Using unmanned aerial vehicles in Antarctica

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Introduction

While Unmanned Aerial Vehicles (UAVs) have become synonymous with military operations, particularly in Afghanistan, they have also been quietly invading the Arctic region of Earth for the purpose of science. UAVs used for scientific research come in various shapes and sizes, just like their military cousins. Some catapult from ships, others launch from running pickup trucks and some take off the old-fashioned way - from icy airstrips (Scientific American, 2010). They can carry a simple camera or a variety of scientific instruments, from radar (or lidar, the laser-based version) to chemical analysis tools and infrared sensors (Scientific American, 2010). This paper investigates:

- What the definition and purpose of a UAV is;
- A selection of UAVs commonly used for scientific research;
- What projects have used or are using UAVs in Antarctica;
- What gaps and issues are there for using UAVs for scientific research in Antarctica; and
- Future alternatives to current UAVs for data collection in Antarctica.

Definition of a UAV

An unmanned aerial vehicle is classified as a powered vehicle that does not carry a human operator, uses aerodynamic forces to provide lift, can fly autonomously or be piloted remotely and carries a payload. A remote controlled aircraft is not a UAV as it does not carry a payload (UAVS, 2011).

The U.S. military defines UAVs as capable of operating without an internal pilot, are tethered by a radio control link and are programmable for both flight and payload operations prior to launch. UAVs are sophisticated systems incorporating lightweight frames, advanced propulsion systems and high tech control systems and payloads (UAVS, 2011). Because of their sophistication, the term Unmanned Aerial System (UAS) is becoming a common alternative to the acronym UAV, however, for this paper the acronym UAV will be used. Other acronyms less commonly used for UAVs are:

- Uninhabited Aircraft Vehicle;
- Unmanned Aerospace Vehicle;
- Unmanned Airborne Vehicle;
- Unmanned Autonomous Vehicle; and
- Upper Atmosphere Vehicle (UAVS, 2011).

UAVs of the future will most likely be fully autonomous with onboard systems able to determine their location, what tasks it should be doing and the most efficient flight-path it should take to complete their pre-programmed task, with the UAV pilot just monitoring what the vehicle is doing (UAVS, 2011).

Purpose of UAVs

The collecting of data is one of the primary reasons for using UAVs. UAVs can penetrate areas and locations that manned aircraft cannot do safely without endangering equipment and life. An important aspect of UAVs is they are reusable- they come back following the completion of a mission and are redeployable (UAVS, 2011).

UAV components

A UAV is not just the vehicle itself but a composition of three elements:

- The vehicle or platform;
- Its payload; and
- Its ground-control system.

The vehicle or platform is comprised of the airframe, propulsion system, flight control system and the precision navigation system. The vehicle is the means to deliver the payload to the optimal position. Because UAVs operate at all altitudes, the propulsion system has to be tailored to the mission. For instance, UAVs operating over long distances and at high altitudes generally require jet engines. The flight control system ensures the UAV follows a precise pre-programmed flight path in the most efficient way when gathering data (UAVS, 2011).

The payload can include such instruments as optical sensors, radars and infrared systems. As the purpose of a UAV is to collect data in dangerous environments, the payload is the most important element in the whole UAV as it determines the payback of the mission. The vehicle itself does not deliver the data; it only transports the payload to the best location for data collection (UAVS, 2011).

The ground-control system contains avionic flight displays, navigation systems, system health indicators and graphical imaging and position mapping. For the pilot to control the UAV, the pilot requires constant data on UAV position and health (UAVS, 2011).

Types of UAVs

There are two broad categories of UAVs- Medium-Altitude, Long-Endurance (MALE) UAVs and High-Altitude, Long-Endurance (HALE) UAVs, where high altitude is greater than 50,000ft and long-endurance is greater than 10 hours. Table 1 shows a sample of UAVs that have been proposed or are used for scientific missions.

Table 1. Selective UAVs that have been used or proposed for scientific missions

UAV (Manufacturer)	Range (km)	Endurance (hrs)	Ceiling (km)	Payload (kg)
Global Hawk (Northrop Grumman)	25,000	36	19.8	910
Helios (Aeroenvironment)	200	15	30	16
Pathfinder (Aeroenvironment)	200	14	24.5	11
Proteus (Scaled Composites)	5,000	14	16.7	1,000
Altair (General Atomics)	4,200	32	15.2	300
Altus-II (General Atomics)	5,600	24	13.7	150
Aerosonde (Aerosonde)	3,000	30	4	5

(Visconti, Carlo et al. 2007)

Experimental projects using UAVs in Antarctica

British Antarctic Survey (BAS)

Scientists from BAS in collaboration with counterparts from the Technical University of Braunschweig (Germany) conducted the first over-flight by UAVs in Antarctica. With four lithium-ion battery-powered UAVs, each with a wingspan of 2m and weighing 6kg, the scientists conducted trials in the austral winter of 2007, followed by 20 flights between October and December 2007 including four over the Weddell Sea (Science Daily, 2008). Apart from the take-off and landing, when the UAVs are controlled by radio, the aircraft were autonomous, flying according to pre-programmed flight paths. Each flight lasted 40mins, covering 40km and taking 100 measurements a second. The UAVs carried instruments to record the exchange of heat between the lower atmosphere and sea ice (Science Daily, 2008). During the Antarctic winter the Weddell Sea freezes and because of its reflective colour, the ice reflects heat and helps cool the planet. According to BAS, because sea ice freezes and melts mainly during the Antarctic winter it is too costly and dangerous for ships and aircraft to gather data and so UAVs are best for providing data to scientists (Science Daily, 2008).

(Science Daily, 2008)

Japan Antarctic Programme

Japan's Antarctic Programme undertook experimental long-distance meteorological observations using UAVs at its Syowa Station for the first time in December 2008. The UAV, with a wingspan of 3m was radio-controlled only during takeoff and landing (Funaki and Hirasawa, 2008). During its autonomous flight, it took measurements from the surface to an altitude of 1,000m. The duration of the flight was 60 minutes covering 110km. Japan had previously used fixed-wing aircraft for its observations at Syowa Station for many years, however, the decision was made to cease operations of its aircraft due to their high maintenance costs and in the future will use UAVs instead (Funaki and Hirasawa, 2008).

Norwegian-U.S. Scientific Traverse of East Antarctica

During 2009, the Norwegian-U.S. Scientific Traverse tested the Cryowing UAV, a UAV with a range of 1,500-2,000km and a payload of 10kg. During the traverse there were three major tasks for the UAV borne sensors:

1. Expand the area of coverage of the ground penetrating radar measurements;
2. Collect high resolution aerial photography to determine surface roughness; and
3. Collect meteorological data including temperature, relative humidity and wind speed and direction.

The UAV conducted a series of 600km patterns over surrounding drill sites and the traverse path. Each pattern was undertaken over a 5-6 hour period (Norwegian-U.S. Scientific Traverse of East Antarctica, 2011).

AAI Corporation – University of Colorado

Over the period September – October 2009, AAI Corporation and the University of Colorado conducted a six-week exploration of the cold, rough katabatic winds present on the coast of Antarctica using the Aerosonde UAV. The Aerosonde UAV has a wing span of 2.9m and a range of more than 3,000km. It can stay aloft for more than 30 hours and carries a payload of 2kg (Shephard, 2009). In order to generate a highly detailed three dimensional map to study the katabatic wind's relationship to Antarctic sea ice formation, AAI's crew flew four UAVs and logged more than 130 hours over a distance of 7,000 miles during their 16 flights. The Aerosonde UAV flew in temperatures as low as -38 degrees Celsius and remained aloft for up to 17 hours during its mission to Terra Nova Bay (Shephard, 2009).

University of Canterbury Geospatial Research Centre

In November 2009, the Geospatial Unit brought to Scott Base a 13kg, 3.5m wingspan UAV for initial trials. The UAV, powered by a large electric motor and lithium-ion batteries, can carry a payload of up to 2kg (Geospatial Research Centre, 2011). During its trials, the UAV, carrying a laser altimeter coupled to a video camera and centimetric precision Inertial Measurement Unit with GPS, conducted six flights collecting data on the surface elevation of the ice along with imagery to allow visual analysis (Geospatial Research Centre, 2011).

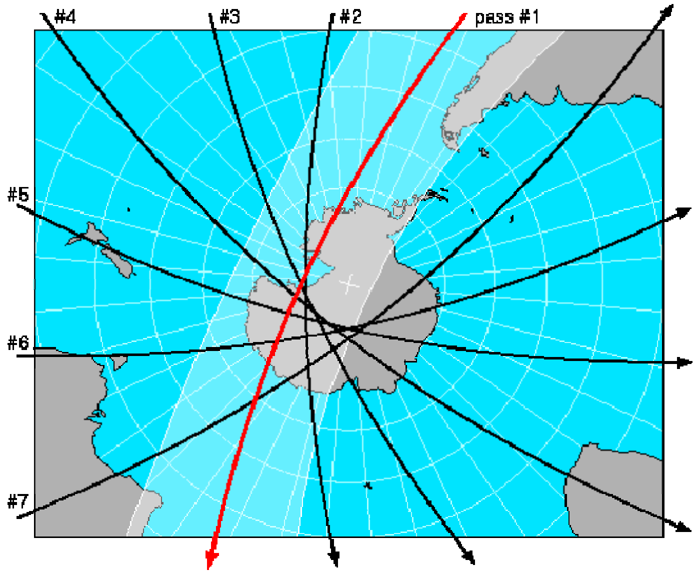
Meridian

The Meridian, a 1,100lbs 26ft wingspan UAV, developed at the University of Kansas under the Center for Remote Sensing of Ice Sheets, completed its first flight over Antarctica on December 31st 2009. The flight lasted 20mins, 14 of which was conducted through autopilot while it flew three 450m radius orbits at 120kts (Center for Remote Sensing of Ice Sheets, 2010). The Meridian has been designed to carry multiple payloads but the primary payload tested was an ice-penetrating radar unit developed at the University of Kansas. The purpose of the initial test was to assess the Meridian's capabilities in the field and verify its radar system. Once further tests are conducted, the aim is to use the Meridian operationally in both Greenland and Antarctica (Center for Remote Sensing of Ice Sheets, 2010).

(Center for Remote Sensing of Ice Sheets, 2010)

<u>What gaps and issues are there for using UAVs for scientific research in Antarctica?</u>

Satellites and aircraft have different spatial and temporal coverage and different payloads. Earth satellites are either Geosynchronous Earth Orbits (GEO) or Low Earth Orbits (LEO). GEO satellites orbit the Earth at the equator and the orbit period is equal to the Earth's rotational period (Visconti, Carlo et al. 2007). Geostationary orbits are useful because the satellite appears stationary with respect to a fixed point on the rotating Earth, therefore it can make repeated observations of the same area. However, due to its orbit being over the Earth's equator, GEO satellites cannot cover the Arctic and Antarctic regions (Atmospheric Sciences, 2011). LEO satellites are used for polar orbits and have twice-daily sun-synchronous circular orbits at altitudes of 850km, therefore providing higher resolution than GEO satellites orbiting at an altitude of just over 35,000km. However, LEO satellites cannot provide continuous viewing of one location as they orbit in a northeast pattern. This means the satellite does not pass directly over the North or South poles, thereby creating a precession in orbit so that it passes over locations further to the west on subsequent orbits (Atmospheric Sciences, 2011).



LEO satellite coverage of Antarctica (Atmospheric Sciences, 2011)

Aircraft are used by scientists for remote sensing and in-situ sampling of the Earth's atmosphere. Aircraft are used for field experiments, monitoring of natural phenomena and satellite validation (Visconti, Carlo et al. 2007). Aircraft can be used for both long-term monitoring of events spanning months to years, such as ozone levels and climate change, and short-term events with time scales of days to weeks. Aircraft can provide six to eight hours of continuous observations of one specific location. Additionally, aircraft collect higher resolution data than satellites as they fly at a lower altitude and face no restrictions on picture resolutions (non-military satellite picture resolutions are restricted to 0.5m) (Visconti, Carlo et al. 2007). Manned aircraft also enable specific flight paths to be followed and data collected. When conducting trace gas observations, aircraft provide in-situ observations with horizontal/vertical resolutions of 0.1/0.01km versus GEO resolutions of 1/5km and LEO resolutions of 10/1km (Visconti, Carlo et al. 2007). Aircraft also carry higher payloads than satellites with aircraft loads ranging from 100kg to 15,000kg versus satellite loads ranging from a few kg to 2,000kg. In addition, unlike the composition of a satellite's payload, an aircraft's payload of instruments is easily interchangeable. However, the disadvantages of manned aircraft are their short duration capabilities (less than 10 hours), modest range (< 3,700km) and the inability to fly in poor conditions (Visconti, Carlo et al. 2007).

UAVs can provide continuous coverage of areas in Antarctica missed by subsequent LEO satellite observations. UAVs can also provide the ability to validate satellite remote sensing with high-resolution in-situ observations. The short-endurance of manned aircraft means they are only capable of providing reconnaissance – high-resolution snapshots of phenomena, while the long-endurance of UAVs enables high-resolution surveillance of phenomena over long periods of time (Visconti, Carlo et al. 2007). Table 2 provides the advantages of disadvantages of UAVs compared to satellites and manned aircraft.

Table 2. UAV versus satellites

Advantages	**Disadvantages**
No complex, expensive rocket launch required	UAVs cannot reach any part of the Earth within a day
Can land to be maintained and payloads changed depending on mission requirement	UAVs cannot cover large areas rapidly like satellites that travel at 7,000m/s
Can provide high resolution polar coverage	UAVs penetrate national airspace and so require clearance
The altitude is lower so higher resolution data can be collected	Environmental impacts of UAV crashes high

(Runge et al, 2007)

Table 3. UAV versus manned aircraft

Advantages	**Disadvantages**
Use less fuel and are economically cheaper to run	UAVs have restricted payload
Can stay aloft for long periods of time providing surveillance	UAVs are unreliable and require a lot of maintenance
Can operate at higher altitudes covering greater areas and providing in-situ data collection	Costs of UAVs are high as they are still in their developmental stage
Can fly in poor conditions unsafe for manned aircraft	Vulnerable to winds during takeoff and landing

(Runge et al, 2007)

Before UAVs either replace or compliment satellites and aircraft as a means of collecting data, UAVs need to overcome susceptibility to damage from high winds and poor reliability. Just like manned aircraft, UAVs face aerodynamic constraints with tradeoffs between maximum altitude, payload, range and airspeed. The lift required for a UAV to remain airborne is proportional to the area of the wing, air density and the square of the aircraft's airspeed (Visconti, Carlo et al. 2007). The lift capability is measured by the term 'wing loading' which is the ratio of the weight of the aircraft to the area of the wings. UAVs with low wing loading have the ability to fly at higher altitudes (Visconti, Carlo et al. 2007). The drawback to low wing loading is the necessity for a large wing; however, UAVs with large wings and low weight are vulnerable to poor ground weather and cross-winds. Takeoffs with large wings are difficult as the wings act as sails and can easily lead to the UAV overturning. This creates the necessity for very calm wind for both takeoff and landing, something that is unpredictable in Antarctica (Visconti, Carlo et al. 2007). At present, UAVs are unreliable compared to manned aircraft, for instance the Predator UAV has a mishap rate of 43 per 100,000 hours (Visconti, Carlo et al. 2007). By applying this ratio to all UAVs, it means one UAV would be lost every 3,000 hours. This rate is ten times higher than current manned fighter aircraft (Visconti, Carlo et al. 2007). Therefore, UAVs require more maintenance than regular manned aircraft. However, there is still enormous potential, listed in Table 4, for using UAVs as a vehicle for data collection:

Table 4. Advantages of UAVs

Advantages	
Lower cost of campaigns	Traditional aircraft used for research requires 2-4 pilots and a ground crew of up to 15. A UAV usually only requires a staff of 2-3 people- lowering the cost of field campaigns
Science platform	The UAV is a science platform and all parameters related to both the instruments and UAV are under the control of the user, ensuring data collection is of the highest quality
Detailed flight patterns	Due to UAV's GPS navigation system and control capabilities, together with their small sizes, very detailed flight patterns can be flown.
Dangerous weather	With no human passengers, UAVs are ideal for flying in dangerous weather conditions. Because human eyes are not required for navigation, it is ideal for flying in poor visibility
Long distances	UAVs can fly up to 30 hours non-stop without the need to refuel and can travel up to 3,000km. UAVs have superior gas mileage than any manned aircraft
Slow speed	As UAVs fly at slow speeds it allows instruments onboard to collect data at a greater sampling rate than is possible on manned aircraft
High resolution data	UAVs have the ability to fly closer to the surface allowing for the collection of very high resolution data
Control software	Operators can monitor vital signals and modify the course of UAVs midflight using radio or satellites. This can be done remotely from any spot on Earth

(Maurer, 2002)

The future

High altitude long endurance (HALE) UAVs

For powered flight, the main issue of operating at high altitudes is the generation of lift in a low density atmosphere. The majority of vehicles operating at high altitudes do so by flying very fast as the speed compensates for the lack of lift from low density air. The Global Hawk UAV pushes the limit both in altitude and endurance for non-renewable energy powered UAVs. To extend the duration beyond an altitude of 60,000ft and endurance of more than 30 hours, a UAV must contain a renewable power source (NASA, 2005). There are several solar-powered UAVs in development stage currently, those being the Helios, Solar Eagle and Zephyr HALE UAVs.

The Helios is a solar-powered HALE UAV that contains a regenerative fuel cell system for energy storage. Its performance is estimated to be 21km (~ 70,000ft) – ideal for polar flights during the summer when solar energy is permanently available (NASA, 2005). To maximise available solar energy, solar panels can also be placed under the wings to collect reflected sunlight from the ground due to the high albedo in Antarctica. One main disadvantage of the Helios is its very limited payloads (NASA, 2005).

Helios (NASA, 2005)

The Solar Eagle HALE UAV is being developed by Boeing to fly at altitudes of 60,000ft with a payload of 500kg. With 400ft long wings, the Solar Eagle would essentially become a pseudo-satellite providing persistent surveillance of large areas. It is envisaged that the Solar Eagle will be able to remain aloft for over five years with no need for refuelling or maintenance (Royal Aeronautical Society, 2010). Without the orbital constraints of satellites, the Solar Eagle would provide flexible, expandable and relocatable data collection at a fraction of the cost of a dedicated satellite (Royal Aeronautical Society, 2010). The challenge, however, will be to design a light yet durable enough wing that can withstand bending and twisting in strong winds. In addition, solar cell reliability and energy storage capacity will need further development if it is to operate continuously unrefueled for over five years (Royal Aeronautical Society, 2010).

In 2009, the UK defence company QinetiQ tested the Zephyr, an ultra-lightweight solar-powered HALE UAV. With a wingspan of 26m and a 2.5kg payload, the Zephyr remained airborne for over two weeks while reaching a record altitude for UAVs of 70,740ft. With solar-charged batteries, the Zephyr has the ability to collect and store solar energy extending its endurance (Royal Aeronautical Society, 2010). The key to the Zephyr being able to remain airborne for long periods of time is its ability to cruise at low speed at high altitude. The design provides low wing loading and low drag minimising energy consumption. In addition, the Zephyr has high propulsion efficiency limiting the amount of energy required to maintain flight (Royal Aeronautical Society, 2010). The onboard avionics have also been designed to require minimal amounts of power during flight. Currently, the Zephyr is designed to carry a payload of only 2.5kg in a nose pod or within the wing. But it is still only a concept HALE UAV and with stronger materials available for its wings and more efficient power systems, it is likely in the future it will be able to carry heavier payloads (Royal Aeronautical Society, 2010). Nonetheless, due to power constraints any scientific instruments onboard will need to be lightweight and extremely energy efficient, potentially increasing the cost of data collection compared to standard aviation gas powered UAVs (Royal Aeronautical Society, 2010).

Zephyr (Airforce-Technology, 2011)

In addition to solar-powered HALE UAVs, Boeing has developed a hydrogen-powered HALE UAV prototype called Phantom Eye. The first HALE UAV to use liquid-hydrogen as its fuel, the Phantom Eye is expected to carry a payload of 250kg, reach an altitude of 65,000ft and remain aloft for over four days (Royal Aeronautical Society, 2010). The key to its performance is the propulsion system containing liquid hydrogen-fuelled 2.5L truck engines and turbochargers. With a 150ft wingspan and two engines, the Phantom Eye would be able to maintain a persistent presence over a selected area (Royal Aeronautical Society, 2010).

Airships

Lighter-than-air vehicles are currently used for either high altitude or long-duration missions. For instance, weather balloons carry heavy payloads and operate at altitudes of 36km (120,000ft). However, weather balloon flight paths are uncontrollable and only operate for short durations (NASA, 2005). For stationary observations, aerostats are secured to the ground with a tether cable and rise up to 5km carrying heavy payloads for up to one week. In order to reach much higher altitudes of 18km, there needs to be an improvement in tether materials to produce a strong enough cable that is also light (NASA, 2005). There is though potential to develop airship UAVs for scientific research particularly over Antarctica as no aircraft, apart from airships, can carry large payloads at high altitudes and remain aloft for months on end. At an altitude of more than 18km, airship UAVs can provide long-term surveillance of a wide area. They can loiter in specific areas and when required move to another area in a short time frame (NASA, 2005). Because airship UAVs would use buoyancy for its lift it would not require as much power as an aircraft which derives its lift by propelling itself through the atmosphere. By creating a renewable energy-powered airship UAV, it can endure flight durations of months on end. Power sources could potentially be combined to extend endurance, for instance there could be a combination of lithium-ion batteries with hydrogen fuel in addition to flexible photovoltaic cells blanketing the upper part of an airship UAV (NASA, 2005).

In recent years Northrop Grumman has been developing a Long Endurance Multi-Intelligence (LEMV) UAV airship. The airship will have the ability to carry a payload of 500kg, stay aloft for 21 days and reach an altitude of 20,000ft. Meanwhile, Lockheed Martin has been developing High Altitude Airships (HAA). The HAA is an untethered, unmanned airship that will operate above the jetstream, at an altitude of 60,000ft, in a geostationary position. At this altitude, maintaining a geostationary position is possible because of minimal wind conditions (Gizmag, 2009, Lockheed Martin, 2011). From that height, the HAA will be expected to remain airborne for up to 10 years while surveying a 970km diameter area and associated airspace (Gizmag, 2009). For the airship to remain aloft for this period of time, the HAA will be powered by solar panels with lithium-ion batteries storing energy for instruments and propulsion units. The benefit of a geostationary HAA is it offers the same capabilities as a satellite but at a fraction of its cost. Additionally, by operating in the stratosphere, the HAA can provide higher resolution data than satellites.

High altitude airship (HAA) (Gizmag, 2009)

Discussion and conclusion

The main benefits of using UAVs versus satellites is they can provide surveillance of one particular region in the Antarctic for long durations of time, gather higher resolution data than satellites can as they fly in the stratosphere and are much cheaper to launch. The main benefits of using UAVs versus manned aircraft in Antarctica is UAVs provide access to areas day or night, year-round in any weather conditions. Because UAVs can fly lower than manned aircraft and follow highly detailed flight paths they collect higher quality data at greater resolution. The UAVs also have a lower environmental impact on the atmosphere as they are more efficient at fuel consumption then manned aircraft while solar-powered UAVs have no emissions at all. Because UAVs can fly from any location to their target destination there is no ecological footprint of having planes and crews located in Antarctica to launch operations from. Therefore, the financial expense of maintaining crews on bases in support of manned aircraft missions is removed as the maintenance crews and pilots of UAVs can be anywhere in the world. Because of rising fuel prices, it is likely in the future that manned aircraft missions will place an unsustainable financial burden on national Antarctic programmes and UAVs will likely be the best replacement. The drawback of UAVs today – small payloads will likely be resolved with technology ever decreasing the sizes of instruments. In the future, UAVs will likely carry a greater array of instruments as technology reduces in size the bulky instruments available today. Materials used for the UAVs are likely to become stronger and less prone to wind damage. Nonetheless, it is likely that UAVs will fly to and from Antarctica rather than be launched from the ice, so less emphasis will be placed on the strength of the materials used as the UAV will fly above the weather systems in the stratosphere. Solar-powered HALE UAVs have the potential to provide larger data sets at higher resolutions for longer durations than manned aircraft and satellites. Solar-powered HALE UAVs can also avoid the weather systems as they fly in the stratosphere. They can also gather data in-situ while hovering over a specific location for months and even years on end. Solar-powered HALE UAVs are also cheaper to launch then satellites and due to their long airborne durations cheaper to maintain. There is the potential for UAV airships to be used for data collection in Antarctica and even replace satellites as they can carry large payloads and maintain a geostationary position – something satellites are unable to do in polar regions. Airships also cost only a fraction of what a satellite costs and can be manoeuvred in a short period of time to a different location while providing higher resolution data. Finally, rather than having scientists on the ground in Antarctica collecting and analysing data from UAVs and airships at great cost, the scientists can be anywhere in the world processing the data resulting in the saving of transport, base and accommodation costs associated with travelling to Antarctica.

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