

Running PILOT: operational challenges and plans for an Antarctic Observatory

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ABSTRACT

We highlight the operational challenges and planned solutions faced by an optical observatory taking advantage of the superior astronomical observing potential of the Antarctic plateau. Unique operational aspects of an Antarctic optical observatory arise from its remoteness, the polar environment and the unusual observing cycle afforded by long periods of darkness and daylight. PILOT is planned to be run with remote observing via satellite communications, and must overcome both limited physical access and data transfer. Commissioning and lifetime operations must deal with extended logistics chains, continual wintertime darkness, extremely low temperatures and frost accumulation amidst other challenging issues considered in the PILOT operational plan, and discussed in this presentation.

Keywords: telescope operations, Antarctica, observatory logistics

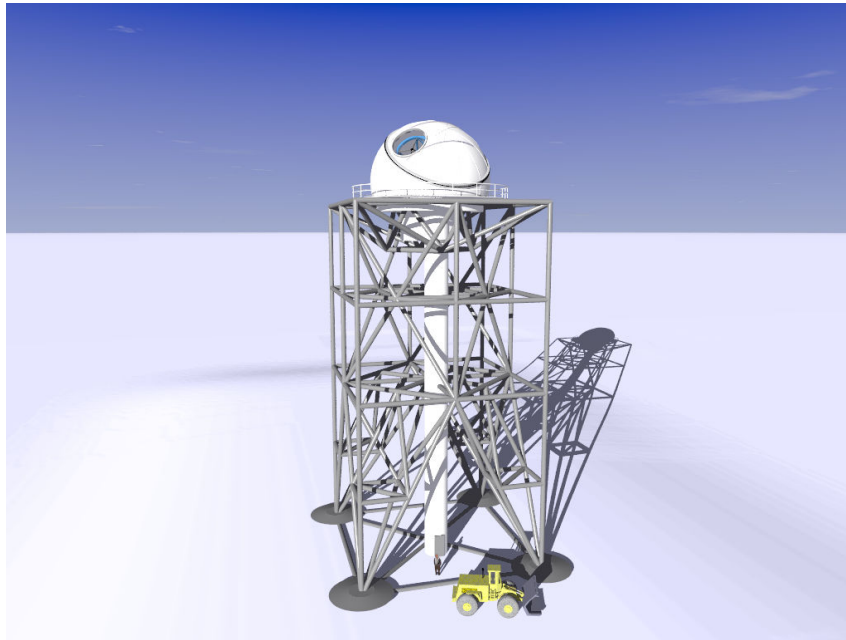


Fig. 1. PILOT is planned as a 2.4m wide field optical/NIR telescope, with two nasmyth foci. Seeing effects are dominated by the lowest 30m or so of the atmosphere, so the telescope is mounted atop a tower to avoid this. The PILOT facility must comprise much more than just the telescope, enclosure and tower components.

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1. INTRODUCTION

PILOT, the Pathfinder for an International Large Optical Telescope, is a proposed 2.4m aperture, diffraction-limited optical/NIR/mid-IR telescope for Dome C on the Antarctic plateau¹. Figure 1 shows the conceptual arrangement, with more details of the telescope discussed in Saunders *et al.* (2008)². It is intended to take advantage of the remarkable seeing and sky brightness conditions of the site³.

The unique characteristics of the site impose difficulties as well as advantages. The Anglo-Australian Observatory is presently working with the University of New South Wales to undertake a conceptual design study for PILOT for feasibility, costing and risk assessment purposes. In order to properly capture the full lifetime facility cost, it is necessary to investigate and plan the operations of the facility as well as the telescope itself.

2. DOME C

Dome C on the Antarctic plateau (Fig. 2) is the intended site for the PILOT telescope. It is amongst the coldest and driest places on earth, within the Australian Antarctic Territory, and is the site of Concordia Station, a permanently occupied French/Italian research station⁴. At 75.12°S, 123.37°E and an elevation of 3250m AMSL, it is roughly 1200km equidistant from Australia's Casey Station, and from the French Dumont d'Urville station, from where Concordia is presently supported. Although Concordia Station is now permanently inhabited, with typically 12 wintering staff, access is limited to a very limited summer season when overland traverses and aircraft are able to reach Dome C from the nearest coastal stations.

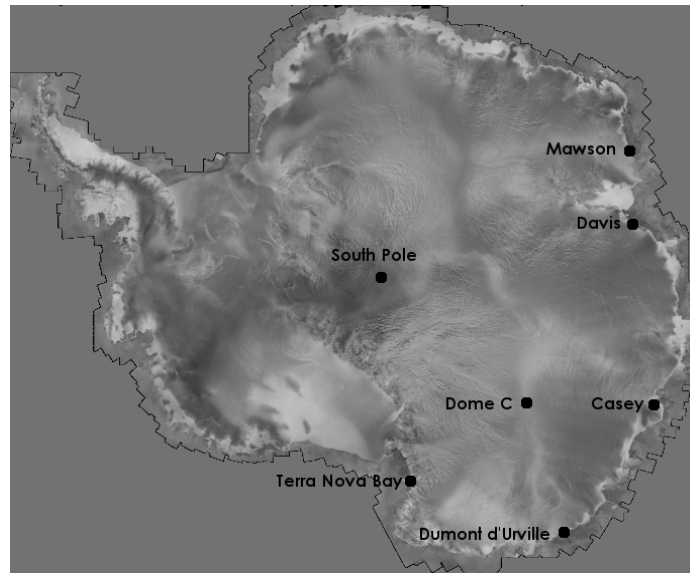


Fig. 2. Location of Dome C, approximately 1200km equidistant from Terra Nova Bay, Dumont d'Urville and Casey stations.

3. ANTARCTIC CHALLENGES TO OPERATIONS

3.1. Temperature and humidity

As mentioned previously, Dome C is particularly cold. An automatic weather station (AWS) set up at Dome C by the University of Wisconsin provides year-round temperature, pressure and wind data. Its temperature sensor is mounted some 3m above the local ice surface. Fig. 3 shows temperature throughout 2006 as being below -60°C for extended periods in winter, and reaching as low as -80°C. A strong diurnal cycle is apparent when the sun is up, and even in deep winter rates of change of temperature can be high.

The design challenges caused by these absolute values of temperature are dominated by the continued performance of lubricants; mechanical clearances that may change due to thermally induced dimensional changes; and the operation of electronics designed for room temperature operation. However, all of these are quite readily overcome with proper mechanical design, so long as the designer bears the temperature requirements in mind. The high rates of change of temperature can be more problematic, especially for components with high thermal mass and tight thermal equilibrium requirements – notably, the primary mirror. Active thermal control has been considered, and unconventional mirror substrates with low thermal mass (e.g. silicon carbide), but current indications are that a relatively conventional lightweighted zerodur primary mirror will have adequate thermal performance².

Although the low air temperature necessarily results in extremely low absolute humidity, measurements show a high incidence of supersaturation, with relative humidity reaching in the order of 105%. This extraordinary condition poses one of the greatest technical challenges to PILOT, since in such supersaturation frost will deposit even on a surface that is at or very slightly above ambient temperature (such telescope optics in thermal equilibrium, as required to control mirror seeing). The proposed technical solution is to dehumidify the air surrounding the telescope, with an airconditioned enclosure ventilated with dehumidified air, as discussed in Saunders *et al.* (2008)².

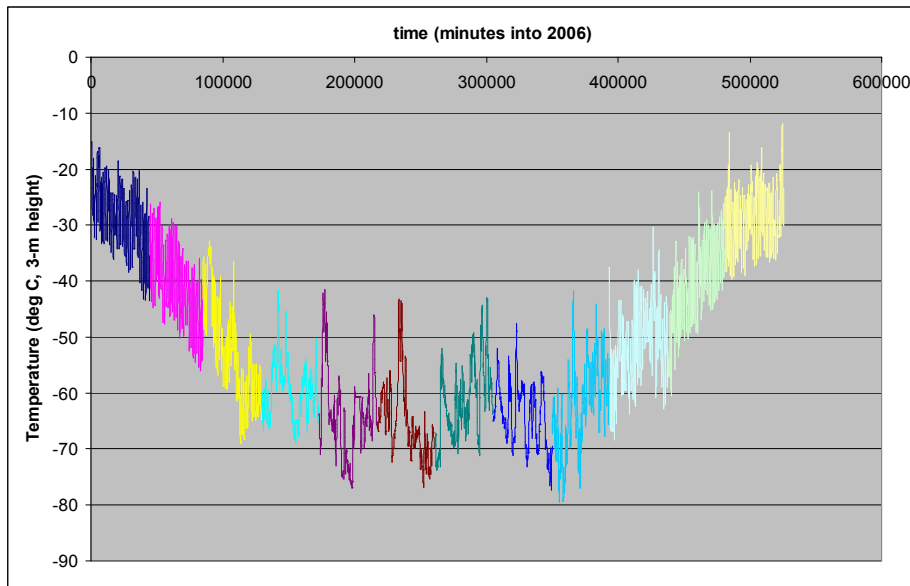


Fig. 3. Data from the University of Wisconsin AWS at Dome C, showing temperature throughout 2006.

3.2. Physical access

Being so remote from the major Antarctic coastal stations, and with extreme low temperatures and limited natural light for much of the year, access to Dome C is possible only for a relatively short (~10 week) season in summer each year. Access is by air or traverse, with three traverses annually supporting Concordia from Dumont d'Urville, carrying some hundreds of tonnes of supplies on sleds pulled by tractors (Fig. 4, Fig. 5). A traverse may take 10 to 14 days to cover the necessary 1200km.

Air access is quite fast but limited in capacity. The Australian Antarctic Division can use CASA C212s from Casey, which have capacity to carry to Dome C ~3 people, each with 55kg baggage, in just a few hours. Other countries use Twin Otter aircraft, which can deliver slightly larger loads to Dome C. Australian flight operations run from November to the end of February. The same access period applies to larger air services, such as the regular Airbus service from Australia to Casey. Air transport is the favoured option for carriage of the telescope data, since a whole year's data is expected to fit comfortably on just a few hard drives and easily carried.



Fig. 4. Caterpillar D7 traverse-type tractor, at AAD for refurbishment.



Fig. 5. 20 tonne sled (this one without suspension). 3 x 7m bed, tare mass 7 tonnes.

More significantly than the ability to transport the required equipment and people, the working season for commissioning crews is very limited. All commissioning work needs to fit between November and February while conditions are balmy enough for safe outside work, and the people comprising the larger commissioning team need to be able to travel out from Dome C before the accessibility period ends. Concordia Station includes a summer camp able to accommodate more than 40 additional staff.

During the major commissioning phases of the project, we anticipate a requirement to transport in the order of 300 tonnes of equipment over two seasons, and dedicated traverses are the only option. After the initial telescope commissioning, traverse-based transport will still most likely be necessary, for fuel as well as carriage of new instrumentation.

3.3. Power supply

Power is required not just for the PILOT telescope itself, but also for the enclosure with air conditioning system; telescope instrumentation; a meteorological monitoring system; local and satellite communications equipment; computer equipment for operations, data reduction and archiving; operator accommodation; and assembly/integration equipment. The largest single component of the PILOT power budget is heating for the enclosure air conditioning system, required to suitably dehumidify the air immediately surrounding the telescope. The total load from these components is estimated to average 20kW, assuming that waste heat (particularly from the telescope instrumentation's cryocoolers) can be effectively used in providing some to the required air heating for the enclosure air conditioning.

It is planned to site the PILOT telescope some 500 to 1000m from the Concordia Station buildings – far enough to minimise light pollution and RF interference, and yet close enough to allow power and communications cables connecting to the Concordia infrastructure. Mere connection to the Concordia power system, however, does not absolve PILOT of providing its own power supply, since PILOT is expected to consume a significant fraction of the total Concordia power budget. The intention is to increase the capacity of the existing Concordia power supply capacity in line with PILOT requirements. PILOT power loads are then drawn from the Concordia supply. This allows maximum advantage to be taken of economies of scale and greater load sharing of a larger installation.

Power at Concordia Station is presently provided by a set of three diesel generators (Fig. 6). Although these generators are rated sufficiently to deliver in the order of 375kW, in practice available power is limited by the supply of diesel. Diesel needs to be brought in to Dome C by tractor traverse from coastal stations – presently the regular traverses from Dumont d’Urville bring some 50,000 to 100,000 litres annually. Fuel consumption of the generators is approximately 0.3 litres per kilowatt hour of electrical energy delivered.



Fig. 6. A set of three 125kW diesel generators provide the electrical power for Concordia Station. (photos - IPEV)

Thus, power capacity is limited by the carriage of the fuel for the existing generators, rather than the generators themselves which have plenty of spare capacity for peak loads. We believe that current logistics support to Concordia (the traverses from Dumont d’Urville) is presently near maximum capacity for delivery of diesel and so the substantial additional requirements of PILOT will need to be met with additional provision of energy, either by more traverses with extra diesel, or with alternative generation capability such as a photovoltaic array or wind turbines.

Transport costs of diesel for this purpose means that simply traversing more fuel to Dome C to provide for PILOT’s 20kW mean load would cost in the order of USD250k annually, and this is certainly a possible option.

Alternatively, PILOT could fund a supplement to the Concordia power supply system by installing a solar powered photovoltaic array. This would provide some part of the summertime load of the station, reducing the diesel burnt at that time and allowing the extra required fuel burn required for PILOT’s needs through the winter.

At any site on Earth, the sun is above the horizon approximately half the time (on average throughout the year) – 4380 hours of direct sunlight annually. Dome C meteorological observations yield an assessment of 80% availability due to cloud, giving 3500 productive hours of sunshine. We estimate our PV array performance, taking in account the low temperature and varying solar incidence onto a vertically-mounted panel, based on experience from the PLATO site testing observatory located at Dome A (Fig. 7 left). PLATO uses panels nominally rated at 165W, and each of these delivers approximately integrated ~2kWh per day when the sun is up – a mean production of 83W, or 50% of rated power.

To fully offset a 20kW PILOT power requirement, we would need a 100kW PV installation delivering an equivalent of 3500 hrs at 50% rated power in a year.



Fig. 7. Alternative power supply options. (left) - Photovoltaic array installed for PLATO, a site testing observatory at Dome A. This nominally 1kW installation uses six panels each rated at 165W, and delivers approximately 200W mean power, integrated over a year (photo - Xu Zhou and Zhenxi Zhu, PLATO deployment team). (right) - One of two 300kW wind turbines at Mawson. (photo – AAD)

The cost of a solar power array is dominated by the panel cost – in 2008, this is approximately \$8k per kW. An installation rated at 100kW would therefore cost approximately \$800k. Such an installation would require 600 panels of 165W each, with a total collecting area excess of 750m², and a total panel mass approaching 10T.

Irrespective of the size of a solar array installed at Dome C, these figures lead us to expect a three year payback period on cost alone from the savings in diesel. Note that a solar installation could be purchased and installed progressively – a potentially attractive options, especially considering that the electrical loads of PILOT will likely increase through its operating life as instruments with larger detector arrays are brought online.

The solar option has another significant non-monetary advantage in the public and political acceptability of alternative energy systems, compared with burning many more tonnes of fossil fuel.

Although Dome C is widely described as one of the calmest places on Earth, wind turbines may also be a competitive solution for PILOT power requirements, carrying the advantage that the power is delivered year-round rather than only while the sun shines. Wind turbines have been very successfully employed on a large scale in Antarctica by the AAD at Mawson (Fig. 7 right). Accordingly, we consider the possibilities of supplementing the Concordia power system with wind generators.

Power in the wind is $\rho Av^3/2$ (ρ is the air density, A the cross sectional area of the flow swept out by the rotor, and v the wind speed). Note that the reduced air density at Dome C further compromises the utility of wind generators compared with a site near sea level. Note particularly that the power goes up as the square of the rotor diameter and as the cube of the wind speed.

Our strawman generator has a 6m diameter rotor, as we can imagine units of this scale being relatively easy to transport and install at Dome C without substantial lifting and handling infrastructure. Modern wind turbine rotors have efficiencies near 35%. The usable power output for a 6m diameter, 35% efficient turbine would only be 120W at Dome C's mean wind speed as measured by the UWisc automatic weather station at Dome C. However, the AWS records the wind speed less than 3m above the surface, and so elevating the wind turbines will give a substantial improvement. The cubic relation of power with wind speed also means that we need to integrate the power delivered against the long term power spectrum of the wind.

Integrating over the 2006 AWS data, we find that a 4.8kW-rated wind generator is required to accommodate peak generation loads when winds may reach 10 ms^{-1} , and our strawman wind generator would be expected to contribute 2.56MWh of energy – the equivalent of burning 768 litres of diesel each year, at a cost approaching \$4000 per year, even based on the pessimistic low-level AWS winds. If the wind speeds were typically increased by 60% by mounting the turbines at 10m rather than 3, then a further factor of four is available in delivered power. Commercial wind turbines of this type cost approximately \$20k uninstalled. If installation costs and the costs of customizing for an Antarctic installation can be managed, this may become a very attractive option, able to supplement the Concordia power supply year-round.

We note that the Dome C PILOT power supply application lends itself to staged implementation and could take advantage of a mix of solar, wind and traditional diesel technologies to offer a robust system solution. Budgetary constraints may make it preferable to only partially implement wind or solar components, deferring the higher future operating costs to an operating budget. Any level of implementation of a solar or wind installation will carry proportionate benefits, with residual PILOT consumption provided by increased shipment of diesel to supplement the Concordia Station capacity. A rigorous evaluation of solar and wind turbine options is planned for PILOT's detailed design phase.

3.4. Communications

No optical fibre or other land-based communications line exists between Dome C and any other Antarctic station, or indeed between Antarctica and the rest of the world. All data communication is either via satellite, or by the carriage of physical media. At present, there are really only two options for satellite communications – use of the Iridium mobile phone satellites, or of geostationary communications satellites (such as the Inmarsat or Intelsat systems). Either is somewhat problematic for a high bandwidth Dome C requirement, as would be required to operate PILOT as a conventional telescope.

The Iridium network offers essentially continuous coverage, but this system is primarily designed for voice communications rather than data. An Iridium channel, costing approximately \$1 per minute while it's used, supports a maximum data rate of only 2400 baud. While this bandwidth can be used for transmission of small amounts of data, sending full frames of science data from astronomical instruments are out of the question, as is running an effective remote desktop type of application for remote low level control of the telescope.

Dome C's latitude is what makes the more traditional satellite communications difficult. These satellites are in geostationary orbits, always approximately 35,000km above the equator. Since Dome C is 75° north, this means that the communications satellites are always very close to the horizon, resulting in significant signal reception difficulties. Concordia Station experience is that Inmarsat ground terminals can be made to work, but only intermittently, with high bandwidths of a hundred or so kbps available for a few hours each day. Intelsat is another geostationary satellite option that can currently provide 128kbps connectivity, but unfortunately the orbit of this satellite is planned to be changed in the near future and will no longer be available from Dome C.

The promising option is an Iridium broadband service planned for rollout later in 2008. This promises up to 128kbps continuous connectivity to Dome C. The cost model for this service is based on data volume, and it will almost certainly still not be possible to transmit all PILOT raw data.

Any satellite communications system will also incur a significant round trip delay time of a few seconds. This has implications for data communications protocols, both for interactive access and large file transfer, although solutions are available.

4. OBSERVING MODEL

4.1. Queue based robotic observing

We note that the main science cases identified for PILOT^{5,6} are dominated by surveys, with some expectation of relatively rapid opportunistic observations of a well-defined type (gamma ray burst followup observations). This effect results from the biggest observing advantages of Dome C over temperate sites, with extremely good seeing allowing high resolution imaging over a wide field of view.

Large surveys are well suited to queue-based observing, and this well suits the limited communications options available to Dome C. Indeed, it is an expectation that telescopes and instrumentation on the Antarctic plateau in general will be well suited to robotic operation^{7,8}.

Accordingly, for routine observing, PILOT is planned to be operate robotically, in a queue-based mode, with an intelligent queue scheduler local to the telescope and responsive to variations in observing conditions. Observers use PILOT's observing support tools to generate observation scripts which are quite compact, and these are transmitted via satellite to the PILOT Observatory control system at Dome C. Switching between instruments under the robotic control will be limited to those instruments that can be selected by the movement of mirrors (such as by rotating the tertiary mirror to select between the two nasmyth ports). Instrument exchanges involving physical exchange of large components may well be limited to the summertime working period or other planned maintenance periods, and so available instrument sets will need to be planned seasonally.

The limited communications bandwidth discussed above makes it quite impractical to transmit all the data collected, or even any really large files. The proposal is to archive all the data locally, and transmit only sufficient reduced data and reports to provide assurance that the system is functioning properly with the expected performance. An automated or semi-automated data reduction pipeline will provide some measure of analysis of all imaging data in order to identify transient objects for possible followup, sending back reports for astronomer perusal. The full archive is physically carried out each year when transport is available.

4.2. Organisational structure

Should development go ahead, the PILOT facility will be commissioned and operated by the Anglo-Australian Observatory as part of its role to operate Australia's major national optical astronomical facilities. A basic system design assumption is that PILOT will share some of the Concordia Station infrastructure. One of the six wintering Concordia scientists will have responsibility for PILOT local operational support.

Across the PILOT organisation, the following staff roles are required. Note that this list is intended to identify required functional roles, and that many of these will require less than a full time person, so this list will not map one-to-one to people. In many cases, several roles can be handled by one person.

- PILOT Board (board structure TBD)
- PILOT TAC
- PILOT Director
- PILOT Operations manager
- PILOT Astronomer
- PILOT Instrument scientist
- PILOT Technical support staff
 - Dome C PILOT facility manager
 - telescope engineer
 - instrument engineer
 - logistics officer
 - communications officer
 - OH&S officer
- Environment officer
- PILOT Telescope scientist
- Concordia liaison
- AAD liaison
- PILOT organisational support staff
 - secretarial support
 - Ops Centre buildings manager
 - IT support
 - Accountant
 - Public relations
 - Personnel manager
 - Legal advisor
- PILOT Dome C operator

- PILOT Commissioning/Maintenance team

4.3. Lifetime facility upgrades

As with most observatories (including extremely remote facilities such as the Hubble Space Telescope), PILOT will be commissioned with only a subset of the expected instrument suite, with new instruments commissioned during the life of the facility. Part of the conceptual design of the PILOT facility is a proposed instrument suite which would be delivered in stages with an annual upgrade cycle. It is likely that beyond this initial suite, other instruments and capabilities as yet undefined will be proposed and folded into the upgrade cycle.

The organisational structure of the PILOT facility supports this upgrade philosophy. The PILOT board, responding to facility development plans initially formulated during PILOT design phases and subject to review and further development during the PILOT lifecycle will initiate procurement of instrumentation and other upgrades from vendors outside the PILOT structure. These vendors could include the AAO, Australian or partner country universities, or other organizations with the capability to develop astronomical instrumentation and a desire for PILOT involvement.

5. PILOT CONCEPTUAL DESIGN

5.1. Functions and subsystems

Running PILOT involves a wide variety of tasks, identified in Table 1. Based on these functional requirements, the PILOT system architectural concept design is shown in Fig. 8, indicating major subsystems and their interfaces.

Table 1. Functional roles of PILOT operational infrastructure.

Training support and planning	
Logistics support and planning (transport)	Consumables to Dome C Spares to Dome C New equipment to Dome C Waste from Dome C Equipment from Dome C (decommissioned or for refurbishment) Personnel to and from Dome C
Logistics support and planning (consumables)	Fuel, lubricants, filters, seals, wire, solder, batteries, minor maintenance supplies, cleaning fluids, wipes, storage media, tape, ties, etc. for Dome C. Office supplies for PILOT office
Logistics support and planning (accommodation)	Winter and Summer staff at Concordia
Logistics support and planning (waste management)	
Maintenance support and planning	Preventative and restorative for Dome C facilities Facility upgrade cycle Maintenance of stores (Dome C and PILOT office)
Communications support and planning	Monitoring of requirements Local communications around Dome C site Comms link between Dome C and PILOT office (high and low bandwidth) Comms between PILOT office and community
Data handling support and planning	Dome C archive Live data transfer Archival transfer PILOT office archive PILOT partner astronomers' use Community release and public archive
Observing preparation support	Provision of observing preparation tools to client astronomers Receipt of observing time applications from client astronomers Processing and review of observing time applications from client astronomers Scheduling of observations (queue preparation) Instrument exchange
Observing support	Telescope and instrument operation

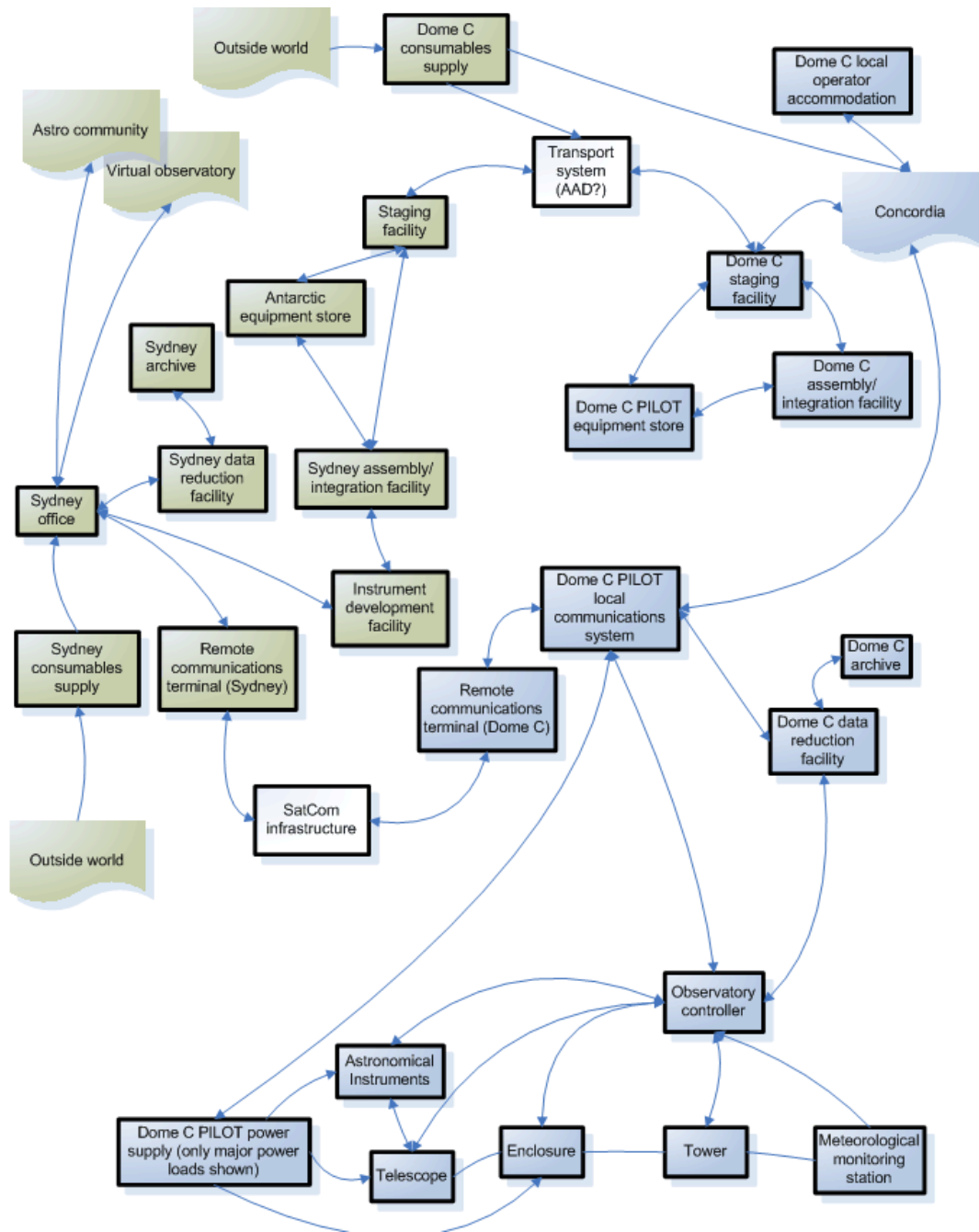


Fig. 8. Subsystem breakdown of the PILOT facility.

5.2. Commissioning

The limited working season available at Dome C makes it unrealistic to install and commission all PILOT components in a single year. Even the following proposed three year plan may be somewhat ambitious, but there are several strategies that can ameliorate the difficulties.

To a much greater extent than facilities at temperate sites, it is critical that PILOT systems be thoroughly tested and integrated before shipping to Antarctica. This includes the major structures (telescope, tower, etc). Effective simulators will also be needed to allow thorough testing of subsystems. Development of PILOT systems will be scheduled in order to fit with the commissioning schedule outlined in Table 2.

Table 2. Draft commissioning schedule for PILOT facility.

Year 1	Year 2	Year 3
<ul style="list-style-type: none"> • basic infrastructure setup (team accommodation, communications infrastructure, power supply, equipment handling) • site preparation • temporary(?) equipment protective accommodation • site communications • tower assembly • meteorological monitoring station 	<ul style="list-style-type: none"> • install other observatory building(s) • dome assembly • telescope assembly protective enclosure • telescope assembly • telescope test • telescope installation • instrument installation (commissioning imager only) • alignment, telescope tuning, TCS parameter setup • acceptance test 	<ul style="list-style-type: none"> • Science survey instrument commissioning

5.3. Decommissioning

The systems engineering process explicitly addresses all stages of a system’s lifecycle, including decommissioning and disposal. Legislated responsibilities for Antarctic operations also require such consideration.

The PILOT facility has a nominal ten-year operational lifetime, although if the facility is successful then it seems likely that the life would be extended. Possible uses for the facility hardware may exist beyond PILOT, for example the telescope could be used as part of an optical, infrared or submillimetre interferometer.

At whatever future time the PILOT facility is subject to decommissioning and removal, the dismantling and carriage out of the structures will be a broadly similar exercise to the carriage in for commissioning. A series of traverses will carry the equipment across the ice to a coastal station, where it will be loaded onto ships for return to Australia and disposal.

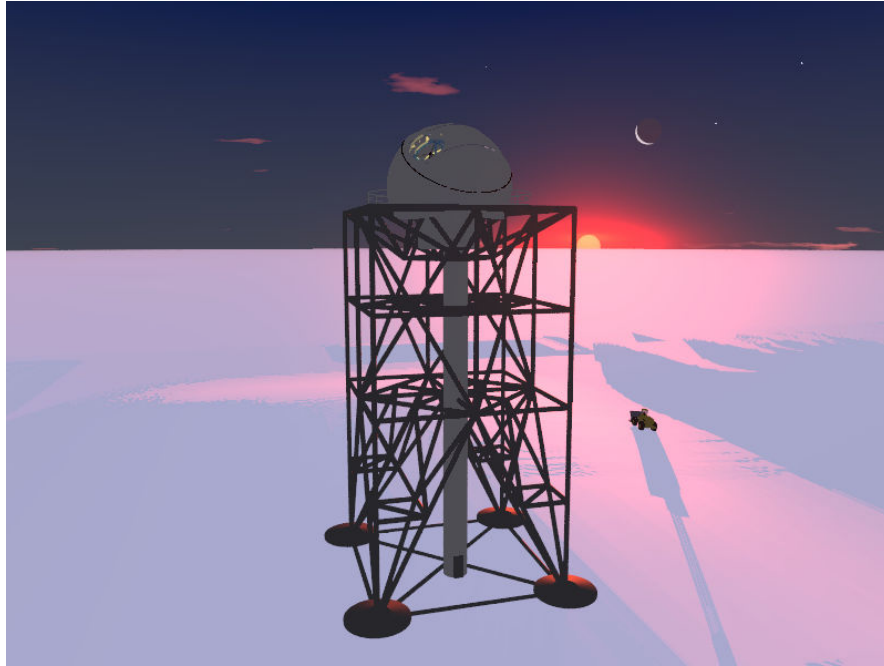
Site restoration does not pose any particular difficulties, as all structures are supported on compacted ice bases, and ice grooming equipment can restore the surface after removal of all equipment.

If the equipment is subsumed into a future facility such as an interferometer, then legal responsibility for decommissioning and site restoration is transferred to the operator of the new facility.

6. CONCLUSIONS

Describing PILOT as ‘a 2.4m telescope for Antarctica’ falls a long way short of capturing the scope of the PILOT facility. Running any observatory involves a wide range of tasks and functions, and an organisational structure to support it. The extraordinary atmosphere of the Dome C site that make it attractive for optical/NIR astronomy also makes it difficult to build and operate an astronomical facility. Even allowing for sharing infrastructure and logistics support with the existing Concordia Station, a substantial part of the overall PILOT project is devoted to logistics and infrastructure, and these aspects are fundamental to the operating model and become important design drivers.

The limited communications capabilities drive the PILOT telescope to robotic, queue based observing, and somewhat uniquely, the full quantity of raw data collected will only become available annually when physically transported out. The seasonally limited access strongly constrains commissioning and upgrade plans.



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