Initial Environmental Evaluation

Halley Relocation Project

BAS Environment Office

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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

CONTENTS

Non-Technical Summary

Initial Environmental Evaluation - Halley Relocation Project

1. Introduction

This Initial Environmental Evaluation (IEE) has been carried out by the British Antarctic Survey (BAS) for the proposed relocation of Halley VI. It covers the selection of the new location, the activities involved in the move itself, and minor changes to Halley infrastructure during the 2016/17 and 2017/18 field seasons. The environmental impacts associated with constructing and operating the station are considered in the Comprehensive Environmental Evaluation (March 2007).

The IEE has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1998).

2. Description of the Proposed Activity

The objective of this project is to relocate the Halley VI station from its current location (referred to as Z6), including all associated science and service infrastructure, to a new location (referred to as Z6A) on the Brunt Ice Shelf that is not at risk from a calving event or other significant change to the ice shelf.

Halley VI was designed and engineered as a re-locatable structure in the expectation that it would need to be moved to a new site in the future. The objectives of the Halley relocation project include selecting an appropriate new location (Site Z6A) on the Brunt Ice Shelf and safely relocating all Halley VI infrastructure (buildings, services, science) to the new location.

Scientific techniques such as Ground Penetrating Radar will be used to assess the preferred location of Site Z6A.

The move process will be carried out by temporarily decommissioning the modules, separating them, then towing them to their new location. Bulldozers will push the rear skis for the modules, thereby providing additional power when needed. A small amount of Exxsol D60 drill fluid may be used to lubricate the skis to ease movement.

The majority of the work will take place over the 2016/17 and 2017/18 seasons. Temporary camps will be in use at the current and new site locations to house the personnel involved in the move and running of the station. A Winter Science Camp will be established to house science staff at the current Halley Site during winter 2017. These camps will be removed as part of the project.

Improvements to the existing infrastructure will also be made to facilitate future relocations and to facilitate operations when BAS operations are supported by a single ship, notably changes to fuel storage, which will involve increased bulk storage of fuel and a decrease in the volume of drummed fuel. Accessible obsolete infrastructure will be removed from the current Halley VI site to reduce the station footprint.

3. Description of the Environment

Z6 site, Z6A site and the traverse routes are located on the Brunt Ice Shelf, which contains no ice-free areas.

The Brunt Ice Shelf does not support any flora, and there are no breeding birds or mammals at the proposed new location of Z6A. The station may very occasionally be visited by small numbers of moulting Adélie and emperor penguins. There is an emperor penguin colony of about 15,000 breeding pairs on the fast ice at 'Windy Creek', located about 30 km from the current Z6 site, over 55 km from Z6A, and 15 km from the nearest ship unloading site. Weddell seals are common on the sea ice adjacent to the ice shelf.

There are no protected areas (Antarctic Specially Protected Areas, Antarctic Specially Managed Areas or Historic Sites or Monuments) on the Brunt Iceshelf, although commemorative plaques are present at Halley, mounted on a sledge in the station environs.

4. Alternatives to the Proposed Activity

Alternatives to the proposal have been examined as follows:

- i) Do nothing: abandon the station
- ii) Do minimum: close the station and remove all infrastructure
- iii) Remove all infrastructure and build a new station at a glaciologically low-risk location
- iv) Relocate the station to a new site upstream on the Brunt Ice Shelf where it will be safe from glaciological threats for approx. 20 years (the remainder of the lifetime of the existing buildings)
- v) Relocate the station to a new site beyond the Brunt Ice Shelf where it is not susceptible to glaciological threat.

Relocating the station upstream on the Brunt Ice Shelf where it will be safe from glaciological threats for the remainder of the buildings lifespan (Option iv) is the only realistic option as it prevents the loss of infrastructure (and associated environmental impact), loss of science capability and is operationally and economically viable.

All other alternatives were not considered viable for scientific, logistical or environmental reasons.

5. Impact Assessment

Environmental impacts associated with the Halley Relocation Project include the emissions from ships, aircraft and the vehicles used to supply the project and move the modules and science equipment, which would have an unavoidable impact on air quality. There is the potential for fuel spills that may contaminate the traverse and station sites and a small volume (approximately 40 l) of drill fluid will be used to lubricate the skis that will contaminate the ice. Waste will be generated which, if handled incorrectly, has the potential to contaminate the ice and impact the wilderness and aesthetic value of the area. It is not feasible to recover all materials from the Halley VI site (such as the steelwork under the snow surface, magnetometer shaft and some cables) and these will remain in Antarctica and impact upon wilderness values in the local vicinity. Discharge of treated sewage will contaminate the ice with nutrient-rich sludge. Given that the activities are proposed on an ice shelf there is little potential to affect flora and fauna. The memorials present at the Halley station will be moved to its new location and will not be affected by the project.

6. Mitigating Measures

An environmental briefing, based upon this IEE, will be given by the BAS Environment Office to all those taking part in the proposed activities.

Appropriate measures are recommended to mitigate any adverse impacts. These will include:

- Logistics will be planned with maximum efficiency.
- Vehicles and equipment used will be selected for their fuel efficiency, and they will be well maintained and switched off when not in use.
- Fuel will be handled in accordance with well-developed procedures and containment tanks engineered to reduce the risk of spills. Staff will be trained in oil spill response.
- An Oil Spill Contingency Plan and spill kit will be in place at both Halley VI current site (Z6) and Halley VI new site (Z6A).
- Wastes will be handled in accordance with the BAS Waste Management Handbook. The planned relocation project will result in less waste remaining in Antarctica than the 'do-nothing' option; however, materials present below the ice surface at Halley VI will remain *in situ*. Surface science equipment will be retrieved.
- Station location and traverse routes will avoid environmentally sensitive areas (e.g. emperor penguin colonies, Antarctic Specially Protected Areas).
- Any use of Unmanned Autonomous Vehicles (UAVs) will be in accordance with the BAS UAS Regulations, will be operated by trained personnel only and will be not be used close to wildlife.
- All equipment will be checked prior to deployment to ensure that it is free of soil and non-native biota, as set out in the BAS Biosecurity Handbook.

7. Environmental Monitoring and Management

Compliance with the BAS Environmental Policy and the mitigation measures outlined in this IEE will be the responsibility of all personnel, but will be overseen by a BAS Station Leader. A report on the implementation and effectiveness of this IEE will be prepared for submission to the Foreign and Commonwealth Office (FCO).

8. Conclusion

This Initial Environmental Evaluation indicates that the Halley Relocation Project is likely to have no more than a minor and transitory impact on the Antarctic environment, provided the recommended mitigation measures identified in this report are carried out. It is therefore concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

Section 1

INTRODUCTION AND SCOPE

1. INTRODUCTION AND SCOPE

1.1. Introduction

The Halley VI station is located on the Brunt Ice Shelf, a 130 m thick floating platform of ice located at a latitude of approximately 75 degrees South. The station accommodates up to 70 scientists and support staff who undertake polar science, field activities and air and sea operations.

Halley VI consists of a modular building structure, completed in 2012, that contains laboratories, living space, accommodation and service infrastructure such as electrical generators. Surrounding the main building are a range of sledge-mounted service buildings providing vehicle garages, workspaces and additional laboratories and accommodation. There are also large numbers of outdoor scientific experiments, many of which require large mast-mounted antenna structures.

The environmental impacts associated with the construction and operation of the Halley VI Research Station (and the demolition and removal of Halley V) are described in the final Comprehensive Environmental Evaluation (CEE) dated March 2007.

In March 2015, BAS scientists noticed that a crevasse in the Brunt Ice Shelf, previously inactive for 30 years, had started to increase in length and width. Predictions based on further scientific data concluded that these glaciological changes threatened the Halley VI Research Station.

To minimise the threat to infrastructure and personnel, the Halley Relocation Project was initiated, with the aim of securing the future of Halley VI from the glaciological threat by moving the station further ‘upstream’ on the Brunt Ice Shelf, to a glaciologically safer location.

The CEE explicitly stated that Halley VI was designed to be moved, although the mechanism for moving it and the location it would be moved to were not considered in that report.

This IEE has been carried out by BAS for the relocation of Halley VI on the Brunt Ice Shelf, Antarctica, and complements the existing CEE. It covers the selection of the new location, the activities involved in the move itself, and minor changes to Halley infrastructure to facilitate changes in BAS shipping operations during the 2016/17 and 2017/18 field seasons.

The IEE has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty*. The Revised Guidelines for Environmental Impact Assessment in Antarctica (Resolution 1, XXXIX ATCM, 2016) were also consulted during its preparation.

1.2. Statutory Requirements

To ensure the protection of the Antarctic environment, the Antarctic Treaty nations adopted the Protocol on Environmental Protection to the Antarctic Treaty (hereafter referred to as the Environmental Protocol), which entered into force in 1998. The UK enforces the provisions of the Protocol through the 'Antarctic Act 1994 and Antarctic Act 2013' and

'Antarctic Regulations 1995/490 (as amended)'.

1.2.1. Annex I – Environmental Impact Assessment (EIA)

One of the guiding principles of the Environmental Protocol is that an EIA be carried out before any activity is allowed to proceed. It states that activities should be planned and conducted on the basis of *'information sufficient to allow prior assessments of, and informed judgments about, their possible impacts on the Antarctic environment'* (Article 3).

Annex I of the Environmental Protocol sets out the detailed regulations for EIA in Antarctica, and establishes a three-stage procedure based on different levels of impact. The levels are:

- Preliminary Assessment;
- Initial Environmental Evaluation (IEE); and
- Comprehensive Environmental Evaluation (CEE).

An IEE is for activities, which are likely to have a minor or transitory impact on the Antarctic environment. It is considered that an IEE is appropriate for the proposed relocation of Halley VI. In the UK the IEE is subject to review by the Foreign and Commonwealth Office (FCO), which also makes the final decision on whether the activity should proceed.

1.2.2. Permits

The Antarctic Act states that certain activities within Antarctica require a permit before being undertaken. The activities included in this IEE will be covered by the BAS Operating Permit, which is organised directly between BAS and the FCO; no Specialist Activity Permits are required.

1.2.3. Purpose and Scope of Document

The purpose of this IEE is to provide information on the proposed activities of the Halley Relocation Project, their potential environmental impact, and a description of how impacts will be avoided or minimized.

The document has been split into the following sections;

- Section 2 describes the proposed activities;
- Section 3 describes the local environment;
- Section 4 describes the alternatives considered;
- Section 5 describes the environmental impacts and the measures proposed to minimise or avoid them; and
- Section 6 provides the conclusions of the IEE.

A non-technical summary has been included at the beginning of the document to provide an overview of the IEE in a clear, concise and non-technical manner as well as outlining the conclusions achieved.

Section 2

DESCRIPTION OF THE PROPOSED ACTIVITY

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2.1. Background to the proposed activity

Scientific data relating to the ice shelf movement is routinely collected and analysed by BAS scientists. In early 2015 changes were identified in a crevasse close to the station. The analysis indicated that the proximity of this crack in relation to the station and its current trajectory mean that it poses a significant risk to the station in future years. Growth of the crack along its current trajectory would isolate the station from the inland portion of the ice shelf, and effectively put it on an iceberg with little possibility of maintaining the long-term viability of the station structure.

The objective of this project is to relocate the Halley VI station, including all associated science and service infrastructure, to a new location on the Brunt Ice Shelf that will not be affected significantly by the changes in the ice shelf.

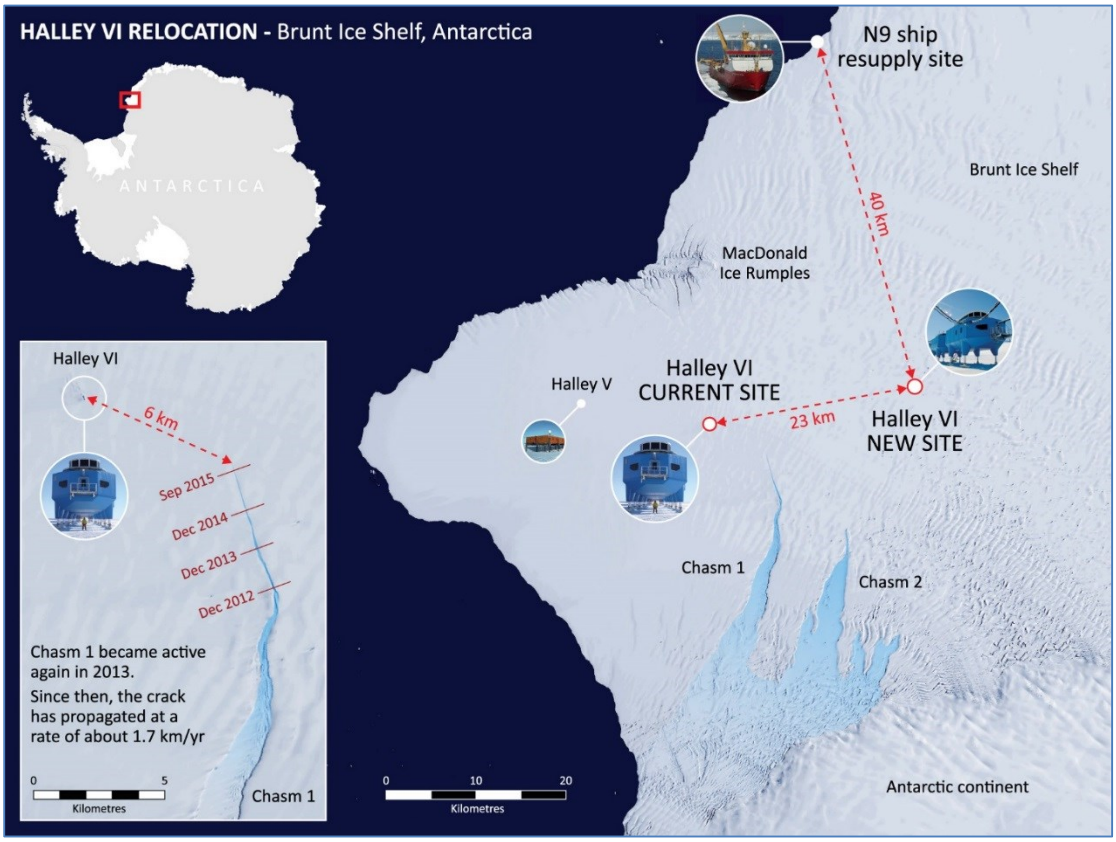
The scientific data leading to this decision is summarised in the project document 'HRP – Scientific Justification' (BAS/0001/HRP/Doc/001) included as Appendix 1.

As described in the Halley VI CEE, Halley Research Station was designed and engineered as a re-locatable structure in the expectation that at one or more points in its life span it would need to be moved to a new site. Despite this, the logistical and engineering challenges of moving this substantial infrastructure in such a remote location are significant.

The objectives of the Halley relocation project can be summarised as follows:

- Pick a new site (site 'Z6A') on the Brunt Ice Shelf that satisfies the site selection criteria that are to be defined during the Project Planning Phase
- Safely relocate all Halley VI infrastructure (buildings, services, science) to the new location
- Complete the relocation within the time constraints (contingent on the rate of propagation of the crack)
- Make improvements to the existing infrastructure to facilitate future relocations, where possible, and to facilitate operations when BAS is supported by a single ship
- Remove all accessible obsolete infrastructure from the Halley VI site
- Minimise disruption to science delivery at Halley VI.
- Reduce station footprint whilst maintaining the same or increased science output (in order to reduce the long-term logistical/maintenance burden)
- Document the relocation procedure for future use

2.2. Location of the Proposed Activity



2.3. Description of proposed activities

2.3.1. Overview of project schedule

Planning for the Halley Relocation Project commenced in April 2015. The 2015-16 season included the delivery of a large amount of project-related cargo to the existing Halley site and fieldwork activities to assess the best location for the new site.

The majority of relocation work at Halley will take place over two Antarctic summer seasons (16/17 and 17/18).

Key activities will be scheduled as follows:

Period	Key activities	EIA
Summer 2015-16 (completed)	• Routine station activities • Cargo logistics – delivery of majority of project cargo to Halley by ship • Field work for selection of new site	Covered by Preliminary Environmental Assessment (approved October 2015)
Summer 2016-17	• Fieldwork to confirm the selection of the new site and traverse routes	

	(geophysical survey and GPS station installation) • Cargo and personnel logistics • Construction of two temporary camps (Z6 and Z6A) to house personnel • Construction of 'winter science camp' to house personnel at Z6 during winter 2017 • Relocation of station modules and supporting infrastructure to new site • Deconstruction and shipping-out of temporary camp infrastructure	Activities covered by this document
Summer 2017-18	• Routine station activities. • Cargo and personnel logistics • Relocation of science infrastructure to new site • Clean-up of old Halley VI site. • Additional bulk fuel containers provided	

The following sections describe the various project-related activities taking place in Antarctica over the 2016-17 and the 2017-18 seasons that are above and beyond normal station operations.

2.3.2. Cargo and personnel logistics

The majority of the equipment required for the relocation project was taken to Halley VI across three ship calls during the 2015-16 season. This included ~40 shipping containers, break-bulk cargo and heavy vehicles, which were stored in depots on the snow surface at Halley, ready for use in 2016-17.

For the 2016-17 season, cargo logistics will be 'business as usual' with two ship calls through the season that will bringing in fuel, routine station cargo and some project cargo (mostly break-bulk). The intention is to back-load the ship as much as possible at last call, thereby taking the opportunity to remove any obsolete cargo from the site.

The demands of the 2016-17 season require a peak of approximately 90 personnel at Halley. Arrival and departure from Antarctica will be via the usual routes: Twin Otter transfers from Rothera, Dromlan flights from Cape Town via Novo Airfield and personnel on the ship.

The 2017-18 season will be run as a routine Halley season, albeit with the science infrastructure relocation work taking place concurrently. In total, approximately 75 personnel will be deployed. Three ship calls are planned, in order to bring in the new fuel infrastructure (sledges and bulk fuel tanks) and remove the remaining obsolete relocation project equipment.

2.3.3. Selection and preparation of the new site

The new site is approximately 24 km ‘upstream’ from the existing Halley site, grid reference S75° 34.5755’ W25° 26.9602’ (as at 9th February 2016).

The site was selected following the analysis of data collected in an extensive fieldwork programme during the 2015-16 season. This is documented in a series of reports prepared by BAS scientists. By the end of this season, the site was flagged out and four drummed fuel depots installed (approximately 800 drums in total).

Further scientific activities will be carried out at the start of the 2016-17 season. These will include the use of Ground Penetrating Radar to check that no crevassing has appeared at the location of the new site, or on the traverse from the current to the new Halley site or on the route from the relief site to the new location. In addition, two new GPS stations will be added and a new range-tracking radar system installed to monitor the chasm. This will alert BAS to any changes in the chasm (such as sudden widening) to protect the safety of staff moving between the current and new Halley sites.

UAS flights will be carried out at the site of Z6A and around the tip of Chasm 1.

During 2016-17 work is required prior to the module moves to get the Z6-Z6A route groomed satisfactorily. Furthermore, substantial snow moving will be required at the new site to level the area where the modules will be deployed.

By the end of the 2017-18 season all infrastructure at the current site will be relocated to this new site.

2.3.4. Operation of the Halley VI (Z6A) Station

Halley Research Station, when moved to its new location (Z6A) will be operated with the same requirements and objectives as at the current location (Z6) and as described in the CEE, with the exception of sewage treatment and fuel storage.

<u>*Sewage treatment*</u>
There have been issues with the incineration of sewage sludge since Halley VI was first operational. To date, the Sewage Treatment Plant (STP) incinerator (integral to the sewage treatment plant) has not been successful in burning the treated sewage sludge. A replacement was fitted, which also failed to work effectively.

Alternative methods to incinerating the treated sewage sludge have been investigated, although nothing could be sourced for the 2016/17 season that was sufficiently hygienic to operate in close proximity to the living quarters and that fits in the space available.
It is therefore proposed that treated sewage from the modules will be discharged into a sewage ‘onion’ for the 2016/17 season until suitable technology for handling the sludge has been identified and commissioned.

For the first month of its operation at the new location (Z6A) the STP will be re-commissioned (having been drained down prior to the move). During this time it is envisaged that the sewage sludge discharged will be untreated or partially treated.

Fuel storage
In order to ready the Station for future resupply by a single ship (i.e. with less frequent resupplies) changes to fuel storage are proposed. There will be more bulk storage and less drummed fuel, which will speed up the delivery time for the equivalent volume of fuel stored on station, and reduce manual handling, waste, and cost.

Thirty new 22,000 litre bulk fuel tanks (and associated sledges) will be purchased to supply fuel to the station, and one new 15,000 litre fuel tank for refuelling aircraft at the skiway.

The maximum number of 205 litre fuel drums stored on the station will drop from 4500 to 200.

2.3.5. Construction, deconstruction and operation of temporary camps

During the module relocation phase of the project in 2016-17, a pair of temporary camps will be constructed to house the c. 90 personnel, with one camp at each site (Z6 at current site and Z6A at new site). These camps are similar to those used for the initial Halley VI build seasons. The camps will be within the perimeter of the current site and the new site.

The two camps are broadly the same in design, the only significant difference being that the Z6A camp will also use the Drewry building to provide some accommodation. They will be constructed out of converted shipping containers, providing bedroom units, washrooms, boot-rooms, a kitchen, a surgery and storage. A large Weatherhaven tent will provide dining and recreation facilities. A plywood corridor between the shipping containers will make them weather-proof.

The camps will be independently powered using external generators, fuelled from the existing Halley bulk tanks. Water provision will be by snow-melt tank. Disposal of sewage and grey water will be through an 'onion', i.e. a heat-traced discharge pipe drilled several metres down into the snow surface.

The intention is that the camps will be decommissioned at the end of the 2016-17 season. As much of the infrastructure as possible will be shipped out at final call (with the limiting factor being the ship's cargo capacity), with the remainder stored in a depot at Halley for removal the following season.

If the 2016-17 season project programme slips, it may be that the temporary camps will be required *in situ* the following season. In this scenario they will be closed down and sealed for the winter, re-opened the following summer and shipped out at the end of the 2017-18 season.

2.3.6. Construction, deconstruction and operation of the WSC

The winter science camp (WSC) is a broad description of the various infrastructure components installed at Z6 during the summer 2016-17 season that will keep the science infrastructure running remotely and house a small maintenance team during winter 2017.

Accommodation
A small team of staff will rotate through the Z6 WSC for the duration of the winter. Their responsibility will be to maintain station power and service the science infrastructure. Their primary accommodation will be the WASP (workshop and stores platform), adapted

specifically for this use. A separate emergency caboose will also be provided for redundancy.

Waste water and sewage
Grey water and urine disposal from this site will be with a standard 'onion', as per the temporary camps.

The WSC will use a dry-bagging toilet. Sealed bags of waste will be transported to the main Halley station for incineration.

Power generation
A redundant pair of generators housed in a shipping container will power the WSC. These will be fuelled from standard Halley bulk tanks, pre-positioned at the start of winter.

Transport
There will be routine transport between Z6 and Z6A throughout the winter for personnel exchange. This will be predominantly by skidoo, with occasionally trips undertaken by Sno-cat or other vehicle.

2.3.7. Relocation of station modules

With all of the personnel moved out of the station modules, the decommissioning and relocation will then take place. This will be a relatively straightforward process.

The first step will be to drain down the wet services, including water and LTHW (low temperature hot water) systems. Fuel levels in the fuel tanks will be reduced as far as possible prior to the move. Then the generators will be turned off and the services between the modules disconnected.

The modules will be towed using heavy vehicles, using the same methodology as was used to move them to the current site. For the lighter modules, this will require three 'prime mover' vehicles attached in series to the front of each module by a towing frame. When additional power is needed, a pair of bulldozers will also push the rear skis. The journey to the new site will take approximately 8-12 hours per module, depending on snow conditions. The heavier modules (particularly the A-module) may require additional vehicles to keep maintain momentum.

One risks is that the module skis may freeze into place, causing a substantial increase in the towing power required to move them initially. This will be mitigated by using Exxsol D60 drilling fluid to reduce the friction between the ski and the snow surface and is a method tested at Halley during the 2015-16 season. Less than one litre of the fluid is used per ski (so <40 litres total). It is not possible to collect up any of the used fluid, but all unused fluid will be disposed of by shipping it back to the UK.

Move activities will be filmed using an Unmanned Aerial System (UAS) to record the move process and generate footage for broadcast.

2.3.8. Relocation of ancillary infrastructure

There is a large amount of ancillary infrastructure to be moved over to the new site. This includes the garage building, the Drewry, waste sledge, fuel depots, bulk fuel tanks, sledges, etc. These infrastructure components are already moved annually to reduce snow deposition, so this is effectively 'business as usual', albeit over a larger distance.

2.3.9. Relocation of science infrastructure to new site

During the 2017-18 season the science infrastructure will be relocated to Z6A. This includes the CAS laboratory, science cabooses and numerous antennas that are mounted on steel towers. In general, these will be craned onto sledges and towed across to the new site.

2.3.10. Clean-up of the old Halley site (Z6)

At the end of the 2017-18 season all waste and infrastructure will be removed from the old Halley VI site, with the following exceptions:

- Automatic weather station – this will be installed and left at the Z6 site for ongoing meteorological monitoring, with annual service checks by skidoo from the Z6A site. (see 2.6.1)
- Lifetime of Halley GPS station – these are identical to the other remote GPS units making up the Lifetime of Halley monitoring network and will be serviced annually by skidoo from Halley. (see 2.6.2)
- Steelwork under the snow surface – the various steel towers at Halley are built on top of steel foundations. Whilst all steel above the snow surface will be removed and reused or shipped out, the foundations will be left buried at Halley (estimated to be 59 tonnes of steel).
- Cables under the snow surface – the electric and communications cabling for the Z6 site is buried under the snow surface and will be left behind.
- Magnetometer shaft – this is a 15 m deep shaft in the snow, lined with plywood. This infrastructure, estimated at 35 tonnes of timber, will be left to bury and be abandoned.
- Sewage/waste water – the 'onions' left behind, from disposal of waste at the Drewry (untreated sewage and grey water) and the modules (partially treated sewage and grey water) will be left behind.

It should be noted that the steelwork, timber and sewage/waste water left behind at the Halley VI site would always have been left in Antarctica. This waste has arisen as part of routine station operations and is not being generated as a result of the need to relocate Halley.

2.3.11. Removal of waste

The project will generate approximately 5-6 ISO container loads of waste building materials. This will be processed using the normal station procedures, with recyclable goods segregated wherever possible.

Hazardous goods (including the D60 drilling fluid) will be shipped out using the standard station procedures. Adequate quantities of materials for packaging and shipping hazardous goods are available on station.

Due to the larger number of people on station (90+ during 2016-17, 75+ during 2017-18), there will be proportionately more waste generated, including kitchen waste. In order to cope with this increased volume, an additional Base General Assistant (Base GA) will be employed. This allows for one Base GA at each site.
An additional ship call is planned for the 2017-18 season (three calls rather than two). This is

partly due to the increased volume of waste for removal, but more importantly, allows shipping out of the c. 40 containers that will make up the temporary camps.

Where possible, the containers will be reused by BAS, with the others going for resale outside of the Antarctic.

2.4. Site selection and Brunt Ice Shelf monitoring

2.4.1. Site selection process

The selection of the new Halley Research Station site was a complex task, managed and overseen by the 'Halley Relocation Site Selection Committee (HRSSC)', a sub-group of the Halley relocation project.

The following guiding principles were used to narrow down the location of the new site:

- Eliminate areas that are economically or logistically unviable. This analysis was covered in the 'HRP - Outline Business Case' document.
- Eliminate areas that are glaciologically high-risk. This, and the following steps, are covered in detail in the minutes of the HRSSC meetings and field reports from Halley during the 2015-16 season.
- Eliminate areas that will increase the carbon footprint (through increased transit time and therefore fuel burn) of the station as explained in section 2.5.1.

The chosen site is approximately 24km 'upstream' from the existing Halley site, grid reference S75° 34.5755' W25° 26.9602' (as at 9th February 2016).

2.5. Environmental impact of site selection

The significant environmental impacts of the new site (versus the existing one) are listed below.

2.5.1. Distance to ship relief sites

The new site (see 2.2) is approximately 49 km from N9, the primary ship relief site, and 53 km from the Creeks (as compared to the current Z6 site, which is 49 km from N9 and 23 km to the Creeks). The impact of this is in the amount of fuel used by vehicles to transit stores and equipment to and from Halley during relief.

Given that the distance to N9 is unchanged, this will continue to be used as the primary relief site, with the Creeks as a backup if N9 is blocked by ice. There is also some ship time planned for the 2016-17 season to investigate possible alternative relief sites.

2.5.2. Distance for relocation

The new site is as close as possible to the existing Halley site, whilst still remaining in a glaciologically lower-risk area. This minimises the amount of fuel required to move the station and all associated infrastructure to the new site.

2.5.3. Site longevity

The new site has been chosen with the intention of providing a site longevity greater than the projected life-span of the module buildings. Therefore, there should, in theory, be no further requirement to move the station again within its lifetime. However, the inherent uncertainties in predicting ice-shelf dynamics mean that this situation could change.

2.5.4. Distance from Windy Bay penguin colony

The Z6A site is a greater distance from the Windy Bay penguin colony (>55 km). This will substantially reduce the number of visits to the colony by Halley personnel due to the logistical difficulties of getting there.

2.6. Remote equipment installations

The following equipment or instruments will be installed, or changed as a result of the relocation project.

2.6.1. Automatic weather station (AWS)

During the 2015-16 season, a remote AWS was installed at Z6A, to gather meteorological data prior to the move. Once the station infrastructure has been moved in the 2016-17 season, this instrument will be moved to Z6. It will remain there for the long-term to continue the data collection. The AWS will be incorporated in the maintenance schedule for all remote field equipment and will be serviced annually by personnel from Halley travelling the site by skidoo. If there is any indication of a rapid change in the Brunt leading to potential loss of the equipment then the AWS will be recovered if possible.

2.6.2. Lifetime of Halley GPS stations (LoH)

The Lifetime of Halley project is a network of GPS stations across the Brunt Ice Shelf, used to monitor changes within the ice shelf. Following the relocation of the modules to Z6A, a GPS station will be installed at Z6. This, similarly to the AWS, will remain in position for the long-term to track the movement of the ice and will be serviced annually by personnel from Halley, travelling to the site by skidoo.
There is also potentially going to be a larger-scale change to the LoH GPS network in 2017-18 or later, with the location of some sites being changed, to provide improved monitoring with the station in its new location. The detail of this has yet to be decided.

2.6.3. VHF repeater

During the 2016-17 and 2017-18 summer seasons a temporary ethanol fuel-cell powered VHF repeater will be installed on the route between Z6 and Z6A. This will be mounted on a sledged caboose and used as a half-way stop on the route.

2.6.4. Z6-Z6A drum line

The existing flagged route between Z6 and Z6A may be marked out using empty fuel drums positioned every 100 m, as occurs with other routes out of Halley. This detail have yet to be confirmed. The drum line currently running from Z6 to Creek 3 will be removed and replaced with flags, primarily due to the anticipated reduction in traffic over this route as a result of the move.

2.7. Duration and Intensity of the Proposed Activity

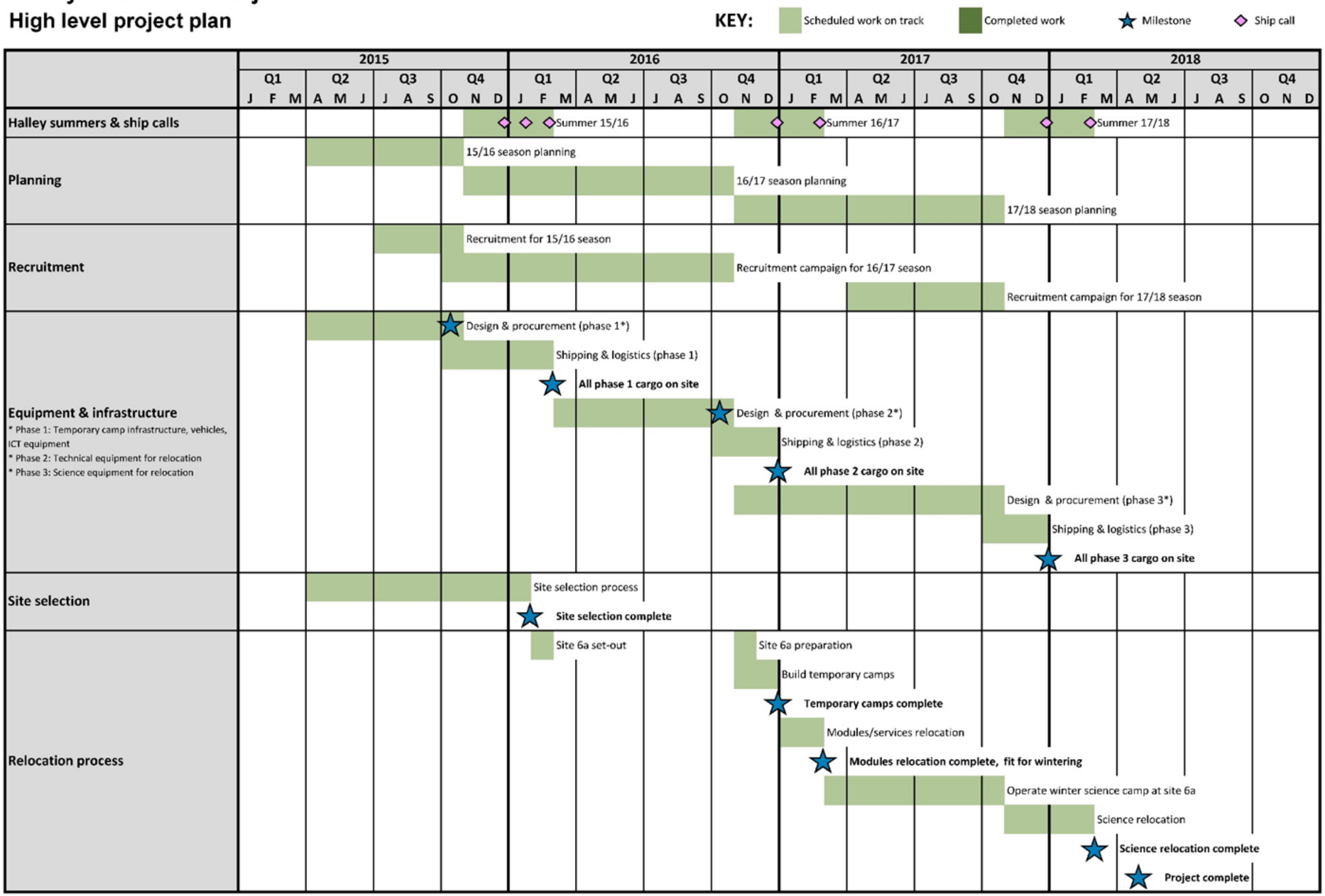
The timeframe for the Halley relocation project, with key dates, is shown on the project plan below.

Logistical activities will be more intense than usual at Halley, with additional staff being present on site over the next two field seasons (90+ during 2016/17 and 75+ during 2017/18), compared to the usual maximum summer staffing (of 52).

The footprint of operations will also increase given that the two sites will run concurrently (at the current and new locations) and the number of ship calls will increase

Halley Relocation Project

High level project plan



Section 3

DESCRIPTION OF THE LOCAL ENVIRONMENT

3. DESCRIPTION OF LOCAL ENVIRONMENT

The existing Halley VI site Z6, the new Halley VI site Z6A and the traverse routes are all located on the Brunt Ice Shelf.

The Brunt Ice Shelf is part of Environment K – Northern latitude ice shelves – in the Antarctic Environmental Domains Analysis (EDA). Environment K is a moderately sized ice shelf environment located in four key areas around the continent, along Victoria Land coast, Eights Coast, southern Antarctic Peninsula and southwest and east coasts of Weddell Sea between latitudes 70°S and 76°S. The environment covers an area of 191,085 km^2, consists entirely of ice shelf, and contains no mapped geology. Climatically the environment is cool with an average air temperature of –13.5°C and has the ninth largest seasonal range at –19.54°C. The average wind speed in the environment is moderate at 12.00 m s^{-1}. As one would expect in an ice shelf environment the slope is almost non-existent at only 2.79°, making it the fourth flattest environment on the continent. Further information on the baseline environmental conditions are included in the Halley VI CEE.

The Brunt Ice Shelf does not support any flora, and there are no breeding birds or mammals at the proposed location of Z6A. The station may very occasionally be visited by small numbers of moulting Adélie and emperor penguins. There is an emperor penguin colony of about 15,000 breeding pairs on the fast ice at 'Windy Creek', about 30 km from Z6, over 55 km from Z6A, and 15 km from the nearest ship unloading site. Weddell seals are common on the sea ice adjacent to the ice shelf.

There are no protected areas (ASPAs, ASMAs or HSMs) on the Brunt Ice Shelf, although commemorative plaques are present at Halley, mounted on a sledge in the station environs, for the following:

- Memorial plaque for Neville S Mann, died 15 Aug 1963
- Memorial plaque for Jeremy T Bailey, David P Wild and John K Wilson, died 12 Oct 1965 (There is also a plaque at Survey Point, Vardeklettane, Heimfrontfjella.)
- Memorial plaque for Miles V Mosley, died 2 Feb 1980

Section 4

ALTERNATIVES TO THE PROPOSAL

4. ALTERNATIVES TO PROPOSAL

The following alternative options to relocating Halley were evaluated and ruled out at an early stage of project planning.

This process is covered in detail in the document 'HRP – Outline Business Case' (BAS/PM/HRP/002C/OBC Appendix 2), from which the following table is taken.

No.	Option	Evaluation
1	Do nothing: abandon station	Complete a planned evacuation of all personnel and portable assets within two years. The Station would then be abandoned. A planned evacuation can be completed within normal BAS operations. Abandoning Antarctic stations is not compliant with the Environmental Protocol or UK Antarctic Act. The environmental impact of doing so would be unacceptable and BAS would risk damaging its reputation. **Option unfeasible due to loss of station infrastructure and environmental and reputational damage**
2	Do minimum: close the station and remove all infrastructure	All station infrastructure would be dismantled and removed from the continent by ship. All personnel would be evacuated. A planned evacuation can be completed within normal BAS operations. A vessel will need to be chartered to remove infrastructure from Antarctica. A project team, vehicles and temporary accommodation will be required to dismantle and remove the Station and Infrastructure. **Option unfeasible due to loss of station and science**
3	Remove all infrastructure, build new station at location with no glaciological threat	All existing station infrastructure would be dismantled and removed from the continent by ship. A new station would be designed and built at a new 'safe' location that was less vulnerable to future glaciological events (for instance on grounded ice, such as the Lyddan Ice Rise). Requirements as Option 2, with the addition of a long lead time to design/build a new station (note: Halley VI took nine years from start of project to finished product). New site may be out of range of aircraft from Rothera (required for logistical support and medi-vacs). **Option operationally and economically unviable**
4	Relocate to new site upstream on Brunt Ice Shelf	All existing station infrastructure would be relocated to a new site on the Brunt Ice Shelf, far enough upstream that it would be safe from glaciological threats for the remainder of the lifetime of the existing buildings (approx. 20 years).

		Distance to new site is approximately 23 km. A project team, vehicles and accommodation could be put in place to dismantle and move the station and infrastructure. The route is acceptable and has been surveyed by skidoo. This option will be challenging to complete within timeframe. There is a small chance that the station may need to be relocated again in the future. **Chosen option.**
5	Relocate to new site beyond Brunt Ice Shelf not susceptible to glaciological threat	All existing station infrastructure would be relocated to a new site that would be safe from glaciological threats e.g. grounded ice on the Lyddan Ice Rise (grounded ice is ice-shelf that overlies land, so carries less of a risk of calving off). A project team, vehicles and temporary accommodation will be required to dismantle and move the Station and Infrastructure. It is not clear whether a viable route exists to the proposed site. It is c. 200 km to the Lyddan Ice Rise, and the route is likely to be too heavily crevassed for a safe and efficient move. Unlikely to be achievable using BAS logistics and therefore may have to charter a vessel. Survey by ship or aircraft is required. New site may be out of range of aircraft from Rothera (required for logistical support and medi-vacs). **Option operationally and economically unviable**

Section 5

IMPACT IDENTIFICATION AND MITIGATION

5. IMPACT IDENTIFICATION AND MITIGATION

The following predicted impacts of moving the Halley station and mitigating measures are based upon BAS experience of operating research stations and logistics associated with deep field projects.

5.1. Impact to Air

Air pollution will result from the use of vehicles in towing the modules and peripheral equipment/containers at Z6 to Z6A and in powering the temporary camps (this is in addition to the 'business as usual' scenario of operating the station and resupplying it as described in the CEE).

The additional logistics required to transport the extra staff employed to move the station will result in increased emissions from the transfer flights to Halley and in additional ship calls to supply the equipment needed to support the move.

Emissions will generally be rapidly and effectively dispersed by the strong and regular winds.

Whilst it is acknowledged that the emissions resulting from the use of vehicles all contribute to a reduction in air quality, the impacts are minor and largely unavoidable.

5.1.1. Mitigating Measures

The proposed logistics will be planned with maximum efficiency in mind by minimising the number of journeys and use of effective and safe route planning. Only BAS vessels will be used, which operate to the ISO 14001 Environmental Management Standard and have a SEEMP (Ship Energy Efficiency Management Plan).

Vehicles and equipment used on site were selected for their fuel efficiency. They will be well maintained and shut down when not required to further save fuel.

The greenhouse gas emissions associated with this project will be incorporated into the BAS Annual Environmental Report submitted to the BAS Executive Team and FCO.

5.2. Impact to Ice

The new station location, the traverse route to it, the resupply traverse route from ship to station and the remote equipment installation sites will all occur on ice, which could be impacted by fuel spills, waste disposal and loss of equipment.

Ice or snow contamination caused by spills and leaks of fuel could constitute potential localised impacts. The maximum quantity of fuel that could possibly be spilled or lost in any single event is 22,000 litres. This would only occur in the event that a transit container became punctured or lost.

Unless recovered quickly, spills would be partially absorbed by the surface snow, although it is anticipated that most will pass quickly through the surface layer to hard ice beneath. At this depth spilt fuel could remain within the ice for decades. There would be little biological effect of a minor fuel spill or leak near the station. Fuel spills occurring during ship to shore fuel transfer would have a greater impact as the receiving environment is more sensitive due to the greater (albeit still limited) presence of wildlife.

Fuels spills and leaks are most likely to occur through overfilling and splashes when transferring from the tank or drum to the vehicle or equipment, or as a result of equipment leaking through faults. The most likely spill volumes, should they occur, would be around 5-10 litres. Should a fuel drum split, then the maximum that could be lost is the 205 litres drum volume.

The D60 fluid used to lubricate the module skis and prevent icing-in will be left on the ice surface throughout the length of the traverse and cannot be retrieved.

An increase in the quantity of hazardous and non-hazardous waste produced by BAS (approximately 5-6 container loads) in Antarctica is expected as a result of the project. This waste, if handled incorrectly, could negatively impact upon the environment. The waste streams generated will include general building waste and additional domestic waste generated due to the higher than normal staff numbers at Halley.

Some waste materials including the steel foundations, power cables, wood (from the magnetometer shaft) and the sewage onions will remain in situ at Z6 as it is not feasible to remove them safely.

There is a risk that the remote equipment may be lost, if in the future they are not maintained, raised above snow level and eventually recovered.

5.2.1. Mitigating measures

BAS makes every effort to prevent accidental fuel spills through careful attention to fuel management at its stations, on ships and in the field.

Only light refined fuels such as AVCAT will be used at Halley, which will degrade more quickly in the event of a spill.

The fuel storage tanks are engineered to reduce the likelihood of a spill arising. They are made from stainless steel, have secondary containment (i.e. are double skinned), are fitted with leakage detection (to show if any fuel has leaked into the containment), have a valve to prevent overfilling and a gauge to show the volume held in the tank (again to reduce the risk of overfilling).

All bulk fuel tanks are inspected annually, prior to being re-filled at relief, to check their integrity and reduce the risk of spills occurring.

Spill response procedures are documented in the Halley VI Oil Spill Contingency Plan. Additional spill response kit will be supplied to ensure availability at both Z6, Z6A and the winter science camp (WSC).

All fuel handling operations will be carried out in accordance with well-developed procedures designed to limit the potential for spills and all staff involved will be trained in spill response.

Drivers with previous Antarctic experience, and preferably those with previous Halley experience, will be recruited to reduce the risk of a vehicle accident giving rise to a spill.

Any fuel spills that occur will be logged on the Accident, Incident, Near Miss and Environmental (AINME) reporting system and investigated by the BAS Environment Office to ensure that any lessons learnt are applied to prevent similar spills occurring in the future. The Foreign & Commonwealth Office are advised of environmental incidents (including fuel spills) in a routine annual report. Should any significant spill (over 1000 litres) occur then the FCO are advised within 24 hours of the event.

Only a small volume (approximately 40 l) of D60 will be used to lubricate the skis. It will degrade on the ice surface as exposed to light and air and therefore poses a negligible risk to the environment.

Staff involved in the project will comply with the BAS Waste Management Policy and will follow the procedures outlined in the BAS Waste Management Handbook (BAS, 2016). Waste handling practices are the same as those described in the Halley VI CEE, with the exception of sewage wastes, which are described below. An additional Base General Assistant (GA) will be employed to assist in waste handling commensurate with the increased volume of wastes that will be generated.

There will be discharge of untreated sewage and grey water at Z6A from the Temporary Camps and Winter Science Camp, which will contaminate the snow/ice by the addition of nutrients and microorganisms. Solid human wastes at the WSC will be bagged for incineration, limiting the impact at that location. Sewage generated on the modules will be treated once the STP has been recommissioned following the move (during the 1 month commissioning time untreated sewage will be discharged). The treated sludge will be discharged into an 'onion' for the 2016-17 season, or until an appropriate workable technology can be found to handle the sewage sludge. The location of areas impacted by the sewage discharge will be recorded for future reference.

Some materials at the existing Halley VI location will be left behind as they are impractical to remove. However, this is considered an acceptable impact of the relocation of Halley VI compared to the 'do nothing' option of leaving Halley in its current location where it is at risk of calving off and creating a greater waste issue.

The relocation of Halley VI also involves changing fuel storage practices, giving a greater emphasis on bulk fuel rather than drummed fuel, which will ultimately reduce the volume of seasonal fuel drum waste arising from Halley which requires disposal.
Remote equipment (GPS stations, etc.) will be retrieved from the field when no longer required. Their position will be recorded on the BAS Operations GIS to reduce the risk that they might be lost.

Any use of UAS to film the Halley relocation will be done in accordance with the BAS UAS Regulations. This will reduce the possibility of a UAS becoming lost in operations.

5.3. Impact to Native Flora and Fauna

High intensity visitation may lead to trampling of vegetation and soils and disruption of animal behaviour and breeding activities; however, there are no significant concentrations of wildlife, and no ice-free ground at or in the vicinity of the transportation route or Z6A.

Windy Creek penguin colony is over 55 km away from Z6A, a greater distance than that from Z6. The increased distance is likely to result in reduced numbers of recreational visits to the colony.

Inter and intra-continental transport provides the opportunity for the introduction of non-native species and/or relocation of indigenous species to new biogeographic regions. Such species translocation can occur in association with importing contaminated cargo, scientific equipment, fresh food, clothing and personal possessions.

The survival of any species inadvertently introduced to the station or along the transportation route is unlikely given the severe climate and lack of appropriate habitat for colonization.

5.3.1. Mitigating Measures

All staff will be briefed on environmental matters including the requirements of the BAS Biosecurity Handbook relating to the prevention of non-native species introductions.

The biosecurity procedures followed will be in line with best practice and will entail adherence to the vehicle cleaning guidelines, boot washing, cleaning personal and scientific equipment, as is standard BAS practice.

Wildlife viewing instructions are in place for all visits to Windy Creek and all staff are fully briefed prior to any recreational visit to the colony.

The UAS Regulations stipulate that flights are to be terminated should any wildlife be encountered, and no flying is allowed in the vicinity of Windy Creek unless accompanied by an appropriate specialist activity permit.

5.4. Impact on Wilderness, Aesthetic and Heritage Values

The relocation of Halley VI increases the operational footprint of the station as the operations will be spread over two sites and intervening traverse route. The activities involved will have a low visual and noise impact. It is anticipated that the layout of Z6A will be similar to Z6, although it will likely occupy a slightly smaller footprint as obsolete equipment from Z6 will be removed.

There is the low risk of equipment or wastes to become lost in the field, which should it occur would reduce the wilderness value of the area. Nevertheless, some materials will be left at the Halley VI site (steelwork, cables, magnetometer shaft, sewage onions etc.) but these will become buried and not visible.

The memorials present at Z6 will be relocated to Z6A, so the relocation project will not impact the heritage values of the station.

5.4.1. Mitigating Measures

Some impact on wilderness is unavoidable, but will be limited by preventing the loss of equipment in the field. The Halley relocation project will reduce the risk of losing the Halley Research Station due to a calving event on the Brunt Ice Shelf.

Any materials left in the field, either by accident or design, will be reported to the BAS Environment Office for inclusion in the "lost equipment log" and their position noted on the BAS Operations GIS.

The new position of the memorial plaques will be reported to BAS Archives so information on their position is retained.

5.5. Cumulative Impacts

A cumulative impact is the combined impact of past, present and future activities. These impacts can be cumulative over time and space.

The impacts associated with the Halley Relocation Project are in addition to those occurring due to standard station operations, which are already addressed in the Halley VI CEE. Discrete science projects are also likely to occur in the region and be covered by separate Preliminary Environmental Assessment when the need arises. The development of the BAS Operations GIS, which shows the location of all activities, will assist in the visualisation of cumulative impacts.

5.6. Environmental Education

It is BAS policy to brief all new recruits on 'Care of the Antarctic Environment' before they travel to Antarctica. An environmental briefing will be given by the BAS Environment Office to all those personnel involved in the project as part of the pre-deployment training.

5.7. Assessment and Verification of Impacts

All personnel involved with this project are responsible for the implementation of measures required to minimise or mitigate the adverse environmental impacts that may otherwise result from the Halley Relocation Project (Table 1). The Relocation Project Manager will nominate a site leader for each phase of the works who will be responsible for the daily on site supervision of each phase of the project. Photographs will be taken of the site and activities at all stages of the project, including the clean-up and removal of the infrastructure at Z6. The Relocation Project Manager will report back to the BAS Environment Office on the implementation of the mitigation measures discussed within this IEE (as is the case with all BAS Environmental Impact Assessments) at the end of each field season. The Environment Office will provide a short report to the FCO on compliance with, and effectiveness of, this IEE.

5.8. Impact Matrix

Table 1 shows a summary of the predicted environmental impacts that may result from the Halley Relocation Project, and how the Project plans to minimise or mitigate these impacts.

Table 1. Impact Matrix

Activity	Issue	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Fieldwork to confirm selection of new site and traverse routes	• equipment installation/use and possible loss • Fuel use and associated emissions	• reduction in wilderness values • Minor but cumulative contribution to regional and global atmospheric pollution inc. greenhouse gas emissions • Contamination of snow/ice from spills (of fuel or from batteries)	Low	Low	• Location of markers and remote equipment logged to reduce risk of accidental lost. Planned retrieval at end of project. UAS used is robust and flying will be in accordance with BAS UAS Regulations, with experienced pilot, to minimise risk of UAS loss. • Well maintained skidoos, and efficient journey planning in use to reduce emissions. • Well-developed fuel handling procedures in use. Staff trained in spill response. • All batteries are of 'non-spillable' type and are sealed and installed inside bespoke containers.
Fuel transfer and storage	• Fuel spills and leaks • Generation of waste drums	• Contamination of snow/ice • Waste materials/resources	Medium	Medium	• All staff will be trained in documented fuel handling and spill response procedures. • Bulk fuel tanks are well engineered with integral containment and mechanisms to prevent overfilling. • Spill equipment available at Z6, Z6A and winter science camp (WSC) and Oil Spill Contingency Plan in place. • Fuel spills to be reported for subsequent investigation by BAS Environment Office. • The decrease in drummed fuel will decrease the volume of waste generated by Halley annually.
Cargo and personnel logistics	• Fuel use and associated emissions • Potential to introduce non-native species	• Minor but cumulative contribution to regional and global atmospheric pollution inc. greenhouse gas emissions • Wildlife/habitat disturbance	High	Low	• Most efficient logistics planned to reduce fuel burn (and cost). • All staff briefed on environmental protection including the biosecurity requirements of the BAS Biosecurity Handbook. Any non-native species inadvertently introduced are not likely to survive the environmental conditions at Halley.
Construction of temporary Camps and Station	• Increased footprint of BAS operations	• Reduction of wilderness values and pristine nature of localities	High	Medium	• Z6A set up on a similar layout to Z6. Increased spread of staff and infrastructure during relocation project unavoidable. Ultimately Z6A will have smaller footprint as

Relocation	• Potential to introduce non-native species • Waste (hazardous and non/hazardous) • Atmospheric emissions • Heritage	• Wildlife/habitat disturbance • Contamination of snow/ice. • Waste materials/resources • Minor but cumulative contribution to regional and global atmospheric pollution inc. greenhouse gas emissions • Impact on memorial plaques			obsolete structures at Z6 removed. Preferable to move station to new location than let it calve off and become waste. • All staff briefed on environmental protection including the biosecurity requirements of the BAS Biosecurity Handbook. Any non-native species inadvertently introduced are not likely to survive the environmental conditions at Halley. • Use of D60 as lube limited in volume, although will cause minor but localised contamination of ice/snow. • All domestic and constructions wastes to be correctly packaged, labelled and removed for safe disposal, in line with BAS Waste Management Handbook. Additional Base GA employed to manage the additional waste arising due to this project. • Majority of Z6 will be removed from its current location. Materials under ice surface (i.e. steel foundations, cables, wooden casing of magnetometer shaft and sewage onions) will remain *in situ*. • Sewage sludge will contaminate the site of Z6A and the temporary camps during 2016/17. With the exception of the c. 1 month commissioning period for the STP, sewage from the modules will be treated prior to discharge (sewage from the temporary camp will be untreated). Solid human waste at the WSC will be collected for incineration. Technology for handling the treated sewage sludge from the modules will be sought for installation during the 2017/18 season to reduce the impact of the station in the longer term. • There is little wildlife to be disturbed. Visitation to the penguin colony at Windy Creek will likely be less than previously the case and is well managed and in accordance with site specific guidance. • The location of the memorial plaques will be recorded in BAS Archives.

Section 6

CONCLUSIONS

6. CONCLUSIONS

This Initial Environmental Evaluation indicates that the Halley Relocation Project is likely to have no more than a minor and transitory impact on the Antarctic environment, provided the recommended mitigation measures identified in this report are carried out. It is therefore concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

7. REFERENCES

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8. AUTHORS OF THE IEE

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9. Appendix 1 – HRP Scientific Justification

See overleaf

Scientific justification for the Halley Relocation Project

Version: 2.0 (approved)

SYNOPSIS: This document provides the background and the scientific justification for the relocation of Halley Research Station.

Author: G. Hilmar Gudmundsson (Glaciologist, British Antarctic Survey)

Preface

Document History:

Version	Date	Reason for Issue
0.1	5/8/15	First draft for internal review
0.2	5/8/15	Reviewed by DGV
0.3	6/8/15	Incorporated feedback from AB
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Document Approvals:

	Name	Role	Signature	Date
Author	G. Hilmar Gudmundsson	Glaciologist, BAS	GHG	4/9/15
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Reference Documents

Clark, T. D. G. (1986a) "Field trip to Conos Chasm, report 1" British Antarctic Survey scientific reports.
Clark, T. D. G. (1986b) "Field trip to Monster Canyon, report 5" British Antarctic Survey scientific reports.
Anderson, R., D. H. Jones, and G. H. Gudmundsson (2014). "Halley Research Station, Antarctica: calving risks and monitoring strategies." Natural Hazards and Earth System Sciences 14(4): 917-927.

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC
SCIENCE OF THE ENVIRONMENT

Table of Contents

1. Introduction

1.1 Purpose of this document

This document is intended to provide the scientific background and justification for the relocation of Halley VI Research Station. The project to establish Halley VI Station in a new location is referred to as the 'Halley Relocation Project'.

1.2 Authority

This document is a product of the 'Lifetime of Halley Committee' (now the 'Halley Relocation Site Selection Committee', HRSSC), a sub-group of the Halley Relocation Project responsible for providing scientific support to the Halley Relocation Project team.

The 'Lifetime of Halley' project is led by G. Hilmar Gudmundsson.

1.3 Executive summary

The conclusion of this analysis is that, taking into account all of the glaciological evidence available, the relocation of Halley VI Station should be completed by the end of the 2017-18 austral summer.

1.4 Overview

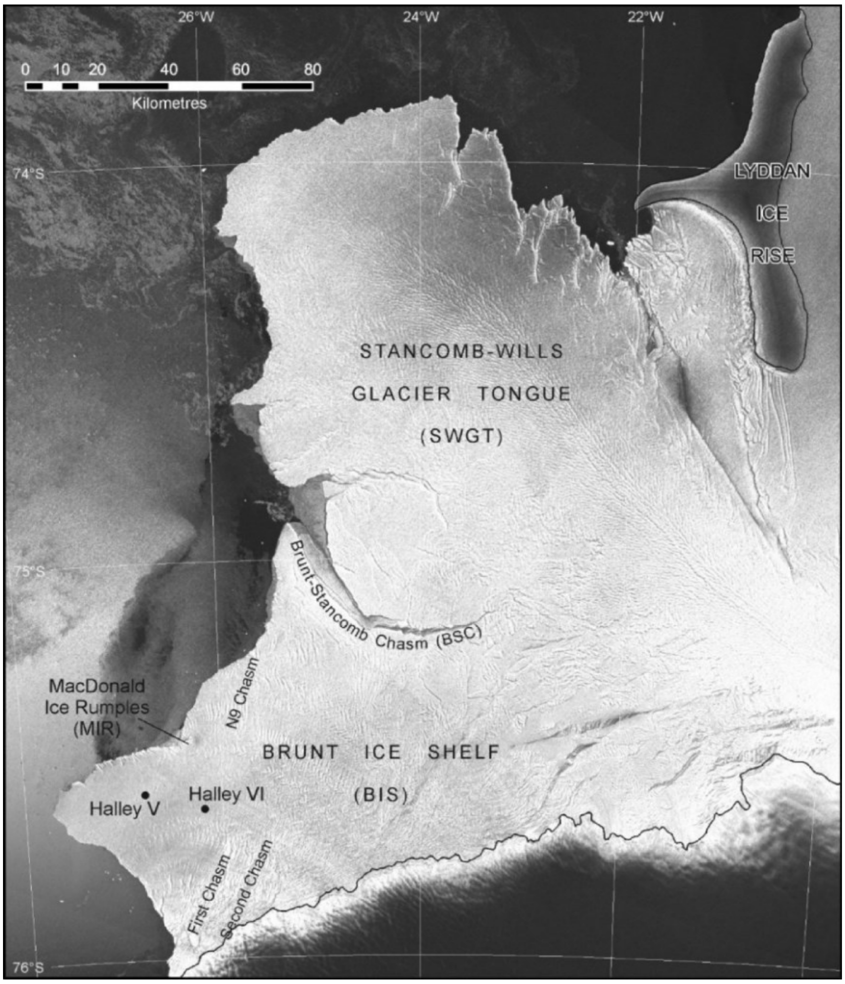

Figure 1. Map of Brunt Ice Shelf and Stancomb-Wills Ice Tongue. Note that Chasms 1 and 2 are marked as 'First Chasm' and 'Second Chasm' respectively.

1. Halley VI is one of the British Antarctic Survey's research stations. Situated on the Brunt Ice Shelf (see Fig. 1). It is occupied throughout the year. Halley VI replaced its predecessors (I – V) which have provided near-continuous measurements of key climatic and atmospheric parameters since the late-1950s. Some of these datasets (e.g., measurements of stratospheric ozone) are globally significant in providing evidence of change in the Antarctic region. The location of Halley VI within the region is important in maintaining the quality and coherence of these measurements.

2. Being built on floating ice, each Halley station is subject to specific engineering difficulties not encountered for stations built on rock. In particular, the annual movement of the ice shelf implies a continuously changing geographic location; the accumulation of snowfall cause the burial of all structures fixed to the ice; the horizontal stretching of the ice shelf requires flexibility in any structure fixed to the ice. Finally, the prolonged period of darkness and extreme cold of the Antarctic winter challenge logistical planning and execution.

3. Halley VI was built at the site of Halley V and then moved across the ice shelf to its current location in 2012. The station was designed to be moved periodically throughout its life, as conditions on the ice shelf required. However, the movement of the station incurs considerable disruption to station activities, and considerable expense.

4. The normal behaviour of all ice shelves is episodic calving of icebergs, causing the removal of sea parts of the ice shelf, and retreat of the ice front. While several of the ice shelves around the Antarctic Peninsula have undergone progressive retreat and collapse in recent years, the Brunt Ice Shelf exists significantly south of the climatic limit-of-viability for ice shelves identified on the Antarctic Peninsula, and together with the recently low rates of change in climate in this area, is not expected to undergo similar retreat or collapse for many decades. However, the structure of Brunt Ice Shelf is known to be complex and it has not been possible to make clear predictions about the likely date of future calving events. For this reason a programme of monitoring, known as the "Lifetime of Halley" project has been undertaken since the design of Halley VI was begun. The aim of that project was to identify and highlight any change in the ice shelf that might put the station at risk from calving events, and provide sufficient advance warning of potential threat to the station infrastructure.

5. Around Dec. 2012, and after at least 30 years of inactivity, Chasm 1 (see Figs. 1 and 2) started to grow towards the Halley VI research station. Prior to this, or around Jan 2010, Chasm 1 started a short-lived growth phase that then came to an end sometime around Feb. 2011 (see Fig. 3).

6. It is not uncommon for cracks to form during the summer months, and to heal again over winter. Therefore ongoing analysis of the crack over several years was required to determine whether it represented a potential threat to the station. This analysis indicates that the proximity of this crack to the station and its current trajectory mean that it poses a significant risk to the station in future years. Growth of the crack along its current trajectory would isolate the station from the inland portion of the ice shelf, and effectively put it on an iceberg with little possibility of maintaining the long-term viability of the station structure. Similarly, there is also a possibility that growth of the crack will deviate towards the station and cause more direct issues for the station structure.

2. Background information about the Brunt Ice Shelf

The Brunt Ice Shelf (BIS) is located at 75º S, 26º W in the eastern Weddell Sea (see Fig. 1). To the north-east of the BIS lies the Stancomb-Wills Glacier Tongue (SWGT), a considerably larger ice shelf than the BIS forming the seaward projections of the Stancomb-Wills Glacier. Despite its name, the Stancomb-Wills Glacier tongue is an ice shelf, just like the Brunt Ice Shelf.

Together, the two ice shelves (the BIS and SWGT), form a continuous floating ice mass and the exact boundaries between the BIS and SWGT are difficult to define. The SWGT is bounded on the north-east edge by the Lyddan Ice Rise and the Riiser Larsen Ice Shelf. The BIS is pinned along the northern margin where it goes aground at the McDonald Ice Rumples (see Fig. 1). The two ice shelves are fed from separate glaciers flowing seawards from the continent. Of these ice shelf tributaries the Stancomb-Wills Glacier is the most prominent one.

As the ice spills across the grounding line, marking the division between the grounded and floating ice masses, large cracks and chasms are formed in the ice at several places. With time these chasms then heal and fill in as sea ice forms within them and snow drifts in from the surface. Along the northern calving front of the BIS a series of jagged “creeks” are found that result from stresses in the ice as it flows around the McDonald Ice Rumples.

The BIS has three rifts of note, named the N9 Chasm, Chasm 1, and Chasm 2 (see in Fig. 1). Both Chasm 1 and Chasm 2 initially formed as open cracks in the vicinity of the grounding line. Subsequently these cracks were filled with sea ice and snow drift. The alignment of the N9 Chasm differs to that of the other chasms and the grounding line. This, as well as the misalignment of neighbouring morphological features suggests that the N9 Chasm may have been formed by a past collision. Chasms 1 and 2 are located upstream of the Halley Research Station (both V and VI).

The N9 Chasm is an old rift that has not shown significant activity since at least 2003. However, in the last two decades the rift has entered the region immediately east of the McDonald Ice Rumples where a calving event occurred in 1971. The other two rifts, Chasms 1 and 2, were created by the regime change of the 1971 calving event, as observed by Halley personnel (Clark, 1986a, b) after the event. Until recently both Chasm 1 and Chasm 2 were inactive. *However more recently Chasm 1 has started to grow, and, as explained in detail below, this recent growth of Chasm 1 presents a possible hazard to the Halley Research Station.*

3. Overview of scientific investigation of the Brunt Ice Shelf

The Halley Research Station, operated by the British Antarctic Survey, has been located on the Brunt Ice Shelf (BIS) in Antarctica since 1956. The first Halley station was built at the conclusion of the International Geophysical Year Trans-Antarctic Expedition, and its location was determined as the end-point of this expedition.

Since 1956, the Halley Station has grown from a simple wooden hut (Halley I) to a series of linked, ski-mounted, relocatable modules (Halley VI). A staff of 10–20 occupy the base through the austral winter, with up to 100 present in the austral summer. The research station has a primary focus on atmospheric sciences, and is the site for many long-term monitoring activities, including the records that first indicated the existence of the Antarctic ozone hole.

3.1 Lifetime of Halley Project

Due to its location on a floating ice shelf (see Fig. 1), it has long been accepted that the Halley Station is subject to particular hazards, with a large calving event being the most obvious and serious.

Due to this inherent risk, BAS has closely monitored the situation and ongoing developments on BIS. These ongoing efforts are referred to as the 'Lifetime of Halley' (LoH) project. For the last 13 years, this project has been led by G. Hilmar Gudmundsson.

Once the move from Halley V to Halley VI was completed in 2012 and Halley VI established in its present location, the activities of the LoH project were reduced but maintained at a low-level. One of those activities maintained was the running of a permanent network of GPS stations, and the analysis of the resulting data. The locations of the GPS stations are shown in Fig. 2.

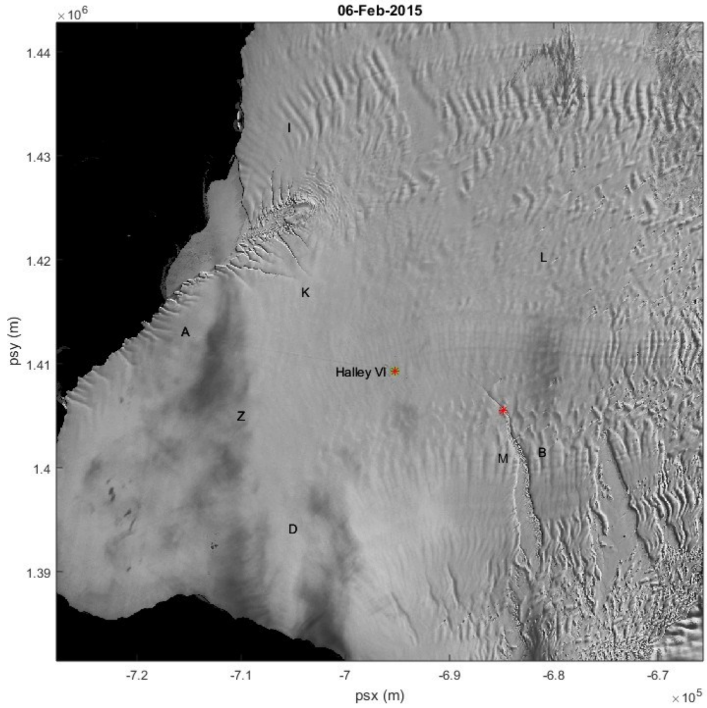

Figure 2. Recent Landsat 8 image of Brunt Ice Shelf (acquired on 6 Feb 2015). The letters indicate the locations of the permanent GPS stations currently (as of 2015) located on Brunt Ice Shelf as a part of the `Lifetime of Halley' project. All nine stations transmit data daily back to BAS HQ in Cambridge. The GPS station Z is at the former location of the Halley Research Station (Halley V).

4. Current situation

4.1 The growth of Chasm 1

The Lifetime of Halley project identified that in late 2012 to early 2013, after at least 30 years of inactivity, Chasm 1 started to grow towards the Halley VI research station (see Fig. 3). It is not uncommon for cracks to form during the summer months, and to heal again over winter. Therefore ongoing analysis of the crack over several years was required to determine whether it represented a potential threat to the station. Analysis of satellite data (Landsat 8, Radarsat 2, Sentinel, TerraSar-X), and in-situ measurements (GPS and GPR), shows that the crack tip is now migrating approximately towards Halley VI.

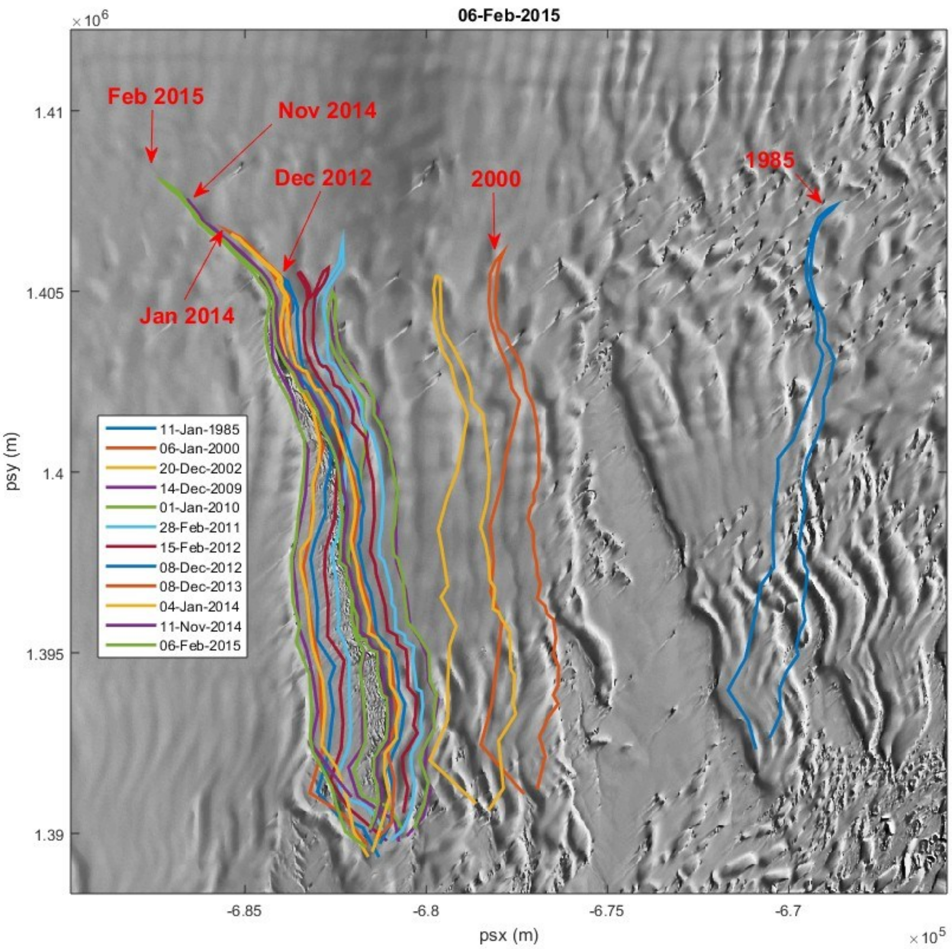

Figure 3. The evolution of Chasm 1. The outlines of Chasm 1, as determined from satellite imagery, are shown over a background Landsat 8 image from Feb. 2015. Each outline shows the geometry and the location of Chasm 1 at respective times. The general movement of Chasm 1 from right to left in the figure, is due to the overall flow of the ice. As the figure shows, after a long period of inactivity Chasm1 started to grow in early 2013. The tip of the Chasm is migrating towards the Halley VI station (see also Fig. 4).

Chasm 1 is not only growing in length, but also in width. The width of Chasm 1 over the last decade is shown in Fig. 4. It is currently about 30 km long and extends over about half of the total width of the Brunt Ice Shelf.

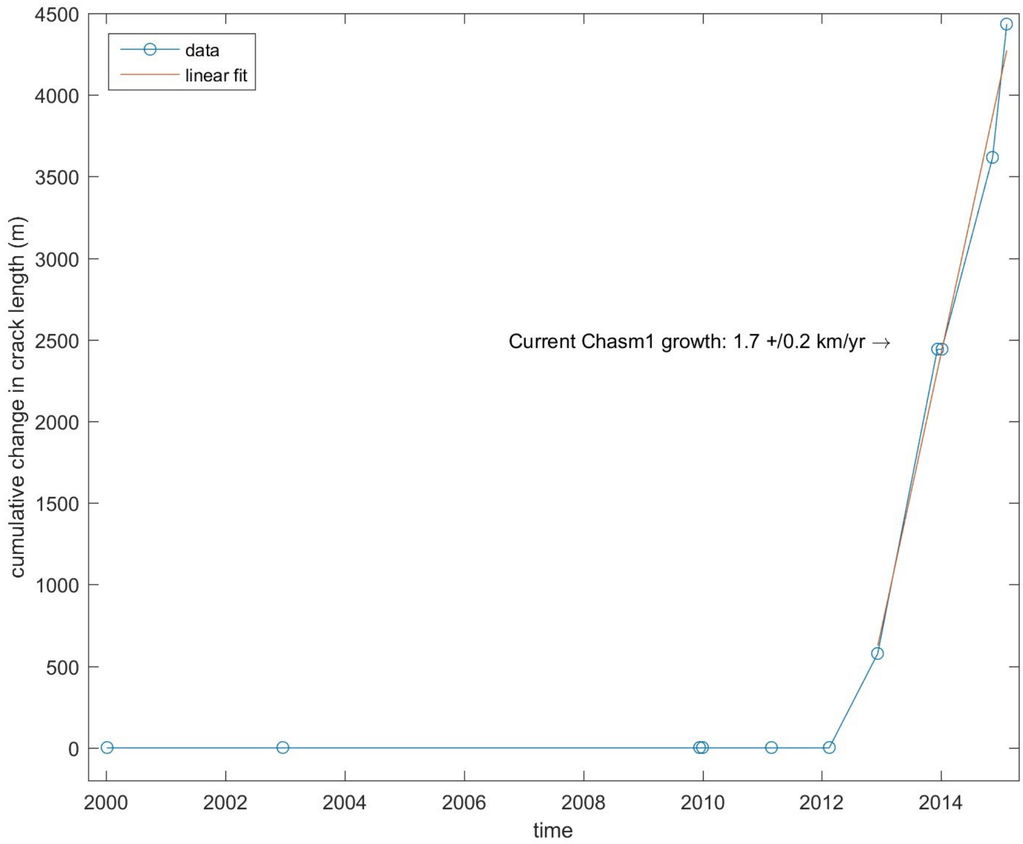

Figure 4. The growth of Chasm 1 with time. The data points (shown as circles) are based on an analysis of satellite images. Currently the tip of Chasm 1 is propagating at a rate of 1.7 +/- 0.2 km /year.

The outlines of Chasm 1 in their correct geographic position (i.e., the movement of Chasm 1 as part of the ice shelf is included) at various different times over the last 30 years are shown in Fig. 3. These outlines were determined on the basis of high-resolution satellite imagery. As the figure shows, after a long period of inactivity Chasm 1 started to grow in early 2013. Plotting the location of the tip as a function of time (see Fig. 4) shows that the crack tip is now migrating at the rate of 1.7 +/- 0.2 km per year. Currently the crack tip is about 7 km away from Halley VI.

A ground-penetrating radar (GPR) survey of the area around the tip of the Chasm 1 was conducted in March 2015. In total, five survey lines each 3 km long with a spacing of 1 km were surveyed (see Figs. 5 and 6). The crack was clearly visible in the data from lines 1 and 2, but not in lines 3, 4, or 5. The survey also showed that Chasm 1 is the only crack in the area. Based on the GPR survey we can be sure that Chasm 1 has not extended to cross survey line 3 and its tip is currently somewhere between lines 2 and 3. This agrees fully with independent analysis done on the basis of satellite imagery.

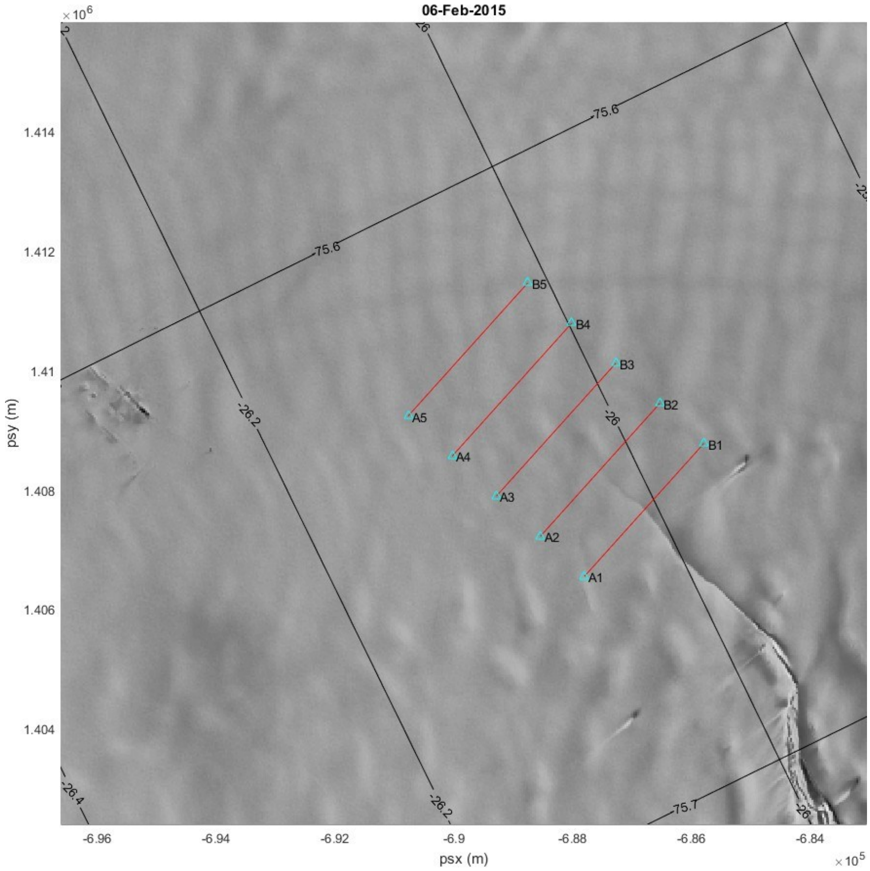

Figure 5. Chasm 1 and the Halley VI research station. The red lines represent recently surveyed GPS profiles. The Halley VI research station is clearly visible towards the left-hand margin of the image. Emerging from the lower right corner is Chasm 1. The image is from 6 Feb. 2015, and as can be seen the tip of Chasm1 was then about 7km away from the research station. The tip is currently migrating at the rate of 1.7 km/yr.

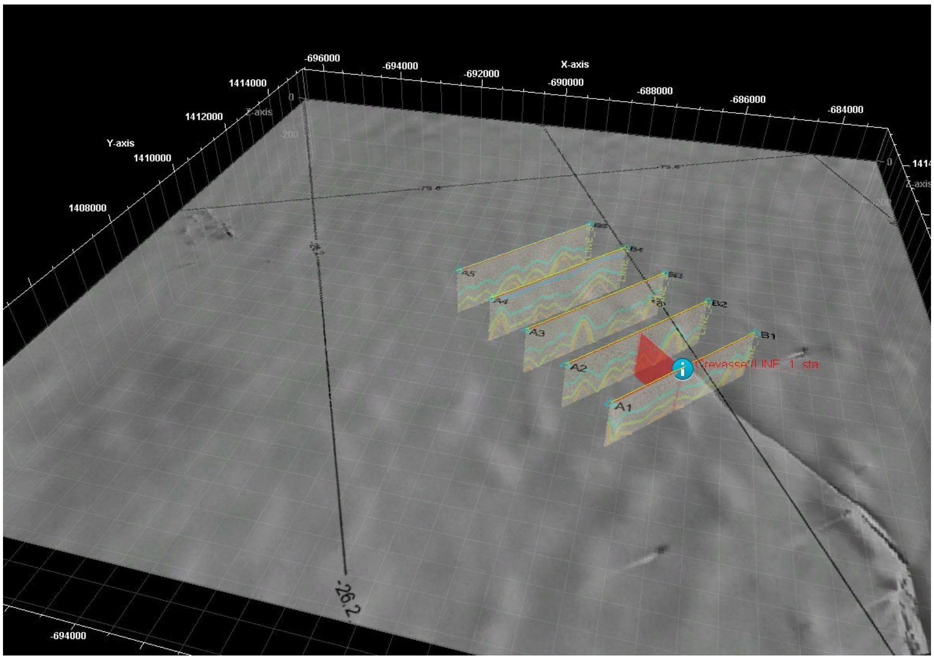

Figure 6. Results of GPR measurements conducted in March 2015. The main objective of the survey was to determine the location of the tip of Chasm 1. The crack was detected in the first two profiles (A1 – B1, and A1 –B2) but not in the remaining three. The location of the crack tip as determined by the GPR survey agreed fully with previous estimates made from analysis of satellite imagery. The Halley VI station can be seen in the image. The satellite image in the figure is a Landsat 8 image from Feb. 2015. The red panel shows the geometry and location of the crack as determined from the GPR survey.

4.2 Current state of the ice shelf

Apart from the growth of Chasm 1, the scientific evidence collected in support of the Lifetime of Halley project does not indicate any other current threats to the station. Neither Chasm 2 nor the N9 fault-line appear to be growing at the moment. The situation around the McDonald Ice Rumples, from which numerous cracks originate, is being routinely monitored and similarly does not appear to suggest any new risk. There are a number of large active rifts on the adjacent Stancomb-Wills Glacier Tongue (which despite its name is an ice shelf just like BIS) but these also do not pose any current risk to Halley VI.

An overview over BAS monitoring strategies on Brunt Ice Shelf can be found in Anderson et al (2014).

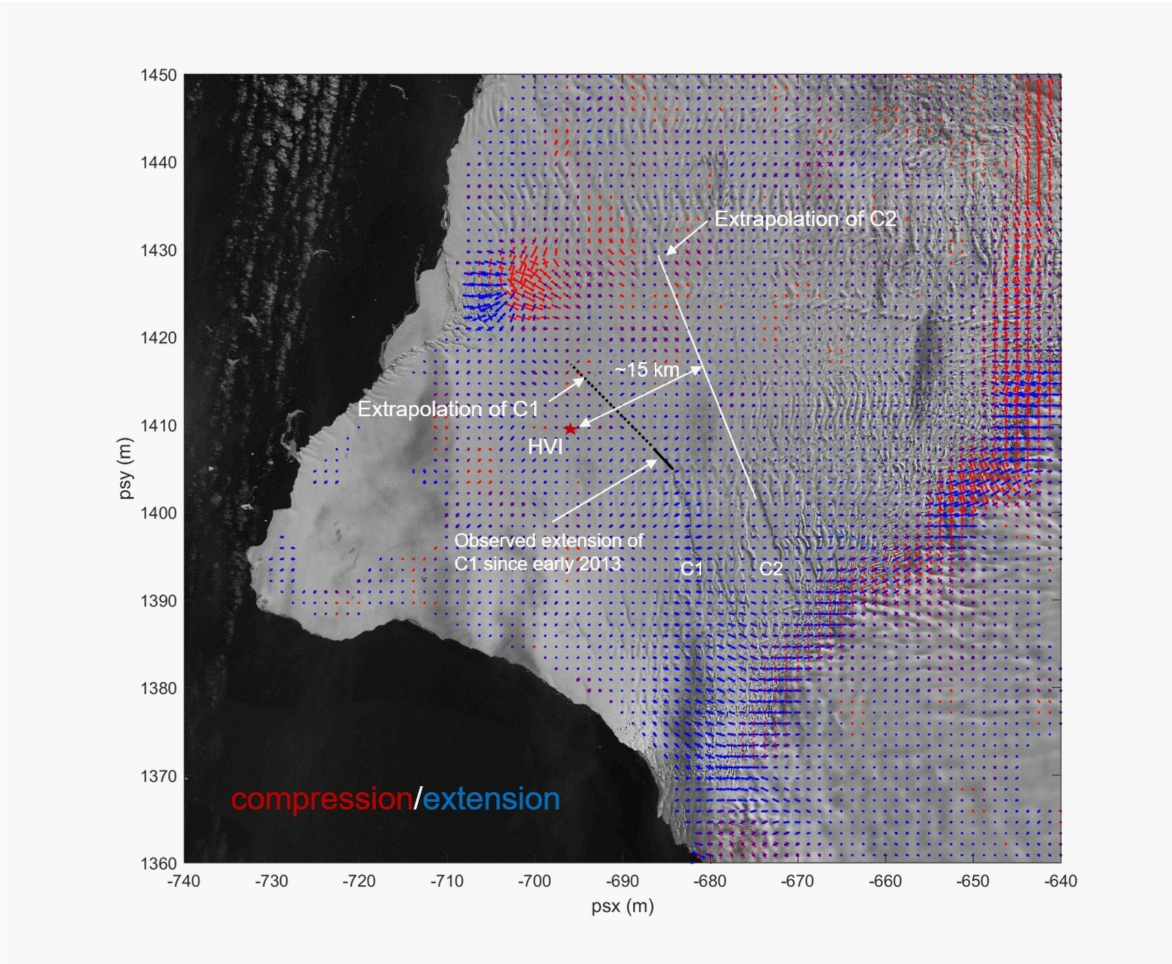

Figure 7. Possible new site for Halley VI. The image shows observed principle strain-rates in June 2015 over a background Landsat 8 image from February 2015 derived from satellite data. The solid black line is the observed extension of Chasm 1 (C1) from the start of the active phase in early-2013, and the dotted black line is a linear extrapolation of the solid one.

5. Predictions and evidence for future changes

Recent data indicates that the northerly tip of Chasm 1 is currently migrating in a direction at a rate of 1.7 km per year. If this growth continues at the same rate, and in the same direction, it will be approximately 3 km upstream of Halley VI in two to three years. At that time, the shortest route between the present location of Halley VI and the inland portion of the ice shelf will be compromised, with options for the relocation of the station onto more secure parts of the ice shelf severely reduced.

Cracks form continuously on Brunt Ice Shelf. It is not uncommon for cracks to form in the vicinity of the grounding line, and then to heal with time as they advect downstream with the ice. Other cracks periodically open up in summer and then freeze over in winter.

Cracks also frequently form in the vicinity of the McDonald Ice Rumples as the ice flows over and around that pinning point (Fig. 1). These are all well-known features of ice flow regime of the Brunt Ice Shelf, and they do not pose a threat to the Halley Research Station.

The current growth of Chasm 1, however, is unusual in a number of ways. The area of activity is not close to the grounding line but well within the central region of the ice shelf. The growth has not been limited to the summer period, but has continued unabated for about 2.5 years by now. The growth is continuous and does not appear to be slowing down or speeding up. This, combined with the fact that the growth of Chasm 1 is taking place in a close vicinity to the Halley VI station, with the crack tip migration getting closer to the station with time, is therefore a genuine cause for concern.

The likelihood that the rate of growth of Chasm 1 will increase in coming months or years cannot be predicted with confidence using any known methodology. Hence the assessment of glaciological risk and advice necessarily remains qualitative rather than quantitative.

However, based on the most up-to-date observations, the window during which Halley VI station can be relocated is limited. If Chasm 1 continues to cross the Brunt Ice Shelf upstream of the station, then the route for relocating the station to safety upstream will eventually become blocked. Therefore it is imperative that action must be taken urgently to ensure the longevity of the station.

6. Investigation of possible relocation sites

The optimal position for relocation of Halley VI cannot be determined from glaciological considerations alone, operational factors (snowfall rates, surface slopes, route to suitable ship mooring sites) are also crucially important. However, potential new sites should be identified for Halley VI that will maximise the period before another relocation is required. For this reason, Halley VI should be moved sufficiently far upstream of Chasm 1 to ensure as it opens the station is securely landward.

Consideration will also be needed as to whether the presence of Chasm 2, which is not presently growing appreciably in length or width, could be considered a potential future risk similar to Chasm 1. Given the similarities between those two rift structures, the most secure position is likely to be not only upstream of Chasm 1 but upstream of Chasm 2 as well (see Fig. 7).

Final recommendation for a new site will only be made once all potential future sites have been surveyed. This is scheduled to take place at its earliest possibility in November 2015.

7. Summary of justification for relocating Halley VI Station

1. After many years of inactivity, in recent years, Chasm 1 has begun to grow. Although the reason for this growth is not clear, there is no glaciological reason to expect it will cease, and we must consider the additional risk to the station.
2. Given continued growth of Chasm 1 at its current rate and on its current trajectory, in 2 to 3 years it will be immediately upstream of Halley VI. After this, the route from the current site toward more secure ice would be increasingly compromised.
3. There is a strong likelihood that, eventually, Chasm 1 will cross the entire Brunt Ice Shelf, forming one or more new icebergs, and isolating the portion of ice shelf on which Halley VI is currently located. If the station remains on this portion of the ice there will be little possibility of maintaining the long-term security of the station structure.
4. There is a lower risk that with a change in the trajectory of the growth of Chasm 1, the crack will deviate towards the station and cause more direct disruption of the station structure and activities.
5. The likelihood that the rate of growth of Chasm 1 will increase in coming months or years cannot be predicted with confidence using any known methodology. Hence the assessment of glaciological risk and advice necessarily remains qualitative rather than quantitative. However, continued monitoring will provide an up-to-date assessment, and will in future months provide a qualitative indication of a magnification or reduction in risk. There remains a possibility that external forces (e.g. tsunami), or internally driven non-linear processes, that we cannot predict with confidence, could accelerate crack growth.

The recommendation by the Lifetime of Halley project, taking into account all of the glaciological evidence available, is to complete the relocation of Halley VI Station by the end of the 2017-18 austral summer.