STAR WARS HOTH

A study of a fictional ice planet by Andrew Wright
Originally submitted for the Astronomy Online course at Swinburne University of Technology

1. Introduction

A long time ago in a galaxy far, far away swift running snow lizards and vicious ice creatures eked out a desperate existence across a frozen wasteland. A frozen planet, bombarded by space debris, its climate scarred by an unknown catastrophe served as a backdrop for a blockbuster movie set in a universe full of strange locations and species. That movie was entitled *Star Wars, Episode V: The Empire Strikes Back* and the ice world was named Hoth.

Hoth's simple ecology and climate hide many secrets, its mysteries making it one of the more interesting of the many planets encountered in the *Star Wars* Universe. This report attempts to explore the unknown Hoth, filling in the blanks by comparing the planet's ecology and environment with that of the only known living planet: Earth. Has Hoth always been a frozen world? Why is the ecology so simple? Are the planet and the depicted species viable? Using physics, biology, chemistry and astronomy I will attempt to answer those questions.

2. The Planet Hoth

Hoth is a world of ice and snow, a white planet gripped in an extreme ice age. It served as a secret base for the Rebel Alliance during *The Empire Strikes Back* until the rebels were driven out by an Imperial assault. It is one of six planets of the Hoth system and the only one to support life. (SWDBWeb). Hoth itself has three Moons (Figure 1), which despite their relatively small sizes are massive enough to cause reasonably strong tides in the sub-ice oceans of the southern hemisphere(SWDBWeb).

Figure 1The moons of Hoth (© Lucasfilm Ltd)

While Hoth appears predominantly white from the ice and clouds, there are dark patches which may be due to the a number of active volcanoes on the surface and mountain ranges which poke their summits up through the ice (SWDBWeb). The average daytime temperature on the surface is -32 degrees Celcius, the nights getting down to -60 degrees (SWDBWeb). This is similar to the range of temperatures experienced throughout the year at Earth's South Pole (recall that the lack of nights during summer and daylight during winter makes direct comparisons difficult) (BASWeb).

Figure 2An Imperial Star Destroyer above Hoth (© Lucasfilm Ltd)

Hoth's hemispheres are divided by a hundreds of metres deep fissure in the ice at the equator. This is perhaps due to the uneven distribution of land in the northern hemisphere and ocean in the south and possibly by the tidal influences of the moons.

Covered by ice, Hoth's geology and surface features cannot compare with those of Earth or most other planets in our solar system. It would be fascinating to have further details about what lies beneath the ice and within the oceans.

3. The Land Ecology

Not many details are known about Hoth's ecology, except that the range of land based life appears to be very small.

3.1 Algae, Lichens, Fungi & Invertebrates

Near the bottom of the food chain is the oceanic algae that live in the ice enclosed oceans. The majority of Earth algae species use photosynthesis as a source of energy, dinoflagellates being the major exception (NMNHWeb). On Earth, algae are known to live inside sea ice (RiceWeb). However, if the depth of the ice covering the oceans is deep enough it is possible that very little, if any, light could be expected to penetrate the ice, ruling out photosynthesis. Perhaps chemosynthetic bacteria with the ability to extract energy from the output of deep sea volcanic vents (VentsWeb) may provide the ultimate source of food.

Figure 3 Overturned bits of Antarctic sea ice with algae at the base. Photograph (courtesy of Charlotte Kelchner, Rice University)

According to the Star Wars Databank (SWDBWeb) sea algae shot out of the ocean by jets of water flowing through cracks in the ice provide a food source for a species of annelid called an ice worm. The ice worms burrow into spires of frozen sea water in search of the algae. Annelids and other small lifeforms are known to feed on algae within sea ice in the polar oceans of Earth (MetaWeb), but the only animal life form in many areas of the Antarctic is the nematode. However, Alaskan glaciers are known to harbour annelid ice worms that feed off the red algae (Hartzell), so a Hoth analogue appears within the bounds of possibility.

Interestingly, the term “ice worm” is also used to describe a speecies of annelid that tunnels through methane clathrate, a methane/water ice found at the bottom of the ocean at low enough temperatures and high enough densities. These ice worms probably feed on chemosynthetic bacteria (MacDonald & Joye 1997).

The existence of an oxygen atmosphere does imply that photosynthesis is occurring somewhere on the planet, unless it is a remnant from a different climatic period. Algae are found in snow and ice on Earth (IceAlgaeWeb) and presumably could survive on the surface of Hoth, while lichens, a fungus/algae symbiont are mentioned as a food source on Hoth (SWDBWeb) and are also known in Antarctica on Earth.

A fungus called “Lumnispice” is also mentioned as living in the equatorial chasm away from the sunlight (SWDBWeb) and may also act as a food source.

3.2 Small Vertebrates

According to the Star Wars Databank (SWDBWeb) a number of other creatures are found on Hoth, including scavengers called “Hoth hogs”, and small rodents termed snowmice and ice scrabblers. Another creature called a dragon-slug lives in the equatorial chasm and, according to the a story in the Databank, is large or fearsome enough to frighten off a pirate trader.

No further details are provided about the above lifeforms and they are not observed in *The Empire Strikes Back*, so further analysis is not possible. No similar analogues live in the Antarctic mainland – all vertebrates derive their food supplies from the ocean.

Rodents generally eat seeds, roots and other vegetation, although some are fish or insectivores (WikiRodWeb). Those rodents found in Arctic regions of Earth, such as lemmings, still require sources of vegetation (Miss2007Web), and do not live in regions that are permanently frozen over. So either the name rodent is a misnomer for the Hoth animals, they are rodents which have adapted to use alternative food source (say, the ice worms, fungus or lichen) or a tundra region does exist on Hoth.

Similarly, the other animals would need to be able survive either using the basic algae, lichen, fungus or nematode food sources, or eating other animals which depend on those sources. Competition for these limited resources probably restricts the diversity of species in the Hoth environment.

3.3 Tauntauns

Tauntauns are one of the two Hoth lifeforms depicted in *The Empire Strikes Back*. The rebels have domesticated the tauntauns for use in mounted patrols.

An alternative name for tauntauns are “snow lizards”, although they have many characteristics that are not associated with Earth reptiles. Mammalian features of tauntauns include a coat of shaggy hair, ear pinnae (the visible external “ear flaps”) (CompAnatWeb), and horns that are somewhat akin to those of rams. The latter is only found on the females of the species and used during headbutting competitions during the mating season. Unlike rams and other artiodactyla (a mammalian order which includes sheep, deer and cattle), the horns are located horizontally behind the eyes rather than towards the top of the head.

Figure 4 Rebel soldier atop a tauntaun (adapted from Reynolds 1998)

Tauntauns must also differ from Earth reptiles in possessing the ability to generate their own internal heat. We can confirm that the tauntaun does not possess some weird internal chemistry that allows it to function in near thermal equilibrium with the external atmospheric temperature by the scene in *The Empire Strikes Back* where hypothermic Luke

Skywalker was stuffed into the sliced open belly of a recently deceased tauntaun for the purpose of warming him up.

Although running on hind legs is not the norm for Earth lizards, it is not unknown – the frill-necked lizard of the Australian desert is one that does so. Bipedal motion may have advantages in an icy landscape as only two feet are in contact with the ground, minimising conductive losses (although the total surface area of the foot may have to increase to support the weight, perhaps nullifying the benefits). The stance of the tauntaun is also at odds with that of Earth lizards, who have a sprawling gait (Lambert et al. 2001).

Figure 5 Big horn sheep (copyright Clifford Kolber - RamWeb)

It does appear as if the term snow lizard is a misnomer for the tauntaun. However, Figure 6 demonstrates possible similarities with a group known as the thunder lizards – the dinosaurs. It is hypothesized that some dinosaurs were warm-blooded, had fur or hair coats (recalling that some evolved into mammals and birds) and some had an upright posture unlike that of lizards (Lambert et al. 2001). The posture of the tauntaun, with its tail hanging limply against the ground, appears to be closer to that of older depictions of erect dinosaurs. Modern portrayals generally display a stiff tail held in an almost horizontal position during forwards movement.

Figure 6 Comparison between a goanna, tauntaun and dinosaur Compsognathus(images courtesy of AdvWeb, DinoWeb, Lucasfilm Ltd)

Tauntauns are described as omnivores, feeding on a sub-ice fungus as well as animals such as ice scrabblers and Hoth hogs when necessary (SWDBWeb). Reynolds (1998) states that their primary diet is lichen. Should the diet of tauntauns primarily be non-animal matter they would presumably need to spend a large proportion of the time grazing on the fungus and lichens. Polar and high mountain lichens on Earth metabolise and regenerate slowly (Attenborough 1984) and would provide little sustenance in Hoth-like conditions to tauntaun sized animals. Furthermore, the recovery of grazed areas would be quite slow. Perhaps geothermal activity might provide an energy source that would allow for faster regrowth and improved nutritional value.

The rebels managed to domesticate the tauntauns as riding steeds, yet it is believed that similar domestication of horses by humans was very difficult and developed over many years of selective breeding (Maidens). In this case we may need to defer to technology or techniques developed through many years of handling a variety of alien species.

3.4 Wampas

Figure 7 Wampa Ice Creature (© Lucasfilm Ltd)

The Wampa Ice Creature represents the pinnacle of the Hoth land food chain. Three metres tall, wampas are bipedal and coated with thick white fur. The wampa attacks its prey by striking it with its paws. The unconscious prey is then dragged back to the ice cave den of the wampa, where it is suspended upside down from the the ceiling by melting and refreezing the ice around the feet.

Like the tauntaun, the wampa has ram like horns on its head positioned level with the eyes. Furthermore, it is also bipedal, so it could be speculated that it is also related the the tauntaun. One major difference is the lack of a tail, and the wampa is also seen to walk with a humanlike gait, rather than the tauntaun's running style.

The wampa would share a similar position in the Hoth ecology to that of the polar bear in Earth's arctic region. Their diet is presumably of tauntauns, judging by the bones on display in the wampa's lair in *The Empire Strikes Back*, and the meat should provide a suitable energy source for a top level predator.

4. Climate

It seems unlikely that Hoth was always a frozen world. The current land ecology appears to be very simple with few distinct species. Yet organisms like the tauntaun and wampa are complex in nature. It is difficult to see how such creatures could have evolved in such an cold and ecologically limited world. Furthermore, without evidence of widespread photosynthesis, questions remain about the source of Hoth's oxygen atmosphere.

Evolution, geology and climate have been inextricably linked throughout Earth's history. The evidence suggests that Hoth was not always such a cold world. What triggered the transition from a warmer environment and presumably richer ecology to the current planetwide freeze where few animals and plants survive?

Considering the various factors that influence the planetary temperature is useful for attempting to isolate possible causes of the current Hoth Ice Age. Climate modelling is intrinsically complex, however we are only concerned with whole planet averages and not of a regional nature. Furthermore, the entire planet basically shares the same climate and assumptions about the distribution of landforms and environments prior to the onset of the ice age is not possible, with the exception that we know of a large oceanic body in the Southern Hemisphere.

4.1 Radiative Flux Equilibrium Equation

If we take the planet Hoth and its parent star as blackbodies in thermal equilibrium we have that:

$$T_e = \sqrt[4]{\frac{F}{4\sigma}(1-A)}$$

(EnBalWeb) where T_e is the effective radiating temperature of the planet in kelvin, F is the solar flux, A is the albedo and s is the Stefan-Boltzmann constant = 5.67 x 10^8 $W/m^2/K^4$. However, a planet is not a perfect approximation to a black body, so the actual average temperature is

$$T_a = T_e + T_{gh}$$

whereT_{gh}'s largest component on Earth is the greenhouse effect.

We will consider each of these factors in turn.

4.2 Solar flux

The temperature of the planet is directly related to the amount of energy that it receives from its parent star. As a star on the main sequence converts more of its hydrogen fuel to helium the core contracts, increasing the rate of fusion and causing the outer layers to expand, raising the star's luminosity. Hence we would not expect Hoth's planetary temperature to be directly related to the parent star's evolution along the main sequence.

It is possible that shorter period effects may contribute a decrease in the solar flux. It has been suggested that the *Little Ice Age* between 1645 and 1715 on Earth corresponded with a period with very few sunspots and reduced solar output (Ribes & Nesby-Ribes 1993). However, this interpretation is controversial (Beckman & Mahoney 1998).

Once a star has left the main sequence, greater variability in flux output is possible. A star of similar mass to the Sun will eventually become a red giant, expanding in size and perhaps warming up outer planets that would otherwise be too cold for life, before eventually collapsing down into a white dwarf of luminosity a hundredth of its main sequence value. The changes here are possibly too dramatic for life to evolve – by the time a star has turned into a white dwarf the outer layers of the solar atmosphere have been shed and any planets close enough to still feel the remnant's succor would have been roasted and probably vapourised in the red giant phase. We know that the star is not in a red giant phase by observing the planet's colour in reflected light (Figure 1, 2) and directly in Figure 9 – it is quite white!

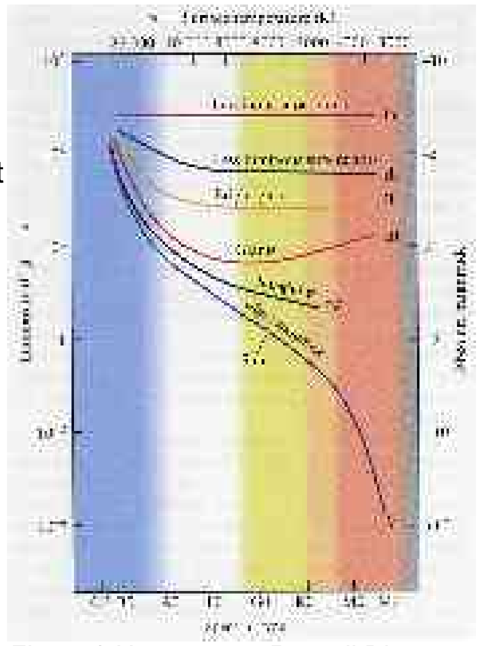

Figure 8 Hertzsprung-Russell Diagram (reprinted from Freedman & Kauffman 2002)

A “blockage” of solar energy reaching Hoth is one method of reducing the flux received without requiring a change in the output of the star. Tarsia et al (1987) demonstrate that one such mechanisms that has been suggested, the passage of the solar system through a cloud of cosmic dust, will probably not trigger an ice age due to the particle sizes. Further discussion is postponed until a later section.

Figure 9 Surface of Hoth, showing its parent star (© Lucasfilm Ltd)

4.3 Albedo

The second, and probably most important element of the radiative flux equation is the *albedo.* This is the fraction of incident light reflected by a body. The higher the albedo, the more light that is reflected back into space.

From the Table 1 it is obvious that the surface features and environment of a planet will make a big difference to its albedo. Earth's average albedo is 0.31 (EnBalWeb), but for Hoth, which is almost entirely snow and cloud bound the albedo would be towards 0.8 or greater. Note that differences in the albedo of the oceans can be explain by the fact that the reflectance of a surface is proportional to its refractive index and the angle of incidence of the incoming light. For the oceans the highest reflectance at oblique angles, while overhead light is strongly absorbed (transmitted into the depths).

Surface	***Albedo***
Ocean	0.03 - 0.8 (overhead - horizon)
Forest	0.05 - 0.2
Sand & Grass	0.2 - 0.3
Fresh snow	0.8 - 0.9
Thick cloud	0.7 - 0.8

Table 1Adapted from EnBalWeb

Figure 7 shows the relationship between Earth's surface temperature and its average albedo (note that it has been adjusted for greenhouse effects). It can be seen that an increase of 20 percent in the albedo would lead to an average surface temperature below freezing. Although this is somewhat of a simplification, it can demonstrate the potential feedback effect on the planetary albedo. Cooling temperatures lead to the formation of more ice and snow, which have a higher albedo than the land or ocean that they replace and cool the planet further.

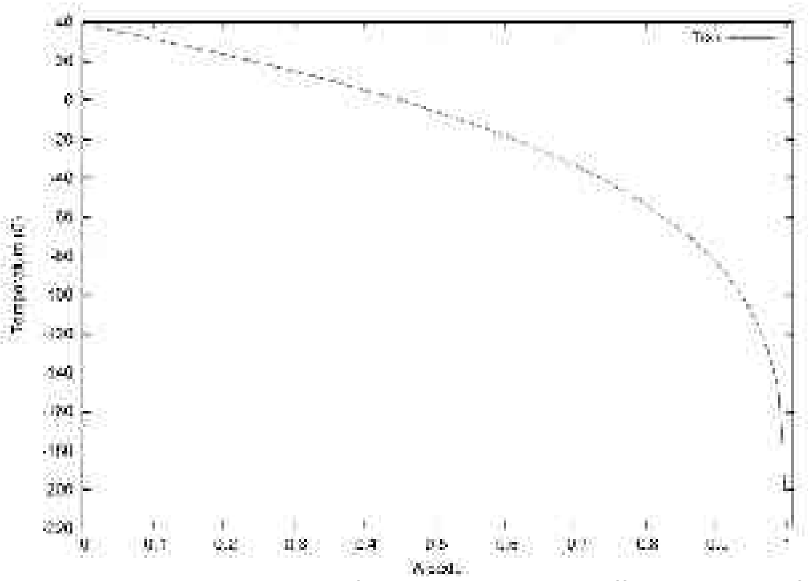

Figure 10 Earth's average surface temperature at different values of the albedo

It should be noted that clouds also have a high albedo and there are other effects that can also lead to changes in the levels of energy absorbed and reflected by the atmosphere. Volcanoes (VolcWeb) and fires, including those generated by a “nuclear winter” scenario (Turco et al 1983) can not only initially cool the surface with an injection of soot and dust that would block incoming light, but also inject sulphur particles high into the atmosphere, increasing the planetary albedo.

An impact of a large asteroid or comet can also throw large quantities of particulate into the atmosphere (Hoyle 1984) as well as igniting widespread fires. The characters in the *Empire Strikes Back* mention a high rate of meteor activity around Hoth. This is probably related to the nearby asteroid field (Figure 11). This field, ascribed to as the result of a “collision between two rocky planets eons ago” (SWDBWeb), features frequent collisions which probably eject material into various trajectories. The high density of the field should imply that the asteroids would accrete relatively rapidly or be dispersed into more widely spaced orbits. Saxton (2001) suggests that another body could be responsible for maintaining the localised asteroid concentration as well as causing periodic swarms into the inner solar system. A question remains about the influence of such a body on the original planets.

It has been suggested by McKay and Thomas (1978) that an encounter by the Earth with a dense cloud of interstellar dust could result in a lowering of temperature in the mesosphere. The formation of ice clouds in the mesosphere would increase the planetary albedo, perhaps by enough to trigger an ice age.

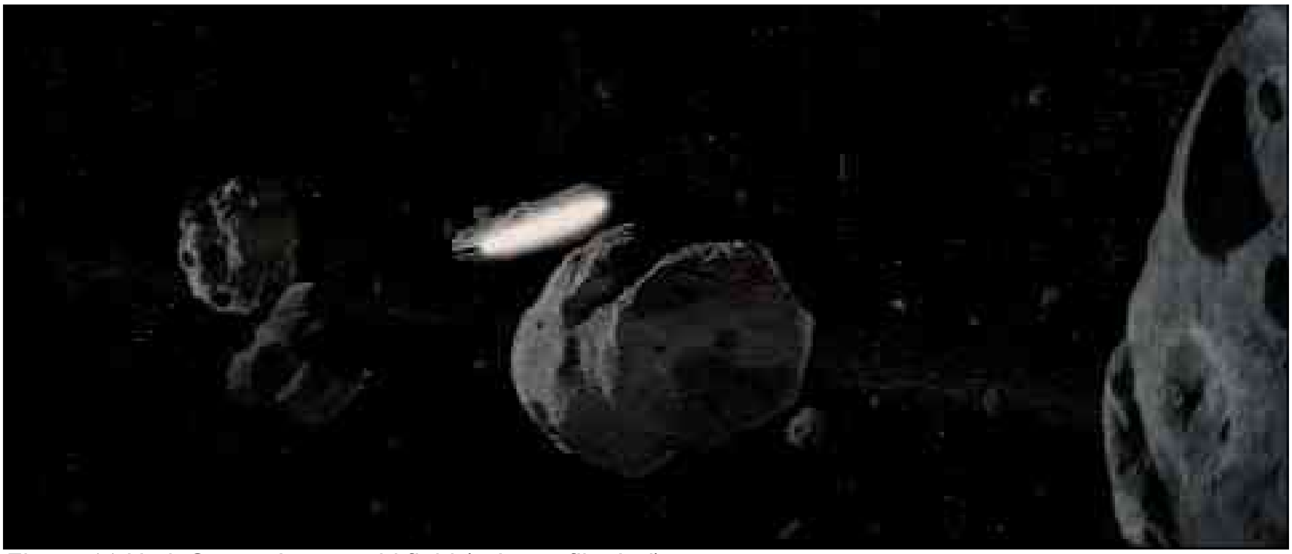

Figure 11 Hoth System's asteroid field (© Lucasfilm Ltd)

Hoyle (1984) also considered the impact of dust in the planet, both from impacts and interstellar dust clouds, coming up the interesting suggestion that fine particulate matter deposited and suspended in the oceans could increase their albedo.

Hoyle's result, along with those of McKay and Thomas (1978) is disputed by Tarsia et al (1987) who find that the suggested dust densities are too high to be compatible with observed values for the interstellar medium. In turn, Pavlov et al (2003), found that Earth should encounter clouds of densities greater than 2000 hydrogen atoms per square centimetre approximately every 100 million years. Their models suggested that this would be enough to cool the planet. Without knowing further details about Hoth's parent galaxy it is diffficult to judge the potential for clouds of interstellar dust and gas to have triggered its ice age.

4.4 Other Triggers

There have been many other suggestions for possible causes of ice ages on Earth that could also have triggered a similar event on Hoth. Shaviv (2002) proposed that the cosmic ray flux could influence Earth's climate (disputed by Rahmstorf et al.2004).

Milankovitch (MilWeb) identified cyclic changes in Earth's orbit, axial obliquity and axial precession that appeared to coincide with climatic events. These could cause increased seasonal variations and differential heating across the planet. The tidal effects of Hoth's three moons could have interesting effects on the planet's axial tilt.

An increase in Hoth's orbital distance from its parent star would decrease the solar flux that it receives. The same body that was responsible for disturbing the orbits of the two planets that collided to form Hoth's asteroid belt may also have had an effect on Hoth's orbit.

4.5 The Greenhouse Effect

It was noted that planets are not perfect blackbodies and that the greenhouse effect was responsible for keeping Earth's surface temperature above that which the radiation equation would suggest. The greenhouse effect involves atmospheric gases including water vapour, carbon dioxide and methane reradiating infra-red radiation back to the planet's surface. Current human activities are thought to be increasing the level of carbon dioxide in the atmosphere and causing the planet to warm.

Carbon dioxide, the primary greenhouse gas, is produced by respiration, the burning of organic material and released from volcanoes. This is largely balanced by plant photosynthesis and by the formation of carbonates by weathering and erosion processes.

Photosynthetic activity has been gradually reducing the levels of carbon dioxide in the atmosphere and increasing the levels of oxygen (Kasting 1993). This reduction is predicted to continue for the Earth (Caldeira & Kasting 1992) until photosynthesis is no longer sustainable at some stage between 500 and 800 million years from the present (Franck et al 1999). Were it not for the fact that the Sun's temperature was also increasing, the Earth reduced greenhouse effect could plunge the Earth into another total ice age.

Should photosynthesis or weathering been even more efficient on Hoth than Earth, or the initial concentrations of carbon dioxide and other greenhouse gases lower, it is possible that Hoth's climate may have been tripped into a frozen state earlier than the prediction for Earth.

It may have already happened on Earth before. Halverson et al. (2002) have suggested that the positioning of Earth's continents at the equator and away from the poles may have disrupted the carbon cycle, reducing the atmospheric greenhouse gases, plunging the entire planet into an ice state.

5. Total ice ages and future prospects

The periods referred to as Ice Ages in most of Earth's history have not involved total planetary freezes such as experienced on Hoth. During the last ice age experienced on Earth the glaciers only reached as far south as New York and the land around the tropics was still warm enough to support coral reefs (Walker 2003). However, there is strong geological evidence to show that Earth experienced a series of total, or near total, freezes around 600 million years ago at the end of the Precambrian era (Hoffman & Schrag 2000). The period during these planetary freezes has been dubbed “Snowball Earth” and appears very similar to that of Hoth.

It is difficult to compare the potential of the Earth to support a Hoth-like ecology during the Snowball Earth periods, as Earth life had barely reached the multicellular stage and was probably restricted to the oceans and other bodies of water (Knoll 2003). However, the events that are believed to have taken place shortly at the end of the Snowball Earth period could make it difficult for organisms such as tauntauns and wampas to survive and may indicate that this is the first total freeze that Hoth has experienced since they evolved.

We know that the Earth recovered from its snowball state. Hoffman and Schrag (2000) suggest that the mechanism for this recovery was a build-up in greenhouse gases. While volcanoes still pumped carbon dioxide out, a lack of photosynthesis and the lack of rain and exposed rock to permit weathering allowed carbon dioxide to build up in the air. After tens of millions of years the greenhouse effect would heat the planet up to temperatures greater than 50 degrees Celcius causing widespread melting and flooding to reverse the Snowball state.

Perhaps larger cold-adapted animals could migrate to polar regions to survive a switchover into a hot planet state. However, even the end of minor ice ages on Earth lead to the extinction of many animals and Hoth's limited land ecosystem may have trouble adapting to new climates. It is a fate that cannot be escaped from as an aging Sun will eventually warm the planet once more.

6. Conclusions

It seems almost certain that Hoth was once a warmer world with a richer ecosystem. A planetary catastrophe, possibly triggered from an event in the solar system or perhaps a geological event, has caused the planet to fall into a deep freeze, leaving it with a very basic ecology. This ecology is highly reminiscent of the Arctic and Antarctic regions of Earth. Despite some taxonomic difficulties, the bottom and tops of the food chain are highly plausible, with algae, fungus and lichens forming the base of the polar food chains on Earth, while wampa ice creatures stand in for polar bears. However, there are still questions associated with the ecology able to support browsing animals. Hoth may be an ecology in decline, or one that has a difficult future ahead of it.

7. Bibliography

7.1 Note on sources

There are many sources of information on the *Star Wars* universe. They are frequently contradictory and often available only by purchase. In writing about Hoth I have taken information in the *Star Wars Databank* on the official website to be canon, as well as the movie of *The Empire Strikes Back*. Other *Star Wars* resources are referred to where appropriate, but not treated them as "fact".

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All screenshots taken from Star Wars: The Empire Strikes Back.

7.2 Software

- Report written using OpenOffice 1.1.1
- Gnuplot was used to generate the plot
- PaintShoPro 6 for manipulating graphics
- Cyberlink PowerDVD used to capture movie screenshots.

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Swinburne Astronomy Online: http://astronomy.swin.edu.au/sao/