National Aeronautics and
Space Administration

Initial Environmental Evaluation/ Environmental Assessment

Southern Hemisphere Ultra Long Duration Ballooning Operations Expansion

August 2014

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Cover images: (front cover)
A Long Duration Balloon (LDB) is inflated at the facility near McMurdo Station.
Credit: Robyn Waserman, National Science Foundation

(back cover)
Antarctica and New Zealand land mass from space.
Google Earth Image

INITIAL ENVIRONMENTAL EVALUATION / ENVIRONMENTAL ASSESSMENT

SOUTHERN HEMISPHERE ULTRA LONG DURATION BALLOONING OPERATIONS EXPANSION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
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Lead Agency:	National Aeronautics and Space Administration
Proposed Action:	Southern Hemisphere Ultra Long Duration Ballooning Operations Expansion
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ABSTRACT:

Prepared in accordance with the 1991 *Protocol on Environmental Protection to the Antarctic Treaty* (as implemented by the Antarctic Science, Tourism, and Conservation Act of 1996), the National Environmental Policy Act of 1969, and Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*, this Initial Environmental Evaluation (IEE) / Environmental Assessment (EA) addresses the proposed launch, flight, termination, and recovery of Ultra Long Duration Balloons (ULDBs) by the National Aeronautics and Space Administration (NASA). Under the Proposed Action, NASA would augment its existing Antarctic scientific ballooning program to include one ULDB test flight in 2014 and then one flight annually from Williams Field, near McMurdo Station, Antarctica. Additionally, NASA would establish a ULDB launch site at the existing airfield near Wanaka, New Zealand to support an initial test flight in 2015 followed by up to two ULDB flights per year thereafter.

This IEE/EA analyzes the potential direct, indirect, and cumulative environmental effects of the Proposed Action and three Alternatives, including a No Action Alternative. Physical, biological, and social resources are evaluated in detail.

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Acronyms and Abbreviations

ACC	Antarctic Circumpolar Current
AGL	above ground level
ASMA	Antarctic Specially Managed Area
ASPA	Antarctic Specially Protected Area
ASTCA	Antarctic Science, Tourism, and Conservation Act
ATC	Air Traffic Control
CEA	cumulative effects analysis
CEE	Comprehensive Environmental Evaluation
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cm/sec	centimeters per second
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CSBF	Columbia Scientific Balloon Facility
EA	Environmental Assessment
EIA	environmental impact assessment
EIS	Environmental Impact Statement
EO	Executive Order
ESA	Endangered Species Act
FR	Federal Register
FONSI	Finding of No Significant Impact
ft	feet
g	grams
GHG	greenhouse gas
GIS	Geographic Information System
GPS	global positioning system
GWP	global warming potential
IAATO	International Association of Antarctica Tour Operators
IEE	Initial Environmental Evaluation
kg	kilograms

km	kilometers
km^2	square kilometer
LDB	Long-Duration Balloon
$LiSO_2$	lithium sulfur dioxide
LLDPE	Linear Low Density Polyethylene
LOS	line-of-sight
m	meters
m^2	square meters
m^3	cubic meter
m/s	meters per second
MCF	million cubic-foot
MOA	memorandum of agreement
MMPA	Marine Mammal Protection Act
N_2O	nitrous oxide
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPR	NASA Procedural Requirements
NRC	National Research Council
NSBF	National Scientific Balloon Facility
NSF	National Science Foundation
O_3	ozone
OSS	Operations Safety Specialist
P.L.	Public Law
PBO	liquid crystalline polyoxazole; also referred to as polybenzoxazole
PDS	probability of direct strike
SPB	Super Pressure Balloon
U.S.C.	U.S. Code
ULDB	Ultra Long Duration Balloon
USAP	U.S. Antarctic Program

USFWS	U.S. Fish and Wildlife Service
UV	ultraviolet
VRLA	valve-regulated lead acid
WFF	Wallops Flight Facility

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1 PURPOSE AND NEED FOR THE PROPOSED ACTION

1.1 INTRODUCTION

Since 1990, the National Aeronautics and Space Administration (NASA) has launched Long-Duration Balloons (LDBs) in Antarctica in support of its research in the Earth and space sciences. NASA typically launches three to five scientific balloons from Antarctica each year, including two to three large balloons and one to two smaller climatology balloons. Historically, these balloons remain aloft for anywhere between 2 hours and 54 days or more, and do not leave the Antarctic continent (see Figure 1-1). At the end of each flight, both the balloon and the scientific payload land on the continent or ice shelf, and are recovered if it is safe to do so (**NSF 2008**).

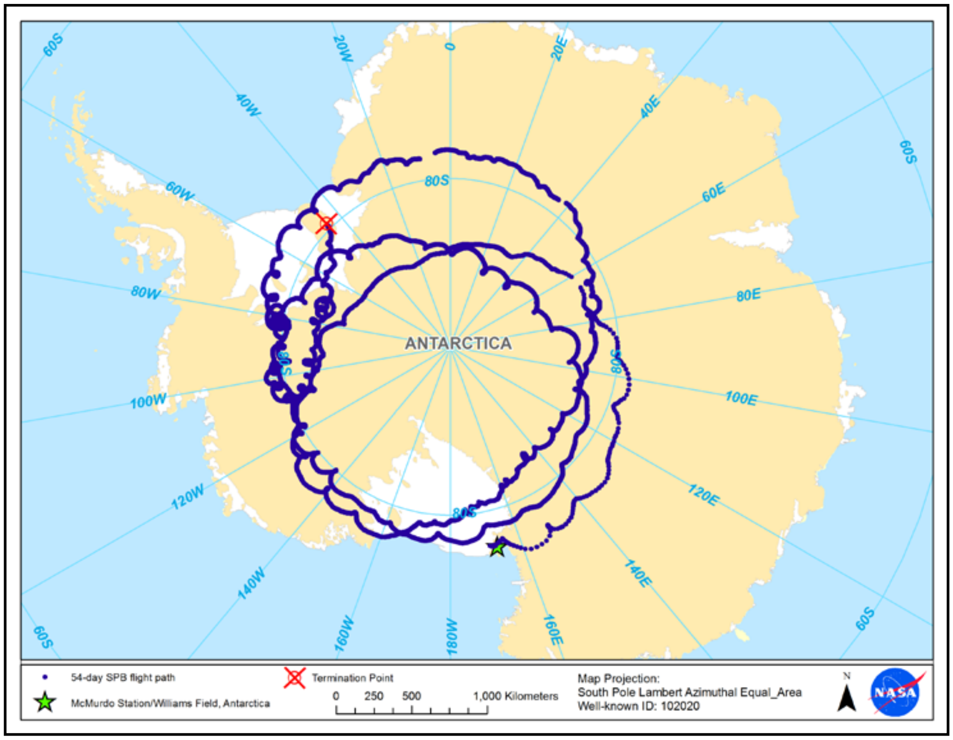

Figure 1-1: Representative Antarctic Balloon Flight Trajectory

As an evolutionary step in balloon technology development, NASA is currently proposing to launch a longer duration test flight of a 532,000-cubic meter (m^3; 18.8 million cubic-foot [MCF]) Super Pressure Balloon (SPB[1]) from the LDB remote facility near Williams Field, adjacent to McMurdo Station, Antarctica, during the December 2014 to January 2015 austral summer season. This ULDB[1] could drift beyond the continental limits of Antarctica and could

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[1] A note about terminology: The term "SPB" refers to the balloon itself, whereas the term "ULDB" refers to the flight duration and mission profile (i.e., >60 days) of the subject balloon system.

hypothetically travel as far north as latitude 40° South (40°S) over the course of its intended 100+ day circumpolar flight. At the completion of its flight, it is possible that the balloon system would land in the open ocean, thereby reducing the likelihood of a successful recovery (**GAC 2003; Mullenax & Schwantes 2014**).

Additionally, following the launch from Antarctica, NASA would conduct a second ULDB mission from Wanaka, New Zealand in April 2015. Planned to be a circumglobal, 100+ day flight of a 18.8 MCF SPB, the balloon would be launched from the Wanaka Airport located at approximately 45°S and travel in an easterly direction between the 29°S and 65°S latitude bands. This balloon would have a higher probability of being recovered in a terrestrial area when it landed (**Mullenax & Schwantes 2014**).

Although the primary purpose of these two flights is to test the ability of the 18.8 MCF SPB system to remain aloft for extended periods of time, if each flight is successful, the scientific demand for the SPB configuration would likely increase, and such ULDB flights would become more commonplace. Therefore, in the longer term (i.e., 2016 and beyond), a maximum of one Antarctica and two New Zealand ULDB flights would be launched annually. As the 18.8 MCF SPB design gains flight heritage, NASA would continue to scale the technology to a larger design, up to approximately 740,000 m^3 (26.2 MCF). This document considers both the initial test/technology demonstration phase and the expected longer-term operational phase of the proposed Southern Hemisphere ULDB program.

1.1.1 NASA's Relationship with the National Science Foundation

NASA's Antarctic scientific ballooning is conducted in cooperation with the National Science Foundation (NSF), which manages the U.S. Antarctic Program (USAP) on behalf of the U.S. Government. A *Memorandum of Agreement* (MOA) *Concerning Cooperation on Matters Related to Balloon Flight Operations in Antarctica* between NASA and NSF outlined the specific responsibility of each agency for the period following signing in 2009 through March 2014. An Interagency Agreement addressing the respective logistical and financial responsibilities of each agency replaced this MOA in 2014. In general terms, NSF coordinates the logistics for conducting NASA's research in Antarctica and is responsible for maintaining U.S.-owned facilities, infrastructure, and aircraft located in Antarctica. NSF is also responsible for ensuring U.S. compliance with the Antarctic Treaty system and its *Agreed Measures for the Conservation of Fauna and Flora* (1964) and its *Protocol on Environmental Protection* (1991). NSF ensures that research proposals in Antarctica are consistent with the international agreements to which the United States is a party, as well as U.S. laws governing activities in Antarctica including the Antarctic Conservation Act of 1978 (Public Law [P.L.] 95-541), which was amended by the Antarctic Science, Tourism, and Conservation Act of 1996 (ASTCA; P.L. 104-227). Additionally, because of NSF's expertise on the Antarctic environment and the logistical role in which it would serve to enable the Proposed Action, NASA requested NSF's participation in developing this document. NSF accepted NASA's request and provided both technical information and review comments.

1.2 PURPOSE OF THIS DOCUMENT

NASA's actions in Antarctica are subject to multiple environmental impact assessment (EIA) processes as prescribed by Article VIII and Annex I to the 1991 *Protocol on Environmental Protection to the Antarctic Treaty*[2] (hereafter referred to as *Antarctic Protocol*), implemented by the United States (U.S.) as the ASTCA of 1996 (16 U.S.C. § 2401 et seq.); the National Environmental Policy Act (NEPA) of 1969 (42 U.S. Code [U.S.C.] § 4321 et seq.)[3]; and Executive Order (EO) 12114, *Environmental Effects Abroad of Major Federal Actions* (44 Federal Register [FR] 1957). Moreover, EO 12114 governs NASA's EIA process for actions affecting foreign nations and the global commons (e.g., the oceans). While the details of each EIA requirement vary somewhat (discussed in more detail in Section 1.3), all three prescribe the same general process by which the environmental effects of a proposal must be evaluated and documented prior to taking the action. The purpose of this document is to satisfy the review requirements incumbent upon NASA in a single, combined EIA document. Therefore, this document contains the necessary components of an *Antarctic Protocol*- and ASTCA-required Initial Environmental Evaluation (IEE), a NEPA-required Environmental Assessment (EA), and an EO 12114 "Overseas" EA.

1.2.1 Relationship to Existing EIA Documentation

Consistent with the approach taken for the Proposed Action under consideration in this document, in 2008 NSF and NASA prepared a combined EIA document for long-duration scientific ballooning in Antarctica entitled *IEE/EA*, *Conduct Long Duration Balloon Program (LDB) Flights in Antarctica* ("LDB IEE/EA"; **NSF 2008**). The LDB IEE/EA's Proposed Action, Alternative A, to conduct two to three LDB flights from Antarctica per year with NSF logistical support, was supported by both author agencies. Requirements for compliance with the USAP Master Permit for disposal of wastes are included as is a comprehensive history of LDB activities in Antarctica from 1988 to 2007 (**NSF 2008**).

Of note is the LDB IEE/EA's description of the operations for supporting scientific balloon flights. In summary, operations are described as primarily affecting terrestrial Antarctic resources, with ocean or off-continent effects being rare. Because the proposed ULDB flights would have a "possible" (more probable than "unlikely" as characterized in the LDB IEE/EA) oceanic landing, and some would be launched from New Zealand, the Proposed Action is outside the scope of the existing LDB IEE/EA. Therefore, this document has been prepared as a

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[2] Article VI of the Antarctic Treaty (1959) states that its provisions apply to "the area south of 60 deg. South Latitude, including all ice shelves…" Similarly, Section 102 of ASTCA (16 U.S.C. § 2402) defines Antarctica as "the area south of 60 degrees south latitude."

[3] Section 104 of ASTCA (16 U.S.C. § 2403a) applies Section 102 (2)(c) of NEPA to Federal agency proposals in Antarctica.

supplemental environmental analysis. As the focus of the LDB IEE/EA is the Antarctic continent, that document is incorporated by reference, with the focus of this document being the potential effects on the resources in the oceans and terrestrial areas north of Antarctica where the balloons could land.

1.2.2 Related Environmental Reviews

In addition to its *Antarctic Protocol* (and correspondingly, ASTCA), NEPA, and EO 12114 EIA obligations, NASA's Proposed Action is subject to three related environmental review requirements under U.S. law. Section 7 of the Endangered Species Act (ESA) (16 U.S.C. § 1531–1544) requires NASA to consult with the U.S. Fish and Wildlife Service (USFWS) and/or the National Marine Fisheries Service (NMFS) for any action on the "high seas" that may affect a federally listed species or designated critical habitat. As an ocean-landing SPB system could potentially affect several listed species, NASA prepared a Biological Evaluation (BE) (**NASA 2014**) to assess the potential effects of its action on these species. Based on the analysis in the BE, NASA determined that its Proposed Action is "not likely to adversely affect" the species under consideration. In an August 11, 2014, letter, the NMFS concurred with NASA's determination, thereby fulfilling NASA's ESA obligations for the Proposed Action.

Similarly, Section 112 of the Marine Mammal Protection Act (MMPA) (16 U.S.C. § 1361–1407) prohibits, with certain exceptions, the "take" of marine mammals on the "high seas" by U.S. citizens, including agencies of the Federal government. All marine mammals are protected by the MMPA, which is jointly overseen by the USFWS and NMFS. Based on the analysis in both the BE (**NASA 2014**) and Section 3.2.2.5 of this IEE/EA, NASA has determined that the Proposed Action is highly unlikely to expose any marine mammal species to a stressor such that a "take" could occur. As such, no additional MMPA coordination with either USFWS or NMFS is required.

Finally, Section 402 of the National Historic Preservation Act (NHPA) (16 U.S.C. § 470) requires Federal agencies to consider the effects of their actions outside the United States on potentially significant cultural resources prior to undertaking an action that may adversely affect them. Accordingly, Section 3.3.4 of this IEE/EA contains NASA's analysis of the potential effects of its Proposed Action on sites of cultural significance. The analysis concludes that it would be highly unlikely for the Proposed Action to adversely affect such sites. Therefore, this assessment fulfills NASA's obligations under the NHPA.

1.3 DECISIONS TO BE MADE

A key decision point under both NEPA and EO 12114 is determining whether the potential environmental effects of a Proposed Action would be "significant." Per Section 3-4 of EO 12114, the scope of this determination is limited to the potential effects on the natural and physical environment; whereas under NEPA, the social environment must also be considered. Under NEPA, when considering whether an environmental effect could be significant, a Federal agency must consider both the effect's context and intensity. In the case of the EO, a potential effect is significant if it "does significant harm to the environment." Under both EIA processes, if the agency's environmental analysis (termed an EA under NEPA, an "Overseas" EA under the EO) finds impacts to be less than significant, the action may then commence. Moreover, per Section 2-5 of EO 12114, much of the EO's provisions do not apply to actions determined to have no significant effect on the environment. Otherwise, if identified effects cannot be mitigated below the significance threshold, the agency must then prepare a more rigorous Environmental Impact Statement (EIS) under NEPA or "Overseas" EIS pursuant to the EO.

Much like NEPA and EO 12114, the level of EIA documentation required by the *Antarctic Protocol* (and correspondingly, Section 104 of ASTCA) is commensurate with the expected level of environmental effects. Two types of EIA documents, IEEs, which are analogous to NEPA-required EAs, and Comprehensive Environmental Evaluations (CEEs), the *Antarctic Protocol's* and ASTCA's EIS equivalent, are prepared for actions affecting Antarctica's resources and not previously determined to have "less than minor or transitory effects." The threshold applied in determining whether an IEE or CEE should be prepared is whether potential effects would or would not be "more than minor or transitory," which, per Section 104 of ASTCA, "more than minor or transitory," has the same meaning as "significant" under NEPA.

If NASA decides to proceed with the Proposed Action based on this IEE/EA, it would be documented in a combined Finding of No Significant Impact (FONSI)/Finding of Not More Than Minor or Transitory Impact. In the case of the decision to prepare an EIS/CEE-level analysis, NASA's decision would be documented in a Notice of Intent published in the *Federal Register*.

1.4 PURPOSE OF THE PROPOSED ACTION

The purpose of the Proposed Action is to mature the SPB system such that it can enable reliable, cost-effective science support at flight durations in excess of 100 days. This technological maturation is expected to grow over the next 10 years from initial test flights to consistent 100+ day flights of SPBs up to approximately 740,000 m^3 (26.2 MCF) in size, supporting various science payloads.

A key component of the SPB system maturation process is the establishment of high- and mid-latitude launch sites that provide both safe and cost-effective operations while still meeting the targeted flight durations and observational needs of the scientific community whom would utilize the SPB system as a research platform.

1.5 NEED FOR THE PROPOSED ACTION

NEED FOR A ULDB

In the National Research Council's (NRC) 2001 decadal survey,[4] *Astronomy and Astrophysics in the New Millennium*, the authoring panel strongly recommended that NASA support the development of a ULDB program as a cost-effective means for enabling high-energy astrophysics missions as well as those using solar and infrared instruments. In the same report, the panel identified principal disadvantages of conventional scientific ballooning as being the short duration of flights and diurnal fluctuations in altitude (**NRC 2001**). The NRC re-stated its position in the 2010 *Revitalizing NASA's Suborbital Program: Advancing Science, Driving Innovation, and Developing Workforce* publication, citing the need for a ULDB platform to enable hard x-ray and gamma-ray astrophysics and solar physics (**NRC 2010**). This same publication states that, "the next step is the development of a 22 million-cubic-foot balloon that can carry a one-ton instrument to an altitude of more than 110,000 feet [ft], then extending the altitude to 125,000 ft, critical for hard x-ray and gamma-ray measurements." NRC further explains that "hard x-ray and gamma-ray astrophysics, however, require the development of a super-pressure balloon capability that will allow the lifting of a standard 4,000 lb [pound] payload to reach more than 125,000 ft and operate at that altitude for approximately 100 days" in order "to catch the rare large solar gamma-ray flares." The NRC's latest decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics*, also supports the use of the ULDB system due to its utility for one of the survey's priority science areas, cosmic microwave background (CMB) radiation, which requires the longer-duration observations afforded by the subject system (**NRC 2011**).

NEED FOR HIGH- AND MID-LATITUDE LAUNCH SITES

Due to favorable climatology that affords multiple circumnavigations about the Earth's pole and consistent float altitudes due to constant sunlight during summer months, balloon launch sites at high latitudes are optimal for enabling astrophysical research, including studies of cosmic ray and solar phenomena. However, high latitude sites also have operational and science limitations that can be met only at mid-latitude sites.

Mid-latitude balloon launch sites offer wider sky coverage, greater freedom from interference from Earth's radiation belts (especially important for gamma-ray astrophysics) (**NRC 2010**), a venue for a fuller range of science disciplines (e.g., planetary, earth, and astrophysics), and true

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[4] NASA relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. NASA's Science Mission Directorate engages the science community in this task through the NRC. The NRC conducts studies that attain science community consensus on key questions posed by NASA and other U.S. Government agencies. The broadest of these studies in NASA's areas of research are decadal surveys. As the name implies, NASA and its partners ask the NRC once each decade to look 10 or more years into the future and prioritize research areas, observations, and notional missions to make those observations.

diurnal cycles, (affording night-time observations), which are desired by some scientific disciplines, including planetary science and CMB experiments.

SUMMARY

The Proposed Action responds to the needs of the scientific community by developing several reliable ULDB designs and launch sites for future astrophysical observations, augmenting NASA's existing programs dedicated to understanding the origin, evolution, and physical processes of the universe. Furthermore, as payload carrying capacity and flight duration increase, ULDBs are expected to become a cost-effective, easily deployable system capable of achieving an essential vantage point (at the top of the Earth's stratosphere) for conducting research in additional disciplines ranging from planetary to earth sciences (**NASA 2005; NSF 2008**).

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2 DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES

The purpose of this Chapter is to provide an overview of the ULDB flights NASA is proposing to undertake (i.e., the Proposed Action) as well as alternatives that could meet all or most of the objectives identified in Sections 1.4 and 1.5 of this document, *Purpose of the Proposed Action* and *Need for the Proposed Action*, respectively. Also included is a “no action” or “no project” alternative.

Following a description of the Proposed Action, the various stages of balloon operations (e.g., deployment, flight, and termination) are explained. However, given that Sections 4.1 through 4.4 of the 2008 Long Duration Balloon LDB IEE/EA (**NSF 2008**) describe in detail the pre-launch preparations, the launch of a scientific balloon from Williams Field, near McMurdo Station, Antarctica, and post-flight recovery on the Antarctic continent, this Chapter provides only a summary of those actions. As such, this Chapter focuses on aspects of the Proposed Action and Alternatives specific to ULDBs that would differ from those already discussed in the LDB IEE/EA.

2.1 PROPOSED ACTION

NASA proposes to augment its existing Antarctic scientific ballooning activities to include an initial ULDB test flight in 2014 followed by one flight annually during the austral summer. These balloons would be launched during the December–January timeframe, and terminated in the months of March or April. Additionally, to provide a lower-latitude launch site option for future ULDB flights, NASA would also establish a launch site at the airfield near Wanaka, New Zealand to enable an initial test flight in 2015 and then up to two flights annually during austral fall (Figure 2-1). Launches would most likely occur during the month of April with flight terminations expected in the months of June or July. Actual launch frequency would be dictated by available funding and scientific demand and, therefore, could be less frequent. However, for the purposes of this IEE/EA, it is assumed that the Proposed Action would involve annual operations at both launch sites over a 10-year period beginning in 2014/15 and would not exceed the operational tempo described herein.

2.1.1 Action Area

For the purpose of this IEE/EA, the Action Area is defined as the area where potential environmental effects may occur. It includes the land, water, and airspace between 29°S and 90°S latitude, as depicted in Figure 2-2. Balloons launched from Wanaka, New Zealand would likely remain between 29°S and 65°S latitude (**Mullenax & Schwantes 2014**), whereas McMurdo Station, Antarctica-launched balloons would most likely remain south of 60°S; however, some flights could travel farther north up to 40 or 45°S latitude (**GAC 2003; Mullenax & Schwantes 2014**). Of the approximately 131.8-million-square-kilometer (km^2) Action Area, approximately 113.3 million km^2 is water, with the remaining 18.5 million km^2 consisting of terrestrial areas (**Bonsteel 2014a**). The Action Area encompasses the entire Antarctic continent,

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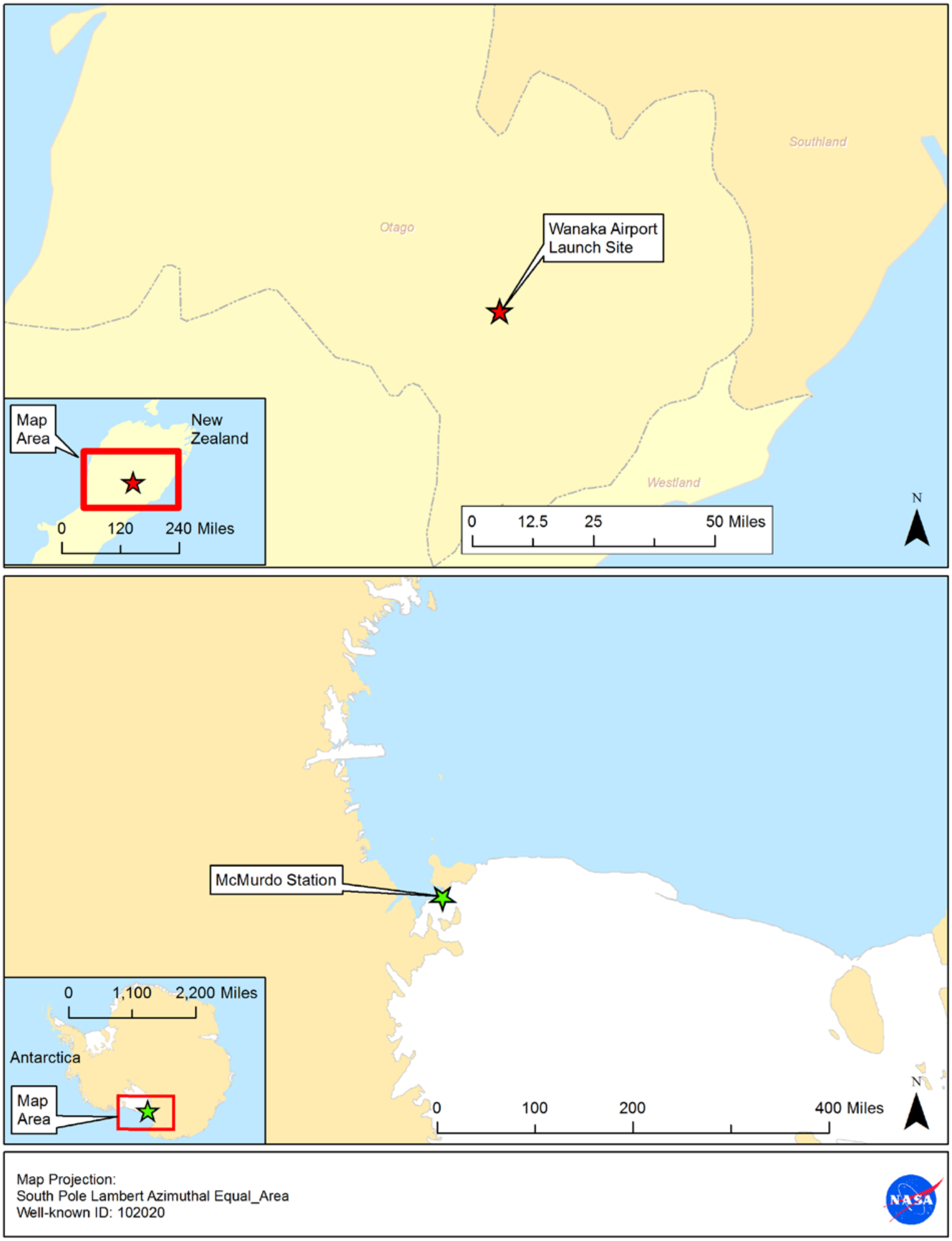

Figure 2-1: Wanaka, New Zealand (top) and McMurdo Station, Antarctica (bottom) SPB Launch Sites

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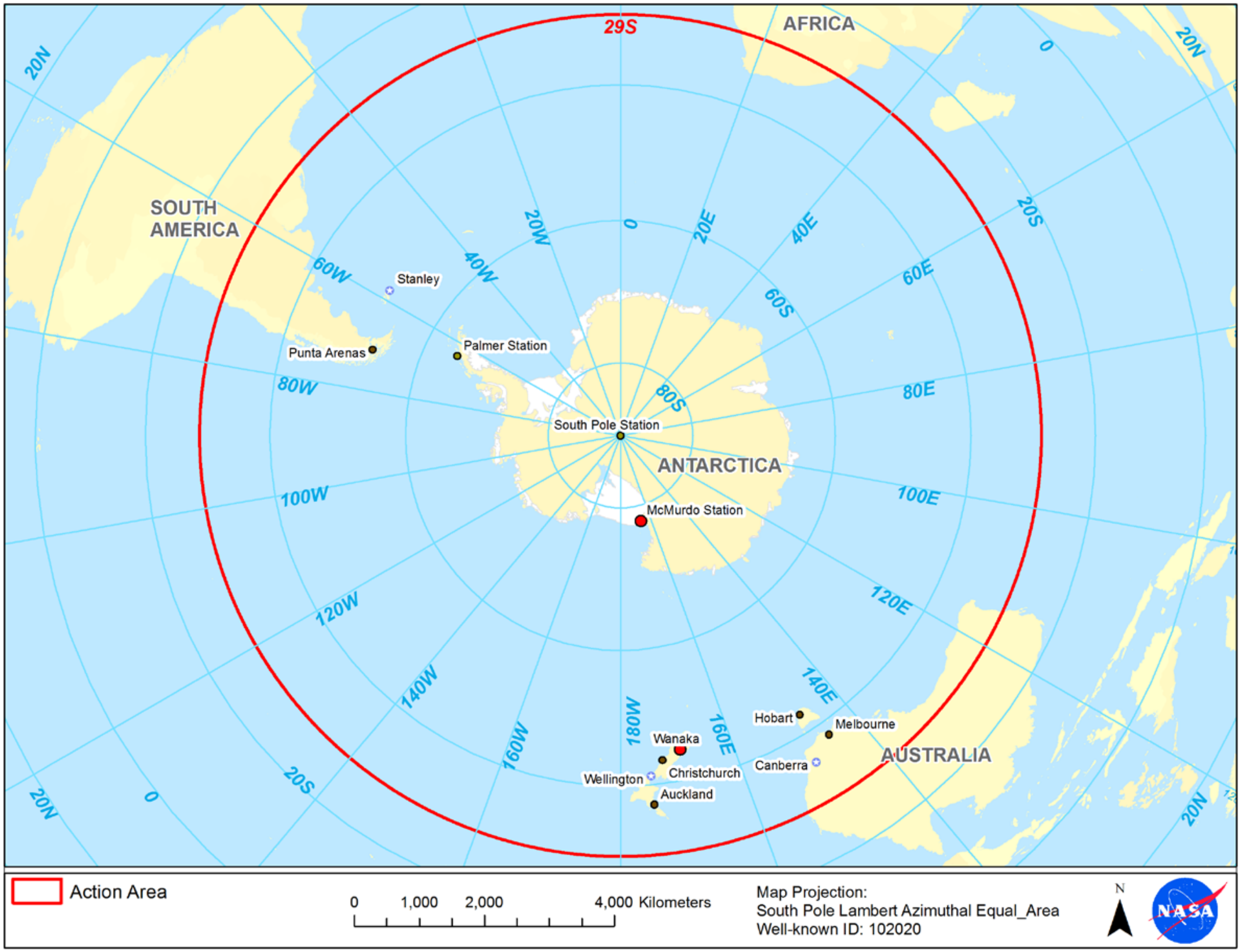

Figure 2-2: Action Area

all sub-Antarctic islands (under various nations' jurisdictions), nearly all of New Zealand, the southern edge of Australia including all of Tasmania, all of Uruguay, and much of Argentina and Chile.

The geographic extent of the Action Area was defined based on three sources: 1) The **GAC 2003** modeling, which calculated the upper boundary of the 95% confidence interval for latitude versus time to be about 40°S at day 120 for a January 15 launch from Antarctica; 2) a balloon safety risk analysis for Antarctic launched SPBs, which set an Antarctic mission boundary at 40°S (**NASA 2009**); and 3) the northern flight boundary of 29°S predicted by the CSBF Meteorology Office for SPB flights launched from Wanaka, New Zealand during austral fall and winter (**Mullenax & Schwantes 2014**).

2.1.1 Rationale for the Proposed ULDB Launch Sites

NASA proposes to conduct its future ULDB operations from Williams Field, Antarctica and Wanaka, New Zealand for several reasons summarized below.

2.1.1.1 Antarctica

NSF 2008 contains a detailed description of why the scientific ballooning community utilizes Antarctica. Although the focus of that document is LDBs, many of the defining qualities of the launch site are shared with ULDBs and are applicable to the Proposed Action. In summary, Antarctica provides enhanced scientific and logistical benefits due to its unique environmental characteristics which include: 1) a dry, turbulence-free atmosphere, emulating conditions equivalent to those aboard an orbiting spacecraft; 2) its position on the Earth's axis, enabling astronomical and astrophysical observations not possible at lower latitudes; 3) its stable stratospheric circulation during austral summer, enabling multiple circumnavigations of the pole while remaining mostly over land; 4) the feasibility of using larger payloads compared to lower latitude launch sites because of its large expanse of unpopulated icy terrain; 5) its unrestricted access for overflight and recovery, in many cases without diplomatic complications experienced in other areas of the globe; and 6) its existing USAP logistical support network, which has the facilities and personnel to prepare, launch, and recover scientific balloons.

2.1.1.2 New Zealand

In addition to the scientific benefits afforded by a mid-latitude launch site (Section 1.5), Wanaka Airport, near Wanaka, New Zealand, is proposed as the second ULDB launch site in the Proposed Action for several reasons, including: 1) its stable stratospheric wind profile, which would maintain circumglobal ULDB flights within a predictable band of latitudes (**Mullenax & Schwantes 2014**); 2) the general lack of densely populated areas that would need to be overflown, particularly during the initial ascent and pressurization phase; 3) the favorable diplomatic relations between New Zealand and the U.S. Government, as well as other sovereign nations within its predicted flight path; 4) its proximity (8 km) to a town (Wanaka) offering amenities (e.g., lodging) for support staff and relative proximity (80 km) to a city (Queenstown) offering enhanced services (e.g., hospital, equipment, shipping); and 5) its existing infrastructure, which would enable a field campaign to be implemented without substantial investment. While 100+ day flights from Wanaka would be preferred, it is likely that the use of ballast and helium off-gassing to maintain a constant altitude in mid-latitude diurnal cycles would limit flights from this site to between 60 and 100 days (**G. Garde, personal communication, 2014**). However, for the purposes of this IEE/EA, the goal of 100+ days of flight is used for both launch sites.

2.1.2 The NASA SPB System

The components of the SPB system are similar to those of the NASA "zero pressure" LDBs regularly flown both in Antarctica (**NSF 2008**) and domestically in the southwest United States (**NASA 2010a**). However, unlike zero pressure balloons, SPBs are designed to fly at a near-constant pressure altitude. Zero pressure balloons exhibit significant altitude variations and shorter flight times, particularly at mid-latitudes where these variations are exacerbated by diurnal cycles; they require ballast to maintain altitude.

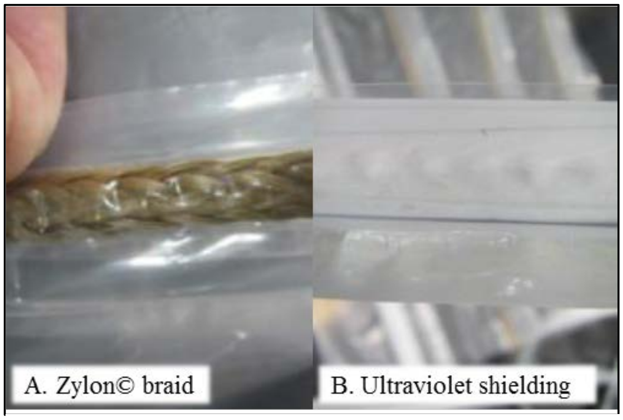

Figure 2-3: PBO Tendon (A) and UV Shielding (B)

The SPB system includes the balloon, parachute, and flight train assembly, and gondola/payload, as described in detail below.

2.1.2.1 Balloons

The balloon is a pumpkin-shaped structure made of 0.038-millimeter (mm; [1.5-mi[5]]) Linear Low Density Polyethylene (LLDPE) with ultraviolet (UV)-shielded 72,000 denier Zylon© (**Toyobo 2005**) (liquid crystalline polyoxazole, also called polybenzoxazole, or PBO, a Kevlar-like material) load-bearing members (Figure 2-3) with a total mass between approximately 2,400 and 2,800 kilograms (kg), depending on its size. The balloon is composed of sections or "gores" defined by the longitudinally aligned PBO tendons (Figure 2-4). At float altitude, internal pressure increases up to 180 Pascals, yielding a pressurized size between 115 and 130 meters (m) wide and 70 and 80 m tall, with a volume between 532,000 and 740,000 m^3 (18.8 and 26.2 MCF; Figure 2-5[A]).

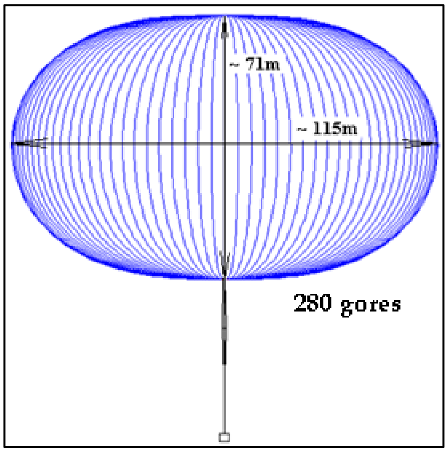

Figure 2-4: Inflated 18.8 MCF SPB

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[5] To provide perspective on the SPB material, the thickness of a standard household Ziploc® brand sandwich bag is 1.5 mil. The heavier freezer bags are about 3 mil thick. One mil is equivalent to one one-thousandth of an inch.

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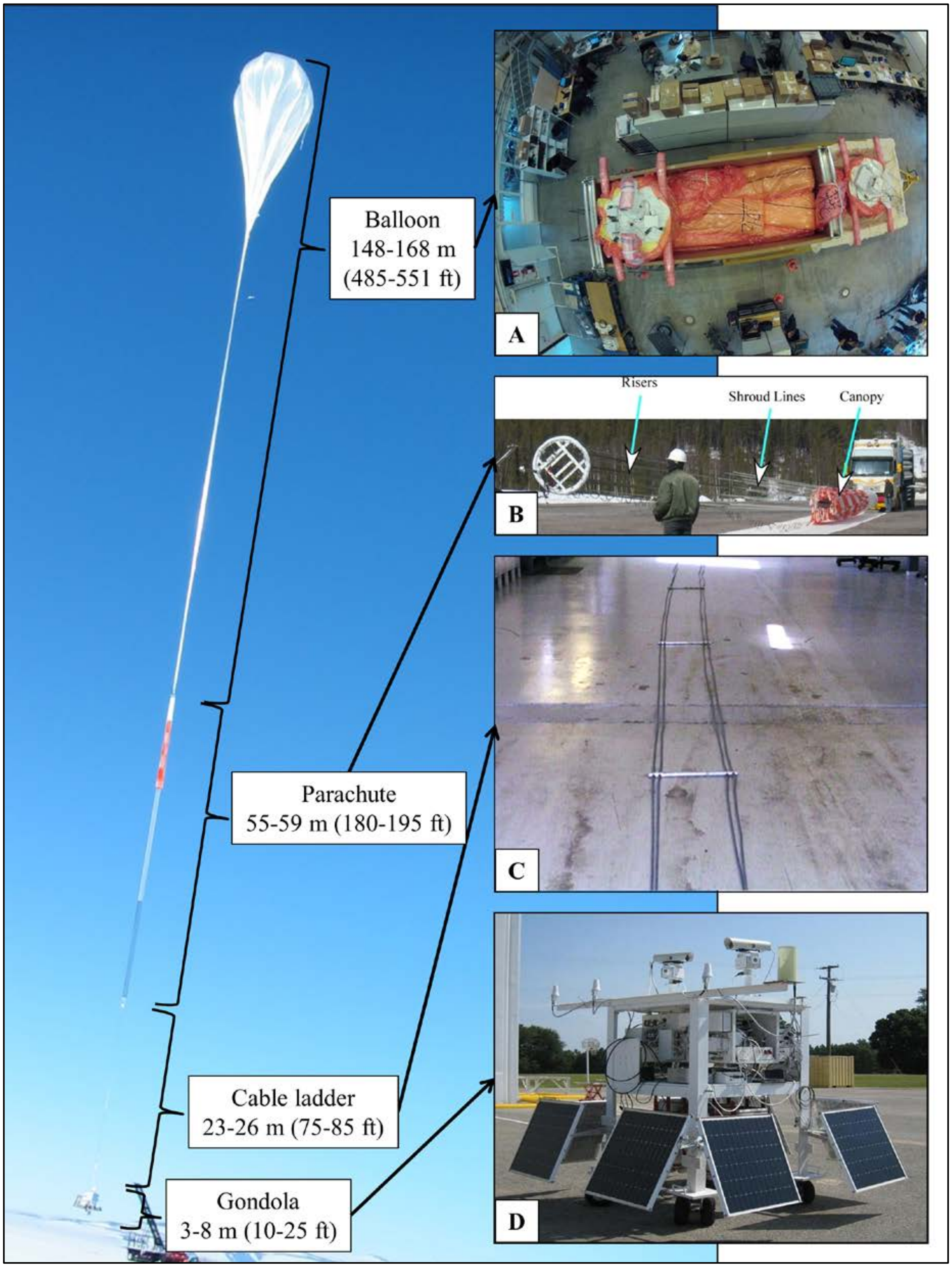

**Figure 2-5: Major SPB System Components:
(A) Boxed Balloon; (B) Furled Parachute; (C) Cable Ladder; (D) Gondola**

Powder-coated aluminum (6000 and 7000[6] series alloys) apex and base fittings act as converging points for the gores, as well as surfaces supporting valves and flight train support structures. The balloon is connected to a parachute assembly by a "terminate fitting," which is an aluminum coupling device containing the electronically activated charges employed to physically separate the balloon from all components below it when the flight is terminated.

2.1.2.1 Parachute Assembly and Flight Train

The parachute assembly includes a 37 to 40 m diameter nylon parachute canopy with risers connected to an approximately 0.9 m diameter bottom ring (Figure 2-5[B]). An aluminum coupler, also containing small electrically actuated charges for parachute and gondola separation, connects the bottom ring to a 26 m long stainless steel cable "ladder" (Figure 2-5[C]). The 0.11 m diameter cable ladder has approximately 12 rungs, each approximately 0.5 m wide. Below the steel cable ladder, another aluminum coupling device connects the flight train to the gondola. The total mass of the parachute assembly and flight train ranges between 400 and 450 kg.

2.1.2.2 Gondola and Payload

Scientific instruments are attached directly to the gondola structure, a rectangular box comprised of coated (powder-coated or painted) steel and aluminum components similar to that in Figure 2-5(D). This is what is often referred to as the "payload." The length and width dimensions of the gondola range between approximately 1.5 and 3 m, with a height dimension ranging between 3 and 8 m. Payload components include mechanical structures made of aluminum and steel, as well as insulated copper wiring, plastic harnesses and fasteners, batteries, and antennas of varying shapes and sizes. The payload also contains between approximately 500 and 700 kg of fine steel shot or silica sand ballast that can be released to control the balloon's ascent and maintain a positive differential pressure and thus a stable altitude. The total mass of the gondola ranges between 800 and 1,800 kg.

2.1.2.3 Materials of Interest

2.1.2.3.1 Pyrotechnics

During launch and flight of the SPB system, three distinct separation events must occur: 1) Release of the tow balloon during inflation and prior to launch; 2) Release of the parachute, flight train, and gondola from the balloon at flight termination; and 3) Release of the flight train and payload from the parachute upon terrestrial landing. To enable such separation, the SPB

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[6] 7000 series aluminum alloys contain approximately 5 to 6 percent zinc by weight. For the entire SPB system, the aluminum alloys contain approximately 4 kg of zinc.

system contains a series of small explosive charges that sever mechanical connections. The largest charge currently employed is just less than 180 milligrams.

For separation event 1, two charges are used; separation event 2 also uses two charges, and for separation event 3, a single charge is employed. Under normal flight conditions for which the landing site is terrestrial, all charges would be expended during flight. However, in the case of a water landing, the charges for separation events 2 and 3 would not be detonated because upon water impact, all unexpended charges would short out in the "safe" position, effectively eliminating the possibility of an in-water ignition.

2.1.2.3.2 Electrical System Components

Small electrical systems are required on the flight train to enable the separation functions described above and to power scientific instruments and flight tracking systems. The entire flight train contains approximately 90 kg of lithium sulfur dioxide ($LiSO_2$) batteries (comparable to approximately 2,800 "CR-V3" lithium cells typically used in consumer photographic/electronic devices (**Energizer Holdings, Inc. n.d.**) and 70 kg of sealed, valve-regulated lead acid (VRLA) batteries (comparable to four large garden tractor batteries).[7] The $LiSO_2$ cells are housed in rigid plastic containers and a metal housing bolted to the fitting on top of the balloon. The lead acid batteries are located on the base of the gondola.

To charge the batteries, the SPB system includes several crystalline-silicon photovoltaic cell arrays, which may contain lead-based solder. In addition, very small quantities of lead-containing solder are used on other parts of the SPB electrical systems. Although the majority of electrical systems are connected with crimps, some soldered connections are still employed, including those in the battery packs. Approximately 400 grams (g) of solder would be used on a balloon's entire electrical system, with 40 percent (160 g) of this solder consisting of lead. This quantity of lead is slightly more than what is contained in four 12-gauge shotgun shells used for small-game hunting. Therefore, in summary, assuming 60 percent of the total lead acid battery mass is composed of lead components (**Sullivan & Gaines 2010**), there would be approximately 40 kg of lead on each SPB flight.

2.1.3 Safety

Ensuring public and employee safety is NASA's highest priority when conducting scientific ballooning operations. As such, the Balloon Program must comply with a host of programmatic and mission-specific safety requirements, including those prescribed by NASA Procedural Requirements (NPR) 8715.3, *NASA General Safety Program Requirement* (**NASA 2008**); NPR 8715.5, *Range Flight Safety Program* (**NASA 2010b**); and RSM-2002C, *Range Safety Manual*

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[7] VRLA batteries are considered "dry" because their electrolyte solution is not vented to the atmosphere. Rather, the electrolyte solution is contained within a fiberglass mesh inside the battery casing.

for Goddard Space Flight Center (GSFC) Wallops Flight Facility (WFF) (**NASA 2013b**). The safety program applies to all phases of a mission.

For each balloon project, the Program prepares mission documentation and supports safety documentation, conducts critical milestone reviews, and engages third-party oversight of its safety practices. Each balloon launch campaign has an assigned team of independent safety and mission assurance personnel located on site during all hazardous activities. The NASA Balloon Program Mission Manager, NASA Range Safety Officer, the NASA-certified Operations Safety Specialist (OSS) share responsibility (within the limits of their jurisdiction) for the safe performance of operations associated with a mission. Within NASA, range safety responsibilities are divided into two general areas – ground safety and flight safety.

Ground safety considers activities associated with pre-flight and post-flight hazardous operations, while flight safety encompasses all activities that pertain to the flight of the balloon after it is launched. Each mission's Ground Safety Plan identifies the hazardous activities that will be performed on the balloon system and ensures that ground-based hazardous operations are consistent with established standards. Each hazardous operation requires that the OSS oversee the process to ensure that the Ground Safety Plan is followed. Examples of typical hazardous operations overseen by a balloon mission OSS include the installation of pyrotechnic devices (e.g., for balloon system termination at the end of flight) and high-pressure operations (e.g., balloon inflation or vessels used onboard the payload for the operation of scientific instruments) during payload assembly and launch operations. A commonly employed ground safety practice is to establish exclusion zones (by roadblock or other audible or visual means) within which only appropriately trained and operationally essential personnel are permitted.

The primary goal of flight safety is to contain the flight of the balloon system and avoid an impact that might endanger human life or cause damage to property. Whereas ground safety is primarily process-based, flight safety assesses risk quantitatively. In flight safety, risk is defined as the probability of the balloon system or mission phase failure based on risk to the public and personnel. During mission planning, a Flight Safety Risk Assessment is performed to determine if the mission can be conducted within an acceptable level of risk. Inputs into the risk assessment include the wind patterns at the launch site, the specific type of balloon and its reliability, and the characteristics of the payload. Once details of the planned flight are known, the safety analyst considers downrange population densities, areas to be avoided, and other constraints to calculate mission risk values. These mission risk values are subsequently compared to NASA-specific weighted criteria before the mission can be approved. If risk values are determined to be above the established criteria, modifications to the flight (e.g., flight trajectory exclusion zones) are then considered in an effort to meet both safety criteria and minimum science requirements. Once safety criteria are deemed suitable, the analyses in the risk assessment are incorporated into a Flight Safety Plan, which is used by the launch personnel to establish launch day constraints (e.g., wind limits) and off-limit areas (e.g., populated areas), which are conveyed to balloon flight controllers.

Flight controllers can accurately predict the landing location of the balloon system to within an approximately 9.25 km radius. Computer-based models developed by NASA consider the weight of the balloon system, existing wind/weather conditions, and other factors to provide a line of trajectory from the coordinate at which the termination command is given to the point of landing. Using real-time tracking software, the trajectory of the balloon/payload is overlaid on an aeronautical chart that shows population centers and sensitive land uses (Figure 2-6).

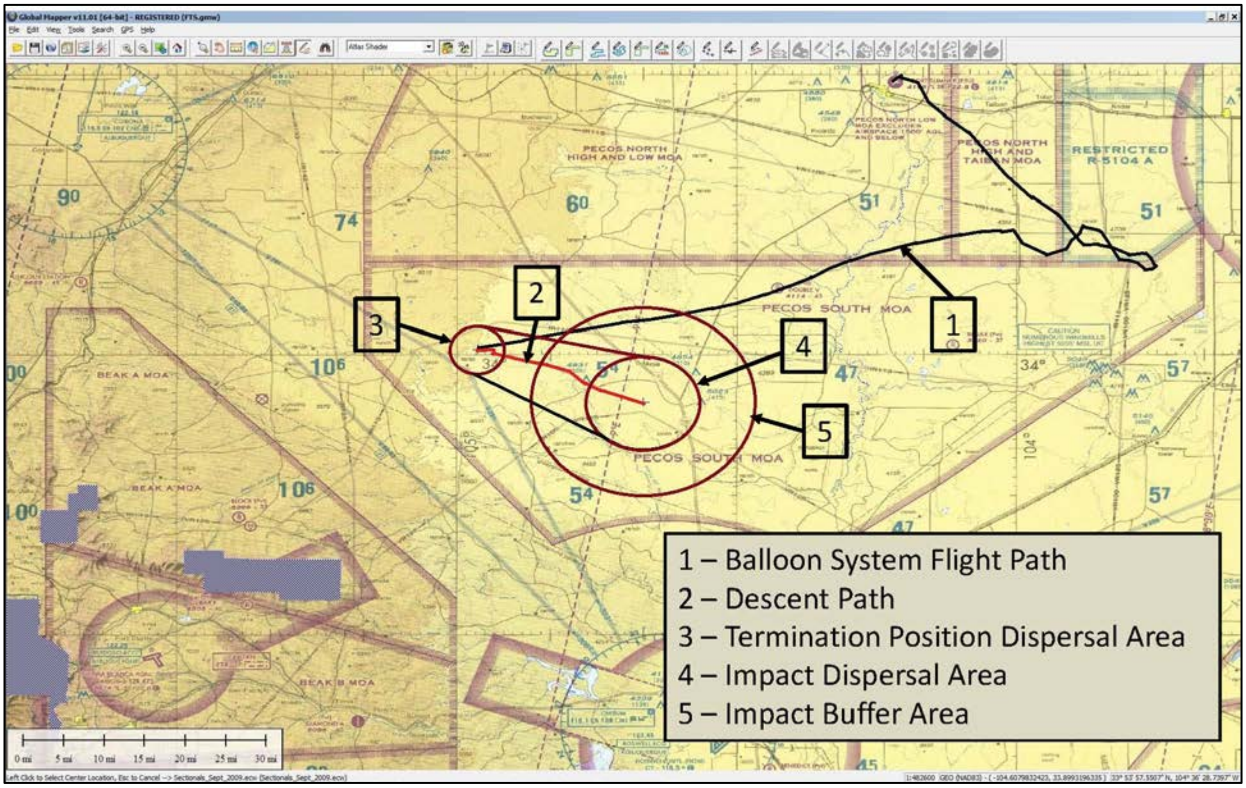

Figure 2-6: Tracking Software Display of Predicted Landing Area

The primary goal at balloon flight termination is to avoid populated areas, which are divided into three classes to facilitate mission planning. Class 1 areas are very small communities, hamlets, and populated intersections with a population of less than 500; Class 2 areas are small towns and incorporated villages with populations of 500 to 4,000; Class 3 areas are the largest towns and cities and contain populations of 4,000 and greater.

The following restrictions apply when planning a flight termination:

1) Class 1 towns may not be directly under the predicted impact point but may be within the impact area (9.25 km radius area).
2) Class 2 cities must be outside of the impact area (9.25 km radius area) but may be within the buffer area (18.5 km radius area).
3) Class 3 cities must be outside the buffer area (18.5 km radius area).
4) Termination will not be initiated within 3.7 km of any town.

Once the balloon system has landed, specific ground safety procedures would be followed to ensure a safe recovery operation. Examples of post-flight recovery operations requiring safety considerations include working in cold weather environments and ensuring that potentially hazardous systems (e.g., small pyrotechnics) have been rendered inactive prior to disassembly.

2.1.4 Pre-Flight Preparation and Launch

2.1.4.1 Specifics of the Antarctica Launch Site

Figure 2-7: Pathfinder Balloon during Inflation

The SPB would be prepared and launched during the austral summer (December–January) from the existing U.S. Antarctic Program facilities on the Ross Ice Shelf at the Long Duration Balloon site near Williams Field approximately 11 kilometers (km) from McMurdo Station. Approximately one week before launch season starts, one or more 4,800 m^3 (0.17 MCF) pathfinder balloons (shown in Figure 2-7) may be deployed to confirm stratospheric conditions are suitable for the planned missions. The pathfinder balloons are equipped with a small electronics package that transmits position information and typically remain aloft for several days after launch. They eventual returning to the ground intact once they lose sufficient lift to remain afloat. Pathfinder balloons land on the Antarctic continent or on the ice shelf and are not recovered (Figure 2-8).

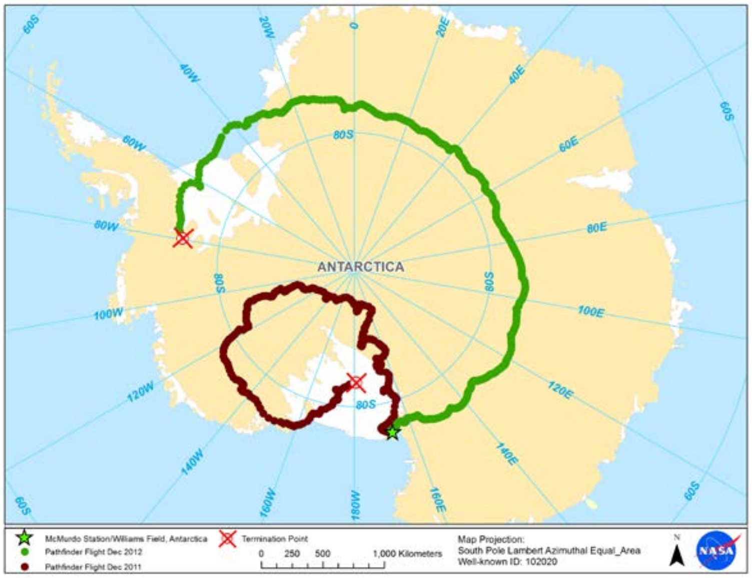

Figure 2-8: Trajectories of Recent Antarctica-Launched Pathfinder Balloons

2.1.4.2 Aspects Common to Both Launch Sites

Figure 2-9: Tow Balloon atop Inflating SPB

Once all balloon systems have been integrated and verified ready for flight, the launch team would use heavy equipment (e.g., a crane), tracked vehicles, and sleds to transport the SPB from the assembly area to the launch site, deploy cords and reels, and dispense helium to the balloon from sled-mounted containers. Unlike zero-pressure balloon systems, SPBs require a 328 m^3 (0.011 MCF) "tow balloon" to lift the heavier SPB top fitting while it is being filled with helium (shown in Figure 2-9). Once enough helium has been transferred to the SPB, the tow balloon is released, where it ascends until it reaches bursting altitude and returns to earth. Tow balloons are recovered within approximately 5 km of the launch site.

2.1.5 Flight

2.1.5.1 Aspects Common to Both Launch Sites

Upon release, the SPB would be expected to ascend at an average rate of approximately 110 to 160 m per minute. Therefore, the balloon system may spend between 3.5 and 5 hours in the ascent stage before reaching a floating altitude between approximately 33.8 and 35.9 km. During launch, ascent, and within the line-of-sight (LOS), the launch site would maintain telemetry control of the balloon. Once the SPB leaves LOS coverage, operational control would be transferred to the Columbia Scientific Balloon Facility (CSBF) Operations Control Center in Palestine, Texas. During its entire flight, the balloon's position would be tracked using an onboard global positioning system (GPS) beacon.

The balloon's altitude would remain at a fairly constant float level (constant pressure altitude), oscillating ±200 m without ballast commands. The balloon's internal pressure and altitude can be controlled via radio commands sent from the command station. If the balloon pressure needs to be lowered, a command is sent to vent helium until the correct pressure is achieved. Should the internal pressure need to be raised, flight controllers can send a command to slowly release a portion of the ballast material until the correct pressure and a slightly higher float altitude is again achieved. It should be noted that while such fine-tune control of the balloon flight is possible by releasing ballast material, gross trajectory control (i.e., steering) cannot be achieved with the balloon system; the balloon system would follow the seasonal prevailing wind patterns encountered during its flight.

2.1.5.2 Specifics of Antarctica Launch Site

The austral summer stratospheric anticyclone that establishes itself over the South Pole provides stable counter-clockwise circulation patterns over the Antarctic continent for approximately five weeks from early to mid-December into mid- to late January. Afterward, the stratospheric anticyclone breaks down, and "stratospheric turnaround" conditions are present, during which winds remain light and variable for a few weeks until the stratosphere adopts a stable clockwise zonal pattern.

Balloon ascents during the austral summer are typically over the Ross Ice Shelf and may track easterly or westerly with slight northerly components. At float altitude, the stratospheric anticyclone provides a stable balloon trajectory between 77°S and 80°S, circling the pole and overflying the Ross Ice Shelf. One complete circumnavigation can take between 10 and 20 days. Once the anticyclone breaks down, trajectories are highly variable, and the flight paths can adopt a more northerly or southerly course depending on position. As such, the flight could track beyond the Antarctic continent (< 70°S) or toward the pole (>80°S). Flight durations exceeding 100 days are expected to have variable trajectories, but they would likely remain below 60°S (Figure 2-10) (**Mullenax & Schwantes 2014; GAC 2003**).

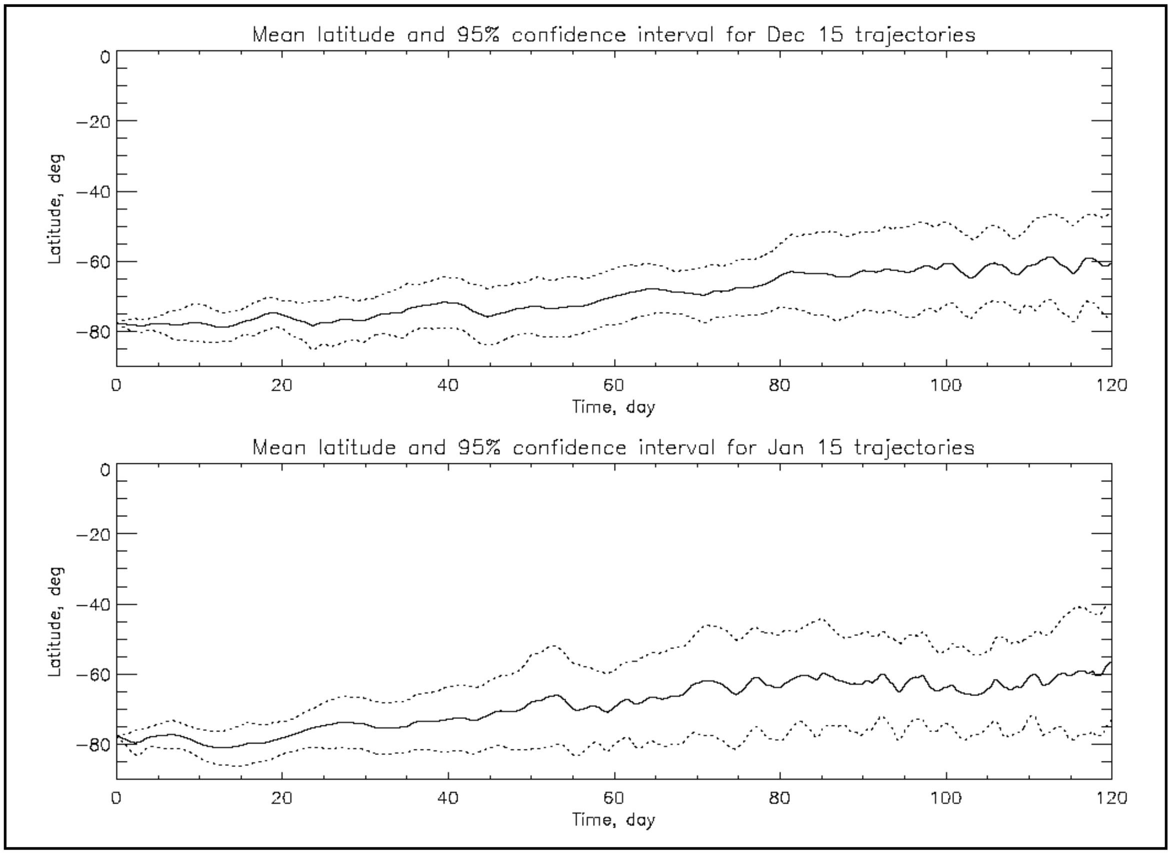

Figure 2-10: Mean Latitude and 95% Confidence Intervals for Antarctica-Launched Balloons (from GAC 2003)

2.1.5.3 Specifics of New Zealand Launch Site

The stratospheric austral fall/winter cyclone produces a stable but dynamic clockwise circulation pattern at the latitude of Wanaka, New Zealand from approximately March 1 through August 31 of each year. Balloon ascents during this period are typically over land, tracking easterly with north or south components. Due to the proximity of eddies to the north and very strong cyclonic flow to the south, balloon trajectories on the average will have latitudinal excursions of +/- 10° to 12° for a 30-day flight, and up to +15°/-20° for a 100-day flight (Table 2-1).

Table 2-1: Mean Latitude Range for Wanaka, New Zealand-Launched Balloons Launch Dates from March 1 to April 31 (from Mullenax & Schwantes 2014)

Flight Duration	**+30 Days**	**+60 Days**	**+100 Days**
Average Latitude Range	34.5°S – 58°S	33.5°S – 60°S	29°S – 65°S

One complete circumnavigation could take between 4 and 20 days, depending on the time of year and latitude. Trajectories during this time of year can show either a northerly or southerly component but reliably overfly South America and New Zealand/Australia.

It is possible that during the ascent of New Zealand-launched balloons, a chase plane would be dispatched or waiting to be dispatched to visually monitor the progress of the SPB system until it has sufficiently pressurized.

2.1.6 Termination

2.1.6.1 Aspects Common to Both Launch Sites

An SPB flight would be terminated if any of these four conditions are met: 1) the balloon meets its comprehensive science objectives and an acceptable termination location is found; 2) the balloon is found to be in poor health and poses a safety concern; 3) the balloon is approaching the operational limits of its flight systems (e.g., power supply); or 4) the balloon is nearing areas not approved for either overflight or recovery.

Using a NASA-developed computer model that takes into account the weight of the balloon flight system and current weather conditions, balloon flight controllers can predict where the balloon and payload would land from the point the termination command is given. The descent trajectory of the balloon/payload is overlaid on an aeronautical chart showing exclusions areas, which include population centers and areas of sensitive land uses (e.g., areas of wildlife congregation, see Appendices A and B) that must be avoided. When planning termination, flight controllers would avoid exclusion areas and would notify the appropriate air traffic control organizations to ensure that the descent path is clear of aircraft.

The overland termination process would be initiated by a command sent to the balloon from the flight control center. The balloon envelope and payload would be mechanically separated using a cable cutter activated by a small pyrotechnic device. The payload release would cause the parachute to open (once appreciable air density is encountered) and would also create a large tear in the balloon, allowing the remaining helium to escape and resulting in a free-fall descent of the balloon envelope. The balloon would descend to earth within approximately 15 to 20 minutes and usually lands within 15 km of the payload (**G. Garde, personal communication, 2013**; see Figure 2-11). The parachuted payload typically descends to the ground in about 45 minutes.

Figure 2-11: SPB Carcass at Impact Site
(2012 Sweden Flight 631NT)

The concept of operations for a termination during open-ocean overflight where there is no possibility of land impact would be different, and would entail releasing the helium gas through valves at the top of the balloon structure. The entire SPB system would remain intact during descent through water impact and submersion.

2.1.6.2 Specifics of the Antarctica Launch Site

Three NASA-commissioned studies have evaluated the fate (i.e., land or water impact) of an Antarctica-launched SPB system upon flight termination. The first, performed by **GAC (2003)**, evaluated 20 potential trajectories over a 10-year historic dataset (years 1980 to 1990) to derive cumulative probabilities of recovering the SPB on both Antarctic and non-Antarctic landmasses (i.e., South America, Africa, and Australia/New Zealand). The study found that the probabilities of a non-Antarctic landmass recovery range from zero (up until day 75 of flight) to just less than 0.005 for a mid-December launch date. The probability of landing on Antarctica trends downward as flight duration increases. However, it remains notably higher than the other landmasses throughout modeled flight, ending at approximately 0.57 at day 100 (Table 2-2).

Table 2-2: Comparison of Probabilities of Impact for 100-Day SPB Flights from Antarctica

Recovery Region	Calculated Probabilities of Impact at 100 Days of Flight	
	GAC 2003	Mullenax & Schwantes 2014
Australia/New Zealand	0.002	0.015
South America	0.001	0.075
Africa	0.001	N/A
Antarctica	0.57	0.59
Oceanic Area	0.42	0.32

A related, though less computationally intensive, study performed by the National Scientific Balloon Facility (NSBF; renamed CSBF after the U.S. Columbia Space Shuttle tragedy) in 2003 indicated a roughly one-in-three possibility of land recovery for an equivalent flight (**NSBF 2003**). A third study, **Mullenax & Schwantes 2014**, employing recent (years 2011–2013) satellite-derived wind data to simulate 156 potential flight trajectories in late November and December, indicated an approximately 59 percent chance of recovery over the Antarctic landmass, an approximately 32 percent chance of an oceanic landing, and a 9 percent chance of non-Antarctic land recovery at 100 days of flight (Table 2-2).

2.1.6.3 Specifics of the New Zealand Launch Site

The **Mullenax & Schwantes 2014** study also considered 183 potential trajectories over 3 years (2011–2013) to calculate probabilities of terrestrial recovery for New Zealand SPBs launched in March and April. In comparison to Antarctica-launched balloons, the probability of a terrestrial recovery in Australia, New Zealand, or South America following termination is higher, ranging from 0.98 at day 30 to 0.75 at day 100 (Table 2-3).

Table 2-3: Probability of Impact Areas for 100-Day SPB Flights from New Zealand with Launch Dates of March 1 to April 31 (from Mullenax & Schwantes 2014)

Flight Duration	+30 Days	+60 Days	+100 Days
Probability of Terrestrial Recovery	0.98	0.96	0.75
Probability of Oceanic Landing	0.02	0.04	0.25

Before NASA issues the command to terminate the balloon flight over land, a tracking aircraft may be dispatched to follow the path of the balloon and payload/parachute, and relay information to the recovery team on the ground. A communication link between the tracking plane, retrieval team, and monitoring command station could communicate when the command to separate the parachute from the payload should be given if the command station loses LOS telemetry due to landforms obstructing the electronic signal.

2.1.6.4 Summary of Flight Termination Scenarios

In summary, after termination of an SPB flight originating from either launch site, the probability of a terrestrial landing is greater than that of an oceanic landing. However, as the potential for an oceanic landing at 100 days of flight ranges from approximately 0.32 for Antarctica to 0.25 for New Zealand, it cannot be discounted. As such, both scenarios are described in further detail below.

2.1.7 Terrestrial Landing

The aspects of a terrestrial landing would be the same from either launch location. Upon landing in a terrestrial area, a semi-automatic parachute release system is used to separate the parachute from the payload to prevent the payload from being dragged and potentially damaged. The footprint of a typical payload is less than 10 square meters (m^2). The footprint of the balloon varies, but it would not likely exceed a few hundred square meters. Parachutes are sized according to the weight of the payload such that the force of impact on the ground is nominally 6.7 meters per second (m/s), which is standard for decelerators. Depending on the length of time between landing and recovery (discussed below), it is possible (especially for Antarctica-landing items) that the SPB system components would be covered with snow.

2.1.8 Oceanic Landing

2.1.8.1 Initial Conditions

An oceanic landing would be different from a terrestrial landing in that the parachute and payload would not be separated from the balloon to ensure that the entire mass would sink to the ocean floor shortly after impact. To estimate the sink rate of the system once in the water, **Shreves & Wilcox (2014)** performed a conservative assessment that concluded the intact SPB system would sink at a rate of between about 0.15 and 0.18 m/s, equating to approximately 540 to 650 meters per hour (Figure 2-12).

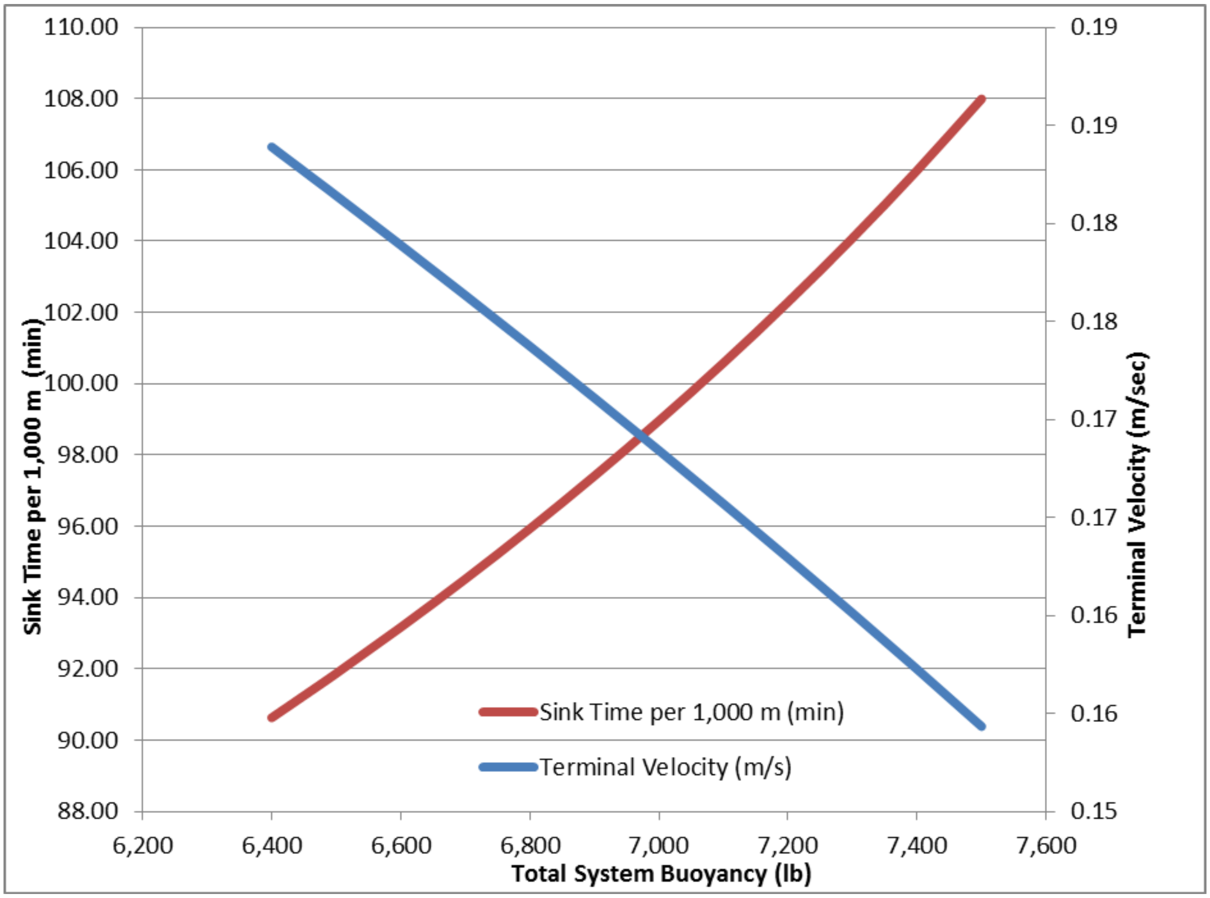

Figure 2-12: Estimated Sink Rate of In-Water SPB System (Based on Shreves and Wilcox [2014])

The time required to reach the ocean floor would depend on the depth of the ultimate landing location. However, Table 2-4 illustrates the times required to reach commonly encountered depth "bins" in the Action Area.

Table 2-4: Estimated Range of Times Required to Reach Selected Depths (based on Shreves and Wilcox [2014])

Depth (m)	Upper (hours)	Lower (hours)
1,000	1.8	1.5
2,000	3.5	3.0
3,000	5.3	4.5
6,000	10.6	9.1
7,000	12.4	10.6

A potential range of horizontal drift distances was also calculated, considering a high current velocity (40 centimeters per second [cm/sec]) at the surface (**Hofmann 1985**) to a low expected velocity (approximately 2 cm/sec) at abyssal depths (**Rodman & Gordon 1982**). Without a detailed analysis of the balloon system's horizontal drag that would resist the current or create lift, the most conservative assumption would be that the SPB system would fully follow the current velocity. Assuming the slowest descent rate of 0.15 m/s, this results in a potential horizontal drift between approximately 0.1 km (current velocity of 2 cm/sec) and 2.6 km (current velocity of 40 cm/sec) per thousand meters of descent (**Shreves & Wilcox 2014**).

2.1.8.2 Fouling

It is possible that once in contact with ocean water, the surface of the balloon could be colonized by fouling organisms (**Wahl 1989**), thereby increasing its density (and sink rate) (**Morét-Ferguson et al. 2010**); however, the degree to which such colonization would occur would correspond to the amount of time the balloon remained at or near the ocean's surface. Additionally, an area's geographic latitude (and corresponding climatic conditions) has been shown to have a marked effect on the degree of biofouling on marine debris. Studies in temperate waters have shown that fouling can result in positively buoyant materials (i.e., plastics) becoming neutrally buoyant, eventually sinking below the surface into the water column after only several weeks of exposure (**Ye & Andrady 1991; Lobelle & Cunliffe 2011**) or descending farther to rest on the seafloor (**Thompson et al. 2004**). Studies of marine debris biofouling in the Southern Ocean indicate that it would most likely occur in latitudes below 60°S (**Barnes 2002**), though there have been reports of accumulated biota on debris washed ashore at higher latitudes (**Barnes & Fraser 2003**). **Barnes (2002)** suggests that persistent freezing temperatures likely limit biological growth on floating materials in the Antarctic (>60°S).

Because of the higher probabilities of Antarctic-launched SPBs landing south of latitude 60°S (90 percent at day 90; 60 percent at day 120; **GAC 2003**), and their expected rapid descent toward the light-deficient ocean floor (**Wahl 1989**), fouling of these items by photosynthetic organisms would be minimal. However, the SPB debris on the seafloor may provide hard substrata for the attachment of opportunistic sessile biota. The epibionts of benthic plastic debris are not as well-known as those of pelagic items. Accounts are limited (e.g., **Holmström 1975**) but indicate a hard ground biota dominated by bryozoans (mosses).

Should New Zealand-launched SPBs enter the ocean, the likelihood of fouling would be relatively higher, though also extremely low because the system would rapidly sink to the ocean floor (where no photosynthetic fouling would be expected due to light extinction). Additionally, the colder climatic conditions during austral winter, when flight terminations (and resultant oceanic landings) would occur are less favorable for biofouling.

2.1.8.3 Degradation

As the degradation rates of materials in the environment are the result of the cumulative effect of multiple site-specific physical, chemical, and biological factors, absolute degradation rates cannot be estimated. Rather, in this Section, the process of degradation of the SPB system materials is discussed qualitatively with relative comparisons made (e.g., degradation process “A” would affect material “X” more so than material “Y”). This approach is applied to be consistent with degradation testing procedures (e.g., **American Society for Testing and Materials 2013**), which advise against providing absolute rates of degradation in the absence of empirical data specific to the particular scenario considered.

2.1.8.3.1 LLDPE Balloon Material

The SPB’s primary material, LLDPE, is in the family of high molecular weight polymers known as polyolefins (**Dow 2012**), which are not easily degraded by abiotic or biotic processes (**Haines & Alexander 1974**). The LLDPE used for the SPB is a three (resin) layer extruded polyethylene film with an UV inhibitor additive incorporated during the extrusion process. This inhibitor mitigates the UV degradation effects expected to be encountered during the production and operational lifecycle of the SPB. For the purposes of this assessment, the term “degraded” refers to the point of embrittlement, which is when the LLDPE material would lose its mechanical integrity. Extensively degraded plastics can become brittle enough to fall apart into powder-like fragments on handling (**Andrady 2011**), an endpoint at which there would be the least potential for adverse interaction with marine species.

Depending on the nature of the causing agent, polymer degradation is classified as photo-oxidative, thermal, ozone-induced, mechano-chemical, catalytic, and biological (**Singh & Sharma 2008**). A plastic in the environment is usually not exposed to only one stressor at a time; therefore its degradation is often the result of the synergistic effects of multiple stressors. For example, an elevated material temperature and the presence of moisture show a considerable synergistic effect on the photo-degradation of the polymeric materials (**Andrady et al. 2003**). Likewise, elevated temperature (such as on beach sand) and mechanical action (such as that caused by waves) can also expedite sunlight-induced degradation rates (**Andrady 2011**).

EFFECTS OF SUNLIGHT

It is expected that photo-oxidative degradation, the process of decomposition of the material by light (most effectively by near-UV and UV wavelengths), would be the primary source of damage exerted on the LLDPE balloon during its approximately 100 days of flight (**Andrady 2011; Singh & Sharma 2008**), especially considering the higher UV dose that would be effected at flight altitude (as compared to that on the Earth's surface). Although the SPB film is treated with a UV stabilizer during the manufacturing process, such stabilizers reduce but cannot completely prevent oxidation (**Feldman 2002**). As such, it can be expected that some light-induced degradation would occur. Furthermore, once initiated, the degradation can continue thermo-oxidatively for some time without the need for further UV exposure as long as oxygen is available (**Andrady 2011**). However, due to the interaction of other environmental factors (discussed in the following paragraph), it is expected that mechanical integrity of the SPB system would not be severely degraded at water impact. Upon entering the water column, the SPB system would rapidly sink below the depths to which UV radiation in clear Antarctic waters has been reported to penetrate (60 to 70 m; **Smith et al. 1992**), eventually resting on the ocean floor (**Shreves & Wilcox 2014**) where exposure to UV light would also not occur (**Gregory & Andrady 2003**), rendering further photo-oxidation improbable.

EFFECTS OF SYNERGISTIC DEGRADATION FACTORS

Other synergistic factors expediting polymer degradation, including elevated temperature (**Ho et al. 1999**), pressure (**Murata et al. 2004**), and mechanical action by waves (**Corcoran et al. 2009; Cooper & Corcoran 2010**) are not expected to measurably contribute to the balloon's degradation. For example, the expected temperature range encountered during the balloon's stratospheric flight would be between -20° and -75°C (**R. Mullenax, personal communication, 2014**), and in contrast to humid environments which can increase degradation rates (**Andrady et al. 2003**), the atmosphere would be very dry. Similarly, near-freezing water temperatures would be expected at abyssal depths where the balloon would remain following flight termination. Additionally, once in the ocean, the relatively constant temperatures (lacking diurnal cycling) and the lower oxygen concentration (as compared to the atmosphere) would slow any resultant degradation (**Andrady 1990; Andrady 2011**).

EFFECTS OF SUBMERSION IN SEAWATER

Due to the hydrophobic character of polyolefins (**Zheng et al. 2005**) the long-term submersion of the SPB system in ocean water would have little effect on the degradation of the LLDPE beyond the sunlight-shielding and thermal regulation (both of which retard degradation) discussed in the preceding paragraph. Although there is the potential for hydrolytic degradation of plastic (due to the formation of hydrophilic carbonyl groups) after sufficient photo-oxidation has occurred (e.g., **Albertsson et al. 1987**), because the SPB would not undergo significant photo-oxidative degradation during its flight (due to the UV inhibitor and constant cold, dry temperatures) and once at depth (due to UV extinction and constant cold temperatures), the resultant effects on the balloon's mechanical integrity are expected to be minor.

POTENTIAL FOR FRAGMENTATION

Plastic items can fragment in the environment as a consequence of prolonged exposure to UV light and physical abrasion (**Andrady 2003; Thompson et al. 2004**). This is particularly evident on shorelines where photodegradation, elevated temperatures, and abrasion through wave action make plastic items brittle, increasing their potential for fragmentation (**Andrady 2011; Barnes et al. 2009**). In consideration of the fact that the SPB system would not undergo substantial abiotic degradation prior to or once in the ocean, it would not be terminated within coastal waters (eliminating the potential for the system to land in a high-energy beach environment), and the depth at which it would ultimately rest would not be subjected to abrasive physical processes (which could cause a “mass” release of particles), it is expected that any resultant fragmentation into smaller pieces, while inevitable over an indeterminate period of time, would be at a very slow, gradual rate.

Even when the balloon envelope fragments into smaller pieces in the long term, it is likely that not all pieces would be positively buoyant due to fouling and/or sediment deposition. Furthermore, once in the water column, the particles could again return to the seafloor. **Van Cauwenberghe et al. (2013)** suggest that once in the water column, small pieces of plastic could reach the sea floor as marine snow, which is produced as a biologically enhanced aggregation of small organic and inorganic particles (**Alldredge & Silver 1988**). Sinking rates of marine snow are estimated to range from 1 to 368 meters per day (**Alldredge & Silver 1988**). Therefore, considering this sink rate, the return of the smaller plastic particles to the seafloor once at the surface could take as little as several months to more than decades.

EFFECTS OF MICROORGANISMS

While plastics will eventually biodegrade in the marine environment, the rate of this process, even in the benthic sediment, is several orders of magnitude slower compared to light-induced oxidative degradation (**Andrady 2011**). The ultimate degradation endpoint for plastics is when all organic carbon in the polymer is converted into carbon dioxide, water and biomass by microorganisms (referred to as complete mineralization [**Andrady 1994]**), the kinetics of which are not well known (**Andrady 2011**). Estimates regarding the amount of time required for such a fate in the marine environment are highly variable, spanning several orders of magnitude from hundreds (**Derraik 2002**) to even thousands of years (**Barnes et al. 2009**), particularly in deep, cold, dark oceans (**Barnes et al. 2009; Bergmann & Klages 2012)**.

High molecular weight plastics such as LLDPE do not biodegrade at an appreciable rate as microbial species that can metabolize them are rare in nature, particularly in the marine environment (**Andrady 2011**). Abiotic degradation of polymers is a necessary first step prior to biological degradation as it increases their surface area for microbial colonization and reduces molecular weight (**Albertsson et al. 1987; Palmisano & Pettigrew 1992**). However, the hydrophobic nature of the LLDPE would interfere with the formation of a microbial bio-film, thus decreasing the extent of biodegradation (**Hadad et al. 2005**). Similar to the above discussion of hydrolysis, the formation of carbonyl groups would increase the potential for biological degradation of the SPB system by microorganisms (e.g., **Albertsson et al. 1987**), however due to the limited amount of abiotic degradation expected during flight and lack of it once on the seafloor, it is expected that this eventual fate would be realized at a future time period estimable only to the level reported in the literature of "hundreds to thousands of years" (e.g., **Barnes et al. 2009**). To provide perspective on the amount of abiotic degradation required before this would potentially occur, it has been found that molecular weights less than approximately 500 grams per mole (g/mol) are needed before microbial growth is supported (**Andrady 2011; Zheng et al. 2005**); the estimated molecular weight of the SPB LLDPE resin is between approximately 25,000 to 160,000 g/mol (**Dow 2013**).

2.1.8.3.2 PBO Tendon Material

Similar to LLDPE, PBO, the material of which the balloon's longitudinal gores is constructed, is highly susceptible to sunlight-induced degradation (**Seely et al. 2004; Said et al. 2006; Walsh et al. 2006**). However, it is for this exact reason that the PBO fabric is encased in a UV-resistant polyethylene film for the SPB, effectively negating the potential for sunlight-induced degradation. The most likely PBO degradation mechanism would be the material's tendency to weaken when immersed in water (**Walsh et al. 2006)**. Despite the tendons being shrink-wrapped in the UV-resistant sleeve, the ends of the tendons would provide a path for water to come in contact with the material. However, the extent to which the water would wick-up the tendons is unknown. It should be noted that the weakening observed by **Walsh et al. (2006)** was due to the loosening of the fibers rather than a chemical degradation process. In consideration of these facts, it is assumed that the PBO tendons would remain intact with no measurable degradation realized.

2.1.8.3.3 Nylon Parachute Material

A conclusion similar to that of the LLDPE and PBO materials may be reached for the nylon parachute system; it is expected that near-UV wavelength light would be the primary source of the material's degradation (**Stowe et al. 1974; Yano & Murayama 1980**). However, given that it would remain furled during the SPB flight, and due to its rapid sink rate to depths below which UV light would reach (**Gregory & Andrady 2003**), realized effects on material integrity would also be negligible.

2.1.8.3.4 Metallic Components

Once the SPB system is in contact with seawater, structural metallic components (i.e., aluminum and steel alloys) would corrode. Likewise, based on research conducted by **Rosak (1985)**, the $LiSO_2$ batteries would corrode, releasing their electrolytes (e.g., SO_2, acetonitrile, and lithium salt) into the water column and expose the internal lithium metal strips to seawater. It is also expected that relatively early in the descent toward the seafloor (i.e., within an hour), the relief valves on the VRLA batteries would fail due to oceanic pressure, exposing the internal lead components to seawater.

As corrosion rates in seawater are from the cumulative effect of multiple site-specific factors, including temperature, pH, dissolved oxygen, currents, and extent of biofouling (**Guedes Soares et al. 2011**), absolute corrosion rates of metallic SPB hardware cannot be estimated. However, some general observations can be made about the fate of these materials. First, given that aluminum and steel SPB components are either powder-coated or painted, their rate of corrosion would be slower than if they were bare metal. When comparing potential corrosion rates of the primary SPB system metals, due to the relatively high dissolved oxygen concentrations of the cold Southern Ocean water at depth (**Gordon 1971**), ferrous materials (i.e., steel comprising the cable ladder and portions of the gondola) would undergo corrosion more rapidly (**Melchers 2005**) than the aluminum components, which tend to form a protective oxide coating that can preserve the material (**Reinhart 1969**). Similarly, items containing lead (e.g., solder), a metal often regarded as highly resistant to corrosion in the marine environment (**Tylecote 1977**), would form a protective inorganic coating on their surface, slowing dissolution. Finally, given lithium metal's highly reactive nature in water, some of the corroded $LiSO_2$ batteries (i.e., those not fully discharged) could exhibit the characteristic, short-duration lithium-water exothermic burning and popping, forming lithium chloride and releasing hydrogen gas (**Rosak 1985**). In the instance of fully discharged batteries, they would be unreactive due to the lithium metal being converted to a lithium oxide (**Aral & Vecchio-Sadus 2008**).

2.1.8.3.5 Summary

In summary, once the SPB system reaches the seafloor where a lack of sunlight would inhibit degradation rates, it is expected that the mass would remain virtually intact for an extended period of time, perhaps centuries or more (**Moore 2008; Barnes et al. 2009; Gregory 2009; O'Brine & Thompson 2010; Schlining et al. 2013**). Moreover, given that the negatively-buoyant balloon envelope would be attached to the top of the parachute, it is expected to act as an "anchor" for the parachute once on the bottom, preventing the parachute from being entrained in bottom currents and remaining suspended or partially deployed while on the bottom (**Shreves & Wilcox 2014**). This end state is further supported by the low current velocities reported at abyssal depths (**Rodman & Gordon 1982**), which would present a negligible amount of lift on the likely amorphous SPB mass on the seafloor (**Shreves & Wilcox 2014**).

Likewise, given the slow corrosion rates of the aluminum fittings connecting the balloon the flight train below it, the possibility of their failure and subsequent "release" of the balloon is highly unlikely. Moreover, even if the balloon were to separate from the remaining flight train, it would be expected to remain on the seafloor due to its negative buoyancy effected primarily by the mass of the PBO tendons and metallic (aluminum) apex and base fittings (**Shreves & Wilcox 2014**).

2.1.8.4 Potential Impact Solely on Antarctic Ice

Given the distance sea ice extends from the Antarctic continent (Figure 2-13), it is possible that an Antarctica-launched SPB would land on or among sea ice. The ice substrate could be either land-fast sea ice (attached to the continent) or floating ice (e.g., an ice berg). The probability for landing on ice would be much greater earlier in flight and would decrease with flight duration. This is for two reasons: 1) the SPB system would most likely remain over the Antarctic continent for most of its flight, drifting north over the ocean only as flight duration increases beyond 60 days (**GAC 2003; Mullenax & Schwantes 2014**); and 2) most Antarctic sea ice melts during the first summer after it forms (**Allison et al. 1993**), leaving only limited multi-year ice along the coast, with most coverage in the Weddell and Ross seas in the February/March timeframe (based on data from **Fetterer et al. 2002**). Because flights would not be terminated over the Antarctic continental shelf waters (Appendix A), much of which correspond with the seaward extent of land-fast ice during the austral summer sea ice minimum, the area where sea ice would most likely be encountered would be the Weddell and Ross Seas.

In the event of an ice landing, the SPB would probably not penetrate the ice surface; rather it would land on the surface in a mass. Antarctic sea ice is commonly overlain by snow that can vary considerably in depth (**Massom et al. 2001**). Regions near the coast that receive blowing snow from katabatic winds and other offshore winds can accumulate a layer of snow approximately 2 m thick; however, average snow thickness is generally between 0.1 and 0.5 m (**Massom et al. 2001**). As such, once on the ice, all or part of the SPB system would become snow covered.

If the SPB landed farther inland on multi-year sea ice or one of the ice shelves, consistent with past practice, NASA and the NSF would most likely recover the SPB system. However, it is possible that the SPB system could be partially recovered or abandoned in place due to safety considerations (**NSF 2008**), particularly if it lands on sea ice far from McMurdo Station (e.g., the northern Weddell Sea). Should the unrecoverable SPB system land on sea ice subject to same-year melting, it would eventually enter the water column later in the season, sink to the seafloor, and experience the same fate as described in Section 2.1.8, *Oceanic Landing*. However, since the flight would likely be terminated during late austral summer, the most likely ice encountered if the SPB system lands on sea ice would be thicker, multi-year ice (**Worby et al. 2008**). Under this scenario, the SPB system would become covered with snow (likely "trapping" it) where it would remain for at least several years. Given the cold temperatures and effective attenuation of UV light by snow cover (**King & Simpson 2001**), negligible degradation of the LLDPE balloon material integrity would be expected.

In the longer term, if the SPB system is left in place, it would eventually enter the water column during the annual thaw of sea ice. However, the system could be subject to submergence and resultant freezing (flood-freeze cycling; **Fritsen et al. 1998**) before realizing this eventual fate, encasing the mass in ice, and potentially covering it with additional snow. Antarctic sea ice does not generally endure more than several seasons; therefore, this cycle would last as long The

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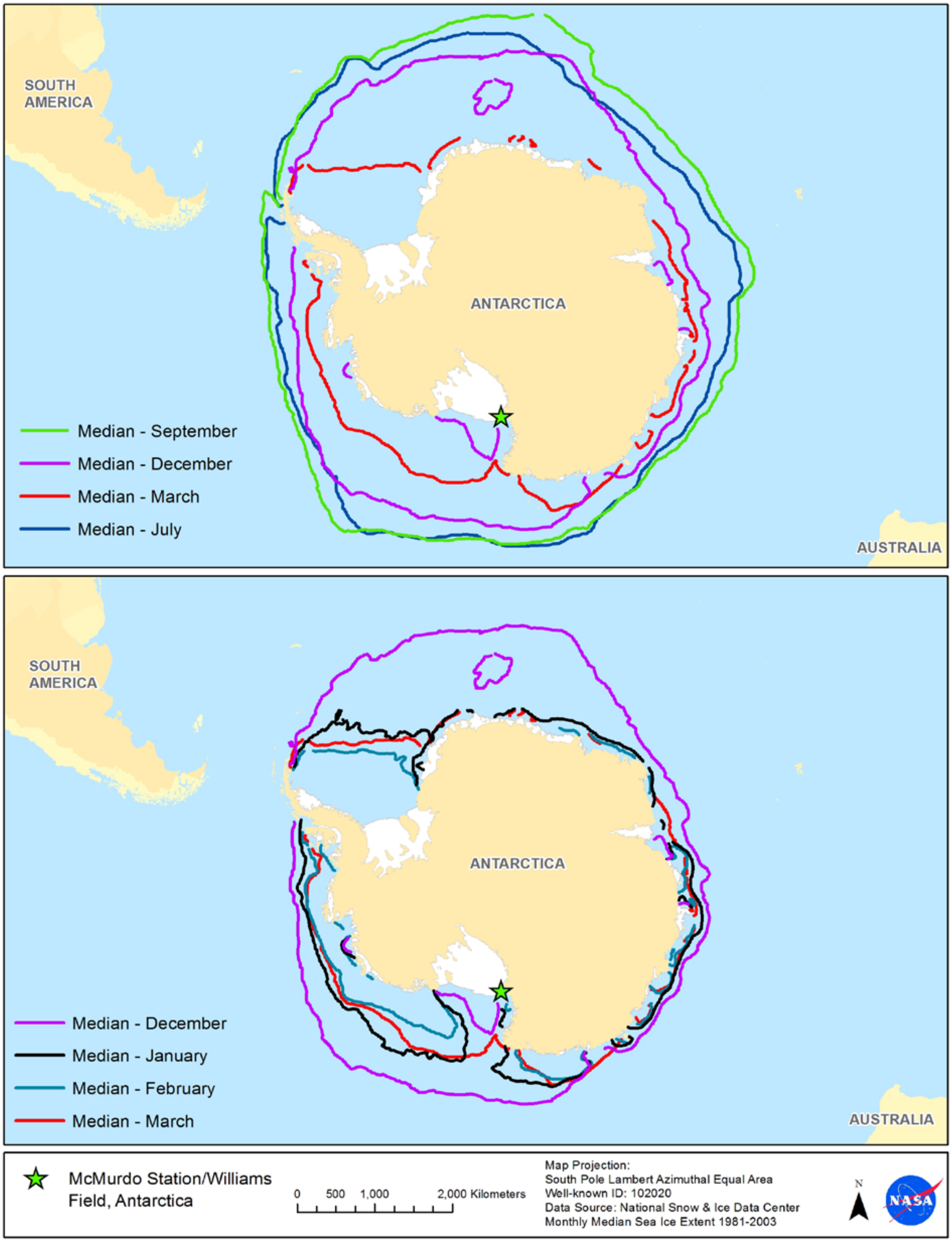


Figure 2-13: Seasonal (top) and Intra-Seasonal (bottom) Antarctic Sea Ice Extent (from Fetterer et al. [2002])

waters surrounding the Antarctic continent are surrounded by icebergs, often large ones, formed by "calving" from the Antarctic ice shelves, larger icebergs, or valley glaciers (**Romanov et al. 2012**). Iceberg concentrations are densest in the south Atlantic Ocean and southern Indian Ocean portions of the Antarctic coastline (**Tournadre et al. 2012**). As such, it is possible that upon termination, the SPB system would land on an iceberg. The average lifespan of Antarctic icebergs is highly variable, and largely dependent on size (**Budd et al. 1980**). As such, if the SPB system were to land on top of a smaller iceberg (i.e., less than several hundred meters long), it would likely enter the water column in a year or less as the berg underwent submarine melting, wave-induced ablation, and rollover (**Budd et al. 1980; Orheim 1980**). However, larger icebergs would likely persist for several years or more (**Budd et al. 1980**) before wave-induced breakage, submarine melting, and/or rollover (**Hamley & Budd 1986**) would dislodge the SPB. In either case, once the SPB system entered the water column, it would experience the same fate as described in Section 2.1.8, *Oceanic Landing*. Furthermore, given that snowmelt is generally low on Antarctic icebergs (**Nicolaus et al. 2006; Haas et al. 2008**), and that frequent storms (**Simmonds et al. 2003**) would likely deposit new or re-distribute existing snow, all or part of the SPB system would remain snow-covered during much of its time atop the iceberg, limiting UV exposure and its effect on material integrity.

During its time afloat on an iceberg, the exact location of the SPB system could not be estimated, as it would depend on a number of factors, including prevailing meteorological conditions and sea ice coverage (**Schodlok et al. 2006**). However, some general observations can be made. Sea ice drift around Antarctica is mostly divergent (**Kottmeier et al. 1992**), with a northerly drift component toward the surrounding open oceans (**Schodlok et al. 2006**). As such, the system would trend toward the northern extent of the Action Area, likely entering the ocean within a latitude range between the iceberg's point of calving and approximately 55°S, the northernmost drift extent of most Antarctic icebergs (**Haas 2010**).

2.1.9 Recovery

2.1.9.1 Terrestrial Recovery

Recovery of the SPB system in terrestrial areas would likely be similar to current recovery activities for all NASA scientific balloon flights, as described in detail in Section 4.5 of the 2008 LDB IEE/EA (**NSF 2008**) or in Section 2.1.6 of the *NASA Scientific Balloon Program Programmatic Environmental Assessment* (**NASA 2010a**), and would involve coordination with local and national government bodies of the area in which the SPB lands. In general, given the ability to track the balloon and payload/parachute during flight, the system could be expeditiously recovered from land provided that all necessary approvals (e.g., termination and recovery agreements) are obtained.

In many instances, a fixed wing vehicle or helicopter overflight of the landing site would be necessary to determine the best means for access. It is also possible that a vehicle with a lift capacity of up to 1,000 kg would be needed to retrieve the heaviest SPB components, including the payload and balloon carcass.

2.1.9.1.1 Antarctica

Following landing of a SPB system in Antarctica, a recovery crew comprised of USAP and CSBF personnel would travel to the site via ski-equipped fixed-wing aircraft or helicopter to locate and inspect the system components. Recovery and transport of the payload would require disassembly of the unit (using hand tools), while retrieval of the balloon carcass, if possible, would involve cutting the fabric and load tapes into manageable pieces for packaging and transport. As necessary, a temporary tent camp may be established at the landing site to house recovery personnel. Depending on site-specific conditions and distance to McMurdo Station, aircraft or overland traverse vehicles may be used to transport the recovered payload, parachute, and balloon to the station (Figure 2-14).

Figure 2-14: Antarctic Payload Recovery

The possibility of recovering the SPB system after termination would be highly dependent on accessibility and weather. Recovery efforts for some SPB missions may not be completed before the end of the austral summer season due to physical constraints at the proposed landing site, weather, or the limited availability of logistical resources. In these instances, recovery efforts would be conducted during the next summer season.

Due to the size and weight of the components making up a SPB system, multiple recovery trips to a landing site may be needed to retrieve the entire payload, parachute, and balloon. Recovered materials would be transported back to McMurdo Station for processing with other USAP wastes for subsequent disposal in the United States (**NSF 2008**).

2.1.9.1.2 Non-Antarctic Landmasses

In the case of a terrestrial recovery outside of Antarctica, the recovery team would collect all sections of the balloon system following the procedure described for general land recovery above, leaving no physical evidence at the recovery site. All items would be shipped back to the United States for disposal or refurbishment for future re-use.

The method of recovery would be dependent on terrain and accessibility. For a landing site near existing roads and passable terrain, trucks and a heavy-lift-capable vehicle would be used to recover SPB system components. In the case of a remote landing site or one that would present safety concerns for standard recovery operations, a fixed wing vehicle or helicopter may be employed to recover SPB components (Figure 2-15). As with recovery of SPB components from the Antarctic continent and ice shelf, multiple trips may be required to recover all system components in non-Antarctic terrestrial settings. Once recovered, scientific equipment would be returned to its owner(s) and all other materials would be transported to the United States.

Figure 2-15: Non-Antarctic Scientific Balloon Component Recovery from the Southwestern United States (A, B) and Northern Canada (C, D)

2.1.9.2 Oceanic Recovery

Recovery from water would likely not be feasible, particularly considering that an oceanic termination would occur away from coastal areas to reduce the potential for impacts on sensitive marine species (described in more detail in Section 3.2.2). Personnel safety could also be an issue, as the vast Southern Ocean waters comprising most of the Action Area are consistently regarded as having the roughest sea-state of all the world's oceans. Mean wave heights range from approximately 4 m during austral summer to more than 5 m during austral winter (**Young 1999**). Moreover, there are few available ports with the capacity to harbor safe, ocean-going vessels capable of operating in these waters. Private tourist and government research vessels operate in the Southern Ocean during the summer months. However, these activities are limited and primarily take place around the waters of the Antarctic Peninsula (**Lynch et al. 2010**), which would be avoided during flight termination (see map in Appendix A). As such, the potential for a ship-based ocean recovery would be unlikely. However, in the remote event a vessel does encounter a SPB system, NASA would encourage its collection for return to land for appropriate disposal.

2.1.10 Measures to Reduce Potential for Adverse Environmental Effects

To reduce the potential for adverse environmental effects, NASA would take the following measures as integral components of its Proposed Action.

2.1.10.1 Modification of Flight Termination Process

As described in Section 2.1.6, NASA would employ one of two location-specific termination processes that would be selected based on the expected landing site (i.e., terrestrial or aquatic areas) at the end of each flight. Developed specifically for the Proposed Action, the process for an aquatic landing would require minor reconfiguration of the termination system to allow a more gradual "valve down" process by which: 1) helium would be vented from the balloon from float altitude down to impact; 2) the parachute would not be opened to slow the descent; and 3) the gondola and flight train would not be separated from the balloon. The primary purpose of this modification is to ensure that the flight train and gondola (composed primarily of metallic items) serve as an anchor to sink the plastic balloon envelope to the ocean floor as soon as possible after oceanic impact. Once on the ocean floor and below the water column strata where most marine species are known to occur in the Action Area, the risk of the SPB system introducing stressors (i.e., entanglement or ingestion) to such species is significantly reduced.

2.1.10.2 Avoidance of Terminating within Most Sensitive Areas

Employing data provided by multiple sources, including the World Database of Protected Areas (**IUCN & UNEP 2009**), National Oceanic and Atmospheric Administration's (NOAA's) Large Marine Ecosystems (LME) program (**NOAA 2013**), and the database of Antarctic Specially Protected Areas (**SAT 2011**), as well as recommendations from the NMFS Office of Protected Resources (**J. Carduner, personal communication, 2014**), NASA identified the most sensitive environmental features in the Action Area. Figure 2-16 and Appendices A and B depict these areas in detail (on a per-continent basis) which include: the continental shelf waters of all landmasses in the Action Area (depths less than 200 m for most continents and up to 1,000 m for Antarctica [**Clarke & Johnston 2003**]); the waters within 80 km of islands and seamounts (those with heights at least 1 km as identified by **Kim & Wessel [2011]**); parks and preserves; and specifically identified areas of particular importance to fish and wildlife species.

The boundaries of these sensitive areas would be identified on SPB real-time flight tracking computer displays and would be categorically avoided when planning a flight termination unless public safety dictated its necessity.

2.1.10.3 Identification of a Preferred Oceanic Termination Area

Though terminating a SPB flight over a terrestrial area is the preferred method, and would be effected for every flight that allows it, should an oceanic termination be necessary at the end of a flight, it is NASA's intention to do so in an area where the likelihood of encountering sensitive marine species (e.g., marine mammals, sea turtles, etc.) would be the lowest. As such, in consideration of the above-described "avoidance areas" and the analysis of potential effects presented in Section 3.2.2 of this analysis, NASA has identified a preferred oceanic termination area in the south Pacific Ocean. Located south of the South Pacific Gyre region known to have low biological productivity (**Polovina et al. 2008**), outside of direct migratory routes between known marine mammal wintering and summer foraging grounds, and characterized by deep water (the bottom of which would be below areas typically utilized by these species in the Action Area), the area is expected to consistently have the lowest density of sensitive species of the Action Area. The area is bounded by the 29°S parallel to the north, the 90°W meridian to the east, the 160°W meridian to the west, and the 60°S parallel to the south (Figure 2-16). It should be noted that, while terminating in this area would be infrequent (probability estimated by **Mullenax & Schwantes [2014]** to be approximately 0.05), and cannot be guaranteed for any flight, NASA would take this area's location into consideration if a water termination were deemed necessary.

2.1.10.4 Annual Reporting

As established during NASA's ESA consultation with NMFS, by December 31 of each year, NASA would prepare and submit to NMFS a report on the outcomes of its Proposed Action. Annual reports would include the following:

a. the dates and locations of all SPB launches;

b. locations (GPS coordinates) of all SPB flight terminations;

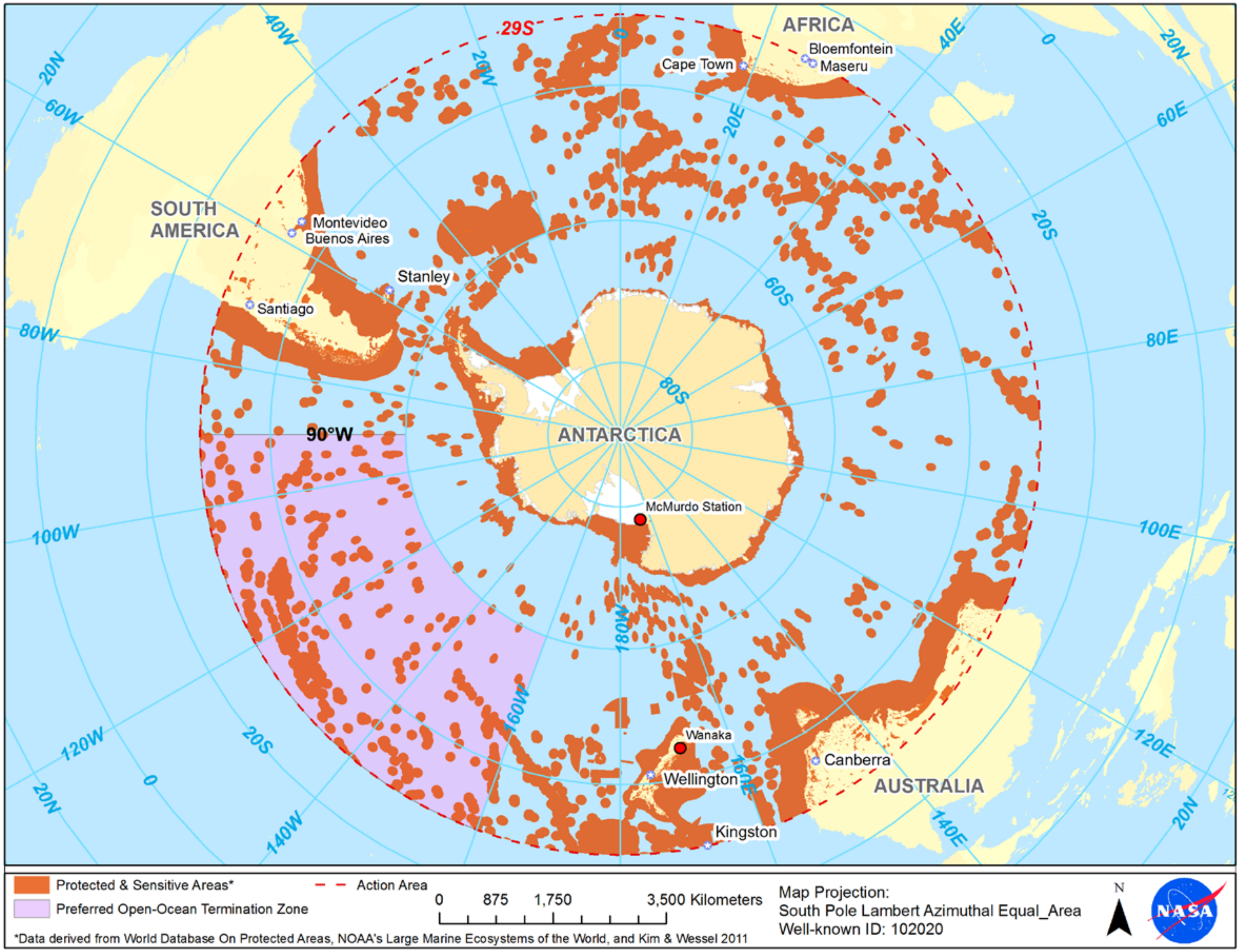
c. for oceanic flight terminations, any available information on the fate of SPBs after flight termination, including sink rate, evidence that SPB components failed to sink, or evidence that SPB components later reappeared on the surface;

d. for oceanic flight terminations, a description of any efforts made to terminate SPB flights in the preferred termination area described in the BE (**NASA 2014**) and this IEE/EA, and outcomes of those efforts;

e. information on any attempts to recover SPBs after flight termination; and

f. any evidence that ESA-listed species were adversely affected by the action.

The subject monitoring and reporting would meet not only NASA's commitments made while consulting with NMFS under the ESA, but also would also serve to fulfill NASA's obligations under Section 104 of ASTCA (16 U.S.C. § 2403a(a)(2)(B)) which requires that "appropriate procedures are put in place to assess and verify the impact of the activity" before proceeding with an action that is the subject of an IEE.



*Data derived from World Database On Protected Areas, NOAA's Large Marine Ecosystems of the World, and Kim & Wessel 2011

Figure 2-16: Protected Areas and Preferred Oceanic Termination Area (from IUCN and UNEP 2009, SAT and Kim & Wessel 2011, NOAA 2013)

2.2 ALTERNATIVES TO THE PROPOSED ACTION

Both NEPA and the *Antarctic Protocol* require agencies to consider alternatives to a proposed action. As such, NASA considered the following Alternatives and compares their potential environmental effects to the Proposed Action in Chapter 3 of this IEE/EA.

2.2.1 Alternative A: Limit Flights to the Antarctica Launch Site

Under Alternative A, NASA would undertake the same actions as described for the Proposed Action, including up to one SPB flight per year from Antarctica. However, unlike the Proposed Action, establishment of a lower latitude launch site (i.e., New Zealand) would not occur.

2.2.2 Alternative B: Limit Flights to the New Zealand Launch Site

Under Alternative B, NASA would undertake the same actions as described for the Proposed Action, including up to two SPB flights per year from New Zealand. However, unlike the Proposed Action, establishment of a higher latitude ULDB launch site (i.e., Antarctica) would not occur.

2.2.1 Alternative C: No Action Alternative

The purpose of assessing a “no action” or “no project” alternative is to provide a benchmark against which the effects of other “action” alternatives may be compared.

Under the No Action Alternative, NASA would not conduct ULDB operations in the Southern Hemisphere beyond its existing operations on the Antarctic continent. Consistent with the conditions of the LDB IEE/EA (**NSF 2008**), LDB deployment and launch operations (which could include both SPBs and zero pressure balloons) would continue from Williams Field, near McMurdo Station, Antarctica, and post-flight termination and recovery would be confined to the Antarctic continent.

2.3 ALTERNATIVES CONSIDERED BUT NOT CARRIED FORWARD FOR ANALYSIS

In the process of developing its ULDB system maturation strategy, NASA considered alternative launch sites and concepts of operation that were ultimately deemed infeasible. These Alternatives are summarized below but are not carried forward for analysis in this IEE/EA.

2.3.1 Alternate Launch Sites

NASA regularly uses Fort Sumner, New Mexico and Palestine, Texas for its conventional (flight durations between 1 and 3 days) scientific ballooning, and Kiruna, Sweden and Williams Field, Antarctica as LDB (up to approximately 40 days of flight) launch sites. Periodically, missions have also been conducted from sites in Australia, Brazil, and Dunedin, New Zealand. The two balloon launch sites in the continental United States offered only short duration flights; therefore, they were the first removed from consideration. However, the four mid-latitude sites could allow longer flight durations, and accordingly were assessed with a particular focus on their ability to meet NASA's range safety requirements should it decide to conduct its operations there. Australia

Alice Springs, Australia, (23.7°S, 133.9°W) was considered as an option that would satisfy the need for a mid-latitude SPB launch site. However, long-duration flights from Alice Springs could overfly densely populated areas, presenting a safety hazard. Therefore, this site was not carried forward for analysis.

2.3.1.1 South America

Two sites in South America were considered for the launch of ULDBs in the Southern Hemisphere: La Rioja, Argentina (29.4°S, 66.8°W), and Osorno, Chile (40.6°S, 73.1°W). The NASA WFF Safety Office conducted a Feasibility Balloon Risk Analysis for these sites in 2011 for one 100+ day flight of a 745,000 m^3 SPB from each site (**NASA 2011**). Results from this study indicated that the safety risks associated with these potential missions exceeded those allowed by the Safety Office. Therefore, these South American sites are not carried forward for analysis.

2.3.1.2 South Africa

The Denel Overberg Test Range (34.6°S, 20.3°E) was suggested as a possible South African launch site for SPB which, like Australia, would satisfy the need for mid-latitude flights. However, the presence of many densely populated areas in the flight path of SPBs launched from this site presented a safety hazard. Therefore, South Africa is not carried forward for analysis as a launch site.

2.3.1.3 Sweden

While short-duration (approximately 4 to 7 days) flights are possible from Kiruna, Sweden (67.9°N, 20.2°E), the lack of an overflight/termination agreement with Russia prohibits flights of any length that would meet the science needs described in Section 1.5. Therefore, the option of Kiruna, Sweden as a launch site is not carried forward for analysis.

2.3.2 Unmodified Oceanic Flight Termination Sequence

During initial formulation of the Proposed Action, a standard flight termination sequence was proposed for in-water landings. This would involve separation of the balloon from the flight train (including parachute) and payload, resulting in two impact areas. In the case of a water landing, the balloon "carcass" would have a high probability of floating and drifting for an inestimable amount of time because of low degradation and bio-fouling rates in cold Southern Ocean waters, potentially posing an entanglement and ingestion threat to marine biological resources (e.g., sea turtles, whales) that occupy the upper water column, as well as a marine navigational hazard. For this reason, the standard flight termination concept of operation was not carried forward for analysis in the case of a water landing.

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3 AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This Chapter describes the baseline environmental conditions (affected environment) and the potential effects (environmental consequences) that the Proposed Action or Alternatives may have on them. Given the large geographic extent of the Action Area and the sheer number of environmental resources within it, details are only provided when they have bearing on the potential effects of the Proposed Action or Alternatives. Therefore, in many cases, only a summary of resources is provided.

3.1 PHYSICAL RESOURCES

This section describes the physical resources potentially affected by the Proposed Action or the Alternatives. Physical resources include air quality and water resources.

3.1.1 Air Quality

Air quality in a given location is described by the concentration of various pollutants in the atmosphere. Atmospheric pollutants can be divided into two general categories: 1) “criteria” pollutants, which include ozone (O_3), carbon monoxide (CO), nitrogen dioxide, sulfur dioxide, particulate matter less than 10 and 2.5 microns in diameter, and lead; and 2) greenhouse gases (GHGs), which include carbon dioxide (CO_2), methane, nitrous oxide (N_2O), O_3, and several hydro- and chlorofluorocarbons.

Each GHG is assigned a global warming potential (GWP), which is the gas’s ability to trap heat; GWP is standardized to CO_2, which has a GWP value of 1. For example, N_2O has a GWP of 310, meaning it has a global warming effect 310 times greater than CO_2 on an equal-mass basis. For simplification, total GHG emissions are often expressed as a CO_2 equivalent (CO_2e). GHGs are relatively stable in the atmosphere and are essentially uniformly mixed throughout the troposphere and stratosphere; therefore, the source location does not affect the climatic impact of GHG emissions, and regional climate impacts are likely a function of global emissions.

The primary emissions from the Proposed Action would result from the burning of fossil fuels in mobile sources (e.g., cars and light trucks transporting personnel and equipment). The U.S. Environmental Protection Agency (EPA) uses 250 tons (227 tonnes) per year in its New Source Review standards as a threshold for listed new major stationary sources in attainment areas. Consequently, for the purpose of evaluating air quality impacts in this IEE/EA, emissions are considered to be minor if the Proposed Action would result in an increase of 250 tons per year or less for any criteria pollutant. No similar regulatory thresholds are available for mobile source emissions, so this threshold is also used to equitably assess and compare mobile source emissions. Recent draft guidance from the CEQ (**CEQ 2010**) indicates that projects having estimated CO_2e emissions greater than 25,000 tonnes warrant further consideration. Accordingly, for the assessment of GHGs, the CEQ-recommended 25,000 tonnes threshold is applied.

3.1.1.1 Affected Environment

The layer of atmosphere closest to the Earth's surface is the troposphere. This layer extends from sea level to about 18 km. The lowest part of the troposphere is referred to as the atmospheric boundary layer. This layer is important in terms of the emission, transport, and dispersion of airborne pollutants. The part of the atmospheric boundary layer between the Earth's surface and the bottom of the inversion layer is known as the mixing layer. Almost all of the airborne pollutants emitted into the ambient atmosphere are transported and dispersed within the mixing layer. All balloon system preparation and recovery activities would occur within the troposphere. However, once afloat, the SPB system would remain in the stratosphere (above the troposphere) until the flight is terminated.

3.1.1.2 Environmental Consequences

PROPOSED ACTION

Helium is used to inflate the balloons and is released during flight and termination; it is non-toxic, non-flammable, and has no harmful effects on the Earth's environment. Cryogens may be necessary, depending on mission requirements and scientific instrumentation used. Generally, cryogens are substances used for refrigeration and used to keep the detectors of scientific instruments very cold, which makes them sensitive enough to produce the readings necessary to the scientific mission. Cryogenic liquid helium and nitrogen are used for some scientific ballooning activities. When used, quantities of these substances would vary between 400 to 500 liters. If exposed to air, these liquids boil off; the resulting gas is inert and does not have an adverse impact on air quality.

The ballast of the balloon system provides stability and control of the balloon during ascent. The amount of ballast material required is dependent on the weight of the payload, the size of the balloon, and the required float altitude to collect the scientific data. Ballast, consisting of very fine glass beads (grain size 0.69 mm to 0.84 mm) or fine steel shot (grain size 0.3 to 0.5 mm), can be released to adjust the float altitude of the balloon system When releasing ballast, the flow rate is no more than 27 kg per minute, and is normally released in 30-second increments. In the United States, EPA regulates particulate matter of size 2.5 and 10 microns (1 micron is equal to 0.001 mm), as these sizes can be easily breathed into the lungs of humans or animals. However, as the particle size of the ballast exceeds 10 microns, neither of these materials are regulated by EPA. Although it would be rare for all the ballast to be released at one time, if it were it would travel in the upper atmospheric winds and be dispersed over hundreds of kilometers.

The Proposed Action would increase fossil fuel-burning vehicle trips to the launch sites where equipment would be transported and support staff would remain during the campaigns. Additionally, the small increase in recovery vehicle traffic (i.e., a modified flatbed truck, private vehicle, and small aircraft) resulting from the Proposed Action would increase both criteria and GHG emissions.

Though emissions were not calculated specifically for the Proposed Action, a recently conducted analysis (**NASA 2013a** and its Appendix F) of operating a launch site and recovering sounding rocket flight hardware in the high Arctic of Alaska is applicable to the Proposed Action due to the similarities of the types of aircraft employed, number of employees engaged, and likely remoteness of the recovery site. Furthermore, it is considered be a conservative proxy because recovery operations under the Proposed Action would be less intensive (fewer flights and more infrequent use of aircraft for terrestrial recoveries). The 2013 analysis found all transportation-related criteria pollutant emissions to be less than 3 tonnes annually, with the exception of CO, which was approximately 20 tonnes per year. Furthermore, CO_2e emissions were estimated to be approximately 230 tonnes annually (**NASA 2013a**), well below CEQ's proposed thresholds triggering further consideration (**CEQ 2010**). Therefore, in summary, no perceptible change in air emissions would be anticipated from implementation of the Proposed Action.

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, those effects would be less intense because fewer flights would take place per year. As there would be more launches annually under Alternative B, the potential air emissions would be greater than for Alternative A but less than the Proposed Action. In absolute terms, the emissions resulting from any of the alternative would be negligible. Air emissions would be the lowest under the No Action Alternative.

3.1.2 Water Resources

This section describes the marine water resources in the Action Area. Freshwater features (e.g., lakes, ponds, rivers, and streams) are not described because NASA would avoid terminating a flight within them. Therefore they would not be affected and do not warrant discussion.

3.1.2.1 Affected Environment

A defining feature of the ocean in the Action Area is its distinct banding, consisting of several somewhat uniform circumpolar belts of water divided by fronts, which are relatively narrow zones of water exhibiting sharp changes in vertical structure, temperature, salinity, and nutrient content (**Belkin & Gordon 1996**). Following the approach taken by **Griffiths (2010)**, the ocean in the Action Area can be divided into three zones based on two of the major fronts (Figure 3-1). The first two are, from south to north: 1) the Antarctic zone, extending from the Antarctic coast north to the Polar Front (also known as the Antarctic Convergence), which has an average latitudinal location of 50°S (**Lutjeharms & Valentine 1984**), though generally farther south in the Pacific (up to 60°S) than the Atlantic and Indian Oceans (approximately 40°S) (**Dong et al. 2006**); and 2) the sub-Antarctic zone, extending from the Polar Front to the Subtropical Front; located at approximately 40 to 42°S (**Lutjeharms & Valentine 1984**). The third zone comprises the remaining portion of the Action Area, and is defined as the Warm Temperate Subtropical zone (**Knox 1960**). It spans from the Subtropical Front to the northern extent of the

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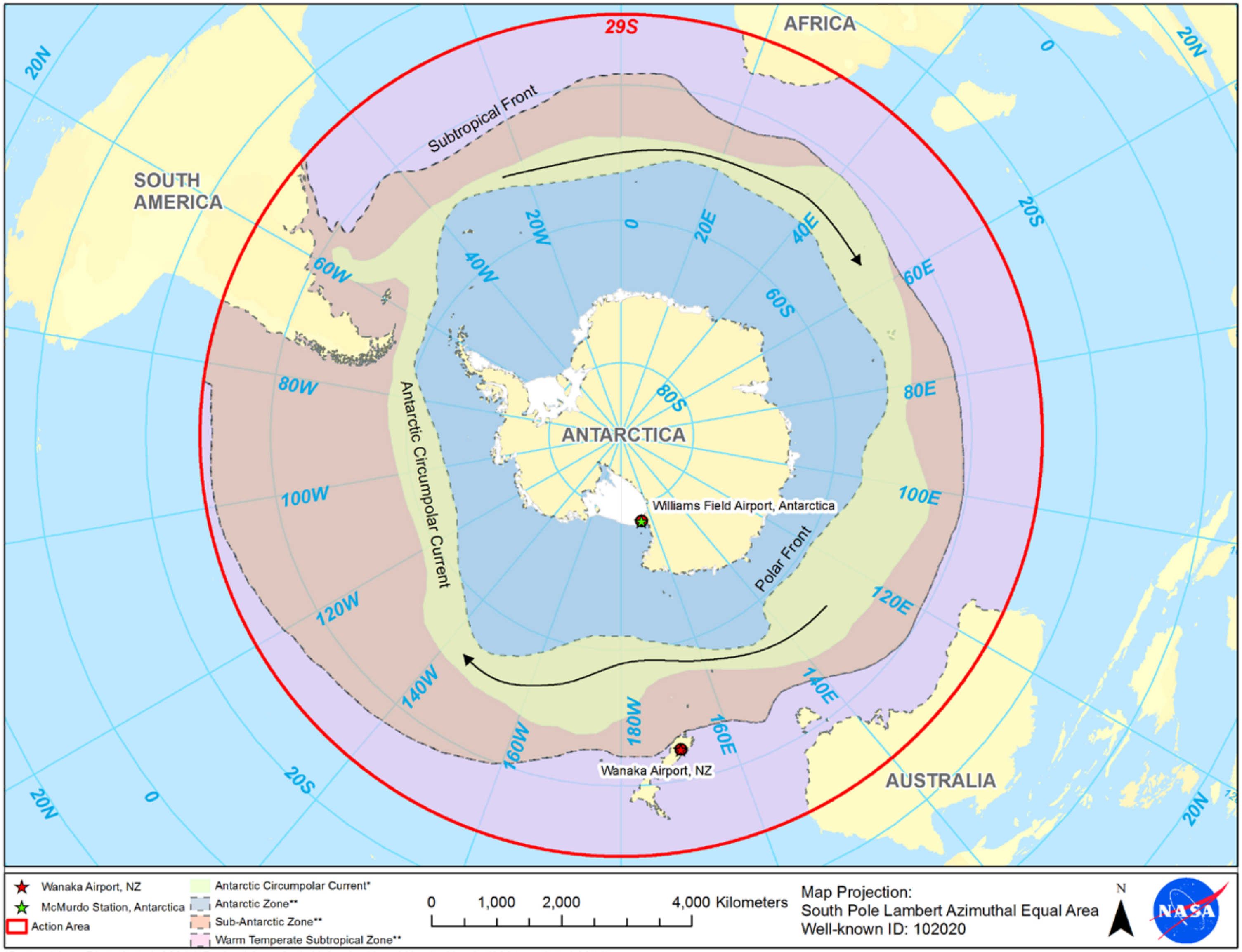


*Derived from Rintoul et al. 2001 **Derived from Orsi, Alejandro H and Harris, Ursula (2001, updated 2014)

Figure 3-1: Oceanic Zones of the Action Area

Action Area and includes New Zealand, southern Australia, both coasts of South America, and southern Africa.

Marking the northern extent of the Antarctic zone, the Polar Front is where cold, northward-flowing surface water from Antarctica meets the relatively warmer, southward-flowing surface waters of the sub-Antarctic Atlantic, Pacific, and Indian Oceans (**Laws 1985**). The temperature gradient across the Polar Front is approximately 1.5 to 2°C (**Moore et al. 1999**). Surface temperatures south of the Polar Front increase from approximately -1.5°C close to the Antarctic continent to 4°C south of the front. The upper water column south of the Polar Front has generally low salinity, except in the Weddell and Ross Seas, where sea ice formation consumes fresh water, increasing the overall salt content. At the seafloor, the Antarctic bottom water also is highly saline (**Orsi et al. 1999**) due to sea ice formation. Oxygen levels are higher in the Antarctic than most other regions of the world. Nutrients (i.e., nitrates and phosphates) and silicate are also found in high concentrations. The waters within this zone are very deep, with more than 90 percent deeper than 1,000 m (**Griffiths 2010**). In this portion of the Action Area, there is a seasonal cycle of sea ice formation and melting. Sea ice coverage increases from around 3 to 4 million km^2 in the summer to 18 to 20 million km^2 in winter (based on data from **Fetterer et al. 2002**). South of the Polar Front, surface currents are wind driven (**Knox 2006**). At higher latitudes, close to the Antarctic continent, easterly winds drive the East Wind Drift, which flows counterclockwise around the continent until deflected northward by the Antarctic peninsula (**Laws 1985**). There the waters join the clockwise flow of the West Wind Drift, or Antarctic Circumpolar Current (ACC), which is driven by strong westerly winds (**Orsi et al. 1995).**

North of the Polar Front, within the sub-Antarctic zone, the moderately fresh, cool sub-Antarctic surface waters are separated from the more saline subtropical waters by the Subtropical Front (**Orsi et al. 1995**). There is a change of approximately 9°C across the Subtropical Front from subtropical waters of 12 to 15°C to sub-Antarctic waters of 3 to 6°C (**Knox 1960**). The sub-Antarctic Zone is a transition zone between the nutrient-rich waters south of the Polar Front and the low-nutrient waters north of the Subtropical Front (**Rintoul & Trull 2001**). Winter mixing extends to great depth (>400 m) compared to the zones to the north and south, forming a vertically well-mixed, high-oxygen water mass that spreads north. In summer, the mixed layer is shallower at 75 to 100 m depth (**Rintoul & Trull 2001**).

North of the Subtropical Front is the Warm Temperate Zone, characterized by southward-moving warmer, more saline waters (temperatures range from approximately 12 to 19°C depending on season) (**Knox 1960**). Within this zone, particularly along the coasts of the major landmasses, are areas of colder surface water created by the mixing of oceanic and coastal shelf waters, resulting in upwelling. Such areas include the west coast of Chile (**Heileman et al. 2008a**), the Patagonian Shelf east of Argentina (**Heileman 2008**), the coasts of South Africa (**Heileman & O'Toole 2008; Heileman et al. 2008b**), the southwest (**Irvine et al. 2008**) and southeast (**Aquarone et al. 2008**) Australian Shelves, and the New Zealand Shelf (**Aquarone & Adams 2008**).

Benthic water temperatures in the Action Area are very cold (<1°C) with a few exceptions, such as shallow areas in the summer (**Clarke et al. 2009**).

3.1.2.2 Environmental Consequences

PROPOSED ACTION

Over time, some corrosion of the aluminum would occur, and in the case of the 7000 series alloy used on the SPB, load-bearing plates would release zinc (**Reinhart 1969**), a heavy metal that could be toxic to living organisms in high enough concentrations. Additionally, it is possible for the lead in the lead acid batteries and soldered electrical connections to corrode over time and release potentially toxic lead compounds into the water column. Finally, corroded $LiSO_2$ batteries could release lithium compounds (regarded as minimally toxic in the environment [**Aral & Vecchio-Sadus 2008**]), sulfur dioxide (which could form sulfurous acid), and acetonitrile, an organic compound which, when in contact with lithium under certain circumstances, can form toxic lithium cyanide (**Rosak 1985**).

However, several factors render the possibility of such metals or compounds measurably affecting water quality highly unlikely. First, the SPB system would contain minute quantities of the subject components (Section 2.1.2.4.2) when compared to the 113.3-million km^2 pelagic environment of the Action Area. Second, the 7000 series aluminum components are powder-coated or painted, reducing the potential degree of corrosion. Third, the lead contained in the photovoltaic cells would be "sandwiched" between layers of glass, effectively sealing the internal lead-containing solder from the environment (**Fthenakis 2003**) unless the cells were severely damaged (i.e., shattered), which is not expected to occur during flight termination and descent. Fourth, based on the findings of the **Rosak (1985)** study, because the $LiSO_2$ batteries would be housed in rigid containers and are not expected to be severely damaged during their descent (in contrast to the batteries described as "mangled" and leaching cyanide by the author of the referenced study), the potential for the formation of lithium cyanide is low. Finally, the slow rate of metal corrosion coupled with the buffering and dilution action of the open ocean make the probability of resultant toxic concentrations of dissolved metals or compounds extremely low.

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, those effects would be less intense because fewer flights would take place per year. Though there would be more launches annually under Alternative B, the potential effects would be essentially the same as Alternative A given the higher probability of a terrestrial flight termination for New Zealand-launched flights. Under the No Action Alternative, there would be no risk to marine water resources, as flight terminations would be limited to the Antarctic continent. In absolute terms, the potential effects on water resources would be negligible under all Alternatives.

3.2 BIOLOGICAL RESOURCES

This section describes the biological resources in the Action Area that could be affected by the Proposed Action or the Alternatives. Biological resources are divided into two categories: terrestrial and marine resources. Some of these biological resources are classified as special status species by the International Union for Conservation of Nature (IUCN), which maintains the “Red List” of globally threatened and endangered species. Additionally, the U.S. ESA applies to listed species (and those proposed for listing) on the high seas.

3.2.1 Terrestrial Resources

This section describes the biological resources of the terrestrial areas in the Action Area, including those in Antarctica, the sub-Antarctic islands, Australia, New Zealand, South America, and South Africa, and includes vegetation, wildlife, and birds.

3.2.1.1 Vegetation

3.2.1.1.1 Affected Environment

Mosses dominate Antarctic plant communities at coastal and moist sites, whereas lichens are most prevalent at higher altitude, inland, or drier sites (**Convey 1996**). In general, farther north on the sub-Antarctic islands, vegetation diversity increases with decreasing latitude, and species include tussock grasses, ferns, mosses, and some introduced grasses and weeds. At the northernmost fringe of the sub-Antarctic islands (e.g., Tristan da Cunha islands, Gough Island), stunted trees and woody shrubs are present, evident of the region’s more temperate climate (**Watson 1975**).

Temperate forests cover much of the landscape in southern Australia (**Gill & Catling 2002**), which is also interspersed with grasslands (**Vesk & Mac Nally 2006**). The dominant types of Australian vegetation in the Action Area are the hummock grasslands in western and southern Australia. Eucalypt woodlands are prevalent in the east, and in the west there are acacia forests, woodlands, and shrublands.

New Zealand has very few annual or deciduous plants; most are evergreen. It has two main forest types: 1) southern beech forest, which is present from Northland south to Fiordland on drier foothills, ridges, and mountaintops; and 2) conifer broadleaf forest, which is located throughout New Zealand, chiefly on the wetter western mountainsides and in deeper gullies and foothills. Tussocks predominate in the New Zealand alpine zone, which also contains patches of stunted shrubs, grass trees, and dense thickets of leatherwoodscrub. Coastal areas are dominated by salt-tolerant trees and grasses. Mangroves (*Avicennia marina*) are present in the tidal mudflats north of Tauranga **(Brockie 2012)**.

A small portion of the African continent is located in the Action Area. This land includes Cape Agulhas, South Africa, and is part of the Cape Floristic Region, an approximately 88,000 km^2 area identified as a biodiversity hotspot (**Myers et al. 2000**). Habitats include the sclerophyllous plant-dominated shrub communities known locally as fynbos (unique to this area), thicket, and forest biomes that support a host of agricultural activities (**Turpie et al. 2003**). The area holds one of the highest known concentrations of IUCN Red Data List plant species in the world (**Cowling et al. 2003**).

Because of its wide range of latitudes and elevations, the "Southern Cone" of South America contains a diverse range of vegetation formations including grass-steppe, shrub-steppe, scrub, desert, tundra, and sclerophyllous, deciduous temperate, and evergreen forests (**Davis et al. 1997**). In the nearly treeless lowland plains of the northern portion of the Action Area, the dominant vegetation types are grassy prairie and grass-steppe, bordered to the west by a winter-deciduous dry-forest band. The arid central-western portion of Argentina contains mostly shrub-steppe vegetation, including an abundance of cacti along the eastern slopes of the mountains. Several plant varieties grow along the Pacific coast of Chile, including shrubby xerophytic communities, evergreen thickets, palm forests, sclerophyllous forest, hygrophilous forest, and deciduous forest. The Altoandina province contains grass-steppe, chamaephyte-steppe, shrub-steppe, and lichens. The Patagonian Steppe is a semi-desert region extending from the eastern slopes of the Andes Mountains to the Atlantic Ocean and is comprised primarily of xeric shrubland, large scrub areas of dwarf shrubs, and grassy steppe. Temperate rain forest occupies the southernmost portion of the continent and Tierra del Fuego.

3.2.1.1.2 Environmental Consequences

PROPOSED ACTION

The lands potentially affected by SPB landing and recovery may be very different, ranging from grassland to desert. Recovery efforts would result in minor temporary impacts to vegetation, including trampling by vehicular and foot traffic. There may be a need to cut down woody vegetation if, for example, the payload and/or parachute were caught in a tree. The extent of the impacts to vegetation would depend on how far from the nearest paved road the payload has landed, the time required for complete payload extraction, and the type of habitat affected. For example, in grassland environments, especially arid grasslands, small-scale disturbances from recovery efforts would have marginal effects **(Guretzky et al. 2006)**. Conversely, in softer, wetter areas, trampling can reduce vegetation height, total cover, and species richness (**Gremmen et al. 2003**). Human-induced disturbance can also lead to the introduction or spread of invasive plant species into a landscape (**Sakai et al. 2001**). To reduce this potential effect, all recovery crews would be required to ensure that tools and equipment are cleaned of soil and plant material prior to effecting a recovery action, and again before leaving the recovery site. However, given the low number of flights annually, the effects on vegetation would be on a very small scale and are highly unlikely to occur repeatedly in the same area.

ALTERNATIVES

While Alternative A would result in the same types of potential effects on terrestrial vegetation as the Proposed Action, the effects would be less intense because fewer flights would take place per year and the terrestrial flora is sparser in the Antarctic environment. As there would be more launches annually under Alternative B, a higher potential for a terrestrial termination and recovery, and more resources potentially affected, the potential effects on terrestrial flora would be the greatest for Alternatives B. However, effects would still be minor in absolute terms due to the seasonality (austral fall and winter) and infrequency of the action. Under the No Action Alternative, there would be little risk to terrestrial vegetation, as flight terminations would be limited to the snow and ice-covered Antarctic continent. As summarized in **NSF 2008**, limited trampling of snow during recovery activities would be the most likely environmental effect.

3.2.1.2 Terrestrial Wildlife and Avifauna

For the purposes of this section, terrestrial wildlife is generally defined as those mammals that may occur within the Action Area and do not rely on the marine environment for their existence. However for Antarctica, truly terrestrial mammals are absent (**Convey 1996**), and on the sub-Antarctic islands, resident mammals are primarily introduced species. Therefore, the discussion of terrestrial wildlife also includes invertebrates. Terrestrial avifauna is defined as landbirds and those avian species dependent on fresh water or continental margins such as shorebirds (following the terminology in **Dingle 2009**).

3.2.1.2.1 Affected Environment

Terrestrial Wildlife

Due to the extreme low temperatures and xeric conditions in much of Antarctica (**Robinson et al. 2003**), the continent is entirely devoid of resident terrestrial vertebrates and insects, but is inhabited, instead, by micro-arthropods such as the Antarctic springtail (*Cryptopygus antarcticus*) and micro-invertebrate groups such as nematodes (**Convey 1996**).

The sub-Antarctic islands, due to their more clement climate relative to Antarctica, are home to a larger variety of endemic species, including arthropods and insects (**Bergstrom & Chown 1999**). However, invasive populations of non-native species, including rodents, cats, and livestock, exist on many sub-Antarctic islands as a result of historical whaling, sealing, and shipping operations, scientific investigation, and tourism; invasive species pose significant threats to endemic species (**Frenot et al. 2005**).

The country of New Zealand spans latitudes from 29°S to 52°S and, as a result, has a wide range of climates (**Craig et al. 2000**). In addition, its geological and biogeographical histories featuring isolation from other landmasses and multiple invasions by ancient species have led to the establishment of unique communities (**Waters & Craw 2006**). It is identified as a biodiversity hotspot (**Myers et al. 2000**). With the exception of two species of bats, New Zealand has no native land mammals. This lack of mammalian interference during the past 65 to 80 million years allowed birds to dominate terrestrial ecosystems, and this has resulted in high endemism of extant species (**Craig et al. 2000**). Due to anthropogenic influences and invasive species, however, many New Zealand habitats and native species populations have been greatly reduced

(**Craig et al. 2000**). For example, seven species of deer and goats were introduced into New Zealand in the 19th and 20th centuries (**Nugent & Fraser 2005**), prompting concerns about their effects on native vegetation (**Wright et al. 2012**).

Because some of the Australian grasslands have been converted to sheep grazing areas, and due to large cities in the area, many populations of native marsupial species (wombats, kangaroos, etc.) in the action have been greatly reduced (**Johnson et al. 2007**). Additionally, invasive species, particularly cats and foxes, have had impacts on native species (**May & Norton 1996**). One part of southwest Australia has been identified as a biodiversity hotspot (**Myers et al. 2000**). The Australian state of Tasmania is home to a varied and unique set of wildlife in a wide range of habitats. Approximately one-fifth of the island has been classified as a World Heritage Area, and more than 30 percent of the land has been placed in a protected status (**Kriwoken et al. 2001**). Like New Zealand and the rest of Australia, mammals on Tasmania are introduced species.

The South African portion of the Action Area contains many endemic species (**Grubb et al. 1999**). Native terrestrial wildlife species include Cape mountain zebra (*Equus zebra*), bontebok (*Damaliscus dorsas dorcas*), and grysbok (*Raphicerus melanotis*) (**Cowling et al. 2003**).

The Action Area includes large expanses of Argentine and Chilean mountains and coasts, areas of Argentine plains, and a small section of Argentine and Uruguayan estuarine habitat. Central Chile, a portion of which exists in the Action Area, has been identified as a biodiversity hotspot (**Myers et al. 2000**). As a result of a common biogeographical past with New Zealand and Australia (**Crisci et al. 1991**), gradual invasions from North America, and a wide variety of habitat types, extant fauna of the Southern Cone are numerous and varied, including many endemics (**Barnosky et al. 2001**).

There are approximately 912 “Red List” terrestrial species in the Action Area, including 417 amphibian, 331 mammal, and 164 reptile species (**IUCN 2012**).

Avifauna

With the exception of occasional vagrants or introduced species, naturally-occurring resident or breeding terrestrial birds are absent from the South Pole to the northern sub-Antarctic islands (e.g., Trista de Cunha group, Gough Island), likely due to the year-round lack of ice-free ground, severe winters, and remoteness of the landmasses (**Watson 1975**). However, as more temperate latitudes are approached, avian species diversity increases to include various perching birds (Order Passeriformes), birds of prey (Order Falconiformes), and waterfowl (Order Anseriformes), among others. Landmasses in the northern portion of the Action Area, New Zealand in particular, host a number of endemics, such as Family Apterygidae, which include the kiwis (**Wilson 2013**).

Most avian species in the Action Area breed during the austral spring and summer months (October through February), with some exceptions. In contrast to their Northern Hemisphere counterparts, most birds in the Action Area, that are not considered seabirds, undertake a much less marked northerly migration from their breeding grounds, likely because more land area at lower latitudes and a milder temperature gradient during winter months (**Newton 2007**). Many Southern Hemisphere species that breed in the Action Area migrate entirely or almost entirely within the Southern Hemisphere itself (**Dingle 2009**). As such, most migrations are short distance and partial, with few species undertaking long-distance migrations. In the mountainous regions of the Action Area (e.g., the Andes of South America), which experience harsh winters, species undertake altitudinal movements to lower elevations for the non-breeding season (**Newton 2007**).

During the austral summer, the northern landmasses in the Action Area receive an influx of wintering migratory birds (e.g., red knot [*Calidris canutus*]) from the Northern Hemisphere. In general, a proportionate number of shorebird species overwinter in Africa, South America, New Zealand, and Australia. However, southern Africa hosts the most species of land and freshwater-dependent birds during this time (**Dingle 2009**).

There are approximately 2,109 “Red List” avian species in the Action Area including terrestrial and seabirds (**IUCN 2012**).

3.2.1.2.2 Environmental Consequences

PROPOSED ACTION

The use of recovery aircraft in remote regions of the Action Area could disturb terrestrial wildlife and avifauna. Generally, helicopters approaching wildlife tend to evoke a behavioral response at a greater distance than do fixed-wing aircraft. However, responses to helicopters range from negligible to minor at distances that would be involved in the search and recovery activities. An exception would be landings and takeoffs, when nearby animals would move away from the site or take cover. Smaller, propeller-driven aircraft flying at altitudes higher than 150 m above ground level (AGL) would cause minimal, if any, response from wildlife (based on data provided in reviews, including **Gladwin et al. 1988; Komenda-Zehnder et al. 2003; Larkin 1994; Manci et al. 1988; and National Park Service 1994**). However, lower-level flight, especially combined with maneuvering such as circling and landing at an identified recovery site, may cause temporary and localized responses such as taking flight by avifauna or running by ungulates (e.g., zebras). Within the United States, aircraft are requested to operate at minimum altitudes of 610 m AGL or higher when overflying wildlife refuges and wilderness areas to minimize disturbance to wildlife resources (**Federal Aviation Administration 2013**). As such, NASA-commissioned search and recovery flights would be required to adhere to this, or similar host-nation-specific altitude restrictions, while transiting from the airfield to the recovery site. Under these circumstances, no adverse impacts on wildlife from the overflight are expected.

Furthermore, wildlife species are most vulnerable to human-induced disturbance during their breeding seasons, when startling effects could lead to trampling or abandonment of young. However, terrestrial search and recovery activities would occur only during non-breeding seasons, reducing the potential for adverse effects. As such, when considered with the infrequency of New Zealand-launched balloons and the programmatic objective of terminating a flight within an area of lowest environmental sensitivity and greatest ease of access, resultant effects would be localized to the vicinity of the search and recovery site, short-term in duration, and range from negligible to minor.

Similarly, wildlife impacts from the use of terrestrial vehicles (e.g., a truck) would be minimal and limited to a temporary startle reaction, as mobile species would likely move away from the recovery area and return once the recovery operations are complete. Direct mortality would be possible for some less mobile species, but this would not be expected to cause any population-level impacts to any species as a whole.

ALTERNATIVES

While Alternative A would result in the same types of potential effects on terrestrial wildlife and avifauna as the Proposed Action, the effects would be less intense because fewer flights would take place per year and the terrestrial fauna population within the Antarctic environment is sparse. As there would be more launches annually under Alternative B, a higher potential for a terrestrial termination and recovery, and more resources potentially affected, the potential effects on terrestrial fauna would be the greatest for Alternative B. However, impacts would still be minor in absolute terms because of the seasonality (austral fall and winter) and infrequency of the action. Under the No Action Alternative, there would be no measurable risk to terrestrial biological resources beyond localized crushing of biota upon landing of the balloon system or trampling during recovery operations (**NSF 2008**).

3.2.2 Marine Resources

This section describes the biological resources of the marine areas in the Action Area, which includes the Southern Ocean and southern portions of the Atlantic, Indian, and Pacific Oceans. While some discussion of coastal marine resources is inherent in describing the resources potentially affected by the Proposed Action, because NASA intends to avoid terminating a ULDB flight in nearshore waters (Section 2.1.11), the focus of this section is the oceanic environment, described in oceanographic texts (**Lalli & Parsons 1997**) as beyond the continental shelf. For most landmasses, this encompasses water deeper than 200 m. However, in Antarctica, the shelf is unusually deep (an average of 450 m, and in places over 1,000 m deep) (**Clarke & Johnston 2003**).

3.2.2.1 Seabirds

Seabirds are those avian species that spend a significant portion of their lifecycle in the marine environment.

3.2.2.1.1 Affected Environment

The Action Area is home to diverse number of seabirds, including Order Sphenisciformes (penguins), Order Procellariiformes (albatrosses and petrels), and Order Charadriiformes (skuas, gulls, and terns) (**Knox 2006**). In contrast to Northern Hemisphere seabirds, marked seasonal migrations are characteristic of these species (**Newton 2007**). During summer, when food is plentiful and available, large numbers of seabirds concentrate near land in high latitude waters. However, during winter, few birds remain in Antarctica other than incubating emperor penguins (*Aptenodytes forsteri*). Most southern species move northward and are distributed widely over the open waters between the Antarctic and Subtropical convergences (**Watson 1975**).

Seabird species are colonial breeders, and egg laying and the fledging of chicks occur on land in the spring and summer. Because there is little suitable snow- and ice-free nesting habitat in the southernmost portion of the Action Area, nesting is often concentrated in available space; thus, colonies can be very large (**Watson 1975**). Chicks have long fledging periods, extending to more than a year in several species. Primary forage sources are crustaceans (largely krill, copepods, and amphipods), squid, fish, and carrion. Both Procellariiformes and Charadriiformes forage at the water's surface, with possible depth ranges of about 0.1 to 3 m (**Laws 1985**), whereas the Sphenisciformes exhibit deeper foraging dives (regular dives to 200 m for king [*Aptenodytes patagonicus*] and emperor penguins, irregular deep dives from 300 to over 500 m [**Kooyman & Kooyman 1995; Kooyman et al. 1992; Wienecke et al. 2007**]). The extent of foraging ranges during the breeding season varies from relatively small in the penguins (Gentoo [*Pygoscelis papua*], 30 km; chinstrap [*Pygoscelis antarctica*], 100 km; macaroni [*Eudyptes chrysolophus*], 120 km; king, 500 km) to larger in the flying birds (petrels [family Procellariidae], 300 to 900 km; albatrosses [family Diomedeidae], up to 2,650 km) (**Laws 1985).**

During austral summer, some seabirds from the Northern Hemisphere migrate into the Action Area (e.g., **González-Solís et al. 2007**).

3.2.2.1.2 Environmental Consequences

PROPOSED ACTION

Direct Strike from Descending SPB: If a flight termination over sea ice were necessary, it is possible that the descending SPB system could directly strike ice-reliant avifauna, including Adélie penguins (*Pygoscelis adeliae*), emperor penguins, and snow petrels (*Pagodroma nivea*). Sea ice is common within the Antarctic Circle, south of 60°S (**Fetterer et al. 2002**), during the December to May flight period for Antarctic activities under the Proposed Action, and is used by emperor penguins as colony sites (**British Antarctic Survey Natural Environment Research Council [NERC-BAS] 2012**) and peripherally by snow petrels as a foraging area (**Croxall et al. 1995**). Adélie penguins winter on sea ice and avoid icy areas during their November to December breeding season (**NERC-BAS 2012**), but are included in this analysis as they, like emperor penguins, molt on ice floes (**Ainley et al. 2003**). These three avian species are classified as Antarctic "sea ice obligate species" due to their dependency on sea ice for breeding and/or foraging habitat, unlike open-water species whose presence tends to fluctuate seasonally (**Ainley et al. 2003**). Assuming that the largest estimated population of these species would be on the surface of the minimum sea ice extent (2013 values; **Fetterer et al. 2002**), a worst-case scenario for direct strike from a descending SPB system was calculated (**Bonsteel 2014b**). Using 30-day flight periods and 10 latitudinal degree probability bins estimated for Antarctic SPB flights (**GAC 2003**), probability of direct strike (PDS) values were developed for Adélie penguins, emperor penguins, and snow petrels. The results indicate that Adélie penguins and emperor penguins would be subject to a maximum PDS of 4.77×10^{-6} and 3.27×10^{-6}, respectively, while that of snow petrels would be 2.02×10^{-5}. Accordingly, the potential for a seabird direct strike on sea ice would be highly unlikely.

Similar PDS analyses were not performed for non-sea ice obligate species because (1) potential impacts to these species in Antarctica were addressed in the LDB IEE/EA (**NSF 2008**) and (2) sub-Antarctic islands are considered sensitive areas which would be avoided during nominal SPB flight termination (Appendix A), thus preventing impacts to breeding habitat in these areas. Moreover, New Zealand-launched balloon PDS was not quantified because of seabirds' wide dispersion in the open ocean (and resultant lower densities and probability of strike) when food becomes scarcer in fall and winter (**Watson 1975**).

Recovery Activities: Although recovery of SPBs launched from New Zealand would likely occur outside of avian breeding season, recoveries of Antarctic-launched SPBs would likely overlap with the times of most active avian breeding (i.e., October to April). Both aircraft overflight and on-the-ground human presence have been shown to disturb nesting seabirds (**Harris 2005** and references therein). A primary concern with disturbance during nesting season is stampeding or trampling of eggs (**Rounsevell & Binns 1991**). Undetected physiological effects may also occur, including changes in stress levels and bioenergetics, or in reproductive behavior (**Harris 2005**). As such, recovery of terrestrial landing SPBs in the coastal zone could induce such stressors to nesting seabirds. However, to reduce the potential for their occurrence, NASA would follow all Antarctic or host country-required aircraft overflight, landing, and approach requirements when conducting SPB recoveries. For example, requirements were adopted by the Antarctic Treaty Consultative Parties in June 2004, which include avoidance of overflying bird colonies at altitudes below 610 m AGL and ensuring that landings are at least 930 m away from colonies unless operationally necessary to maintain safe operations (**Harris 2005**). Additionally, NASA would avoid terminating Antarctic-launched SPB flights within Antarctic Specially Protected Areas (ASPAs), many of which contain large colonies of breeding birds. Should entry into an ASPA be necessary, all recovery operations would be conducted in accordance with the area's specific management plan. In this case, minimal disturbance-related effects on nesting seabirds would be expected.

Interaction with In-Water SPB System: Seabirds have also been reported entangled in marine debris. However, entanglement harms fewer species than ingestion **(Laist 1997**). According to entanglement records reviewed by **Laist (1997)**, Charadriiformes are less likely to become entangled in marine debris, followed by Procellariiformes and Sphenisciformes. It is most likely that seabirds become entangled accidentally when seeking natural prey items in the entangling debris.

Ingestion of oceanic plastic debris has been reported for the three primary orders of seabirds in the Action Area (**Ryan et al. 1987**). However, Procellariiformes are at greatest risk for both ingesting debris and experiencing long-term deleterious effects due to their surface foraging habits and the inability for most species to regurgitate non-digestible items such as plastics (**Azzarello & Van Vleet 1987; Day et al. 1985; Ryan et al. 1987**). **Fry et al. (1987)** suggest that two classes of plastic debris pose the greatest risk of ingestion by seabirds: 1) debris ranging from 1 to 5 mm in diameter, which seemed to be most frequently ingested by plankton-feeding seabirds; and 2) larger items up to 20 x 80 mm, which are principally encountered by larger marine birds, such as albatrosses. Additionally, it has been suggested that if the color of a debris item resembles the preferred prey of foraging seabirds it is more likely to be ingested (**Day et al. 1985; Ryan et al. 1987; Verlis et al. 2013**). **Ryan et al. (1987)** found clear particles the least attractive to Procellariiformes and reds the most attractive because of their resemblance to red-pigmented crustaceans. In a recent study, **Verlis et al. (2013)** found that white colored debris items were most frequently ingested by Australian shearwaters, suggesting that they resembled fish and/or squids.

Therefore, in the short- to mid-term (i.e., decadal to centennial scale), the SPB system would pose a negligible risk to both Procellariiformes and Charadriiformes due to its rapid sink rate to depths below which these species forage (**Shreves & Wilcox 2014**), its mostly clear coloration, and large size. While in relative terms, the SPB system could pose a greater risk to Sphenisciformes due to their deeper dives when foraging, the absolute risk to these species is equally low because all flights would be terminated outside of coastal waters (at depths greater than approximately 1,000 m), and the SPB system would sink in less than an hour (**Shreves & Wilcox 2014**) below the maximum dive depths observed for these species.

In the long term (i.e., centennial scale or greater), the possibility of the balloon system fragmenting into smaller buoyant pieces, which could be more readily ingested by either Order of seabirds, cannot be completely discounted. However, because of the very slow degradation rate at the seafloor, and the few abrasive physical processes there, the fragmented particles would likely be released gradually and be distributed over a wide temporal period. Additionally, when considered over the entire pelagic portion of the Action Area and the distributed/dilute nature of the degraded particles, the probability of a seabird encountering a concentration of plastic items from the degraded balloon system hundreds or more years into the future is very low. In the unlikely instance that a seabird was to ingest a small item of the degraded balloon system, interference with alimentary processes would not be expected to occur. This is because, if the material is weak enough to degrade from the SPB system it would likely be too weak to cause an obstruction of the gut once ingested (**Andrady 1990**).

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, the effects would be less intense because fewer flights would take place per year. Though there would be more launches annually under Alternative B, the potential effects would be essentially the same as Alternative A given the higher probability of a terrestrial flight termination for New Zealand-launched flights. Under the No Action Alternative, there would be no measurable risk to marine avifauna, as flight terminations would be limited to the Antarctic continent and all ASPAs (many of which were established to protect bird colonies) would be avoided.

3.2.2.2 Benthos

3.2.2.2.1 Affected Environment

In contrast to high latitude waters of the Northern Hemisphere, the Southern Ocean benthos is relatively rich and diverse (**Clarke 2008; Clarke & Johnston 2003**). The dominant (in terms of species diversity) Antarctic benthos are polychaetes (worms), gastropods (snails), bryozoans (moss animals), amphipods (small crustaceans), isopods (small crustaceans), porifera (sponges), and bivalves (shellfish) (**Brandt et al. 2007**). With regard to species distribution, **Brandt et al. (2009)** identified similar general patterns for bivalves, gastropods, and polychaetes, with the most species on the Antarctic continental shelf, decreasing species numbers on the upper slope (approximately 1,000 m depth), and then constant species numbers at bathyal and abyssal depths. The pattern in isopods showed an opposite trend; species numbers were lower on the shelf and upper slope, increasing at bathyal and abyssal depths. These findings generally correlate with those of **Linse et al. (2007)**, who found that in the Weddell Sea, overall abundance of deep-sea macrobenthos was lower than that of the Antarctic continental shelf by several orders of magnitude.

Farther north in the Action Area, **Griffiths et al. (2009)** reviewed spatial distribution patterns of benthic organisms in Antarctica, the sub-Antarctic islands, New Zealand, Tasmania, South Africa, and South America, finding highest species diversities in the eastern waters of New Zealand, Tasmania, and South Africa, and lowest numbers in South American and Antarctic waters. The authors noted similarities between South American and Antarctic benthic fauna; however, there was little similarity with the more species-rich waters of New Zealand and Tasmania.

3.2.2.2.2 Environmental Consequences

PROPOSED ACTION

Interaction with In-Water SPB System: The blanketing effect of the SPB system on the seafloor could damage benthic organisms within its immediate footprint, most likely by smothering or entanglement (**Bergmann & Klages 2012**). Likewise, it could inhibit the exchange of gas between pore water and seawater, leading to anoxia and hypoxia in the underlying sediments, which in turn could alter the benthic community structure (**Goldberg 1994, 1997; Mordecai et al. 2011**). Furthermore, the SPB debris on the seafloor may provide hard substrata for the attachment of opportunistic sessile biota, increasing local diversity (**Mordecai et al. 2011; Morét-Ferguson et al. 2010),** though at the cost of replacing existing species and leading to non-natural alterations of community composition (**Bergmann & Klages 2012**). The epibionts of benthic plastic debris are not as well-known as those of pelagic items. Accounts are limited (e.g., **Holmström 1975**) but indicate a hard ground biota dominated by bryozoans. In summary, although there would likely be localized adverse effects on benthic organisms, in consideration of the low number of SPB launches each year, the small footprint of the SPB system when considered within the larger context of the oceanic Action Area, and the avoidance of terminating a flight in continental shelf waters (where species diversity is highest), resultant effects are expected to be undetectable.

Furthermore, although marine invertebrates have been shown to ingest microscopic plastic particles (e.g., **Browne et al. 2008; Thompson et al. 2004; Ward & Shumway 2004**), given that the plastic components on the SPB system would undergo a very slow degradation process on the ocean floor, the short- to mid-term (i.e., decadal to centennial scale) likelihood of the material fragmenting into particles small enough for benthic organisms to ingest is very low. In the long term (i.e., centennial scale or greater), the possibility of the balloon fragmenting into small particles of varying degrees of buoyancy (therefore exposing an unknown proportion to benthic organisms) cannot be completely discounted. However, as suggested by **Andrady (2011)**, the deep ocean environment would not be favorable for the formation of microplastics (i.e., pieces less than 5 mm in size [**Arthur et al. 2009**]) due to cold temperatures, a lack of sunlight, relatively low oxygen concentrations (as compared to air), and the lack of abrasive physical processes (such as waves). Therefore, if fragmentation were to occur, plastic particles would likely be released gradually over a long period of time. As such, when considered within the context of the low number of SPB flights and the larger pelagic environment of the Action Area, the Proposed Action would result in a negligible adverse effect on benthic organisms.

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, the effects would be less intense because fewer flights would take place per year. Though there would be more launches annually under Alternative B, the potential effects would be essentially the same as Alternative A because of the higher probability of a terrestrial flight termination for New Zealand-launched flights. Under the No Action Alterative, there would be no measureable impact on benthos, as scientific balloons would be terminated over the Antarctic continent or the ice shelves.

3.2.2.3 Marine Fish

3.2.2.3.1 Affected Environment

In comparison to the other oceans of the world, relatively few fish species inhabit the Southern Ocean portion of the Action Area, largely because of the extreme ocean depths of the Action Area **(Knox 2006)** and the gradient in the Polar Frontal Zone and Antarctic Circumpolar Current (**Clarke et al. 2009**), which isolate Antarctic shallow water species from northern continents and vice versa. Of the fish species occurring in the Action Area, the majority are of the suborder Notothenioide, an endemic coastal demersal group that includes Antarctic cod, plunder fish, dragon fish, and ice fish (**Barrera-Oro 2002**). **Hureau (1994)** described the fish species of the Southern Ocean in terms of three major zones: 1) the high Antarctic, predominately notothenioids (cod icefish); 2) the seasonal pack-ice zone, mostly represented by myctophids (lantern fish); and 3) the northerly ice-free zone, comprised primarily of meso- and bathypelagic myctophids. The composition of benthic and bentho-pelagic fish species inhabiting the deep-water portion of the Action Area is not well known; however, studies have identified notothenioids, ophiidids (cusk eels), and liparidids (snailfish) (**Knox 2006**).

Nearshore, demersal fish forage heavily on benthos and zooplankton, whereas offshore species depend more upon zooplankton and nekton (**Barrera-Oro 2002**). Many of the mesopelagic fish forage in the upper water column during the summer months because of its high plankton diversity, but inhabit deeper waters during winter (**Knox 2006**). Of particular note is the Antarctic silverfish (*Pleuragramma antarcticum*), which serves an important ecological role in the Antarctic zone as prey for predators at higher trophic levels, including birds, seals, and whales (**Hureau 1994**).

In lower latitudes in the Action Area, species diversity increases (**Barrera-Oro 2002**), and given the large size of the Action Area, there is an abundance of aquatic habitats. For example, the aquatic biota in the varied near-shore habitat areas of New Zealand, Tasmania, and southern Australia (**Jenkins & Wheatley 1998**) are different from the salinity-dependent assemblages found in the Río de la Plata estuary (**Jaureguizar et al. 2003**), the inhabitants of the Magellanic marine province of Argentina and Chile (**Spalding et al. 2007**), or those species adapted to the rocky, exposed coasts of Cape Agulhas, South Africa (**Bustamante & Branch 1996**).

There are approximately 65 “Red List” species of marine fish in the Action Area (**IUCN 2012**). The scalloped hammerhead shark (*Sphyrna lewini*) was ESA listed on July 3, 2014, (79 FR 38213). For this species, there are four listed Distinct Population Segments (DPS) potentially occurring within the Action Area. Two DPSs, Eastern Atlantic and Eastern Pacific, are listed as endangered, while the Central and Southwest Atlantic and Indo-West Pacific DPSs are listed as threatened.

3.2.2.3.2 Environmental Consequences

PROPOSED ACTION

Interaction with In-Water SPB System: Plastic ingestion has been documented in various fishes, including rays (**Anastopoulu et al. 2013**), sharks (**Cliff et al. 2002**), tunas (**Manooch & Mason 1983**), lancetfish (**Jantz et al. 2013**), opahs (**Jackson et al. 2000**), marine catfish (**Possatto et al. 2011**), estuarine drums (**Dantas et al. 2012**), and various small mesopelagic fishes (**Boerger et al. 2010**; **Davison & Asch 2011**). Several authors have suggested that the types of debris ingested may be related to how closely an item resembles preferred prey (e.g., **Jackson et al. 2000; Boerger et al. 2010**) and/or a particular species’ foraging habits (e.g., epipelagic foraging vs. benthic foraging) (**Anastopoulu et al. 2013**). Additionally, **Carson (2013)** suggested that debris ingestion could be incidental to a species attempting to consume fouling organisms attached to the item. Because of oceanic flights being terminated outside of coastal waters and the short duration (i.e., several hours) that the descending SPB system would be within the epi- and meso-pelagic strata of the water column, it is expected (in relative terms) that the species at greatest risk for ingesting SPB materials would be oceanic benthic foragers. However, because the SPB system would only slowly degrade once on the seafloor, it is expected that in the short- to mid-term (i.e., decadal to centennial scale) the plastic material would not fragment into smaller, ingestible pieces (e.g., **Lusher et al. 2013**).

In the long term (i.e., centennial scale or greater), the possibility of the balloon fragmenting into smaller pieces, which could be more readily ingested by benthic or pelagic fish, cannot be completely discounted. However, because of the very slow degradation rate at the seafloor, and the few abrasive physical processes there, the fragmented particles would likely be released gradually and be distributed over a wide temporal period. Additionally, when considered over the entire pelagic portion of the Action Area and the distributed/dilute nature of the degraded particles, the probability of a fish encountering a concentration of small plastic items from the degraded balloon system hundreds or more years into the future is very low. In the unlikely instance that a fish was to ingest a small item of the degraded balloon system, interference with alimentary processes would not be expected to occur. This is because, if the material is weak enough to degrade from the SPB system, it would likely be too weak to cause an obstruction of the gut once ingested (**Andrady 1990**). Furthermore, because some fish have been shown to excrete ingested plastics (**Hoss & Settle 1990**), it is probable that, if only small quantities of the degraded balloon material were ingested, it would not result in lethal effects.

Similarly, entanglement of fish in marine debris has been reported (e.g., **Cawthorn 1985**; **Cliff et al. 2002; Wegner & Cartamil 2012**), with the majority of encounters associated with derelict fishing gear (review in **Laist 1997**). Once on the ocean floor, the SPB system would remain an amorphous mass for the foreseeable future. While the possibility for fish to enter the balloon or parachute envelope and become entrapped cannot be completely discounted, compared to derelict fishing gear, which is designed to trap fish, the risk presented to fish species by the SPB system is substantially less. Furthermore, because of the low number of SPB flights per year, detectable adverse effects on demersal fish would not occur.

ALTERNATIVES

While Alternative A would result in the same types of effects on marine fish as the Proposed Action, the effects would be less intense because fewer flights would take place per year. Though there would be more launches annually under Alternative B, and a greater diversity of fish species at lower latitudes, the potential effects would be essentially the same as Alternative A because of the higher probability of a terrestrial flight termination for New Zealand-launched flights. Under the No Action Alterative, there would be no measureable impact on marine fish, as scientific balloons would be terminated over the Antarctic continent or the ice shelves.

3.2.2.4 Sea Turtles

3.2.2.4.1 Affected Environment

The leatherback sea turtle (*Dermochelys coriacea*) is the one species of large marine turtle that could be present within the Action Area. Leatherbacks are a highly oceanic species and have been shown to undertake long journeys of over 2,800 km, in some cases reaching cold seas far from their tropical nesting grounds (**Hughes et al. 1998**). Leatherbacks can forage in the cold temperate regions of the oceans, occurring at latitudes as high as 71°N and 47°S; however, nesting is confined to tropical and subtropical latitudes (**Eckert et al. 2012**). Low density nesting has been recorded along the northern (Northern Territory) and eastern (New South Wales and Queensland) coasts of Australia; however, these areas are north of the Action Area (**Limpus 2009**).

Leatherback sea turtles are the deepest reptilian divers; maximum dives ranging from 630 m (**Hays et al. 2004**) up to 1,280 m (**Doyle et al. 2008**) have been observed in the Atlantic Ocean. However, dives are typically much shallower (generally <300 m) (**Houghton et al. 2008**). Leatherbacks primarily forage on cnidarians (jellyfish and siphonophores) and, to a lesser extent, tunicates (pyrosomas and salps) at or just below the sea surface (**NMFS & USFWS 1998**).

Though there have been documented observations of leatherback sea turtles in the Action Area (e.g., **Lambardi et al. 2008; Block et al. 2011; Benson et al. 2011; Bailey et al. 2012**), and within near-freezing water temperatures that would be encountered in the Action Area (**James et al. 2006**), recent studies suggest that water temperatures of approximately 15°C present a thermal barrier beyond which leatherbacks will not cross except for brief periods (**McMahon & Hayes 2006; Shillinger et al. 2011**). Therefore, if individuals were in the Action Area, they would most likely be present in its northernmost extent during the austral summer, migrating farther north as waters cooled.

The leatherback sea turtle is both listed as endangered under the ESA and on the “Red List” (**IUCN 2012**).

3.2.2.4.2 Environmental Consequences

PROPOSED ACTION

Interaction with In-Water SPB System: Given their primarily oceanic habitat and deep foraging dives, it is possible that leatherback sea turtles may encounter or approach the descending balloon envelope and subsequently become entangled (**Carr 1987**). Sea turtles have been observed to feed under floating debris and could become entangled. **Balazs (1985**) reported sea turtle entanglements involving monofilament line, ropes, netting, cloth debris, tar, and plastic bands around the neck.

However, multiple factors render this potential stressor highly unlikely. First, SPB launches from Antarctica (the site having the greater probability of an ocean impact following termination

[**GAC 2003; Mullenax & Schwantes 2014**]) are expected to be infrequent, not exceeding one per year. Though New Zealand-launched flights would be more frequent (perhaps as many as twice per year) their probability of landing in the open ocean is lower during all flight durations (**Mullenax & Schwantes 2014**). Second, based on the analysis in **GAC 2003**, the mean latitude of a December-launched SPB originating from Antarctica would remain at or below 60°S latitude, well south of waters habitable for leatherbacks, for the entire duration of its flight and subsequent termination.

New Zealand-launched balloons would remain within the 29 to 65°S latitude bands, within which leatherbacks would be expected to occur in greater numbers than areas farther south; however, considering the lower probability of a water termination scenario (**Mullenax & Schwantes 2014**) and the avoidance of terminating a flight within coastal areas of greatest sea turtle concentration (**Saba 2013**), the likelihood of interaction with an individual is equally as low. Third, should a water landing occur following a SPB launch from either site, given that the payload and flight train would remain attached to the balloon, the item's expected sink rate would effectively remove it from the water column stratum most commonly frequented by migrating and/or foraging leatherbacks in less than one hour (**Shreves & Wilcox 2014**). Though it is possible that the ultimate location of the SPB on the seafloor could be within the range of depths observed for diving leatherbacks (maximum recorded dive depths to 1,280 m **[Doyle et al. 2008]**), it has recently been determined from satellite telemetry that very deep dives (>300 m) are rare (**Houghton et al. 2008**), making up only 0.4 percent of all dives. Finally, the low density of leatherbacks in the Action Area makes the likelihood of an individual becoming entangled in the descending and or seafloor-resting SPB system highly unlikely.

Leatherback sea turtles have been reported to ingest a wide variety of plastic materials, including monofilament line, various small colored pieces, polystyrene balls, clear thin plastic sheets, and numerous whole plastic bags (**Barreiros & Barcelos 2001; Bugoni et al. 2001; Sadove & Morreale 1990**). In a comprehensive review of 37 sea turtle/debris ingestion studies undertaken since **Balazs (1985)**, **Schuyler et al. (2014)** found that leatherbacks were highly susceptible to plastic ingestion, likely due to their feeding preferences. Leatherback sea turtles feed almost exclusively on jellyfish (**Bjorndal 1997**), and it has been hypothesized that they feed on plastic that resembles their prey (**Sadove & Morreale 1990**; **Schuyler et al. 2012**). Of the multiple stages in a sea turtle's life, the oceanic phase appears to be at greatest risk **(Schuyler et al. 2014)**. As such, it may be concluded that individuals within the primarily oceanic Action Area could be at risk for ingesting the LLDPE (plastic) material comprising the SPB, resulting in either lethal or sublethal effects.

However, multiple factors render this potential outcome also a highly unlikely event. In addition to those discussed regarding entanglement, the size of the SPB system makes it questionable as to whether a leatherback would perceive the item as prey and attempt to ingest it. For example, in a study of leatherbacks foraging in the northern Atlantic Ocean, **Heaslip et al. (2012)** found that the diameters of gelatinous prey ingested by the observed individuals ranged between 3 and

22 cm (the larger being the diameter of a soccer ball). Though the authors state that the documented prey size is likely understated, their findings suggest that the substantially larger SPB system would not be within the size range of prey typically encountered (and ingested) by leatherbacks.

In the long term (i.e., centennial scale or greater), the possibility of the balloon fragmenting into smaller buoyant pieces, which could be more readily ingested by leatherbacks, cannot be completely discounted. However, because of the very slow degradation rate at the seafloor, and the few abrasive physical processes there, any fragmented particles would likely be released gradually and be distributed over a wide temporal period. Additionally, when considered over the entire pelagic portion of the Action Area and the distributed/dilute nature of the degraded particles, the probability of a leatherback encountering a concentration of plastic items from the degraded balloon system hundreds or more years into the future is very low. In the unlikely instance that a leatherback was to ingest a small item of the degraded balloon system, interference with alimentary processes would not be expected to occur. This is because, if the material is weak enough to degrade from the SPB system, it would likely be too weak to cause an obstruction of the gut once ingested (**Andrady 1990**).

Finally, the low density of leatherbacks in the Action Area makes the likelihood of an individual interacting with the SPB system at any point during its presence in the water column or on the seafloor highly unlikely.

ALTERNATIVES

Alternative A would not present a risk to sea turtles given the geographic separation between the maximum observed southern latitude of the species (47°S [**Eggleston 1971**]) and the expected maximum northerly extent of Antarctica-launched balloons (**Mullenax & Schwantes 2014; GAC 2003**). Therefore, it presents the least potential for impact of the Alternatives. Though Alternative B could present a relatively higher risk of a sea turtle encountering a descending SPB, it is still considered negligible given the lower probability of water termination (**Mullenax & Schwantes 2014**) and the rapid descent of the balloon below the typical and maximum observed foraging depths of the species. Under the No Action Alterative, there would be no impact on marine turtles, as scientific balloons would be terminated over the Antarctic continent or ice shelves.

3.2.2.5 Marine Mammals

3.2.2.5.1 Affected Environment

A diverse assemblage of marine mammal species, including pinnipeds, cetaceans, sirenians, and marine otters inhabit the Action Area.

Pinnipeds

Both otariids (sea lions and fur seals) and phocids (earless, or "true" seals) are present in the Action Area. Otariids breed and give birth on ice-free lands along the coast, with species of sea lions in coastal New Zealand, Australia, South America, and the sub-Antarctic islands. Southern fur seal species (*Arctocephalus* spp.) are present along the coasts of all landmasses (**Berta 2009**). Though some phocids breed on land (e.g., southern elephant seal [*Mirounga leonina*]), most mate in the water or on ice, giving birth in spring or summer (**Berta 2009**). Phocids are present on the coasts of all landmasses in the Action Area, with four species (crabeater seal [*Lobodon carcinophagus*], Ross seal [*Ommatophoca rossi*], Weddell seal [*Leptonychotes weddellii*], and leopard seal [*Hydrurga leptonyx*]) confined to the Antarctic ice (**Costa & Crocker 1996**). The maternal care of pinnipeds is unusual among mammals because females give birth on land or ice but feed entirely at sea, and some species undertake long foraging trips (e.g., approximately 600 km offshore for South American Juan Fernandez fur seals [*Arctocephalus philippii*] [**Francis et al. 1998**]) before returning to their pups to feed them.

In general, otariids forage in the upper 100 m of the water column, with female New Zealand sea lions (*Phocarctos hookeri*) the deepest divers, averaging approximately 125 m per dive with dives as deep as 500 m (**Stewart 2009**). Primary forage items include fish, cephalopods, and crustaceans. Phocids forage on similar prey items as the otariids but at deeper depths, with the majority of species foraging within the upper 200 m of the water column (**Stewart 2009).** The maximum recorded depths are between 400 and 800 m, depending on species (e.g., crabeater seal [**Burns et al. 2004**]), leopard seal [**Nordøy & Blix 2009**], Ross seal, [**Blix & Nordøy 2007**]). Two phocid species, Weddell seal and southern elephant seal, forage at the greatest depths, averaging between 200 and 400 m (700 m maximum) for the former (**Schreer & Testa 1996**), and 300 to 600 m (2,400 m maximum) for the latter (**Costa et al. 2010**).

There are approximately 14 "Red List" pinniped species in the Action Area (**IUCN 2012**).

Cetaceans

Both suborders of cetaceans, mysticetes (baleen or filter feeding whales) and odontocetes (toothed whales), are present in the Action Area. Odontocetes comprise the greatest number of marine mammal species in the Action Area and include ziphiids (beaked whales), pontoporids (river dolphins), delphinids (ocean dolphins), and porpoises. Some species are confined to coastal areas over the continental shelf, while others remain primarily in deep ocean waters throughout the year.

In contrast to the pinnipeds, many of the large cetaceans (both mysticetes and odontocetes) in the Action Area are migratory (**Laws 1977**). In the austral spring and early summer (November to mid-December), large whales move from low latitude breeding and wintering grounds south into the northern and mid reaches of the Action Area. By austral mid-summer (December to January), blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and southern right (*Eubalaena australis*) whales congregate at foraging grounds within a band of latitudes corresponding in varied ways with the ACC, the continental shelf, ice extent, and preferred prey (**Laws 1977**). Along the southern boundary of the ACC, a biologically productive region of upwelling produces high densities of prey species (particularly Antarctic krill) and consequently the highest densities of both foraging baleen and odontocete whales (**Tynan 1998**).

As the season progresses into late austral summer (February and March), the pack ice continues to retreat south. Blue, minke (*Balaenoptera bonaerensis*), southern right, and sperm (*Physeter macrocephalus*) whales tend to move farther south, closer to the pack ice and the edge of the continent. Killer whales (*Orcinus orca*) tend to be the most southern-reaching, commonly found among dense pack ice (**Kasamatsu & Joyce 1995**). Sei and fin whales tend to stay within or north of the southern boundary of the ACC. As austral fall approaches (April to May), all whale species begin to move north toward the coasts of Australia, New Zealand, the Straits of Magellan and southeastern Argentina, and Africa. By austral winter (May to July), most of these large cetaceans are in breeding and calving regions predominantly to the north of the Action Area. However, the southern right whale breeds in areas near New Zealand, southern Australia, and Argentina in the Action Area. A small group of humpback whales may winter along the western coast of Chile and southern Argentina in the Straits of Magellan and Tierra del Fuego. Furthermore, some individuals of several species, blue and sperm whale, in particular, may remain in the middle and more northerly regions (40°S to 60°S) of the Action Area throughout the austral winter. A large portion of the minke whale populations and the smaller odontocetes (e.g., delphinids) are resident in the Action Area year round (**Laws 1977**).

The mysticetes in the Action Area forage within the upper 200 to 300 m of the water column (**Ponganis 2011** and references therein). The odontocetes are deeper divers, foraging primarily on mesopelagic and bathypelagic cephalopods and fish. With only a few exceptions (e.g., pilot whales), the delphinids forage at the shallowest depths, generally within the upper 250 m of the water column, with some species occasionally foraging deeper than 500 m (e.g., bottlenose dolphin [*Tursiops truncates*] [**Klatsky et al. 2007**], Fraser's dolphin [*Lagenodelphis hosei*] [**Dolar 2009**]). The deepest foraging species (all of which primarily inhabit oceanic waters) are the beaked whales, sperm whales, and pilot whales, which have been found to exhibit dives averaging 1,400 m (**Schorr et al. 2014**), between 400 and 600 m (**Miller et al. 2013**), and between 500 and 1,000 m (**Soto et al. 2008**), respectively. Maximum recorded diving depth for each whale type is approximately 3,000 m (**Schorr et al. 2014**), 1,900 m (**Teloni et al. 2008**), and 1,500 m (**Wells et al. 2013**), respectively.

There are approximately 20 cetacean species on the "Red List" in the Action Area (**IUCN 2012**). Six of these species are listed as endangered under the ESA, including the southern right, blue, fin, sei, humpback, and sperm whales.

Sirenians

One "Red List" species of sirenian, the dugong (*Dugong dugon*) (**IUCN 2012**), is known to occur (at the southern extent of its range) in the Action Area, along the east coast of South Africa and the east and west coasts of Australia (**Reeves et al. 2002**). The dugong is a shallow water species, typically occurring in waters less than 25 m deep, foraging on benthic vegetation (**Reeves et al. 2002**).

Marine Otters

In the Action Area, one "Red List" species of marine otter (*Lontra felina*) (**IUCN 2012**) occurs in insular (up to several km offshore) and mainland areas of rocky coastline along western Chile and potentially southern Argentina (**Valqui 2012**). It is known to use coastal areas from approximately 30 m inland to 150 m offshore (**Sielfield & Castilla 1999**). Usually a solitary animal, this species forages primarily in water depths less than 15 m (**Villegas et al. 2007**), on crustaceans, mollusks, and fish, occasionally eating birds and small mammals (**Larivière 1998**).

3.2.2.5.2 Environmental Consequences

There would be no direct strike, entanglement, or ingestion risks to sirenians or marine otters, as their coastal habitats would be avoided when terminating a SPB flight. As such, the potential effects on these species will not be discussed further. This section, therefore, focuses on pinniped and cetacean species within the Action Area.

PROPOSED ACTION

Direct Strike from Descending SPB: NASA adapted an equation employed for evaluating the risk of balloon flights to persons on the ground (**Beyma 2011**) to calculate a per-launch PDS at flight days 30, 60, and 100 for each cetacean species in the Antarctic portion (i.e., south of 60°S) of the Action Area. Using cetacean population growth trends presented in the referenced data sources, populations were escalated from the date of the estimate into the future 10 years from the first proposed SPB launch considered in this IEE/EA (i.e., year 2024) to account for population increases over the course of the action. Based on the analyses in **NASA 2014**, the maximum PDS value for all cetaceans considered was 1.01×10^{-6} for the humpback whale; the lowest maximum PDS for cetaceans was 5.49×10^{-9} for fin whales. Considering the extremely low estimated PDS for cetacean species from a SPB system, no adverse effects to these species are expected from the Proposed Action.

Sea ice extent during the months of December to May is generally confined to the Antarctic Circle, south of 60°S (**Fetterer et al. 2002**). These areas are used by crabeater, leopard, Ross, and Weddell seals for haul-out and breeding (**Costa & Crocker 1996**). The PDS for these species was estimated in **Bonsteel 2014b**, as it was for cetaceans, with the assumption that the total estimated maximum populations of these pinniped species would be concentrated above water on the minimum sea ice extent (2013 values). Overflight probabilities from the **GAC 2003** study for Antarctic SPB flights were used to determine the probability of a SPB system being located within 10 latitudinal degree bands at 30, 60, 90, and 120 days of flight following a December or January launch. As such, the resulting values are conservative and represent a worst-case scenario of direct mortality to these species from a SPB system landing on sea ice.

For example, the upper population density of crabeater seals, the most abundant Antarctic pinnipeds (**Costa & Crocker 1996**; **Bengston 2009**; **Southwell et al. 2012**), estimated around 2.24 individuals per square kilometer on sea ice, would yield the maximum PDS value for all pinnipeds considered: 5.45 x 10^{-5}, or 0.00545 percent. Meanwhile, the lowest maximum PDS for Antarctic sea ice-using pinnipeds is 1.2 x 10^{-6} for Ross seals population estimates (**Thomas & Rogers 2009**). The maximum PDS values for population estimates of leopard seals (**Rogers 2009**) and Weddell seals (**Thomas & Terhune 2009**) are 2.4 x 10^{-6} and 5.45 x 10^{-6}, respectively. The actual probability of impacting Ross and Weddell seals may be lower in view of new insights into these species' usage of sea ice (**Southwell et al. 2012**). Considering the extremely low estimated PDS for pinniped species from a SPB system landing on sea ice, no adverse effects to these species are expected from the Proposed Action.

Quantitative estimates of direct strike risk to cetaceans from New Zealand-launched SPBs were not calculated for several reasons. First, during the timeframe within which New Zealand-launched balloons would fly in the Action Area (austral fall and early austral winter), the majority of cetaceans would have migrated to calving and overwintering grounds, many of which are north of the Action Area, and those calving grounds in the Action Area would be avoided when planning a flight termination. Second, the probability of a water landing at day 100 is approximately 38 percent less than that of an Antarctica-launched balloon, effectively reducing the risk of direct strike by at least that much. Finally, the water area in the expected New Zealand SPB flight latitudes (29°S to 65°S) is approximately four times larger than that below 60°S (**Bonsteel 2014a**), which would result in non-calving area species densities (and resultant probabilities of direct strike) at least four times lower than the extremely remote probabilities presented above. Therefore, it was qualitatively concluded that the risk of directly striking listed cetaceans with a New Zealand-launched SPB would be notably less than that of an Antarctica-launched SPB. Likewise, given that lower-latitude pinnipeds would be concentrated in coastal areas that would be avoided when planning a flight termination (in contrast to the large areas of sea ice habitat in the Ross and Weddell Seas, which extend beyond the avoidance areas), the risk of strike can also be qualitatively discounted.

Recovery Activities: Studies on the effects of aircraft overflight on pinnipeds have shown varied results, with reactions ranging from visible disturbance (**Born et al. 1999**) to little obvious effect (**Southwell 2005**). A primary concern with disturbing pinnipeds is the potential for their rushing from land, potentially leading to the trampling of pups and/or mother–pup separation, potentially inducing mortality (**Efroymson et al. 2001**). As such, recovery of terrestrial or ice-landing SPBs in the coastal zone could induce such stressors to hauled-out pinnipeds. However, to reduce the potential for their occurrence, NASA would follow all Antarctica or host nation-specific aircraft overflight, landing, and approach requirements when conducting SPB recoveries. Additionally, NASA would avoid terminating SPB flights within ASPAs, many of which were established because of their importance to marine mammals. Should entry into an ASPA be necessary, all recovery operations would be conducted in accordance with the area's specific management plan. In this case, minimal disturbance-related effects on pinnipeds would be expected.

Given that recovery operations would not be conducted in the event of an oceanic landing, the likelihood of a recovery aircraft encountering a cetacean is highly unlikely, though possible within the Antarctic pack ice, where cetaceans (e.g., minke whale and killer whale) could be utilizing a polynya as a breathing hole (e.g., **Ainley et al. 2007**). To be exposed to either the sound or the visual stimulus associated with an overflight, the animal would have to be at or near the water's surface. In general, smaller delphinid cetaceans react to aircraft overflights either neutrally or with a startle response, whereas the more "cryptic" species (e.g., ziphiids) have been shown to be more sensitive, often diving when overflown (**Wursig et al. 1998**). It has also been reported that for both large mysticete and odontocete cetaceans, reactions to aircraft overflight are mixed; however, the extent of effects would be to cause a dive, turn, or other minor change in behavior. Research does not indicate that the occasional overflight would cause long-term displacement of whales (**Richardson et al. 1995**). As such, the effects on cetaceans from recovery operations are expected to be negligible.

Entanglement in In-Water SPB System: According to records reviewed by **Laist (1997)**, entanglement with marine debris is a greater risk to marine mammals than ingestion. For marine mammals, entanglement in marine debris appears to be most common among seals and sea lions (pinnipeds), particularly the eared seals (otariids), less common in baleen whales (mysticetes), and rare among toothed whales (odontocetes).

For seals and sea lions, curiosity and play appear to be important factors causing animals to seek out and interact with entangling debris (**Laist 1987**). Most interactions involve pups and juveniles (**Laist 1997**). However, multiple factors render the occurrence of this potential stressor highly unlikely. First, SPB launches from either launch site would be infrequent. Second, the avoidance of terminating within coastal areas of greatest pinniped concentration would make the likelihood of interaction with an individual (particularly a pup or juvenile) low. Third, should the SPB land on Antarctic ice, it would likely be recovered shortly thereafter. Finally, if a SPB launched from either site were to land in the water, since the payload and flight train would remain attached to the balloon, the item's expected sink rate would take it below the maximum foraging depths observed in nearly all Action Area pinnipeds species in less than one hour (**Shreves & Wilcox 2014**).

However, southern elephant seals feed far offshore, often thousands of kilometers away from their pupping islands (**McConnell et al. 1992**). They are also the deepest foraging pinniped species in the Action Area (**Costa & Crocker 1996**), with a maximum recorded dive depth of approximately 2,400 m (**Costa et al. 2010**). Accordingly, in relative terms, it is the pinniped species that would be at greatest risk for encountering the SPB system. However the time to reach depths beyond their deepest recorded foraging dives is still brief, on the order of 2 to 3 hours. Upon reaching the seafloor at depths more than approximately 2,500 m, none of the pinniped species in the Action Area are likely to interact with the SPB system.

Traveling or feeding baleen whales could become entangled in the SPB system once it enters the water column. Primarily "lunge," or "ram" feeders, these large mysticetes move through the water column opening their mouth rapidly to strain the water for concentrated prey. Humpback whales also move into the Action Area during the same period but feed on both euphausiids and schooling fish primarily in the upper 100 m. Humpbacks are described as “swallowers” rather than “skimmers,” moving rapidly toward the sea surface to gulp tightly concentrated prey. Should feeding whales encounter the floating or descending SPB, the debris could enter the buccal cavity, wrap around and damage baleen, lodge within the esophagus, or become wrapped around the tongue or rostrum. Feeding or traveling whales might encounter the SPB mass and get their pectoral or caudal fins entangled. While fishing gear has been the primary type of debris observed on entangled cetaceans (e.g., humpbacks [**Garcia-Godos et al. 2013**]), entanglement in other types of plastic-based materials has also been reported (e.g., fin whales [**Sadove & Morreale 1990**]) (**Baulch & Perry 2014**).

However, multiple factors render the potential for a mysticetes interacting with the SPB system highly unlikely. First, SPB launches from Antarctica (the site having a higher probability of an ocean impact at termination) are expected to be infrequent, not exceeding one per year. Second, the mysticetes in the Action Area generally feed in the upper 200 m of the water column. Those not engaged in foraging behaviors would remain at even shallower depths. Because the SPB system would be expected to sink rapidly following water impact, the material would not be available for entanglement except for a brief period (i.e., less than an hour) during its descent to the ocean floor (**Shreves & Wilcox 2014**).

Both lethal and non-lethal entanglements in marine debris have been reported for both small and large odontocetes (**Baulch & Perry 2014**). However, the generally shallower foraging depths of most delphinids in the Action Area and the short time required for the SPB system to sink below their maximum recorded foraging depths (**Shreves & Wilcox 2014**) render the potential for their encountering the descending SPB system highly unlikely. In consideration of these facts, the remaining discussion in this section focuses on the deepest diving species: the sperm whales, beaked whales, and pilot whales.

Sperm whales feed at greater depths than mysticetes and most other odontocete species, and sometimes at or near the seafloor (**Mathias et al. 2012; Miller et al. 2013; Teloni et al. 2008**), potentially putting them at higher risk for entanglement with the SPB system once it is on the seafloor. However, dive depth data from studies of high latitude sperm whales indicates that while individuals occasionally forage at the seafloor, typical feeding is at shallower depths than their temperate or tropical counterparts (e.g., **Teloni et al. 2008**; **Wahlberg 2002**; **Miller et al. 2013**; **Mathias et al. 2012**). As such, while it is possible that a foraging sperm whale could encounter the SPB system once on the seafloor, it would be unlikely given their tendency to more frequently forage higher in the water column.

To further support this conclusion, **Bonsteel (2014a)** analyzed Antarctic (south of 60°S) bathymetric data (**Arndt et al. 2013**) using a geographic information system (GIS) (**ESRI 2010**) to determine the distribution of water depths in the Action Area. The analysis indicated that nearly 90 percent of the waters between 60°S and 70°S (the area expected to contain the most sperm whale foraging near the ice edge) are deeper than 2,000 m, which is greater than the deepest recorded high latitude sperm whale foraging dive (1,900 m; [**Teloni et al. 2008**]). Likewise, **Bonsteel (2014a)** performed a similar GIS-based analysis of bathymetric data from **IOC et al. (2003)**, showing that approximately 90 percent of waters overflown by New Zealand-launched flights (between 60°S and 29°S) are deeper than 2,000 m, with the majority of depths between 3,000 and 6,000 m. Therefore, while the possibility of a high latitude sperm whale undertaking a deeper (greater than 2,000 m) foraging dive to the ocean floor cannot be discounted, when considered in conjunction with the fact that most recorded foraging has occurred at shallower depths, the low density of individuals in the Action Area, and the low number of launches per year, the probability of a foraging sperm whale becoming entangled in the SPB system on the seafloor would be very low. Likewise, given the rapid sink rate of the SPB system (**Shreves & Wilcox 2014**), the debris would be below the stratum of the water column most commonly used for sperm whale foraging in approximately one to three hours, rendering the potential for entanglement negligible.

Ingestion of In-Water SPB System: Based on data from **Laist (1997)**, pinnipeds have the fewest recorded ingestions, and cetaceans are the group with the highest percentage of species ingestion records. Similar to entanglement, both lethal and non-lethal incidents of ingesting marine debris have been reported for small and large odontocetes (**Baulch & Perry 2014**). Again, sperm whales may be more susceptible to ingestion of debris as they feed within a wide range of the water column (**de Stephanis et al. 2013**). Fatalities associated with ingestion of plastic bags and other materials have been reported in sperm whales (**e.g., Arbelo et al. 2013; Jacobsen et al. 2010; Walker & Coe 1990**). However, given the large portion (90 percent) of deep (more than 2,000 m) waters in the portion of the Action Area (**Bonsteel 2014a**) expected to contain the highest number of foraging individuals, and relatively shallower "typical" foraging depths observed in high latitude individuals, the likelihood of a foraging sperm whale encountering the SPB system is remote. Additionally, **de Stephanis et al. (2013)** summarized 17 sperm whale debris ingestion incidents reported worldwide, finding that the mass of ingested debris ranged from approximately 20 g to 2.5 kilograms; surface areas ranged from under 1 m^2 to approximately 30 m^2. Based on squid morphometric data from **Bolstad (2007)** and **Semmens & Jackson (2005)**, this range of debris sizes generally corresponds with the size and mass of the forage resources most commonly identified (*Moroteuthis* spp.) in the stomachs of Southern Hemisphere sperm whales (**Kawakami 1980**). As such, while the data from these studies cannot completely discount the possibility of a foraging individual attempting to ingest the SPB system, they do further support the conclusion that ingestion would be unlikely, as both the most commonly ingested prey and debris items reported ingested, are substantially smaller.

Though much less studied than sperm whales, beaked whales have been reported as also ingesting plastic items (**Arbelo et al. 2013; Baulch & Perry 2014**). However, the SPB system would be below the deepest average foraging depth reported in a study thus far (**Schorr et al. 2014**) in less than two hours, and below the maximum recorded dive depth (also in **Schorr et al. 2014**) in less than four hours **(Shreves & Wilcox 2014).** Additionally, studies of beaked whale prey size (e.g., **Sekiguchi et al. 1993, 1996**) indicate similar results as with sperm whales; the typical prey ingested by species in the Action Area is significantly smaller than that of the intact SPB system. Therefore, when these factors are considered in conjunction with the extreme depths in the Action Area and the general lack of concentrated populations (**Mead 2009**), the probability of an individual ingesting any of the SPB components is extremely remote.

Both short-finned (*Globicephala macrorhynchus*) and long-finned (*Globicephala melas*) pilot whales have been reported as ingesting marine debris, though less frequently than sperm or beaked whales (**Baulch & Perry 2014**). Despite recorded dive depths at higher latitudes between 1,000 and 1,500 m (**Wells et al. 2013**), it has been found that such deep dives are infrequent, with the vast majority (approximately 90 percent) occurring within the upper 100 m of the water column (**Heide-Jørgensen et al. 2002**; **Wells et al. 2013**), even when in waters exceeding 2,000 m deep (**Heide-Jørgensen et al. 2002**). As such, given that the SPB system would be below the depth most frequently utilized by the species in less than one hour, and, for over 90 percent of the Action Area (**Bonsteel 2014a**), below their maximum recorded dive depth in less than 2 hours, the probability of an individual encountering the system during its descent or on the seafloor is low. This, when considered in conjunction with the infrequency of the SPB flights and low density of the species in the Action Area, renders the potential for a pilot whale interacting with the SPB system negligible. Furthermore, in the unlikely instance that a pilot whale were to encounter the SPB system, because its preferred prey items are substantially smaller than the SPB system (**Santos et al. 2014**), and that little, if any, degradation of the plastic material into smaller pieces would be expected in the short- to mid- term (i.e., decadal to centennial scale), it is unlikely that the individual would attempt to ingest the item.

In the long term (i.e., centennial scale or greater), the possibility of the SPB system fragmenting into smaller pieces, which could be more readily ingested by pinnipeds or cetaceans, cannot be completely discounted. However, because of the very slow degradation rate at the seafloor, and the few abrasive physical processes there, the fragmented particles would likely be released gradually and be distributed over a wide temporal period. Additionally, when considered over the entire pelagic portion of the Action Area and the distributed/dilute nature of the degraded particles, the probability of a listed species encountering a concentration of plastic items from the degraded balloon system hundreds or more years into the future is very low. In the unlikely instance that a listed species were to ingest a small item of the degraded balloon system or a prey item (e.g., zooplankton; a primary forage item for mysticetes) that had previously ingested a plastic particle (e.g., **Fossi et al. 2012**), interference with alimentary processes would not be expected to occur. This is because, if the material is weak enough to degrade from the SPB system it would likely be too weak to cause an obstruction of the gut once ingested (**Andrady 1990**).

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, the effects would be less intense because fewer flights would take place per year. Though there would be more launches annually under Alternative B, the potential effects would be essentially the same as Alternative A because of the higher probability of a terrestrial flight termination for New Zealand-launched flights. Under the No Action Alterative, there would be no measureable impact on marine mammals, as scientific balloons would be terminated over the Antarctic continent or the ice shelves. All known seal pupping areas would be avoided consistent with past practice.

3.3 SOCIAL ENVIRONMENT

For the purposes of this Section, social resources include wilderness and aesthetic values, scientific return, transportation, and cultural resources. Although Section 3-4 of EO 12114 excludes the social environment from the range of environmental resources to be considered under it, a discussion of such resources for non-Antarctic areas (i.e., latitudes less than 60°S) is still provided in this Section such that a comparison of alternatives can be made.

3.3.1 Wilderness and Aesthetic Values

Wilderness values are conventionally defined as relating to large natural areas undisturbed by human activity, whereas aesthetic values relate to perceptions of scenic beauty (**Summerson & Bishop 2012**). Given the strong correlation between the two (**Summerson & Bishop 2012)**, they are considered as one resource in this Section.

3.3.1.1 Affected Environment

At the global scale, **Mittermeier et al. (2003)** conducted an analysis of terrestrial areas possessing wilderness characteristics defined by a maximum population density, minimum land area, and intactness, among other traits. Based on this macro-scale assessment, large areas of wilderness were identified in the Action Area, including the Southern Cone of South America (Magellanic forests and Patagonia), Australia (the deserts in central-southern portions of the country), the island of Tasmania (Tasmanian World Heritage Wilderness Area), and Antarctica (**Mittermeier et al. 2003**). Furthermore, at a smaller geographic scale, numerous lands in the Action Area have been given special designation and warrant additional discussion below.

Antarctica

Because of its historic isolation from human settlement, Antarctica is considered to have substantial wilderness value (**Tin et al. 2008**). In fact, Antarctica's wilderness and aesthetic values are specifically afforded protection under Article 3 of the *Antarctic Protocol*. However, due to growth in both scientific research programs and tourism, the intensity and diversity of human activities in Antarctica have continued to increase. Approximately 53 active research stations now exist in Antarctica, with a peak capacity of approximately 4,000 people in summer and 1,000 in winter. The Antarctic tourism industry accounted for an additional 34,000 persons entering Antarctica during austral summer 2012–2013 (**IAATO 2013**). The most obvious signs of human activity (and consequently decreasing wilderness values) are around research stations and the Antarctic Peninsula, the most popular tourist destination (**Tin et al. 2008**). In contrast, human presence on the Antarctic polar plateau is low (**Tin et al. 2008**). Wilderness values are one of several factors that contributed to the designation of the seven Antarctic Specially Managed Areas (ASMAs) and 71 ASPAs. Furthermore, one ASMA and three ASPAs specify wilderness values in their management plans (**Tin & Hemmings 2011**).

Non-Antarctic Landmasses

Farther north in the Action Area, several countries, including Australia (**Watson et al. 2009**), New Zealand (**Higham et al. 2000**), and South Africa (**Paterson 2010**), have enacted wilderness legislation affording special protections to certain lands so they maintain wilderness values. Many of these lands are within the boundaries of established parks and preserves and are depicted by continent in Appendix B.

3.3.1.2 Environmental Consequences

PROPOSED ACTION

All SPB pre-flight preparation activities would occur within developed areas that are currently used for aerospace-related activities. Additionally, following launch, the balloon system would be visible to the naked eye for less than one hour. As such, these components of the Proposed Action would be expected to have no measurable effects on aesthetic and wilderness values in the Action Area.

Due to the time required to arrange recovery of the SPB system, components of the system could remain at a terrestrial landing site for up to several years following flight termination. Therefore, discovery of the SPB system could negatively impact some persons’ wilderness experience, as it would be evidence of human presence in an area otherwise devoid of such effects. Conversely, others may find it a positive experience to discover such an item. The effect would be influenced by the perception of the individual. The intensity of the impact would depend on where the SPB lands and how often users of the affected area see it prior to its recovery. Given the remote and vast Action Area, many items would likely go unnoticed. In that case, there would be little or no impact. In contrast, although the physical extent of the impact site would be small and limited to the area immediately surrounding the landing site (thereby deemed minor in most circumstances), its long-term presence in a high-value environmental feature such as a park or preserve would most likely intensify the effect. However, to offset the potential for landing in the most sensitive terrestrial areas, flights would not be terminated within the designated “avoidance areas” depicted in Appendix B. Moreover, consistent with past practice, should the SPB system land in a terrestrial area, it would be recovered as soon as practicable, in consultation with the respective landowner or manager. During terrestrial recovery of the SPB system, persons within sight or earshot of the operation may hear or see a participating aircraft, and could potentially become annoyed by its presence (e.g., **Fidell et al. 1996**). However, such effects would be infrequent, short term, and localized.

If the SPB system lands in the ocean, because NASA would avoid terminating a flight near the coast (where persons would be most likely to encounter it), and the brief amount of time required for the system to sink to abyssal depths (**Shreves & Wilcox 2014**), it would not be expected to have a discernible effect on the marine aesthetic and wilderness values in the Action Area. Additionally, as there would be no post-flight recovery actions taken in the instance of a marine landing, there would be no recovery-related effects (e.g., aircraft overflight) on aesthetic and wilderness values. Should the SPB system remain on sea ice for several years between its termination and entering the ocean, given that it would likely remain snow covered, the likelihood of its presence detracting from Antarctic aesthetic and wilderness characteristics is very low.

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, the potential effects on aesthetic and wilderness values would be confined to the Antarctic continent and ice shelves. Likewise, Alternative B would have similar effects on aesthetic and wilderness values, though they would be confined to the lower latitude non-Antarctic landmasses. The No Action Alterative would have essentially the same effects as Alternative A; however, none of the effects would be related to ULDB flights.

3.3.2 Scientific Return

Article 3 of the *Antarctic Protocol* requires consideration of the effect of a proposal on the value of the Antarctic for the conduct of scientific research. Since such consideration is specific to actions conducted in Antarctica (**Ensminger et al. 1999**), this section focuses specifically on the geographic region of the Action Area south of 60°S.

3.3.2.1 Affected Environment

Since the coordinated international conduct of scientific research in Antarctica began with the 1957/58 International Geophysical Year, and subsequent signing of the Antarctic Treaty in 1959, Antarctica has hosted basic research in many disciplines, including aeronomy and astrophysics, atmospheric chemistry, biology, Earth sciences, ocean and climate systems, glaciology, and environmental science (**USAPEP 1997**). Twenty-eight nations conduct Antarctic research programs. The activities range from austral summer-only seaborne expeditions that focus on particular science questions to year-round operations that span the research disciplines relevant to the Antarctic.

3.3.2.2 Environmental Consequences

PROPOSED ACTION

The launch and flight of the SPB from Antarctica would have negligible effects on scientific return. Though it is possible that the release of steel shot ballast from the SPB system could affect future studies on Antarctica (**McCold et al. 1995**), it is highly unlikely because of the low number of flights annually, the highly dispersed nature of the releases, and relatively small quantities of steel shot when spread across the Antarctic continent and surrounding waters.

It is also possible that the presence of abandoned materials at a specific landing site could affect scientific observations, though effects would be localized and would not contribute to a cumulative regional effect. For example, items left in the field could potentially affect glaciological or geophysical studies. However, because the locations of abandoned items would be documented in the post-flight recovery plan review for each mission, information would be readily available and minimize the risk of adversely affecting future field activities (**NSF 2008**).

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, Alternative B would be unlikely to adversely affect Antarctic scientific return given the tendency of New Zealand-launched balloons to remain at latitudes below 60°S (**Mullenax & Schwantes 2014**). The No Action Alterative would have essentially the same effects as Alternative A; however, the potential for affecting marine research would be negligible because flights would be terminated only over the Antarctic continent or the ice shelves.

3.3.3 Transportation

This Section includes a discussion of potential effects of the ULDB flights on both air and maritime transportation.

3.3.3.1 Affected Environment

Marine Transportation

A variety of private and government-owned vessels are operated in the Action Area, including container ships, tankers, and members of military fleets (**Endresen et al. 2003**). Most commercial ship traffic travels in the Pacific and Atlantic Oceans, north of 45°S (**Schreier et al. 2007**), with smaller-scale areas of concentration in the waters off Cape Agulhas, South Africa, Cape Leeuwin, southwestern Australia, the eastern coasts of Brazil and Uruguay, and the waters between the Southeast Cape of Australia and Cape Reinga, New Zealand (**Endresen et al. 2003; Halpern et al. 2008**).

Though shipping traffic at higher latitudes is comparatively smaller than that at mid-latitudes, marine traffic in the Antarctic has increased over the past decade, and includes both large and small commercial tourism vessels, private yachts, fishing vessels, whaling boats, research vessels, and vessels supplying Antarctic scientific research stations (**Aronson et al. 2011**). Of these types of vessels, tourist vessels represent the fastest growing proportion, with the western coast of the Western Antarctic Peninsula being the most frequently visited region of the continent (**Lynch et al. 2010**). According to data from the International Association of Antarctica Tour Operators (IAATO), 53 vessels are currently registered with the organization, ranging from small sailing vessels carrying as few as 5 passengers to cruise ships accommodating over 2,400 passengers. The IAATO membership conducted 258 round-trip marine voyages to the Antarctic region in 2013, representing over 34,000 tourists, crewmembers, and staff (**IAATO 2013**). The majority of these vessels' homeports are in South America, although visitors also access Antarctica via Australian, New Zealand, and South African gateways (**Bertram et al. 2007**). Most of high latitude ship traffic occurs during the austral summer (**Lynch et al. 2010**) when weather conditions are most favorable. IAATO's data is specific to its membership; the number of non-member, privately owned sailing vessels and yachts that routinely make passage to the Antarctic region is unknown. Approximately 50 each licensed commercial fishing vessels (**CCAMLR 2014**) and research program supply vessels (**WHOI n.d**.) are known to operate within Antarctic waters.

Air Transportation

According to the IAATO, airborne tourism is becoming increasingly popular (**IAATO 2013**). More than 1,500 people visited Antarctica via IAATO member aircraft in the 2012–2013 season on 24 flights. The IAATO expected this number to remain fairly constant in the 2013–2014 season. No estimates are available of the number of departures for aircraft not registered with the IAATO.

Proposed high-speed civil transport aircraft would cruise at an altitude of about 20 km (**Stolarski et al. 1995**; **Dameris 1998**; **Prata 2009**); commercial aircraft typically occupy airspace between altitudes of 10 and 15 km (**Stolarski et al. 1995**; **Schumann 1997**; **Prata 2009**); and visual flight rules aircraft are usually found below 9 km (**Federal Aviation Administration 2013**), with those flying above 5.5 km requiring strict adherence to Air Traffic Control (ATC)-assigned flight levels (14 CFR 91.159). Regardless, these vertical ranges are well below the float altitude of SPB systems (between approximately 33.8 and 35.9 km), essentially preventing interaction between SPBs and aircraft during nominal flight operations. Furthermore, despite regional growth between 1999 and 2008 (**New Zealand Ministry of Tourism 2008**), global density of air traffic in the Action Area is relatively low. This is evidenced by the fact that the countries of Chile, New Zealand, and South Africa each had a total number of flights in 2009 (domestic and international combined [**Oxford Economics 2011b, c, and d**]) less than the total number of flights in 2013 (559,080, excluding cargo [**Los Angeles World Airports 2014]**), from one major U.S. airport, Los Angeles International Airport (LAX). However, the number of combined domestic and international Australian flights in 2009 (689,400 flights [**Oxford Economics 2011a]**), was slightly higher than those of LAX flights in 2013.

3.3.3.2 Environmental Consequences

PROPOSED ACTION

The primary concern about maritime traffic would be the potential for a ship to encounter a SPB system and the balloon or flight train becoming entangled in the ship's propeller system. The consideration of such an incident occurring is particularly important in the Southern Ocean, where high seas (**Young 1999**), inclement weather, and sea ice pose substantial perils to transportation. However, several factors render this occurrence a highly unlikely event. First, the density of ship traffic in the context of the large, oceanic portion of the Action Area is very low. Second, the highest density (in relative terms) of ship traffic is expected to occur in the portion of the Action Area corresponding with latitudes flown by New Zealand-launched balloons (**Schreier et al. 2007**), which have a high probability (greater than 75 percent depending on flight duration [**Mullenax & Schwantes 2014**]) of terrestrial landing. Third, as SPB flights would not be terminated in pre-defined coastal zones (Appendix A), the areas of most ship traffic (**Endresen et al. 2003**; **Halpern et al. 2008; Lynch et al. 2010**) would be avoided. Finally, an ocean-landing SPB system would descend below the draft depths of even the largest oceangoing cargo ships (e.g., Ultra Large Crude Containers or Triple-E container ships having drafts up to approximately 25 m), in less than approximately 5 minutes (**Shreves & Wilcox 2014**).

Direct strike from a descending SPB system is also highly unlikely because of the size of the Action Area. Randomness of air and maritime traffic, as well as balloon overflight, was identified in **NASA 2009** as factors that reduced the possibility of SPB impact to these forms of transportation to below the acceptable risk criterion. Furthermore, notification of airplanes during ascent and descent, and the presence of an onboard transponder, further reduce the probability that a descending SPB system would present a hazard to air traffic (**NASA 2009**).

Under the Proposed Action, NASA would ensure that international operations standards are employed to reduce the potential for impacts to air traffic. Through the use of international agreements, the issuance of Notices to Airmen (NOTAMs), and sharing of flight positional data, NASA would receive concurrence and authorization for operations before conducting them. Prior to launch operations, NASA would submit a NOTAM to the local ATC authority at intervals of 24 hours, one hour, and upon launch of the balloon. During ascent, balloon operations staff would maintain contact with the ATC and submit notices at 3 km intervals until the system ascends above a given airspace, usually 18.3 km, which would be attained approximately 2 to 2.5 hours from launch. Throughout the flight, access to real-time flight data would be provided to applicable ATCs. Once the system is at float and mid-transit, NOTAMs would be submitted at intervals of 24 hours, one hour, and upon entrance into a neighboring ATC airspace. During preparations for termination operations, balloon operations staff would submit NOTAMs one hour before termination and upon termination, and would maintain constant communication with applicable ATCs until ground impact (**G. Garde, personal communication, 2014**). As such, besides potentially requiring a short-term diversion of aircraft during balloon ascent and descent, no effect on air transportation would be expected.

ALTERNATIVES

While Alternative A would result in the same types of effects as the Proposed Action, the effects would be less intense because fewer flights would take place per year and not many ships travel in Antarctic waters south of 60°S. The potential effects of Alternative B would be similar to the Proposed Action but slightly more pronounced than for Alternative A because of the larger amount of ship and air traffic at mid-latitudes. Under the No Action Alterative, there would be no measureable impact on transportation, as scientific balloons would be terminated over the Antarctic continent or the ice shelves.

3.3.4 Cultural Resources

Cultural resources are defined as prehistoric or historic sites, buildings, structures, objects, or other physical evidence of human activity that are considered important to a culture or community for scientific, traditional, or religious reasons. Cultural resources potentially affected by the Proposed Action fall into two general categories: nationally and internationally protected cultural sites. As the Proposed Action would occur outside the boundaries of the United States, no sites in the Action Area are listed in the National Register of Historic Places ("National Register"). However, Section 402 of the NHPA requires that:

> *"Prior to the approval of any Federal undertaking outside the United States which may directly and adversely affect a property which is on the World Heritage List or on the applicable country's equivalent of the National Register, the head of a Federal agency having direct or indirect jurisdiction over such undertaking shall take into account the effect of the undertaking on such property for purposes of avoiding or mitigating any adverse effects."*

3.3.4.1 Affected Environment

The scope of this IEE/EA does not include investigation and elaboration of every cultural site important to each nation in the Action Area; however, these could be identified during the development of termination/recovery agreements with each nation. Data for the United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage List is readily available and summarizes those cultural sites of international importance. Candidate sites must meet at least one of 10 selection criteria based on the 1972 World Heritage Convention. The 25 World Heritage Sites in the Action Area are shown in Figure 3-2, with details provided in **Bonsteel 2014c**. Additionally, many of the ASPAs (Figure 3-3) were established based on their cultural significance.

3.3.4.1 Environmental Consequences

PROPOSED ACTION

Direct effects of balloon launch, flight, and termination would be limited to the possible effect of the balloon system landing on a historic property, potentially damaging it. Furthermore, ground-disturbing recovery efforts also have the potential to damage a resource or its integrity. However, such an event would be highly unlikely. NASA would avoid all known culturally significant areas by utilizing its predictive model for planning flight termination, employing the most current geospatial information on culturally significant sites, and coordinating with the respective landowner prior to undertaking a recovery operation. If, during recovery operations, indications of a culturally significant resource were discovered (i.e., a "chance find"), the

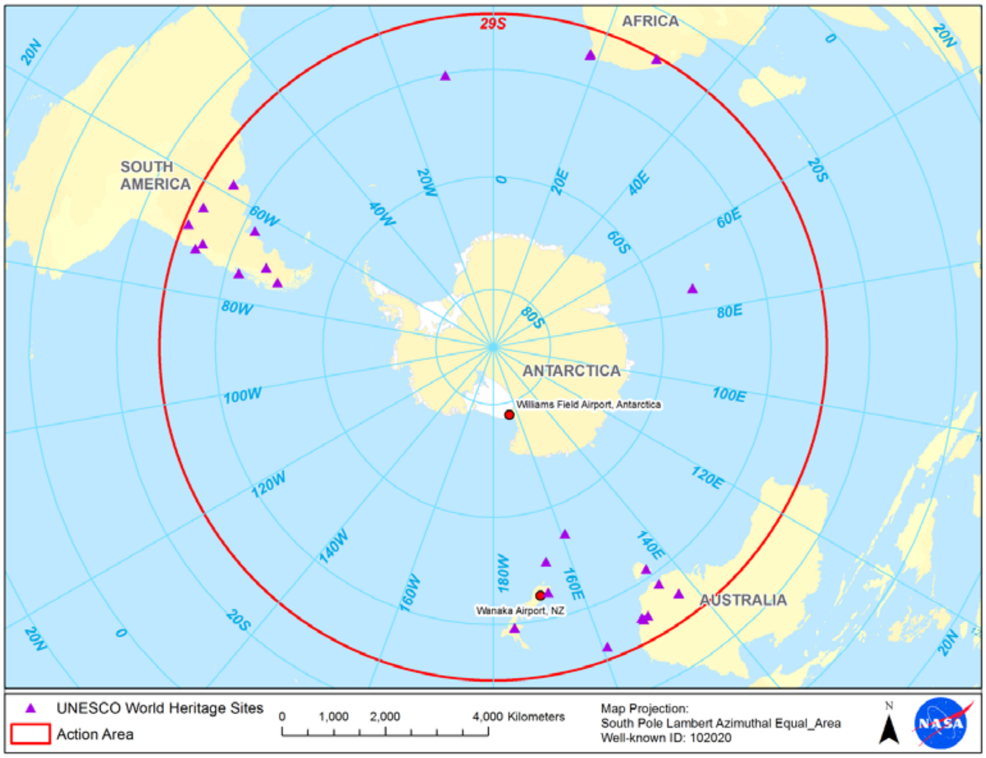
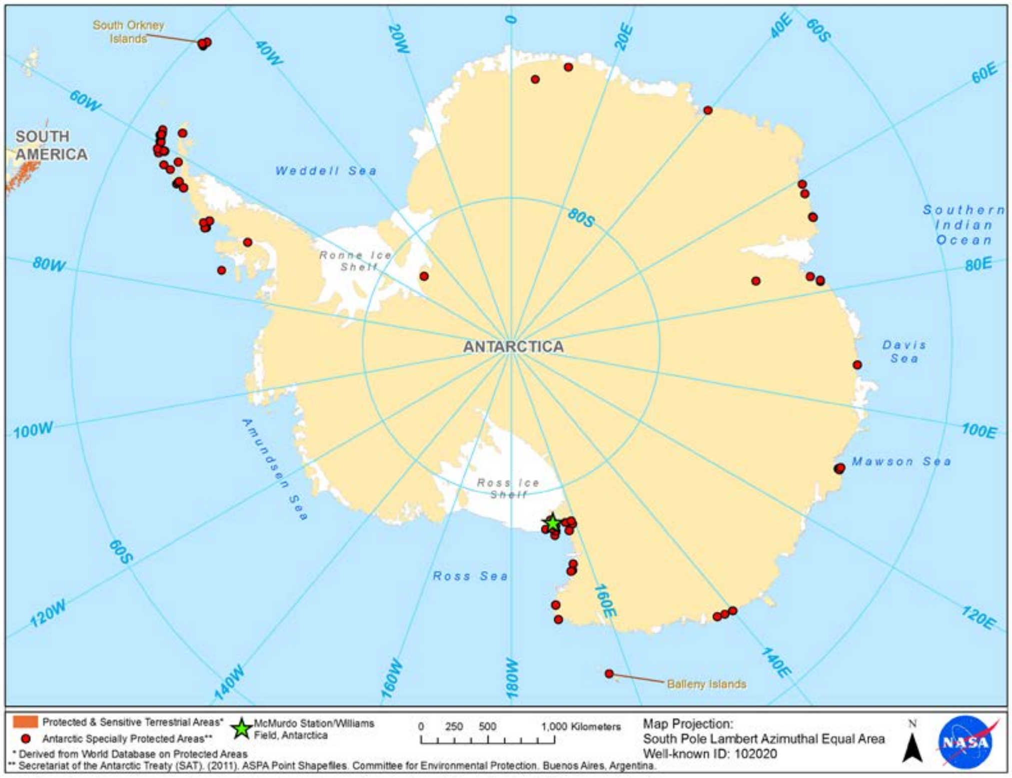


Figure 3-2: UNESCO World Heritage List Sites in the Action Area



* Derived from World Database on Protected Areas
** Secretariat of the Antarctic Treaty (SAT). (2011). ASPA Point Shapefiles. Committee for Environmental Protection. Buenos Aires, Argentina.

Figure 3-3: Antarctic Specially Protected Areas recovery team would contact the landowner prior to proceeding. Furthermore, to maintain awareness of any sites added to the World Heritage list or the register of ASPAs, these mapping data would be reviewed annually and updates made to the avoidance maps as needed. For these reasons, and because there have been no documented adverse impacts to cultural resources throughout the Balloon Program's U.S. operational history (**NASA 2010a**), no impacts to cultural resources are anticipated from the Proposed Action.

ALTERNATIVES

Alternative A would have the same type of potential effects as the Proposed Action; however, as there are relatively fewer World Heritage Sites within the latitude bands most commonly flown for Antarctica-launched balloons, the probability of an impact would be lower. Similarly, Alternative B would have lesser potential effects than the Proposed Action because it would entail fewer flights, and balloons would not fly within latitude bands that could affect ASPAs. Under the No Action Alternative, no measurable effect on cultural resources would be expected, as all flights would be terminated on the Antarctic landmass. All ASPAs, some of which were established due to their cultural significance, would be avoided when planning a termination.

3.4 CUMULATIVE EFFECTS ANALYSIS

This section provides 1) a definition of cumulative effects analysis, 2) a description of current and reasonably foreseeable future actions relevant to cumulative effects, 3) an analysis of the interaction the Proposed Action may have with other actions, and 4) an evaluation of cumulative effects potentially resulting from these interactions.

3.4.1 Definition of Cumulative Effects Analysis

The key function of a cumulative effects analysis (CEA) is to determine whether other actions are inducing additive stressors on the same resources that may be affected by the Proposed Action under consideration.

The first step in assessing cumulative effects involves defining the scope of the other actions and their interrelationship with the Proposed Action. The scope must consider both geographic and temporal overlaps among the Proposed Action and other actions, as well as the nature of interactions among them.

3.4.2 Scope of Cumulative Effects

The scope of this CEA was defined by four key factors: 1) the relevant cumulative *issues* related to the Proposed Action under consideration in this IEE/EA, 2) the *geographical boundary* within which additive effects would be reasonably expected, 3) the *temporal boundary* during which such effects would be expected to occur, and 4) *other actions* that could interact with the same resources affected by the Proposed Action.

Given that the SPB system included in the Proposed Action would sink to the ocean floor and remain there for the foreseeable future (**Shreves & Wilcox 2014**), and supported by this

IEE/EA's preceding analyses of potential effects on physical, biological, and social resources, NASA has determined that the relevant *issues* to be assessed in this CEA include the potential impacts to marine benthic communities from either smothering or entanglement. Given that the SPB system would land within the band of latitudes between 29°S and 90°S, this is also the *geographical boundary* of this CEA. The *temporal boundary* of the CEA is the timeframe between the present (i.e., 2014) and 10 years into the future, as that is the planning horizon for the Proposed Action considered in this IEE/EA. *Other actions* identified that may affect benthic communities include other ballooning operations in the Southern Hemisphere along with miscellaneous oceanic debris.

3.4.3 Current and Reasonably Foreseeable Future Actions

3.4.3.1 Balloon Operations

Across the world, small balloons carrying radiosondes are used to provide weather data at various heights throughout the atmosphere. Each year, as part of the USAP, the McMurdo and South Pole stations in Antarctica launch over 1,000 of these small meteorological balloons (**McCold et al. 1995**). **McCold et al**. **(1995)** estimated that between the USAP and meteorological balloons launched by other countries from Antarctica, more than 9,000 meteorological balloons per year could affect marine organisms. Outside of Antarctica and within the coastal regions of the geographical boundary of the CEA, New Zealand currently launches meteorological balloons twice daily from five stations, Australia from 15 stations, South Africa from two stations, Chile from two stations, and the Falkland Islands from one station (**University of Wyoming 2014**). Therefore, approximately 18,250 meteorological balloons are launched per year from the 25 stations outside of Antarctica. Altogether, within the CEA geographical boundary, approximately 27,250 meteorological balloons are launched per year.

Based on the analysis in **McCold et al. 1995**, if, instead of bursting in the upper atmosphere, all of the 27,250 meteorological balloons launched per year eventually enter and sink in the approximately 113.3 million km^2 of ocean in the Action Area (Section 2.1.1), then a maximum of about 114,450 m^2 of the sea bottom and its associated benthic community could be covered by balloon membranes each year. This assessment is considered conservative because these membranes would be expected to incur some degree of folding; therefore, the actual area covered annually would likely be less. Consequently, over the 10-year temporal boundary of the Proposed Action, a conservatively derived maximum of 1,144,500 m^2, representing only 1.0 x 10^{-6} percent of the total benthic area in the CEA area, would be impacted by meteorological balloons.

The Proposed Action of this IEE/EA includes the launch of three SPBs per year over the 10-year temporal boundary, with the 26.2 MCF SPB as the largest to be launched. Based on the probability statistics presented in **Mullenax & Schwantes 2014** and **GAC 2003**, it may be conservatively assumed that over this time, approximately four Antarctica-launched and five

New Zealand-launched balloons would enter the ocean and descend to the seafloor. Assuming a 24 m^2 payload (Section 2.1.3.3), a 41,400 m^2 balloon (**H. Cathey, personal communication, 2014**), and 230 m^2 parachute (**G. Garde, personal communication, 2014**) the combined footprint of each 26.2 MCF SPB system would be approximately 41,650 m^2. Therefore, SPB materials alone would cover up to approximately 1,250,000 m^2 of benthic area, or 1.0×10^{-6} percent of the total benthic area in the Action Area, under the Proposed Action.

When considered cumulatively, all balloon materials could cover up to approximately 2.0×10^{-6} percent of the total benthic area within the geographic boundaries of this CEA. As such, while adverse localized effects would likely be unavoidable (described in Section 3.2.2.2.2), the potential effects would be negligible when considered within this larger geographic context.

3.4.3.2 Marine Debris

Plastic debris consists of particles that have diameters as small as several millimeters to big plastic-filled “ghost nets” having a weight of 2,000 kg (**Hammer et al. 2012**). Research in the North Sea showed that, of all plastic debris annually dumped into the sea, 15 percent is floating on the surface, 15 percent is washed ashore, and eventually, 70 percent will sink to the sea bottom (**Barnes et al. 2009**).

Gregory & Ryan (1997) summarized the findings of several research projects related to marine debris accumulation in the Southern Hemisphere. They concluded the following generalities:

- The proportion of plastic in marine litter is reasonably consistent, between 60 and 80 percent.
- Density, in terms of number of items per area, is highly variable and is highest near population centers.
- The proportion and relative abundance of debris from fishing and shipping activities increases away from population centers and closer to fishing grounds. It reaches a maximum at remote, unpopulated islands.
- Quantities floating on the high seas are higher around Southern Africa and Oceania. Elsewhere, quantities are very low, reflecting dispersal and dilution with distance, and never approach those reported for the Northern Hemisphere.
- Evidence from remote oceanic islands suggests a southward-decreasing, strong latitudinal gradient in litter densities from subtropical and temperate waters through the Subtropical Convergence to the Polar Front and beyond. The major oceanic fronts are effective barriers to the passage of pelagic litter, which tends to concentrate along these fronts.

Barnes et al. (2010) reported, on a coarse geographic scale, a summary of densities of marine debris at sea in and adjacent to the Southern Ocean. The “worst case” densities per 10 degree latitudinal and longitudinal square were converted to densities per square kilometer. Using information presented above (**Gregory & Ryan 1997; Barnes et al. 2009),** where 60 to 80 percent of all marine debris is plastic, and 15 percent of all plastic marine debris floats while 70 percent sinks to the seafloor, it was conservatively calculated that approximately 181 million plastic items are on the seafloor within the geographic boundary of the Proposed Action. **Barnes et al. (2009)** classified marine debris by size, stating that "plastics have been found on the seabed of all seas and oceans across the planet, but macro-debris is still very rare in the Southern Ocean, particularly in deep water." Therefore, using the next largest size classification of meso-debris at 5 to 20 mm, a very conservative area for the 181 million sunken plastic items was calculated to be approximately 3,625 m^2 or 3.0 x 10^{-9} percent of the total seafloor area within the CEA area.

When considered cumulatively, SPB materials and oceanic debris could cover up to approximately 1.0 x 10^{-6} percent of the total seafloor area within the geographic boundaries of this CEA. As such, while adverse localized effects would likely be unavoidable (described in Section 3.2.2.2.2), the potential effects would be negligible when considered within this larger geographic context.

3.4.4 Irreversible and Irretrievable Commitment of Resources

Irreversible and irretrievable resource commitments are related to the use of nonrenewable resources and the effects this use could have on future generations. Irreversible effects primarily result from the use or destruction of a specific resource (e.g., energy and minerals) that cannot be replaced within a reasonable time frame. Irretrievable resource commitments involve the loss in value of an affected resource that cannot be restored as a result of the action (e.g., extinction of a threatened or endangered species or the disturbance of a cultural resource).

For the Proposed Action, most resource commitments are neither irreversible nor irretrievable. Most environmental consequences are short-term and temporary, such as minor disturbance to the natural environment from landing and recovery activities.

Helium, a non-renewable resource, exists in small quantities in the Earth's atmosphere and is mined from underground pools where it accumulates as a by-product of the Earth's production of natural gas. In 2006, the total helium reserves and resources of the United States were estimated to be 20.6 billion m^3, and worldwide resources (exclusive of the United States) were projected to be 31.3 billion m^3 (**USGS 2013**).

In 2012, estimated consumption of helium in the United States was 50 million m^3 (**USGS 2013**). Inflation of a 26.2 MCF ULDB and tow balloon in preparation for launch requires approximately 6,800 m^3 of gaseous helium. Under the Proposed Action, up to three balloon flights would occur each year using approximately 20,400 m^3 of gaseous helium. If the 2012 annual consumption totals are applied to this proposal, annual helium use for the Proposed Action would represent approximately 0.04 percent of the U.S. total consumption, a negligible commitment of resources.

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5 GLOSSARY OF TERMS

Abiotic, *adjective (adj.)*: non-living

Ablation, *noun (n.)*: removal, as of ice or snow through erosion, melting, or sublimation

Abyssal, *adj.*: regarding seafloor areas below the continental shelf slope

Acacia, *n.*: a species of African tree typically found in a savannah setting

Aeronomy, *n.*: the study of the atmosphere

Alimentary, *adj.*: regarding the digestive system

Amorphous, *adj.*: lacking distinct form or rigidity

Amphipod, *n.*: a crustacean of the order Amphipoda

Anoxia, *n.*: a lack of oxygen

Anticyclone, *n.*: a circular, clockwise pattern of wind in the Northern Hemisphere, or counterclockwise in the Southern Hemisphere

Apex, *n.*: top or summit

Austral, *adj.*: regarding the Southern Hemisphere

Bathyal, adj.: relating to the area of the continental slope between 200 and 4,000 meters in depth

Bathypelagic, *adj.*: regarding the vertical section of the ocean below the reach of sunlight, approximately 1,000 to 4,000 meters in depth; overlies the abyssopelagic zone and is overlain by the mesopelagic zone

Benthic, *adj.*: regarding the bottom of a body of water

Benthopelagic, *adj.*: related to the bottom of the ocean

Benthos, *n.*: those species existing in or on of the floor of a body of water

Biofouling, *n.*: a coating or contamination comprised of organic substances, microorganisms, and/or encrusting organisms such as barnacles

Buccal cavity, *n.*: the space within the jaws, mouth, and cheeks

Carbonyl, *n.*: a chemical functional group comprised of a carbon atom double-bonded to an oxygen atom, as that found in ketones

Caudal, *adj.*: relating to the tail

Chamaephyte-steppe, *n.*: grasslands featuring chamaephyte flora (woody vegetation with buds forming at or just above the ground)

Copepod, *n.*: small aquatic and limno-terrestrial crustaceans

Cosmic Microwave Background, *n.*: the afterglow radiation left over from the hot “Big Bang” which formed the universe about 14 billion years ago; it can provide scientists with insight into the origin, evolution, and content of the universe

Demersal, *adj.*: regarding the area near or at the bottom of a body of water

Diurnal, *adj.*: regarding the day-night cycle

Electrolyte, *n.*: an electrically-charged ion in solution, or the solution itself

Empirical, *adj.*: relating to real-world observations or the results of scientific testing

Endemic, *adj.*: naturally existing in, or restricted to, a particular area

Epibionts, *n.*: organisms which colonize surfaces, including those of other organisms

Epipelagic, *adj.*: related to ocean waters between the surface and approximately 200 meters of depth; also known as photic or euphotic; overlies the mesopelagic zone

Eucalypt, *n.*: any of the plants in the genera Eucalyptus and Angophora

Exothermic, *adj.*: emitting heat, usually as a result of a chemical or physical reaction

Fledging, *n.*: the point at which, or the process whereby, juvenile birds leave the nest

Flood-freeze cycling, *n.*: the process of ice growth through melting of snow or submergence, followed by freezing

Fynbos, *n.*: the unique, mostly-endemic assemblages of plant species found in southern South Africa, comprised of reeds and sclerophyllous (leathery-leaved) and microphyllous (small-leaved) woody vegetation

Gamma-ray, *n.*: a highly-energetic wave within the range of 200 kiloelectron volts to 200 megaelectron volts

Grass-steppe, n.: steppe areas consisting primarily of grasses

Hummock grassland, *n.*: grasslands in Australia typified by vegetation in the genus Triodia

Hydrolysis, *n.*: the splitting of a molecule through the addition of water

Hydrolytic, *adj.*: regarding the process of hydrolysis

Hydrophobic, *adj.*: water-resistant or -repellant, as oil

Hydrophilic, *adj.*: water-soluble or readily forming chemical bonds with water, as alcohol

Hygrophilous, *adj.*: growing in or inhabiting moist or damp locations

Hypoxia, *n.*: a state of low oxygen concentration

Katabatic, *adj.*: a term used to describe dense air moving as wind down a slope, particularly with regard to the formation of Antarctic sea ice

Leatherwoodscrub, *n.*: high-altitude areas of thick shrubs found in New Zealand

Lichen, *n.*: fungi containing symbiotic algae or blue-green cyanobacteria

Macrobenthos, *n.*: organisms living at the bottom of the body of water and 0.5 millimeters or larger in size

Marine snow, *n.*: flakes or clumps of organic and inorganic material that falls through the water column to the ocean floor

Mesopelagic, *n.*: the vertical region (depths between 200 and 1,000 meters) of the ocean below the reach of sunlight; also, *adj.*: pertaining to this layer

Mineralization, *n.*: the degradation of a material into carbon dioxide, water, and minerals through organic processes

Mole, *n.*: the mass of approximately 6.02×10^{23} units of a substance

Morphometric, *adj.*: relating to the study of physical form

Near-UV, *n.*: ultraviolet (UV) light between 300 and 400 nanometers in length

Nematode, *n.*: worms of the phylum Nematoda

Obligate, *adj.*: relating to specific habitat requirements

Patagonia, *n.*: the area of southeastern Argentina comprised of steppe, desert, and coastal habitats

Pelagic, *adj.*: regarding the open water; this is sometimes divided into five separate ecological zones which are, proceeding from the surface to the bottom, the epipelagic, mesopelagic, bathypelagic, abyssopelagic, and hadopelagic zones

Photic zone, *n.*: the vertical area of the ocean illuminated by sunlight sufficient for photosynthesis

Photovoltaic, *adj.*: related to technology which transforms light into electricity

Polymer, *n.*: a molecular substance made up of numerous linked molecule units, or monomers

Polynya, *n.*: a persistent area of open water amid sea ice

Pore water, *n.*: water found within the space between sediment grains or particles

Pyrotechnics, *n.*: explosive devices

Resin, *n.*: a viscous or solid substance used to make plastics

Rostrum, *n.*: a beaklike, elongated anterior portion of the face or head

Sclerophyllous, *adj.*: having tough leaves adapted to dry conditions

Scrub, *n.*: vegetated areas consisting of low-growing trees and/or shrubs; also, this kind of vegetation assemblage

Sessile, *adj.*: attached directly to a surface

Shrub-steppe, *n.*: grasslands featuring shrub vegetation

South Pacific Gyre, *n.*: a large counterclockwise current found in the South Pacific Ocean

Southern Cone, *n.*: the portion of South America generally south of the Tropic of Capricorn, including Argentina, Brazil, Chile, Paraguay, and Uruguay

Steppe, *n.*: flat plains usually devoid of trees

Stratum, *n.*: a layer

Stratosphere, *n.*: the portion of the atmosphere between the top of the troposphere and 50 kilometers above the Earth's surface

Telemetry, *n.*: long-distance communication of measurements or other data

Thermo-oxidatively, *adv.*: related to oxidization by heat

Tierra del Fuego, *n.*: a chain of islands at the southernmost tip of South America

Troposphere, *n.*: the layer of the atmosphere closest to the Earth's surface

Tundra, *n.*: Arctic or high-altitude plains devoid of trees and subject to low temperatures

Tussock grass, *n.*: a grass that grows in a bunched form

Upwelling, *n.*: an area where cold, nutrient-rich ocean currents rise to the surface; also, *v.*: the movement of water resulting in an upwelling

Ultra-violet (UV), *n.*: light between the wavelengths of 10 nanometers and 400 nanometers

Xeric, *adj.*: dry

Xerophytic, *adj.*: adapted to existence in dry conditions

6 PREPARERS AND CONTRIBUTORS

The following persons contributed to the preparation of this IEE/EA.

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NSF		
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LJT & Associates, Inc. (contractor to NASA)		
Michael Bonsteel	Environmental Scientist	Purpose and Need, Alternatives, Biological Resources, Social Environment, Figures
Alexander Brown	GIS Analyst	Figures
Shari Silbert	Environmental Scientist	Cumulative Effects Analysis, Document Review, Editor
Charles Ward	Environmental Scientist	Social Environment
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Appendix A

Sensitive Marine Areas to be Avoided During Flight Termination

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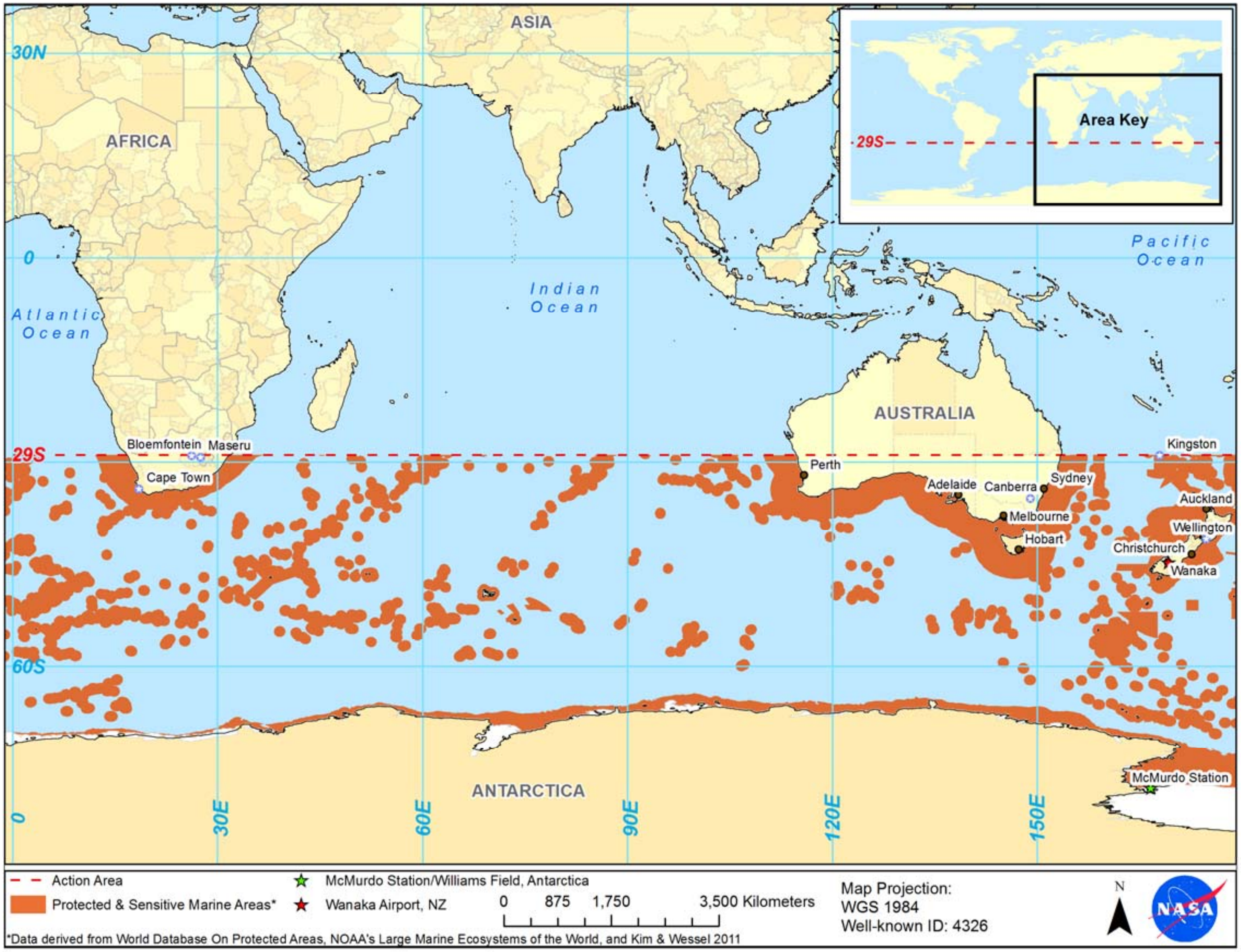

Figure A-1: Protected and sensitive marine areas to be avoided during flight termination: Eastern World

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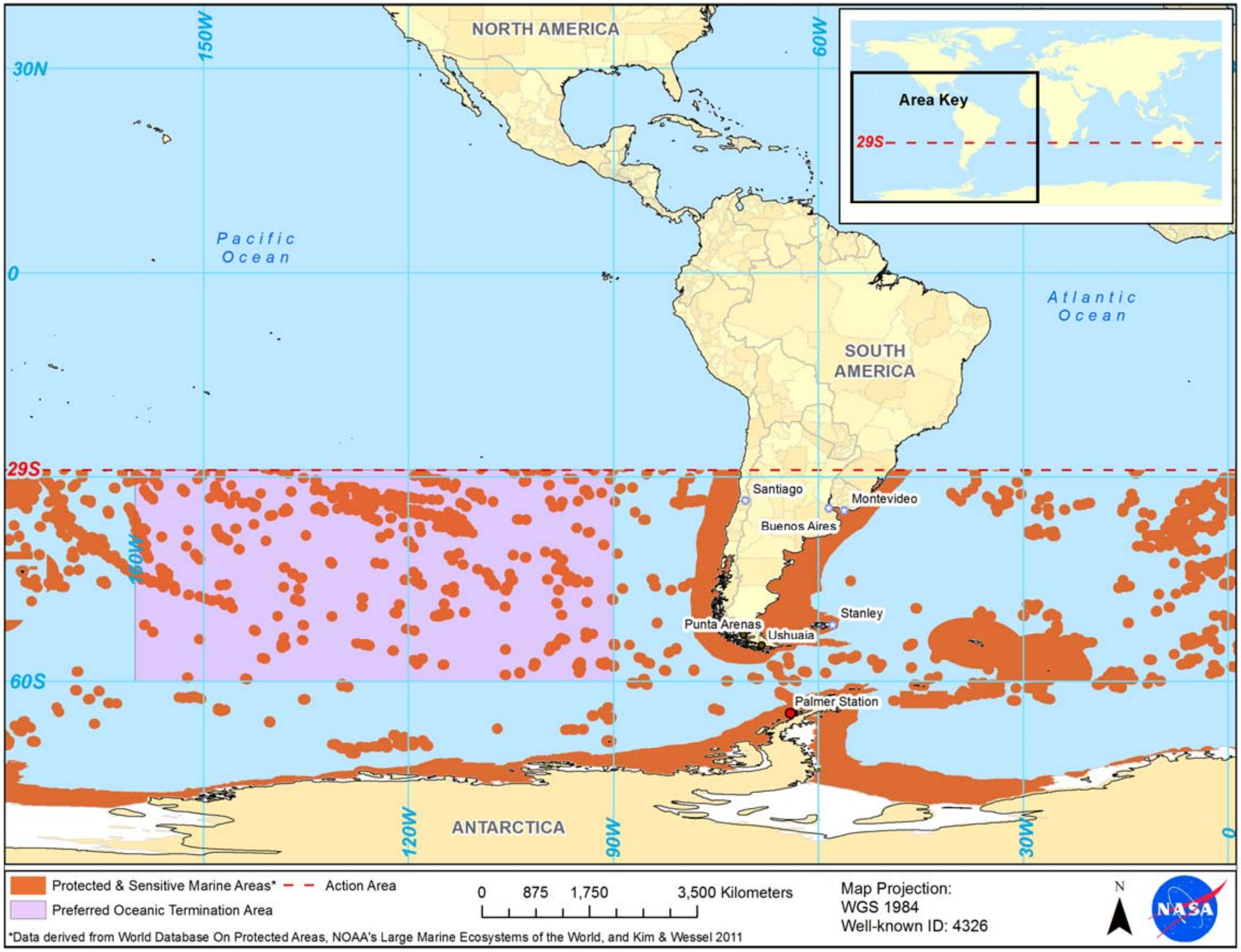

Figure A-2: Protected and sensitive marine areas to be avoided during flight termination: Western World
Includes preferred oceanic termination area

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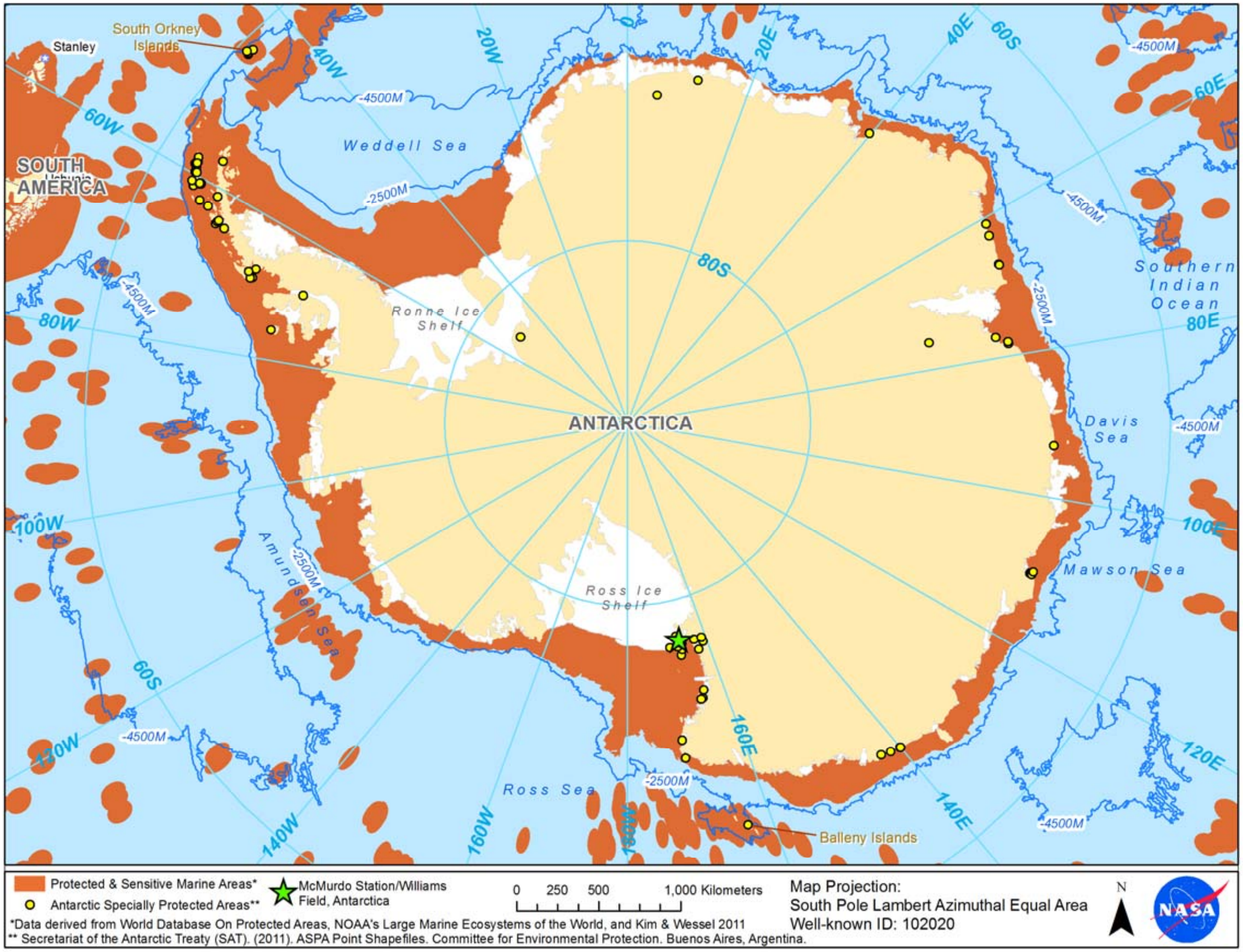

*Data derived from World Database On Protected Areas, NOAA's Large Marine Ecosystems of the World, and Kim & Wessel 2011

** Secretariat of the Antarctic Treaty (SAT). (2011). ASPA Point Shapefiles. Committee for Environmental Protection. Buenos Aires, Argentina.

Figure A-3: Protected and sensitive marine areas to be avoided during flight termination: Antarctica

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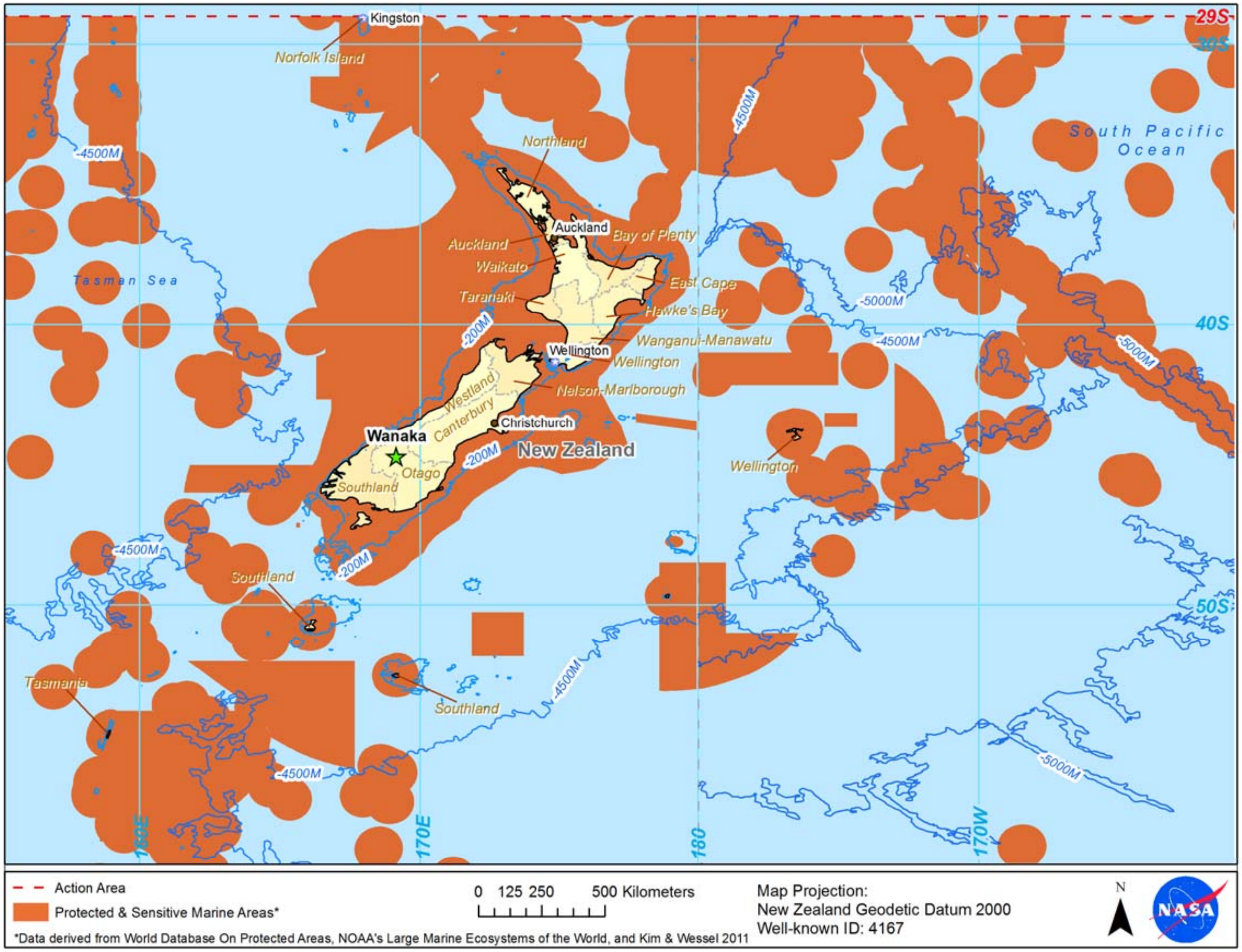

Figure A-4: Protected and sensitive marine areas to be avoided during flight termination: New Zealand

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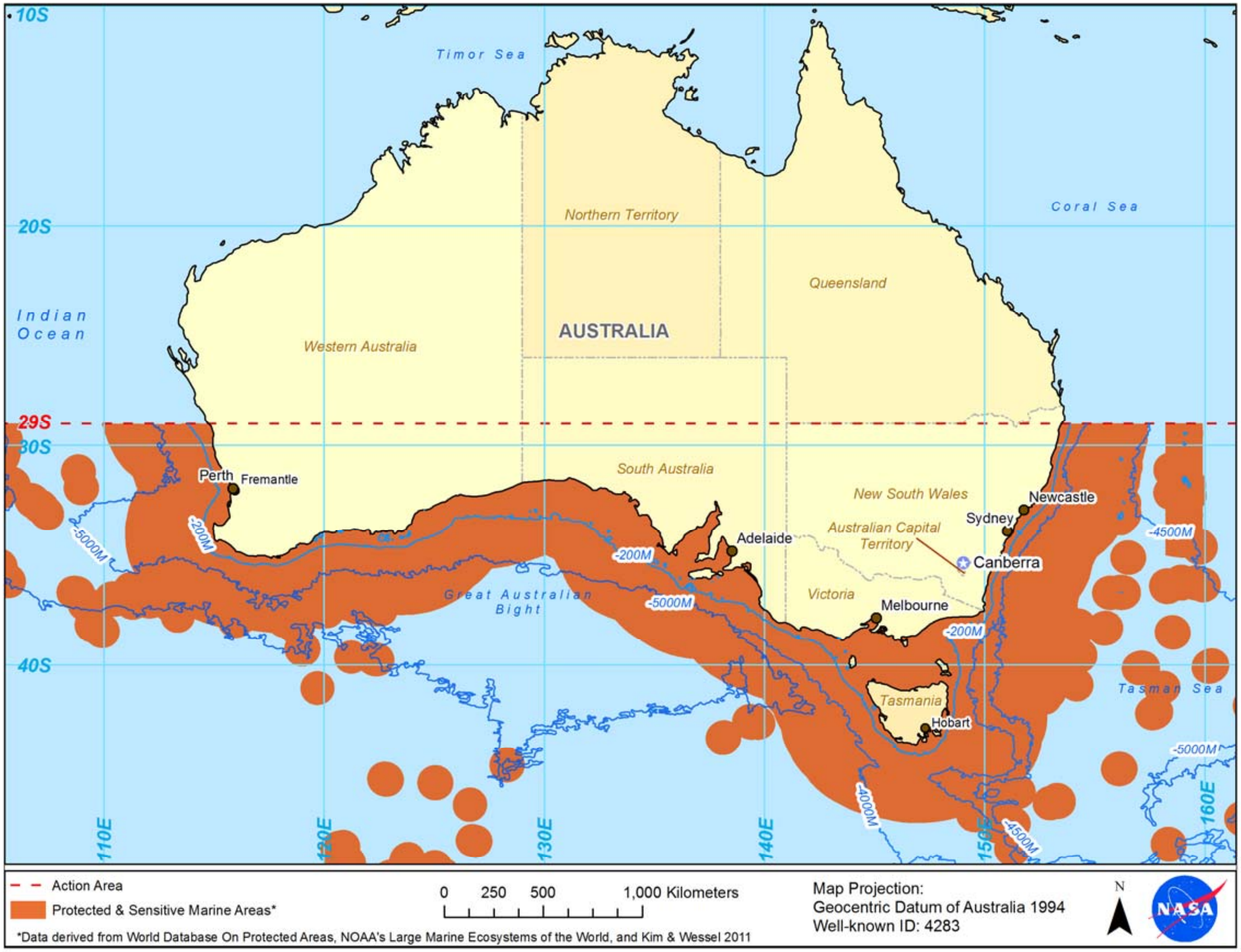

Figure A-5: Protected and sensitive marine areas to be avoided during flight termination: Australia

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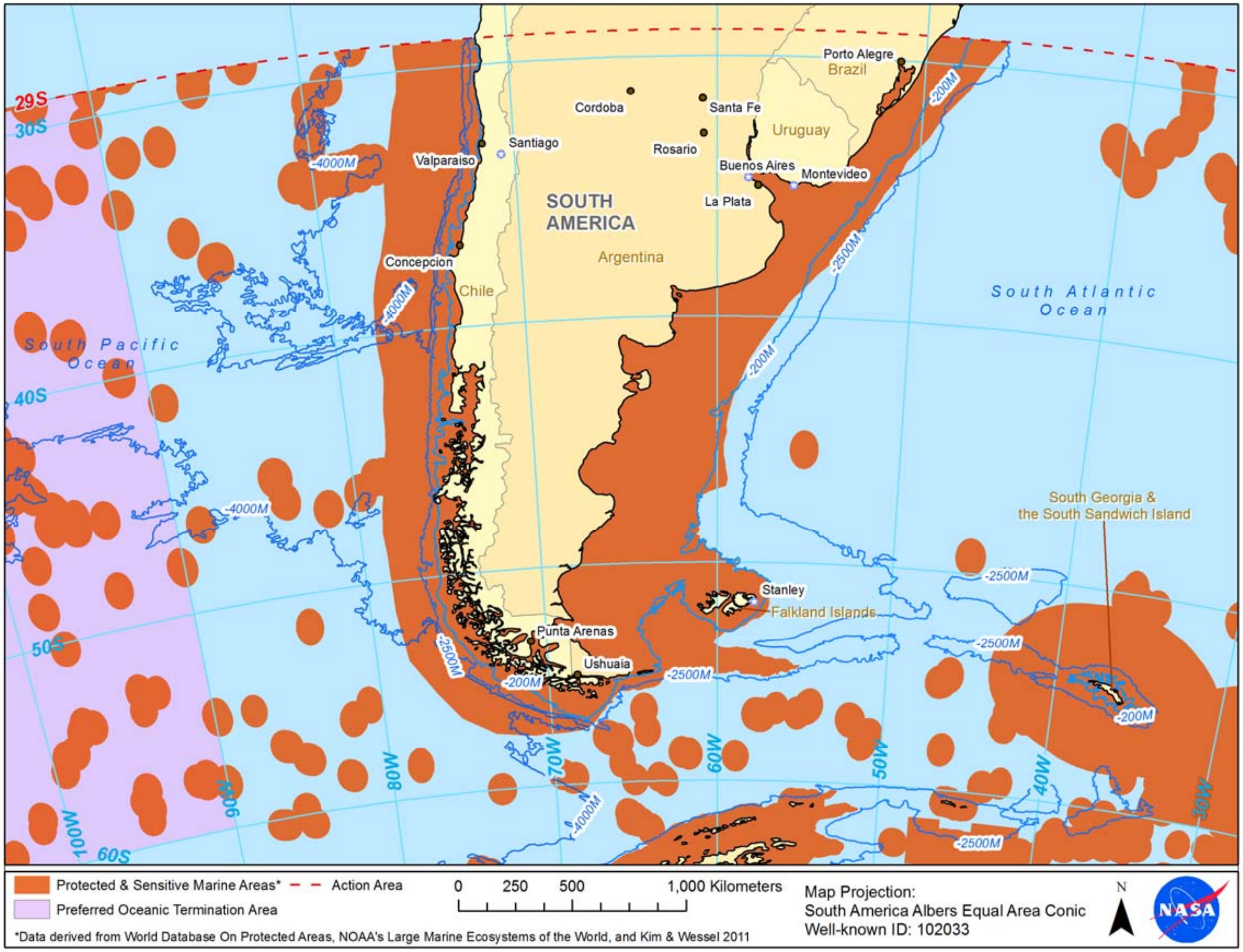

*Data derived from World Database On Protected Areas, NOAA's Large Marine Ecosystems of the World, and Kim & Wessel 2011

Figure A-6: Protected and sensitive marine areas to be avoided during flight termination: South America
Includes a portion of the preferred oceanic termination area

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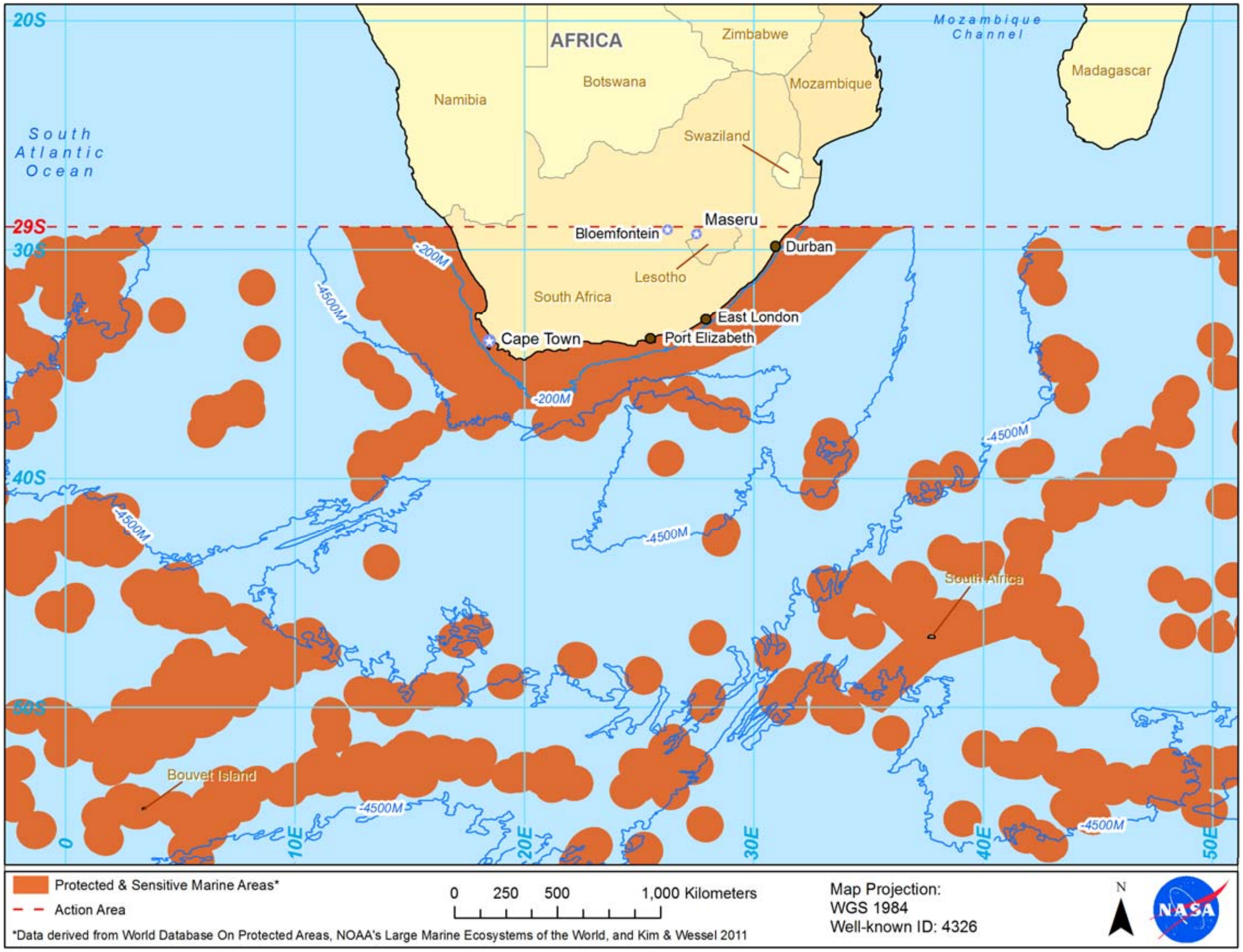

Figure A-7: Protected and sensitive marine areas to be avoided during flight termination: Africa

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Appendix B

Sensitive Terrestrial Areas to be Avoided During Flight Termination

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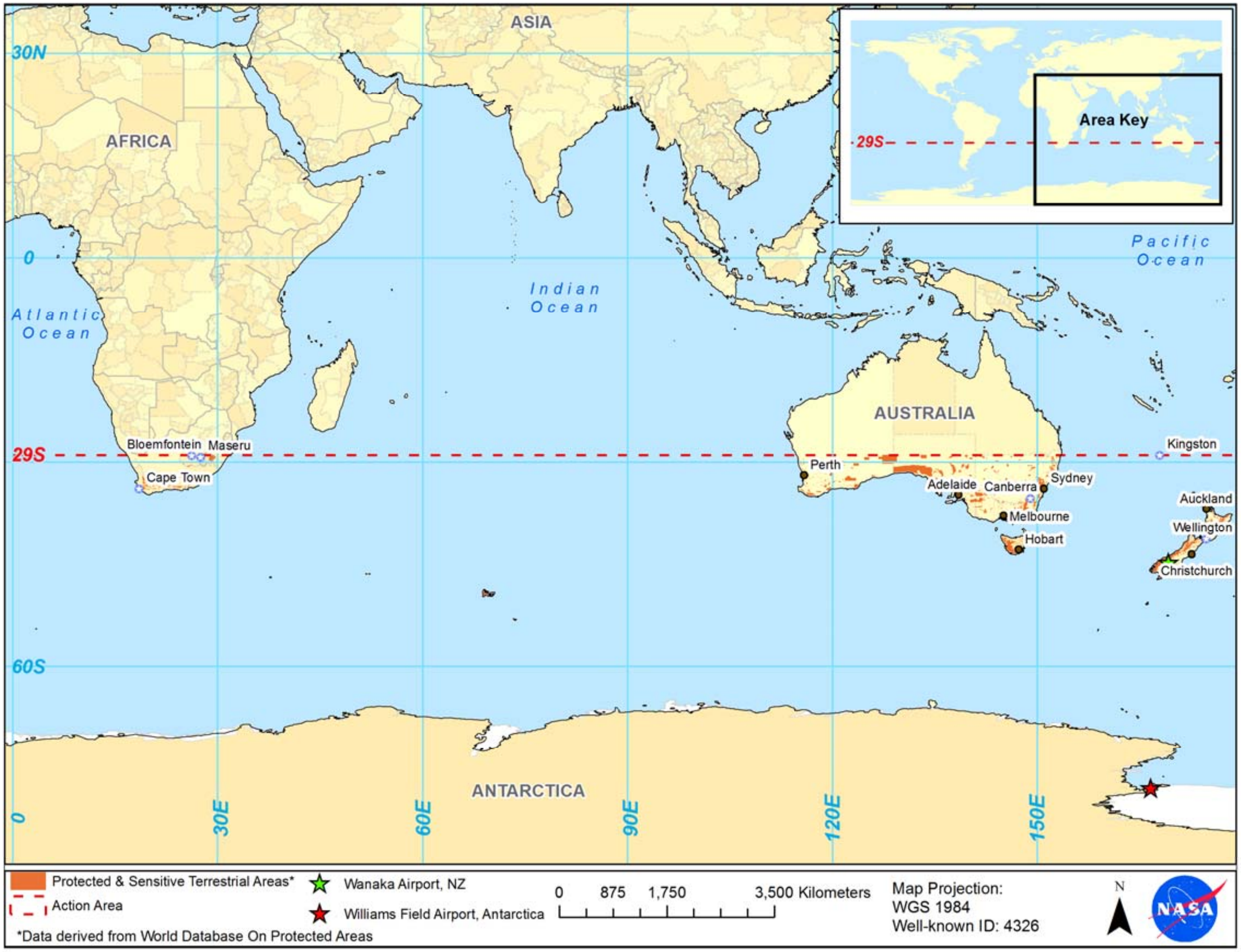

Figure B-1: Protected and sensitive terrestrial areas to be avoided during flight termination: Eastern World

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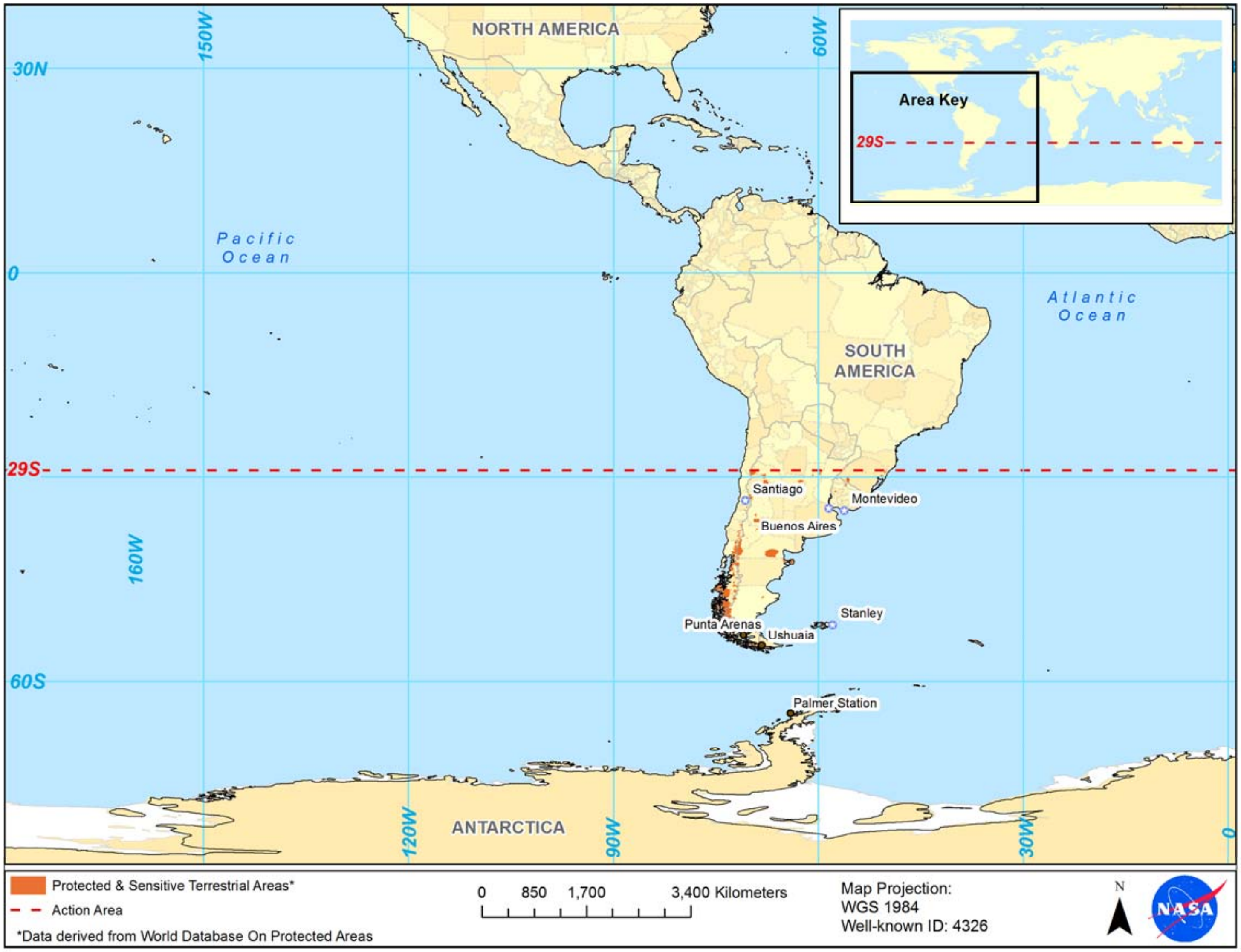

Figure B-2: Protected and sensitive terrestrial areas to be avoided during flight termination: Western World

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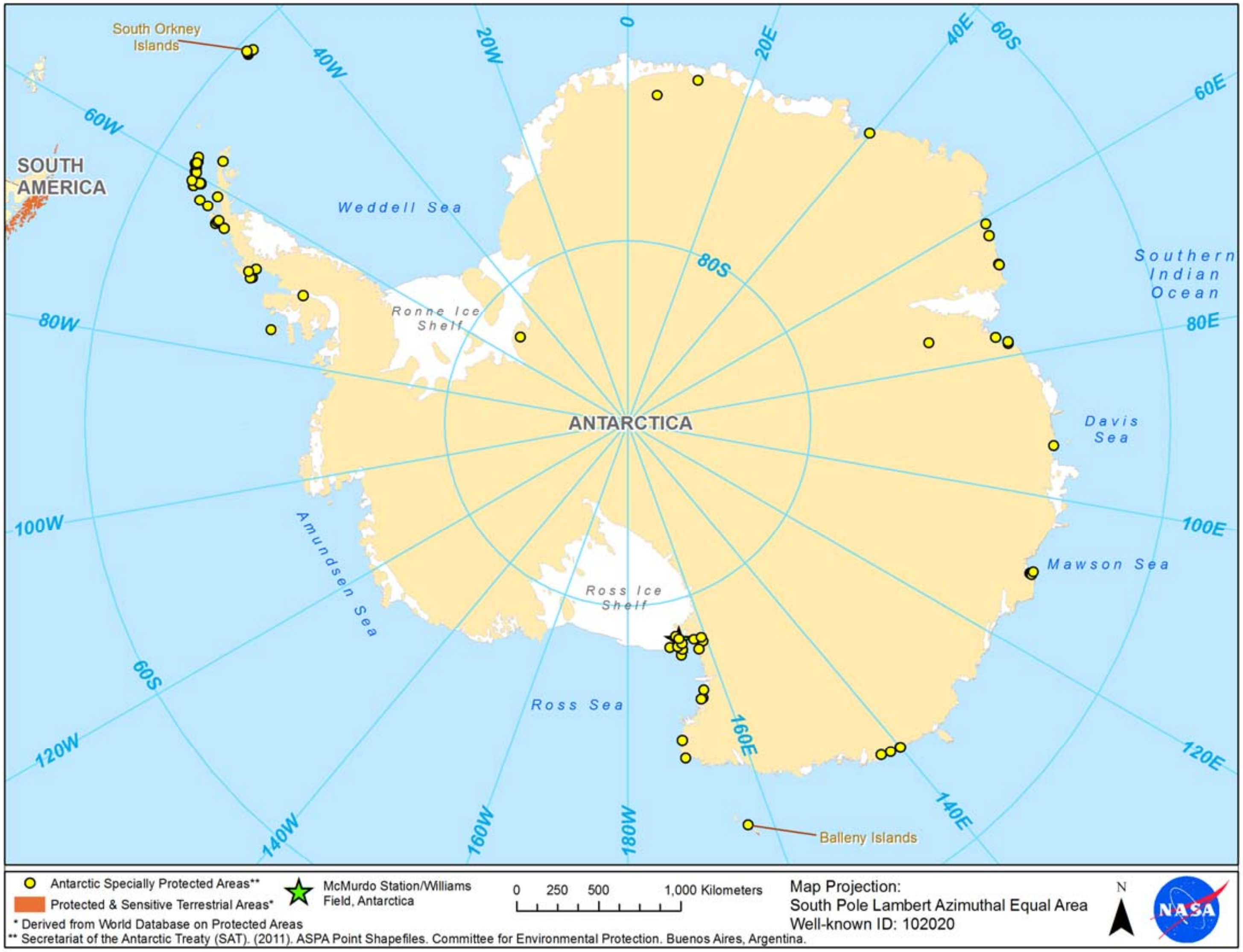

Figure B-3: Protected and sensitive terrestrial areas to be avoided during flight termination: Antarctica

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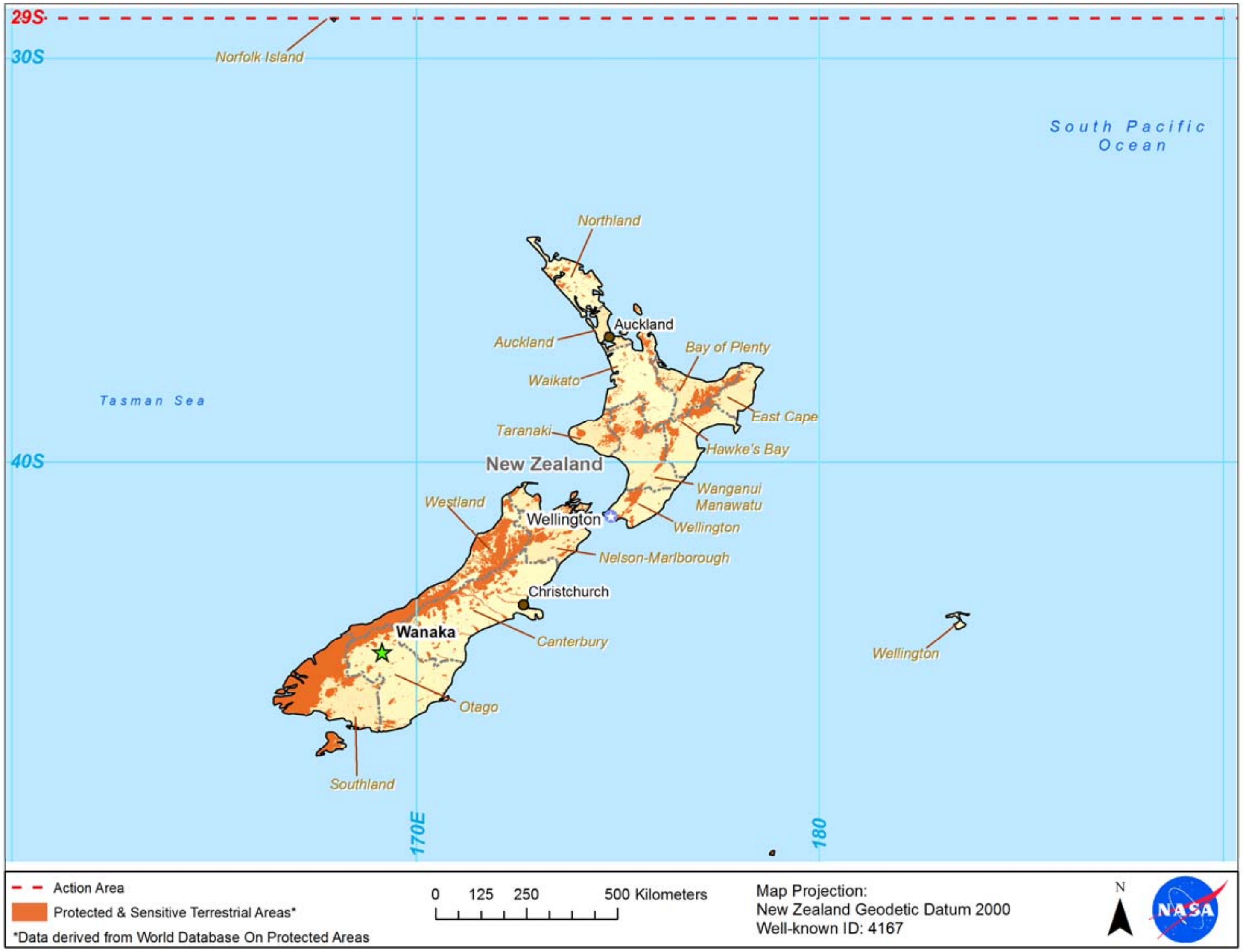

Figure B-4: Protected and sensitive terrestrial areas to be avoided during flight termination: New Zealand

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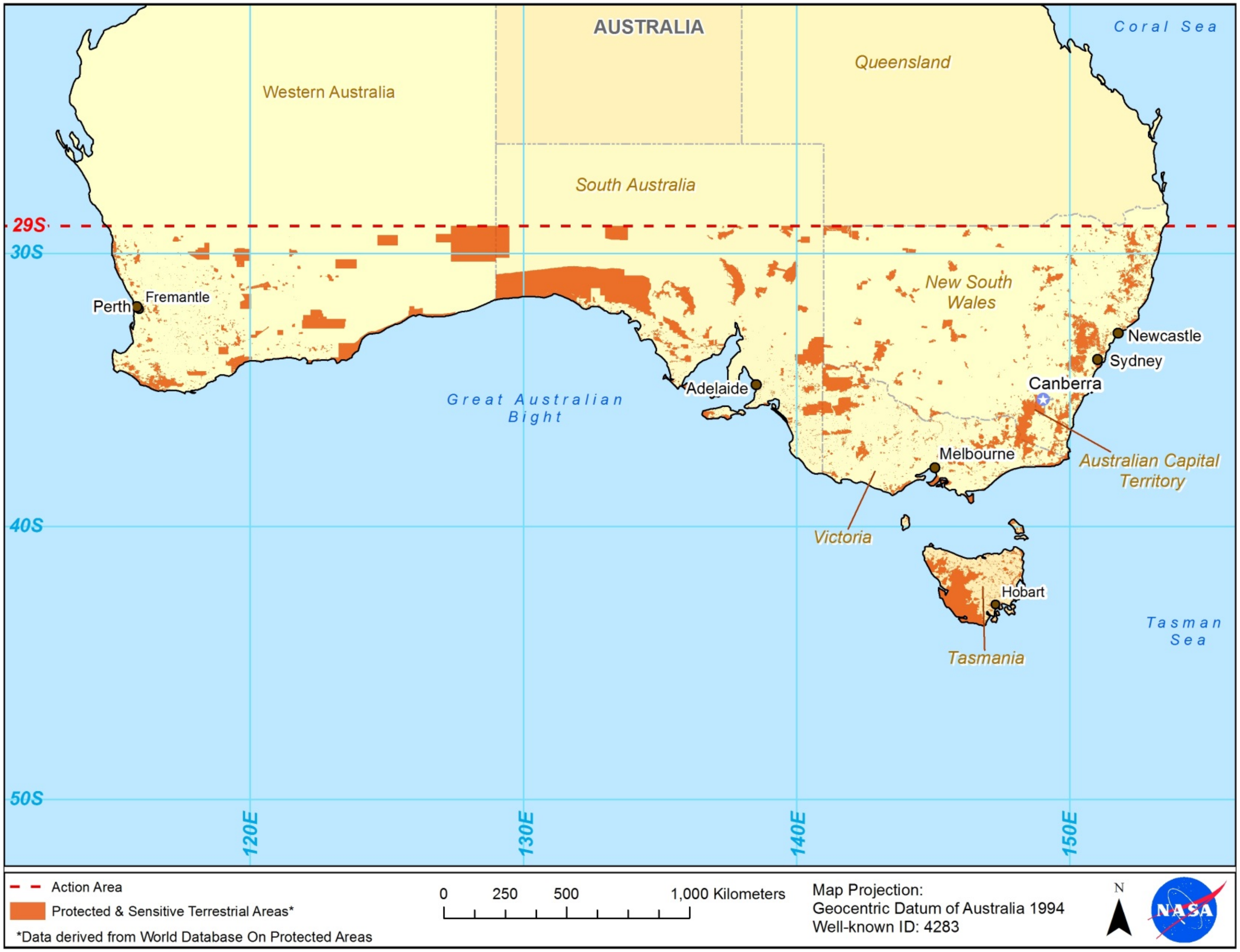

Figure B-5: Protected and sensitive terrestrial areas to be avoided during flight termination: Australia

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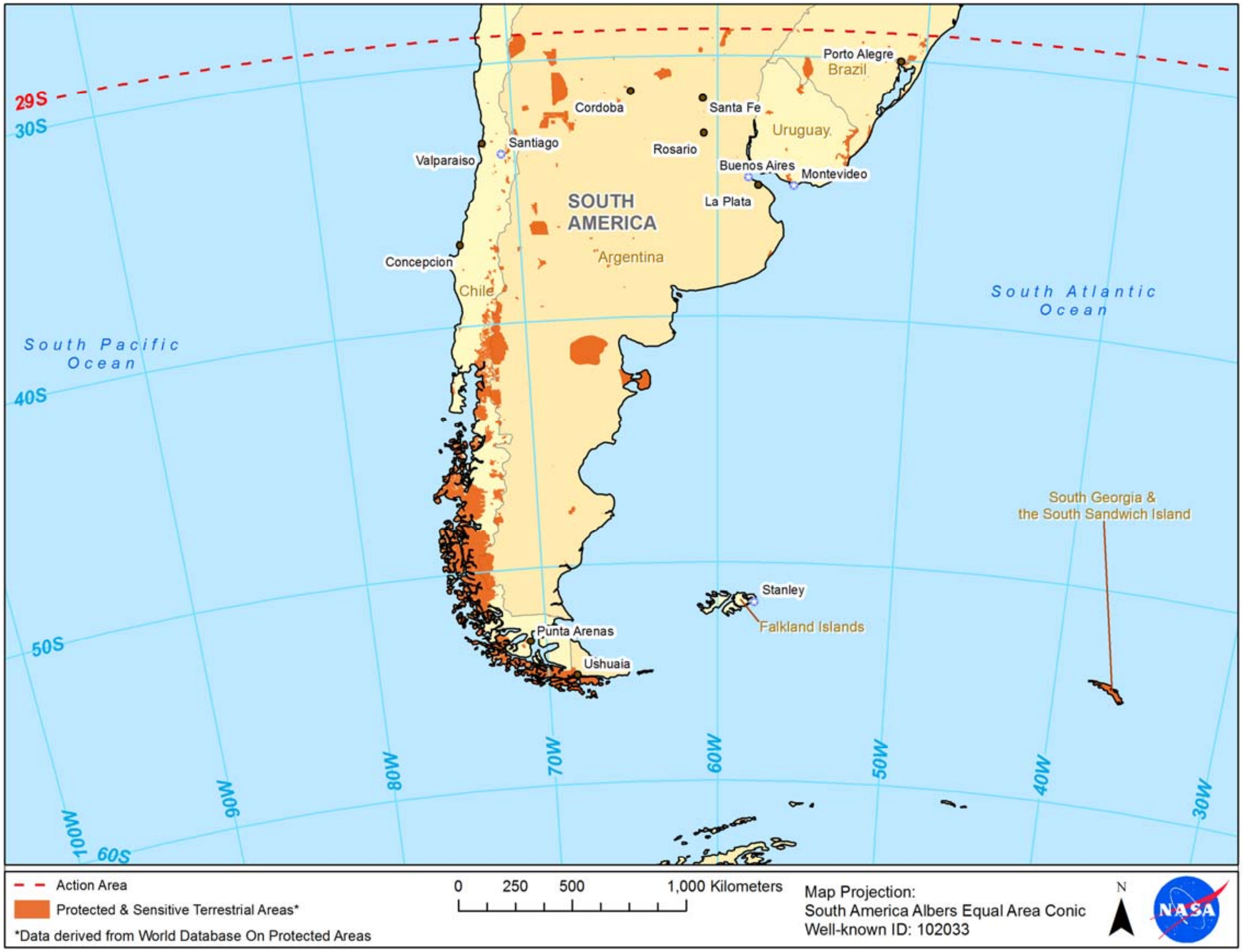

Figure B-6: Protected and sensitive terrestrial areas to be avoided during flight termination: South America

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Figure B-7: Protected and sensitive terrestrial areas to be avoided during flight termination: Africa

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Goddard Space Flight Center

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Image U.S. Geological Survey
Image PGC/NASA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO