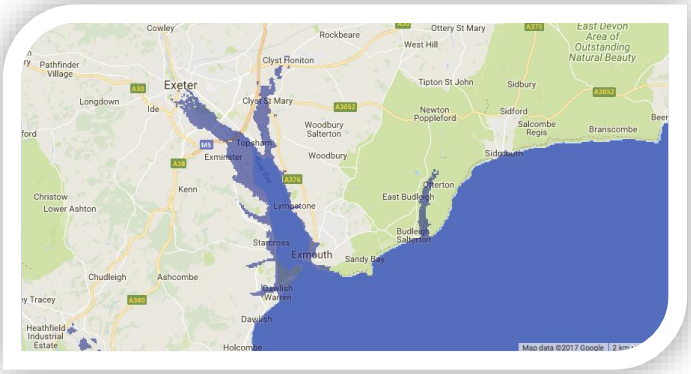
Did you know: if the *entire* Antarctic Ice Sheet was to melt, the water released would raise global sea level by an estimated ***58 metres!***

This is a highly unlikely scenario, but we can think about the impacts of different ice sheets melting by visualizing what different sea level rises would mean for the coastlines of the globe:

What is the potential sea level rise?
Marine West Antarctic Ice Sheet: ~3 metres
Weddell Sea sector: ~13 metres
East Antarctic Ice Sheet: ~54 metres
Whole Antarctic Ice Sheet: ~58 metres
Antarctica & Greenland combined: ~65 metres
Potential worst case scenario sea level rise by 2100: 1 metre[1]

You are going to use the **Flood.Firetree website**, which uses Google mapping data to visualise the possible impact of sea level rises: http://flood.firetree.net/

You can use the drop-down box at the top of the map to change the extent of the inundation from this default setting. Note that the areas along the shore of the estuary, and up the rivers flowing into the sea on the map below, turn blue as these are at risk of flooding.



Using the website, explore the world, and zoom in as necessary.

Which areas of the world would be most affected by the sea level rises in the list above?

See if you can find some of the low-lying Pacific states such as Kiribati and Tuvalu, as well as larger countries such as the Netherlands and Bangladesh.

- Which countries have low-lying coastlines which are particularly at risk?
- Identify some important cities, which would be at risk from flooding at different levels of sea level rise.

Make a note of them in the table on the next page

Countries of the world at greatest risk	Major world cities at greatest risk

Rate these cities on a scale of 1 to 10 (1 being the least likely to be affected and 10 being the most likely to be affected)

- Amsterdam
- Beijing
- Cairo
- Cape Town
- Copenhagen
- Dhaka
- Lagos
- London
- New York
- Rio de Janeiro
- Singapore
- Sydney
- Tokyo
- Wellington

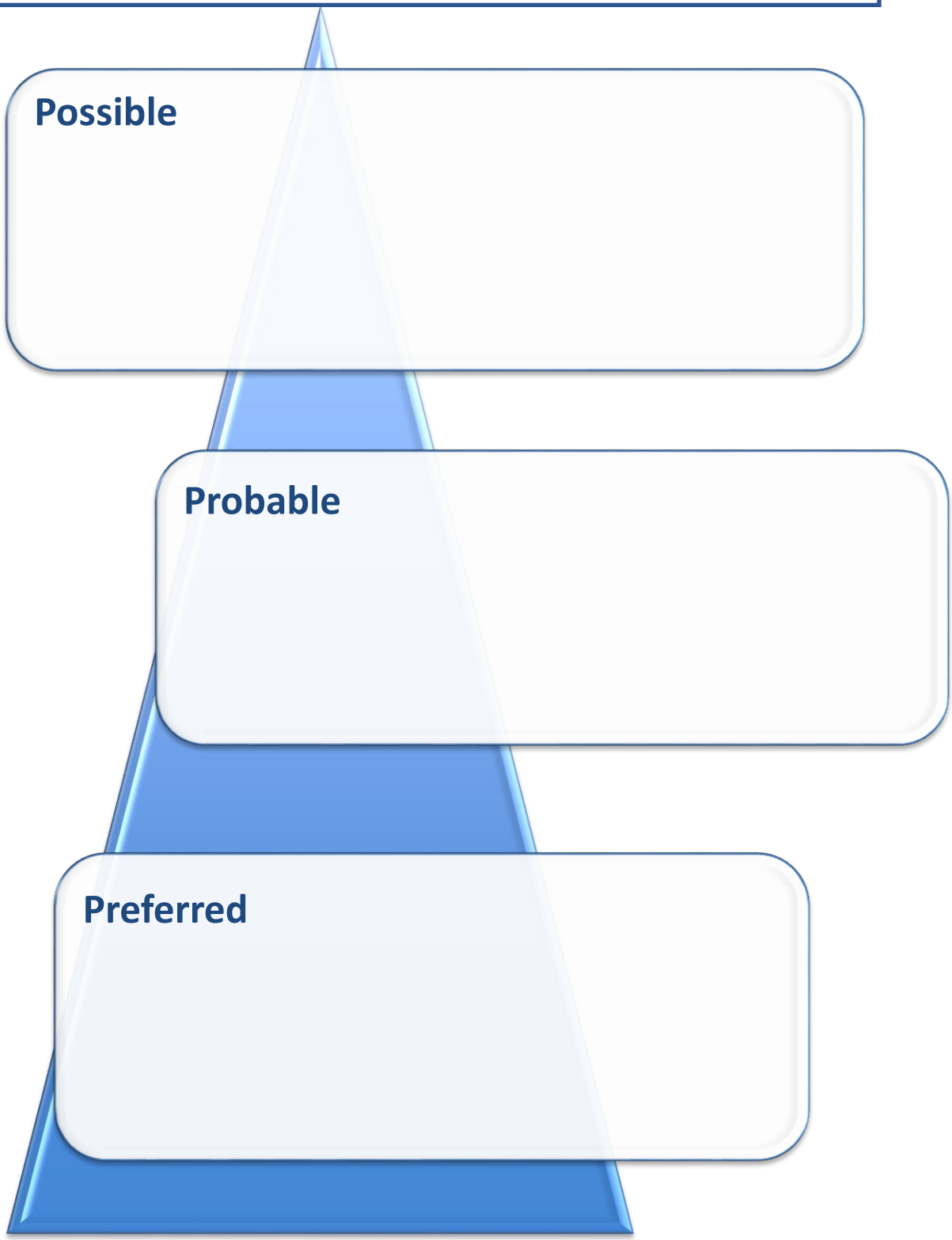
Note on sea level rise:

*Much of the ice in Antarctica is held in the larger East Antarctic Ice Sheet, where large parts are well above sea level. Scientists don't expect these areas to be as vulnerable to climate change. The West Antarctic Ice Sheet is a largely marine ice sheet, however, so is more vulnerable to increased melting from changes in ocean circulation. If the marine parts of the West Antarctic Ice Sheet were to collapse it would raise sea level by about **3 metres**.*

How accurate do you think tools like this are? What are some issues with the way that they show sea level rise?

[1] DeConto, R. M., & Pollard, D. (2016). Contribution of Antarctica to past and future sea-level rise. Nature, 531(7596), 591.

Frosty Futures



Best case scenario in 100 years:

Achieved by…

Worst case scenario in 100 years:

Achieved by…

Meet the Characters

What's in a name?
The names of the characters in the game were inspired by ice features, explorers and local wildlife. *Not all the characters are real animals*.

Ronne

Ronne is an **emperor penguin** – she is the first penguin you get when you play the **Ronne Ice Shelf** world. The Ronne Ice Shelf was named for American Edith Ronne, one of the first women to stay in Antarctica over the winter. It is also named for her husband, Finn Ronne, a Norwegian explorer and scientist. His father, Martin Ronne, was also a polar explorer and was part of Roald Amundsen's successful expedition to the South Pole.

Filchner

Filchner is a **gentoo penguin**, the Filchner Ice Shelf was named for German Wilhelm Filchner, Leader of the 1912 German Antarctic Expedition which discovered the Filchner Ice Shelf.

Sanae

Sanae is a special rainbow-penguin, named after the South African National Antarctic Expedition (SANAE) - the first South African National Antarctic Expedition, whcih departed early in December 1959, and whose bases are named after this expedition. For more information see: https://www.comnap.aq/Members/SANAP/SitePages/Home.aspx

Fuji

Fuji is a Japanese unicorn-penguin. We named Fuji after one of the Japanese Antarctic stations: Dome Fuji station. For more information see **http://www.nipr.ac.jp/english/**. Fuji is a "*kirin*" unicorn, a mythical creature, considered as a good omen.

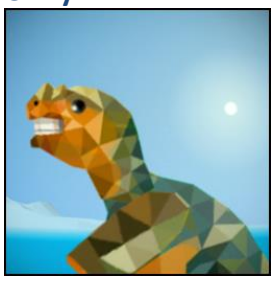
Vostok

Vostok is a Russian firebird-penguin. We named Vostok after the Russian Antarctic station located above subglacial Lake Vostok. The firebird penguin is a mythical glowing, flaming bird. Vostok Station is where the coldest ever temperature was recorded in 1983: https://www.livescience.com/9795-story-earth-coldest-temperature.html

Xue Long

Xue Long is a Chinese snow-dragon-penguin. We named Xue Long *(Snow dragon)* after the Chinese icebreaker ship of the same name. The snow-dragon penguin is a mythical fire-breathing creature. The Chinese operate several research stations in Antarctica including the Great Wall station.

Chilly



Chilly is a titano-penguin: named Chilly in honour of the Chilean Antarctic Program. For more information see **www.inach.cl** . The titano penguin is the biggest dinosaur penguin ever found, a number have been found across Patagonia.

Erebus

Erebus the leopard seal is named after HMS Erebus: one of the ships, used during the expedition of James Clark Ross to Antarctica in 1839-1843. In Greek mythology, Erebus is a deity: the god of darkness - so best to steer clear of him! The other ship in the expedition was called **HMS Terror** - can you find the character "Terror" in the game?

Alba

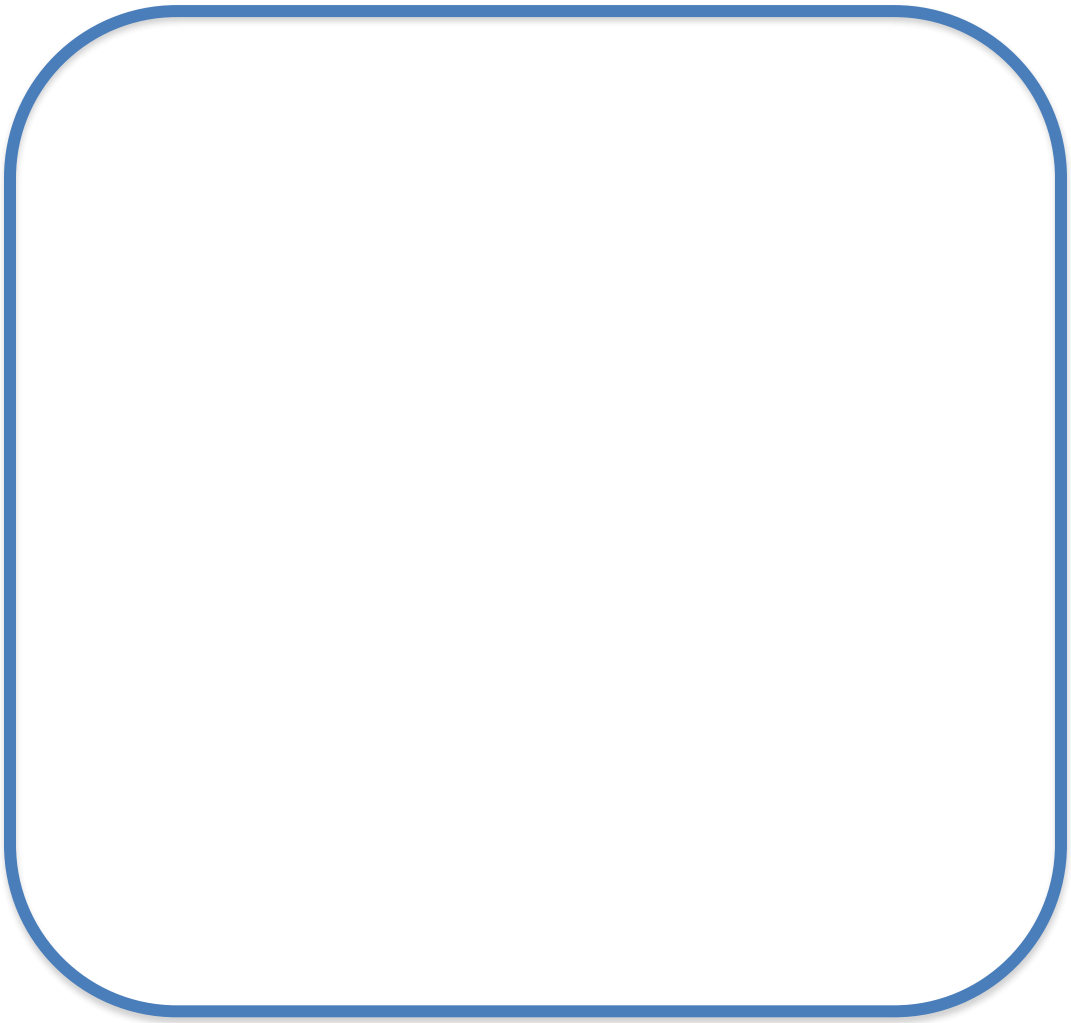
Alba the Albatross is named after a little girl who had a tough start in life, and who has a name very suitable for an Albatross!

Your ideas here

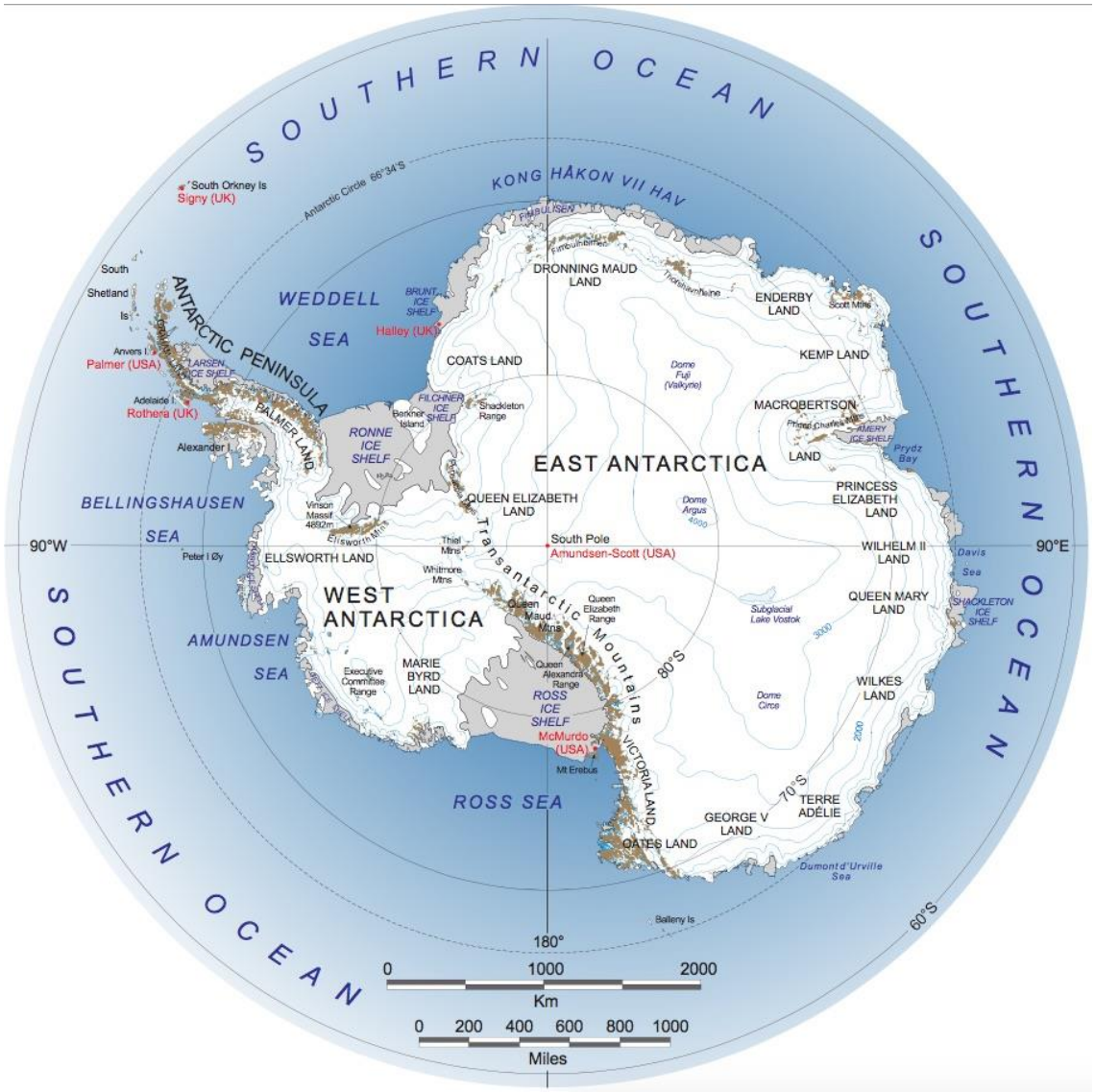
If you were asked to create a new character for the game, what creature would you include, and who (or what) would you name them after? Draw and write your ideas here. We'd love to see your ideas.
Contact us on Twitter @iceflowsgame to show us what you produce.

My character is called:

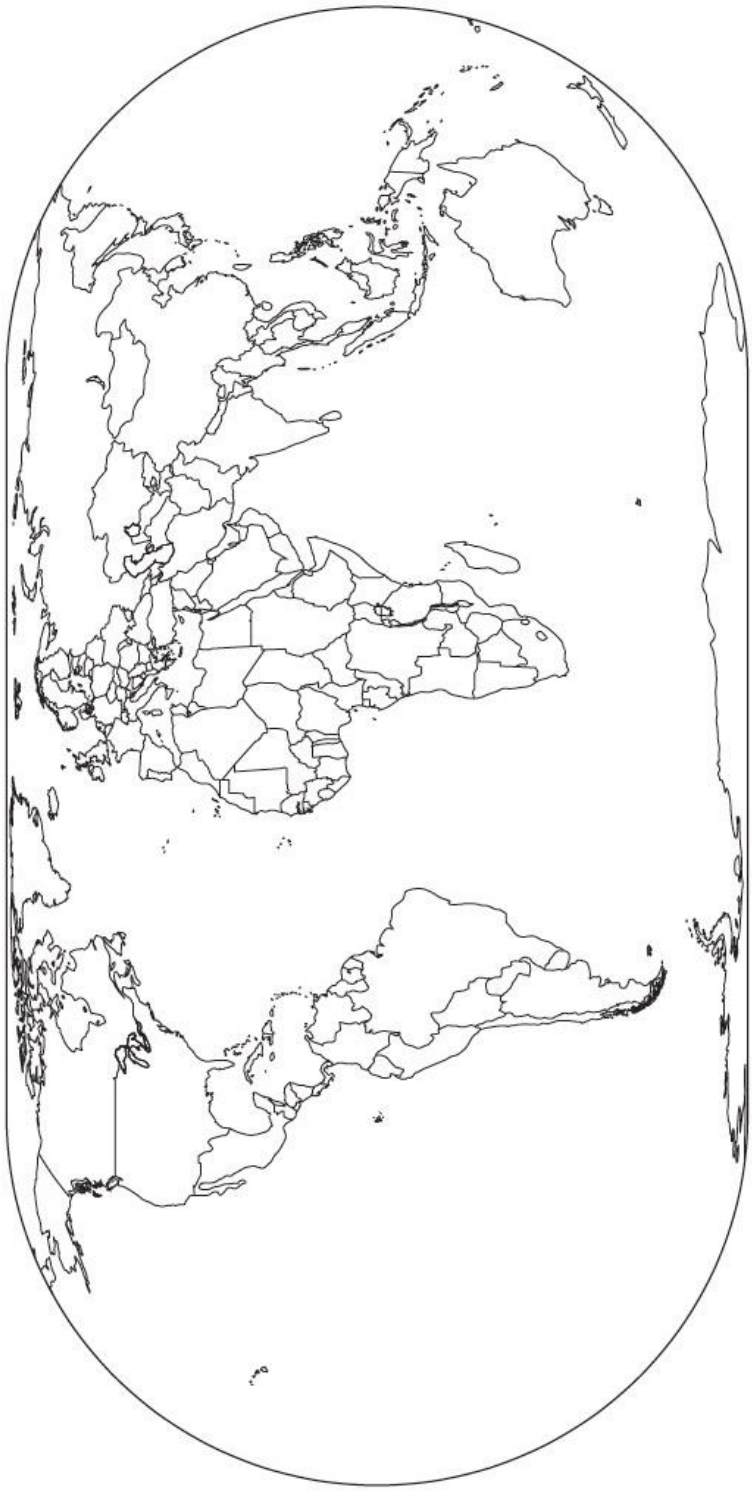
Details:



Map of Antarctica



Blank World Map



Geography Specification Documents

GCSE Geography

Where is Ice mentioned in the Specification documents for the GCSEs?
There are no specific mentions of Ice Sheets in Antarctica and their movement, but ice, its formation, and its impact on the landscape is included in several of the specifications.

Specification	Topic	Subject content
AQA	3.1.3.4 Glacial landscapes in the UK	Ice was a powerful force in shaping the physical landscape of the UK.
Edexcel 'A'	Optional sub topic 1C: Glaciated upland landscapes and processes Key Idea 1.11 A variety of physical processes interact to shape glaciated upland landscapes Topic 2: Climate Change The global climate was different in the past and continues to change due to natural causes	Glacial processes that once operated in the glaciated upland landscape: glacial erosion (plucking, abrasion and freeze thaw), transport (on or within the ice) and deposition. Mention of the role of ice cores in helping to reconstruct past climates. Negative effects that climate change is having on the environment and people (changing patterns of crop yield, rising sea levels and retreating glaciers)
Edexcel 'B'	**Topic 1: Hazardous Earth** Enquiry question: How does the world's climate system function, why does it change and how can this be hazardous for people? Global climate is now changing as a result of human activity, and there is uncertainty about future climates	Mention of ice cores as a way of finding out about past climates, and changes to the system. Could explore the notion of melting ice sheets as part of this changing climate system. Evidence for how human activity is causing climate change (sea level rise and warming oceans, global temperature rise, declining Arctic ice, increased extreme weather events) and the possible consequences on people
Eduqas 'A' & 'B', OCR 'A' and WJEC	**No relevant content**	**n/a**
OCR 'B'	**Topic 2: Changing Climate** What evidence is there to suggest climate change is a natural process?	The pattern of climate change from the beginning of the Quaternary period to the present day. The range and reliability of evidence relating to climate change including

	Topic 4: Sustaining Ecosystems Is there more to polar environments than ice?	evidence from sea ice positions, ice cores, global temperature data, paintings and diaries. Outline the distinctive characteristics of Antarctica and the Arctic, including climate, features of the land and sea, flora and fauna. The interdependence of climate, soil, water, plants, animals and human activity in either the Antarctic or the Arctic polar region A case study to examine one global example of sustainable management in either the Antarctic or the Arctic by investigating global actions such as Earth Summits or the Antarctic Treaty

Download links for full specification (PDF downloads)

AQA: http://filestore.aqa.org.uk/resources/geography/specifications/AQA-8035-SP-2016.PDF
Edexcel 'A': https://qualifications.pearson.com/content/dam/pdf/GCSE/Geography-A/2016/specification-and-sample-assessments/Specification_GCSE_L1-L2_Geography_A.pdf
Edexcel 'B': https://qualifications.pearson.com/content/dam/pdf/GCSE/Geography-B/2016/specification-and-sample-assessments/Specification_GCSE_L1-L2_Geography_B.pdf
OCR 'B': http://www.ocr.org.uk/Images/207307-specification-accredited-gcse-geography-b-j384.pdf

Suggestions for using the game at GCSE level

- The game could be set as a task before the first teaching of some elements of glaciation e.g. the way that ice forms, and students could be asked to explain some of the content knowledge that underpin the game.
- Students could be asked to research the particular ice sheets on which the game is modeled, and explore the significance of the names of the Penguins: their names are not random, but based on significant locations within the continent.
- They could also consider which other parts of the specification they have covered could usefully be turned into a game in a similar way to that of IceFlows.
- Introduce students to the Pinterest boards, and ask them to curate their own board, or perhaps create a **Flipboard** magazine using the app on a mobile device.
- Develop a 'hot seat' activity where students need to prepare to sit in the hot seat and be quizzed on the ideas that underpin the game, or the locations in which the action takes place.

Edexcel 'B' is the specification with the closest match to the ideas explored in the IceFlows Game.

GCE AS/'A' Level Geography

Where is Ice mentioned in the Specification documents for the GCEs?
There are no specific mentions of Ice Sheets in Antarctica and their movement, but ice, its formation, and its impact on the landscape is included in several of the specifications.

Specification	Topic	Subject content
AQA	3.1.4 Glacial systems and landscapes 3.1.4.1 Glaciers as natural systems	Systems in physical geography: systems concepts and their application to the development of glaciated landscapes – inputs, outputs, energy, stores/components, flows/transfers, positive/negative feedback, dynamic equilibrium. The concepts of landform and landscape and how related landforms combine to form characteristic landscapes.
	3.1.4.2 The nature and distribution of cold environments	The global distribution of cold environments. Physical characteristics of cold environments. Climate, soils and vegetation (and their interaction).
	3.1.4.3 Systems and processes	The global distribution of past and present cold environments (polar, alpine, glacial and periglacial) and of areas affected by the Pleistocene glaciations. Glacial systems including glacial budgets. Ablation and accumulation – historical patterns of ice advance and retreat. Warm and cold based glaciers: characteristics and development. Geomorphological processes – weathering: frost action, nivation; ice movement: internal deformation, rotational, compressional, extensional and basal sliding; erosion: plucking, abrasion; transportation and deposition.
	3.1.4.4 Glaciated landscape development	This content must include study of a variety of landscapes from beyond the UK and may also include UK examples. Origin and development of glaciated landscapes. The relationship between process, time, landforms and landscapes in glaciated settings: characteristic glaciated and periglacial landscapes.
	3.1.4.6 Quantitative and qualitative skills	Students must engage with a range of quantitative and relevant qualitative skills,

		within the theme landscape systems. These should include observation skills, measurement and geospatial mapping skills and data manipulation and statistical skills applied to field measurements.
Edexcel	Topic 2: Landscape Systems, Processes and Change Option 2A: Glaciated Landscapes and Change **How has climate change influenced the formation of glaciated landscapes over time?** 2A.2 Present and past Pleistocene distribution of ice cover. **What processes operate within glacier systems?** 2A.4 Mass balance is important in understanding glacial dynamics and the operation of glaciers as systems. 2A.5 Different processes explain glacial movement and variations in rate How do glacial processes contribute to the formation of glacial landforms and landscapes? How are glaciated landscapes used today? 2A.11 There are threats facing fragile active and relict glaciated upland landscapes.	a.The definition and importance of the **cryosphere** and its role in global systems and classification of ice masses by scale and location (ice sheets, ice caps, cirque and valley glaciers, and ice fields) and polar and temperate environments. b. The present-day distribution of high latitude ice sheets and evidence for Pleistocene ice sheet extent. c. The present-day distribution of high altitude glaciated upland landscapes and evidence of relict landscapes from the Pleistocene. Glacial mass balance system and the relationship between accumulation and ablation in the maintenance of equilibrium. The importance of positive and negative feedback The process of accumulation (direct snowfall, avalanches and wind deposition) and the process of ablation (melting, sublimation, calving, evaporation and avalanches). The reasons for the variations in the rates of accumulation and ablation, and the impact these variations have on the mass balance over different timescales. Polar and temperate glaciers have different rates of movement. There are different processes that are important in the movement of glaciers (basal slip, regelation creep, internal deformation). Global warming is having a major impact on glacial mass balances, which in turn risks disruption of the hydrological cycle (meltwater, river discharge, sediment yield, water quality) *Climate warming is a context risk, meaning that successful management of these unique and fragile landscapes is*

		increasingly challenging, with a need for coordinated approaches at global, national and local scale
Eduqas	Optional Theme 1.2: Glaciated Landscapes 1.2.1 The operation of a glacier as a system 1.2.2 Climate change and the glacier budget over different time scales	• The glacial system including inputs, outputs, stores and transfers of energy and materials • Change in the inputs to and outputs from a glacier over short and long-time scales • The glacial budget including glacier mass balance and equilibrium • Positive and negative feedback in the glacier system
OCR	1.1.2 Option B – Glaciated Landscapes How can glaciated landscapes be viewed as systems? 1.a. Glaciated landscapes can be viewed as systems. 1.b. Glaciated landscapes are influenced by a range of processes.	A conceptual overview of: • the components of glaciated landscape systems, including inputs, processes and outputs • the flows of energy and material through glaciated systems • glacier mass balance. Potential influences on glaciated landscape systems of: • climate, including precipitation totals and patterns • geology, including lithology and structure • latitude and altitude • relief and aspect on microclimate and glacier movement.
WJEC	Optional theme involves the study of glaciated and formerly glaciated landscapes shaped by valley glaciers and ice sheets, bearing erosional and depositional imprints of the passage of glacier ice in a range of features. Study will take place within a systems framework, focusing on spatial and temporal variations in the geomorphological processes that operate within glaciated landscapes and how the flows of energy and movement of materials combine to create specific landforms.	The glacial system including inputs, outputs, stores and transfers of energy and materials Change in the inputs to and outputs from a glacier over short and long-time scales The glacial budget including glacier mass balance and equilibrium Positive and negative feedback in the glacier system Types of ice mass at a range of scales including cirque glaciers, valley glaciers, highland ice field, piedmont glaciers and ice sheets and sea ice • Past distribution of valley glaciers and ice sheets during the Quaternary Ice Age • Present day distribution of ice masses including valley glaciers and ice sheets

Some schools may also be using the International Baccalaureate and iGCSE specification.

The new IB Geography Specification has an option called Extreme Environments https://ibpublishing.ibo.org/proof/apps/dpapp/guide.html?doc=d_3_geogr_gui_1702_1_e&part=2&chapter=3&section=3

This includes a Skills requirement: How glacial systems and climatic data are best represented graphically.

Download links for full specifications for GCE Geography

AQA: http://filestore.aqa.org.uk/resources/geography/specifications/AQA-7037-SP-2016.PDF
Edexcel: http://qualifications.pearson.com/en/qualifications/edexcel-a-levels/geography-2016.html
Eduqas: http://www.eduqas.co.uk/qualifications/geography/as-a-level/

Suggestions for using the game at 'A' level

- Students could be asked to critique the game, or suggest how it might be changed to reflect some of the processes that they have been exploring in class. How does the ice system shown in the game connect with other processes on a variety of scales?
- Explore the structure of ice, and the way that it is able to flow. Students could be asked to record a short video, or create an 'explainer video' which shows the process of getting from snowfall, to a moving ice mass, and how ice reacts to changes in environmental conditions
- Students could prepare a short activity with younger students to introduce them to the processes involved
- Climate change is identified in some of the specifications as a risk which is producing an uncertain future and therefore needs management. What are the options for actions, which might affect the scale of ice features featured in the game?

The Edexcel Specification includes a synoptic theme of Futures and Uncertainties, which connects with the activity we have included on preferred futures for Antarctica.

There are contrasting approaches when making decisions about geographical issues that will affect people in the future. These include business as usual, priority towards more sustainable strategies and radical alternatives (mitigation and adaptation). Choice of objective will affect both people and the environment in very different ways (risk, resilience and thresholds). The outcomes of choices made today are uncertain for a range of reasons, including scientific, demographic, economic and political uncertainty.

Ice Flows Glossary

*These are usually shown as **bold words** in the resource pack text.*

Ablation: another word all processes of ice loss, which reduces the size of an ice sheet or glacier.

Albedo: the reflectivity of a surface, or how much of the sun's energy (**insolation**) is absorbed or reflected. Fresh snowfall can reflect back as much as 90% of the energy. When meltwater pools form on the surface, the albedo is reduced, and more heat is absorbed by the ice mass. In the Arctic, dark carbon from ships increases albedo, as does ash from volcanic eruptions.

Calving: the loss of ice due to pieces breaking off a larger ice mass into the sea; a natural part of an ice shelf life cycle.

Crevasses: cracks in the surface of the ice which may go some way down through the ice mass; a sign of stress acting on the ice, sometimes caused by changing velocity or direction.

Cryosphere: that part of the earth which relates to the presence of water as ice, including frozen ground, ice sheets and sea ice.

Englacial: within the ice.

Frozen ground: ground which has been below freezing for at least two years - the term ***permafrost*** is also used to describe this frozen ground.

Glacier: a perennial mass of ice and snow, originating on land, and showing evidence of past and present flow.

Ice Sheet: a large glacier (larger than 50 000 km^2) that completely covers the underlying topography. Can be several kilometres thick.

Ice Shelf: a large area of floating glacier ice extending from the coast where glaciers flow into the sea - the seaward extension of an ice sheet. Can be hundreds of metres to kilometres thick.

Ice stream: a zone of faster flowing ice within an ice sheet, often corresponding to lows in the subglacial topography; the fast flow results in strain within the ice which may be visible as crevasses.

Iceberg: a floating ice mass which has broken off a glacier or ice shelf which terminates in the sea.

Insolation: incoming solar radiation, which is quite low in Polar regions due to the angle of the sun in the sky and the length of the day at certain times of the year.

Sea ice: ice forming on the surface of the sea when the water is cold enough to freeze.

Sea level change: a change in the height of global sea level relative to the land due to the melting of glaciers and ice sheets. This is affected by changes in the land as well as in the ocean – the land can be 'rebounding' or rising if an ice sheet has been removed in the past.

Subglacial: underneath the ice.

Supraglacial: on top of the ice.

Additional reading and resources

If you would like to know more about the polar environments, which are modeled in the Ice Flows game, here are a few options for you:

Discovering Antarctica website – developed by the Royal Geographical Society, in association with the British Antarctic Survey.
http://www.discoveringantarctica.org

Discovering the Arctic website – companion website to Discovering Antarctica, also developed by the Royal Geographical Society, which includes a series of useful sections on ice sheets and sea ice.
http://www.discoveringthearctic.org.uk
@RGS_IBG on Twitter
@BAS_News

Antarctic Glaciers
http://www.antarcticglaciers.org/
Developed by Bethan Davies from Royal Holloway University of London.
@AntarcticGlacie

Landsat Image Mosaic of Antarctica (LIMA)
https://lima.usgs.gov/

For maps and graphics of Antarctica and other Polar regions check out Grid Arendal
https://www.grida.no/

Formation of Glacier Ice
https://nsidc.org/cryosphere/glaciers/questions/formed.html

Glaciers Online
http://www.swisseduc.ch/glaciers/
A range of images of ice features around the world

British Antarctic Survey:
http://www.bas.ac.uk
Information on ice sheets from the BAS
https://www.bas.ac.uk/about/antarctica/geography/ice/

Royal Geographical Society resources on Glacial environments
http://www.rgs.org/OurWork/Schools/Teaching+resources/Key+Stage+3+resources/Glacial+environments/Glacial+environments.htm

Project Midas website – focusing on Larsen C
http://www.projectmidas.org/
@MIDASonIce

Report on Filcher-Ronne Ice Shelf research:
https://www.bas.ac.uk/project/weddell-sea-ice-sheet-and-climate/

Books

Klaus Dodds: "The Antarctic: A Very Short Introduction" (OUP, 2012)

Peter Knight: "A quick introduction to glaciers and glacial landscapes" (Createspace, 2015)

Gabrielle Walker: "Antarctica: An Intimate Portrait of the World's Most Mysterious Continent (Bloomsbury, 2013)

James Woodward: "The Ice Age: A Very Short Introduction" (OUP, 2014)

Stories about ice shelf collapse and glaciers melting

The Independent has a page of Antarctic news:
http://www.independent.co.uk/topic/antarctic which keeps up to date with research and stories about Antarctic Ice:
e.g.
http://www.independent.co.uk/environment/miles-antarctic-ice-collapse-into-sea-scientists-research-ross-shelf-ice-columbia-university-a7745471.html
http://www.independent.co.uk/environment/antarctic-larsen-ice-shelf-collapse-sea-levels-increase-three-metres-catastrophic-collapse-climate-a7839371.html

Where do icebergs go after they break off?
A map showing historic iceberg tracks is here: http://www.esa.int/spaceinimages/Images/2002/07/Historical_iceberg_tracks
https://www.scientificamerican.com/article/what-to-believe-in-antarctica-rsquo-s-great-ice-debate/

To find out more about what life in Antarctica is like, there is an entertaining insight into the life of Union Glacier here: https://vimeo.com/107231188
Kalle Ljung's dramatic film would also be good to show when introducing the continent's dramatic landscapes to students: https://vimeo.com/124858722

Mark Brandon article: https://theconversation.com/when-an-antarctic-iceberg-the-size-of-a-country-breaks-away-what-happens-next-39257

Check out the blog for more resources: **http://blogs.exeter.ac.uk/iceflowsgame**.

Follow Ice Flows on Twitter: **https://twitter.com/iceflowsgame** for the latest news on ice sheet changes, and future developments

Follow Ice Flows on Facebook: **http://www.facebook.com/iceflowsgame**

See videos on YouTube: https://www.youtube.com/channel/UCTaAwsFruWTL78aIHz1EYGg

We've made a Pinterest board of images, which you can see here **https://www.pinterest.co.uk/geoblogs/iceflows-game-resource/**

We've also made a Spotify play-list of songs which have an icy theme to them. Let us know if we've missed out an obvious addition: spotify:user:geoblogs:playlist:0JImIPlG2t0Xgl4u0twaPs

Contact us via Twitter on @iceflowsgame
You can also e-mail us: iceflowsgame@gmail.com
We'd love to hear from you about how you are using this pack.

"067_Stange_Ice_shelf" (CC BY-NC-SA 2.0) by Mark Brandon

Anne Le Brocq, University of Exeter

The work of Anne Le Brocq, who was the originator of the Ice Flows Game, is described here:
http://geography.exeter.ac.uk/staff/index.php?web_id=anne_le_brocq

Anne obtained her undergraduate degree in Geography at the University of Bristol, then moved to the University of Edinburgh where she gained an MSc in GIS. She returned to Bristol for her PhD, before embarking on postdoctoral research at Durham University. She moved to the University of Exeter in March 2010 for a NERC fellowship, and is now a Senior Lecturer in Physical Geography.

Broad research specialisms:

Ice sheet modelling, ice sheet subglacial hydrology, Remote Sensing & GIS applications in glaciology, currently dabbling in computer games and game-based learning.

Ice Flows Game

"Ice Flows" is a game is built on a simple representation of how ice flows in Antarctica and how it responds to changes in the environment - through changes in snowfall and ocean temperature. It allows players to impose climatic changes to control the extent of the ice sheet to guide penguins to fish; if they get it wrong, the penguin may meet its doom in the jaws of a Leopard Seal. The aim is to promote understanding of the complexity of the ice sheet system by enabling players to carry out their own ice sheet model experiments, much like the scientists working on the research. The game has a number of levels relating to unique ways different parts of the Antarctic will respond to climate change.

Ice shelves in a warming world: Filchner Ice Shelf system, Antarctica

This project aims to investigate what will happen in the near-future to the Weddell Sea region of the Antarctic Ice Sheet, and the impact changes here could have on global sea-level by the end of this century. The project combines field data collection and modelling, covering the atmosphere, oceanography and glaciology of the Weddell Sea Sector.