katestone
www.katestone.global

Greenhouse Gas and Climate Risk Assessment for the Arnhem Space Centre

Prepared for:

Equatorial Launch Australia

May 2023

Final

Prepared by:

Katestone Environmental Pty Ltd
ABN 92 097 270 276
Ground Floor, 16 Marie Street | PO Box 2217
Milton, Brisbane, Queensland, 4064, Australia

www.katestone.global
admin@katestone.com.au
Ph +61 7 3369 3699

Document Control

Deliverable #:	D22075-2
Title:	Greenhouse Gas and Climate Risk Assessment for the Arnhem Space Centre
Version:	1.0 (Final)
Client:	Equatorial Launch Australia
Document reference:	D22075-2 Greenhouse Gas and Climate Risk Assessment 1.0 (FINAL).docx
Prepared by:	Rebecca Wilson and Oliver Stockdale
Reviewed by:	Craig Miller
Approved by:	Craig Miller
	5 May 2023

Disclaimer

https://katestone.global/report-disclaimer/

Contents

Executive summary ... v

1. Introduction ... 1

2. The Project ... 2
   - 2.1 Location and regional context ... 2
   - 2.2 Current infrastructure ... 2
   - 2.3 Proposed Activities ... 3
     - 2.3.1 Construction ... 3
     - 2.3.2 Operations ... 4

3. Policy and legislative context ... 5
   - 3.1 National policy ... 5
   - 3.2 Climate Change Act 2022 ... 5
   - 3.3 Climate Change (Consequential Amendments) Act 2022 ... 5
   - 3.4 National Greenhouse and Energy Reporting (NGER) ... 5
   - 3.5 Northern Territory Policy ... 6
     - 3.5.1 Climate Response Plan ... 6
     - 3.5.2 Greenhouse Gas Emissions Management for New and Expanding Large Emitters ... 6

4. Greenhouse Gas Assessment ... 7
   - 4.1 Greenhouse gas emission estimation method ... 7
     - 4.1.1 Activity data ... 7
     - 4.1.2 Emissions factors ... 8
   - 4.2 Greenhouse gas emission results ... 10
   - 4.3 Reporting obligations ... 12
     - 4.3.1 NGER ... 12
     - 4.3.2 Greenhouse gas emissions management for new and expanding large emitters ... 12
   - 4.4 Greenhouse gas mitigation strategies ... 12

5. Climate Change Assessment Method ... 14

6. Current Weather and Climate ... 16
   - 6.1 Overview ... 16
   - 6.2 Climatic Drivers ... 17
     - 6.2.1 Indo-Australian monsoon ... 17
     - 6.2.2 El Niño Southern Oscillation ... 17
     - 6.2.3 Madden-Julian Oscillation ... 17
     - 6.2.4 Indian Ocean Dipole ... 18
   - 6.3 Seasonality and rainfall ... 18
   - 6.4 Temperature ... 19
   - 6.5 Wind speed ... 20
   - 6.6 Humidity ... 24
   - 6.7 Extreme weather events ... 24
     - 6.7.1 Extreme temperatures ... 24
     - 6.7.2 Extreme rainfall ... 25
     - 6.7.3 Flood potential ... 25
     - 6.7.4 Storms and extreme winds ... 26
     - 6.7.5 Bush fires ... 30

7. Climate change ... 32
   - 7.1 Climate change data ... 32
   - 7.2 Data presentation ... 33
   - 7.3 Temperature ... 33
   - 7.4 Rainfall ... 36
   - 7.5 Wind Speed ... 37
   - 7.6 Extreme weather events ... 38
     - 7.6.1 Extreme temperatures ... 38
     - 7.6.2 Bushfire weather ... 39
     - 7.6.3 Extreme rainfall ... 41

7.6.4 Extreme wind speed 44
7.7 Climate change summary....44
8. Climate Hazard Screening 47
8.1 Scenario 1: Extreme heat days....48
8.1.1 Infrastructure....48
8.1.2 Operations....48
8.1.3 Surrounding environment 48
8.2 Scenario 2: Tropical storms 49
8.2.1 Infrastructure....49
8.2.2 Operations....49
8.2.3 Surrounding environment 50
8.3 Scenario 3: Coastal infrastructure and sea level rise....50
8.3.1 Infrastructure....50
8.3.2 Operations....50
8.3.3 Surrounding environment 50
9. Climate Change Risk Management 51
10. Conclusion 54
11. References.... 55

Tables

Table 1 Frequency of launches for each fuel type 4
Table 2 NGER annual reporting thresholds – greenhouse gas emissions and energy use 6
Table 3 Summary of actual (FY 2021/22 – FY 2022/23) and projected activity data (2023/24 – 2026/27)....9
Table 4 Emission factors....10
Table 5 Summary of projected emissions (kgCO_2-e)....11
Table 6 Contribution of Project's Scope 1 emissions to current GHG emissions (MtCO_2-e) for Australia and the Northern Territory 12
Table 7 Climate variable identification....15
Table 8 Sources of historical climate data and availability....17
Table 9 Monthly and annual average fluctuations in relative humidity (%) for the Gove Airport Bureau monitoring station for the period 2000 - 2010....24
Table 10 Summary of temperature extremes from the Gove Airport SILO Climate Data 25
Table 11 Summary of rainfall extremes from the Gove Airport SILO Climate Data 25
Table 12 Monthly and annual maximum wind gusts (m/s) recorded at the Gove Airport Bureau monitoring station for the period 2000 - 2010 26
Table 13 Time elapsed between naming of cyclone and moving within 400 km radius of ASC 30
Table 14 Data indicators and sources used in this analysis 33
Table 15 Summary of average wind speed variation (%) for RCP8.5 in the Monsoonal North region....37
Table 16 Summary of climate projections for key climate variables associated with the ASC 45
Table 17 Provisional climate change risk management measures for the ASC 52

Figures

Figure 1 Site location and surrounding areas 2
Figure 2 Existing and proposed Stage 2 layout of the Arnhem Space Centre (image supplied by ELA) 3
Figure 3 Conceptual rocket launch pad (image supplied by ELA)....3
Figure 4 Nearest Bureau of Meteorology station to the Arnhem Space Centre 16
Figure 5 Annual rainfall and seasonality of the ASC and surrounding region....18
Figure 6 Deviation from mean rainfall and ENSO events for ASC region, 1960 – 2020 19
Figure 7 Monthly mean maximum and minimum temperatures from the SILO Climate Database (Gove Airport, NT)....20
Figure 8 Annual average wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)....21
Figure 9 Seasonal wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)....22

Figure 10 Diurnal wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)....23
Figure 11 Map of flood potential in Australia (Geoscience Australia, 2007)....26
Figure 12 Map of named cyclones crossing within 400 km of the ASC, 1984/85 - 2019/20 seasons....28
Figure 13 Annual total number of tropical cyclones that passed within 400km of the ASC during the 1984/85 to 2019/20 storm seasons....29
Figure 14 Number of named cyclones per month, 1984/85 to 2019/20 seasons....30
Figure 15 Number of bushfires recorded, 2000-2020....31
Figure 16 Months in which bushfires occurred, 2020 - 2021....31
Figure 17 NRM Cluster Map (CSIRO and BoM, 2015)....32
Figure 18 Observed mean temperature for the ASC and surrounding region for the period 2000 – 2020 (SILO)....34
Figure 19 Projected mean temperature for the ASC and surrounding region for the period 2036 – 2065 (CSIRO ACCESS model RCP8.5)....35
Figure 20 Projected mean temperature for the ASC and surrounding region for the period 2056 – 2085 (CSIRO ACCESS model RCP8.5)....35
Figure 21 Projected annual rainfall (mm) for the ASC and surrounding region for the period 2036 – 2065 NorESM model RCP8.5....36
Figure 22 Projected annual rainfall (mm) for the ASC and surrounding region for the period 2056 – 2085 NorESM model RCP8.5....37
Figure 23 Average number of days per year above 35°C observed in the region for the period 2000 - 202038
Figure 24 Average number of days per year above 35°C observed in the region for the period 2040 - 205939
Figure 25 Average number of days per year with severe fire danger (FFDI>50) observed in the region for the period 1986 - 2005....40
Figure 26 Average number of days per year with severe fire danger (FFDI>50) observed across Australia for the period 2040 – 2059 RCP 8.5 CSIRO ACCESS....40
Figure 27 Maximum 1 day rainfall (mm) with 5% AEP for the baseline period (1986 - 2005)....41
Figure 28 Maximum 1 day rainfall (mm) with 5% AEP for the period 2040 - 2059 (RCP 8.5 Warm Wet)....42
Figure 29 Annual mean run-off in the current climate (2021)....43
Figure 30 Change in the annual mean run-off in 2036 - 2065 compared to the baseline period of 1990 (RCP 8.5)....43

Glossary

Term	Definition
µg/m^3	micrograms per cubic metre
µm	microns
°C	degrees Celsius
°K	degrees Kelvin
J	joules
km	kilometres
kPa	kilopascals
m	metres
m/s	metres per second
m^2	square metres
m^3	cubic metres
t	tonnes
Nomenclature	**Definition**
CH_4	Methane
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalents
IPCC	Intergovernmental Panel on Climate Change
N_2O	nitrous oxide
Abbreviations	**Definition**
ASC	Arnhem Space Centre
BoM	Bureau of Meteorology
CCiA	Climate Change in Australia
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
EA	Environmental Authority
EF	Emission factor
ELA	Equatorial Launch Australia
EP Act	*Environment Protection Act 2019*
EPA	Environment Protection Authority
EP Regulations	*Environment Protection Regulations 2020*
FFDI	Forest Fire Danger Index
GHG	Greenhouse gases
GCM	Global Circulation Model
NEPC	National Environment Protection Council
NGER	National Greenhouse and Energy Reporting
NT	Northern Territory
RCP	Representative Climate Pathways

EXECUTIVE SUMMARY

Katestone Environmental Pty Ltd (Katestone) was commissioned by Equatorial Launch Australia (ELA) to complete a Greenhouse Gas (GHG) and Climate Risk Assessment of the Arnhem Space Centre (ASC).

ELA is seeking to amend its Environmental Approval (EA) to allow for the Stage 2 expansion of ASC (the Project). To do so, ELA will make a referral to the Northern Territory Environmental Protection Authority (NT EPA) under the *Environment Protection Act 2019* (EP Act). Under the EP Act referral process, the NT Government expects a proponent to show:

- How it will be minimising GHG emissions to contribute to the NT Government's goal of net zero GHG emissions by 2050.
- How it has accounted for or is adapting to the changing climate, i.e., weather events under a changing climate that could pose a material risk to operations and that consequently could lead to an adverse impact on the environment.

Greenhouse Gas Assessment

Diesel use for electricity generation and vehicles has been the largest source of Scope 1 GHG emissions in the first two years of operation of ASC (~160,000 – 171,000 kgCO_2-e/y). This is projected to increase under the Project to 409,000 kgCO_2-e/y in 2027 as activity at the site increases. The projected increase in rocket launches between 2024 and 2027 will see rocket fuel become the largest source of Scope 1 emissions (~360,000 – 700,000 kgCO_2-e/y) with LOX/RP1 being the main source of these emissions. There is significant uncertainty about GHG emissions from some of the rocket fuels due to their proprietary composition, but this may be resolved over time as more data is made available or collected.

Sources of Scope 3 emissions will include the barging and trucking of diesel and rocket fuels as well as the supply of construction materials as the site expands. Initially, transport of water to the site will contribute significantly to Scope 3 emissions until a lake is built to source water onsite. There is uncertainty about the final quantities of activities and materials contributing to Scope 3 emissions however and this will become clearer as site and infrastructure design is finalised and procurement and activities commence. The remote location of the site means that Scope 3 emissions from transport will be higher than for an equivalent urban or regional site.

Based on current projections, ELA will not have NGER or NT Government reporting obligations. However, continual monitoring of GHG emissions should still occur to ensure that reporting thresholds are not breached and to understand GHG emissions as the activity evolves so that there is an ongoing focus on minimising emissions where possible.

There are limited options for ELA to reduce its GHG emissions given the remoteness of the site and the key activity being rocket launches. Direct emissions from diesel combustion for electricity can be minimised through actions such as:

- Generator control systems to match supply with load
- Load management and energy efficiency measures
- Back up batteries to store excess generator supply
- Solar PV and batteries
- Use of biodiesel.

Direct emissions may be offset through actions such as:

- Land use change

- Investment in certified carbon sequestration projects in the Northern Territory.

Direct and indirect emissions may be offset through sealing the road between Nhulunbuy and the ASC with cold emulsion containing a high proportion of biochar.

ELA and its clients may also support research into and monitoring of the pollutants including GHGs released by the combustion of different types of rocket fuels in different types of engines, and/or promote research into the development of low GHG fuels.

Climate Risk Assessment

Current and projected weather patterns and the increased likelihood of extreme conditions may pose a material risk to the successful and safe operation of the ASC. The site is in a tropical monsoonal area of Australia and has a defined wet season and dry season. Tropical cyclones are common during the wet season and transitions to and from the wet season, and many have formed and tracked within 400 km of the ASC in recent history. Typical dry season weather conditions are unlikely to have a material impact on operation of the ASC if operations are managed appropriately. For example:

- Mean daily maximum temperatures range from 27.9 to 33.0°C, which is below the 37°C limit for safe operating conditions for humans outdoors.
- Strong wind gusts are possible at any time of the year and may exceed the 12.8 m/s criteria for a safe launch. Wind gusts are smallest during the dry to wet transition season during November and December.
- Most tropical cyclones occur during the dry to wet transition season, the wet season, and April of the wet to dry transition season (although they have been recorded in May). The number of cyclones per season within 400 km of the ASC has ranged from 0 - 4.
- Natural and human-caused bushfires and smoke plumes are common in the region during the dry season, which may affect timing of some launches.

Climate change projections suggest that there are material risks to human health, infrastructure, and successful operations of the ASC that will need to be managed. For example:

- The number of hot days >35°C is projected to increase from < 5 per year to 30 – 50 per year by 2050. This may have an adverse effect on human health, infrastructure condition, and fuel conditions.
- The magnitude of short duration intense rainfall events may increase by up to 50mm in any one day, which may exceed infrastructure drainage capacity and cause damage to roads.
- Extreme wind gust speed may increase, although there is less certainty around this projection.
- The number of cyclones that form is projected to decrease; however, the intensity of those cyclones that do form is expected to increase. Cyclones of greater intensity will potentially result in the delay of site activities, may damage site infrastructure as well as off-site critical infrastructure (e.g., the Port) and may interrupt supply lines for an extended period of time.

Three climate risk scenarios have been developed based on an understanding of extreme weather and climate parameters and a provisional understanding of ASC operations. These focus on:

- Extreme heatwave conditions and effect on:
    - Infrastructure and fuel
    - Launch operations
    - Human health and well-being.

- Tropical storm and effect on:
    - Infrastructure and fuel
    - Human health and well being
    - Critical offsite infrastructure and supply chain.
- Storm surges and sea level rise and effect on critical offsite infrastructure and supply chain.

These scenarios have been developed to allow ELA to think about the range of plausible risks and the risk management strategies that could be developed to allow for continued business operations, avoiding detrimental impacts to human health and operations.

1. INTRODUCTION

Equatorial Launch Australia (ELA) has commissioned Katestone Environmental Pty Ltd (Katestone) to conduct a Greenhouse Gas and Climate Risk assessment for the ongoing development of the Arnhem Space Centre (ASC) in Nhulunbuy, Northern Territory.

ELA is seeking to amend its Environmental Approval (EA) to allow for the Stage 2 expansion of ASC (the Project). To do so, ELA will make a referral to the Northern Territory Environmental Protection Authority (NT EPA) under the *Environment Protection Act 2019* (EP Act). The existing EA was assessed under the previous *Environmental Assessment Act 1982* where the decision was made that the "potential environmental impacts and risks of the proposed action are not so significant as to warrant environmental impact assessment by the NT EPA under provisions of the EA Act at the level of a Public Environmental Report or Environmental Impact Statement".

Proposals that have the potential to have a significant impact on the environment now require referral to the NT EPA in accordance with s48 of the EP Act and the *Environment Protection Regulations 2020* (EP Regulations) (DEPWS, 2021).

Under the EP Act referral process, the NT Government expects a proponent to show:

- How it will be minimising GHG emissions to contribute to the NT Government's goal of net zero GHG emissions by 2050
- How it has accounted for or is adapting to the changing climate, i.e., weather events under a changing climate that could pose a material risk to operations and that consequently could lead to an adverse impact on the environment.

The EP Act also requires several general duties of a proponent (s43), including:

- (e) to consider the principles of ecologically sustainable development in the design of the proposed action
- (f) to apply the environmental decision-making hierarchy in the design of the proposed action.

ELA wishes to understand whether activities associated with the proposed development or operation of the ASC have the potential significantly impact the environment or meet a referral trigger with respect to GHG emissions and climate change.

The objectives of this report are to:

- Assess projected Scope 1 GHG emissions from the Project, including emissions due to:
  - Combustion of diesel for construction and operation (including electricity generation)
  - Combustion of liquid, solid, and hybrid rocket propellant during fixed testing and launching.
- Assess projected Scope 3 emissions from construction materials used in the expansion of the ASC.
- Identify options for minimisation or reduction of GHG emissions during construction and operation of the Project.
- Assess material risks to the construction and operation of the ASC including subsequent environmental impact from weather events under current climate change projections.

2. THE PROJECT

2.1 Location and regional context

The ASC is located on the Dhupuma Plateau, approximately 20 km due south of Nhulunbuy, in the East Arnhem region of the Northern Territory (Figure 1). The vegetation on the plateau is largely open Darwin stringybark (*Eucalyptus tetrodonta*) woodland with sparse understory and grasses, and moderate organic litter, over skeletal laterite soils. The plateau has steep breakaways with tributaries draining into several waterways including Wathawuy (Latram River and Goanna Lagoon), Dalywuy Bay, and Port Bradshaw.

The ASC is 12°S from the equator, meaning that it can provide launches into equatorial low earth orbit, geosynchronous equatorial orbit, lunar orbit, and deep space.

Land tenure was secured in 2017 with the granting of a 40-year lease. Construction began in 2021 and the launch facility license was granted in May 2022, with the first of three successful launches commencing in June 2022 and the remaining two in early July 2022.

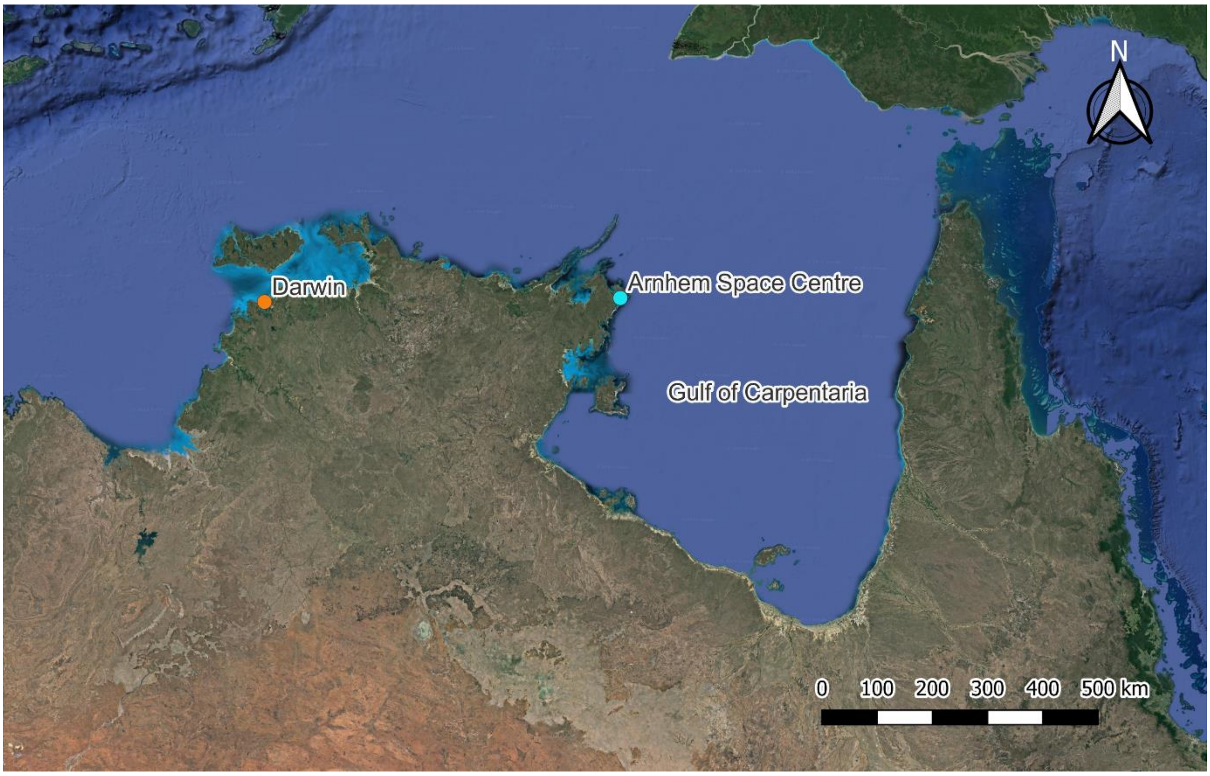


Figure 1 Site location and surrounding areas

2.2 Current infrastructure

The current site (ASC Site 1) is in the top left of Figure 2 with the proposed expansion in the remainder of the picture. Several structures are currently located at ASC Site 1, including a rocket launch pad, mission support buildings (Launch Control, Mission Control, Range Control, Administration), Vehicle Assembly Building, Payload Integration Facility, staff accommodation, amenities, and a caretaker's accommodation. The site and buildings are accessible via graded, unpaved roads. All structures on site are expected to have a design wind rating of 232 km/h (cyclonic, AS/NZS 1170.2).

Figure 2 **Existing and proposed Stage 2 layout of the Arnhem Space Centre (image supplied by ELA)**

2.3 Proposed Activities

2.3.1 Construction

Construction of Stage 2 is proposed to commence in early - mid 2023. ELA is in the process of confirming final site design and engineering drawings.

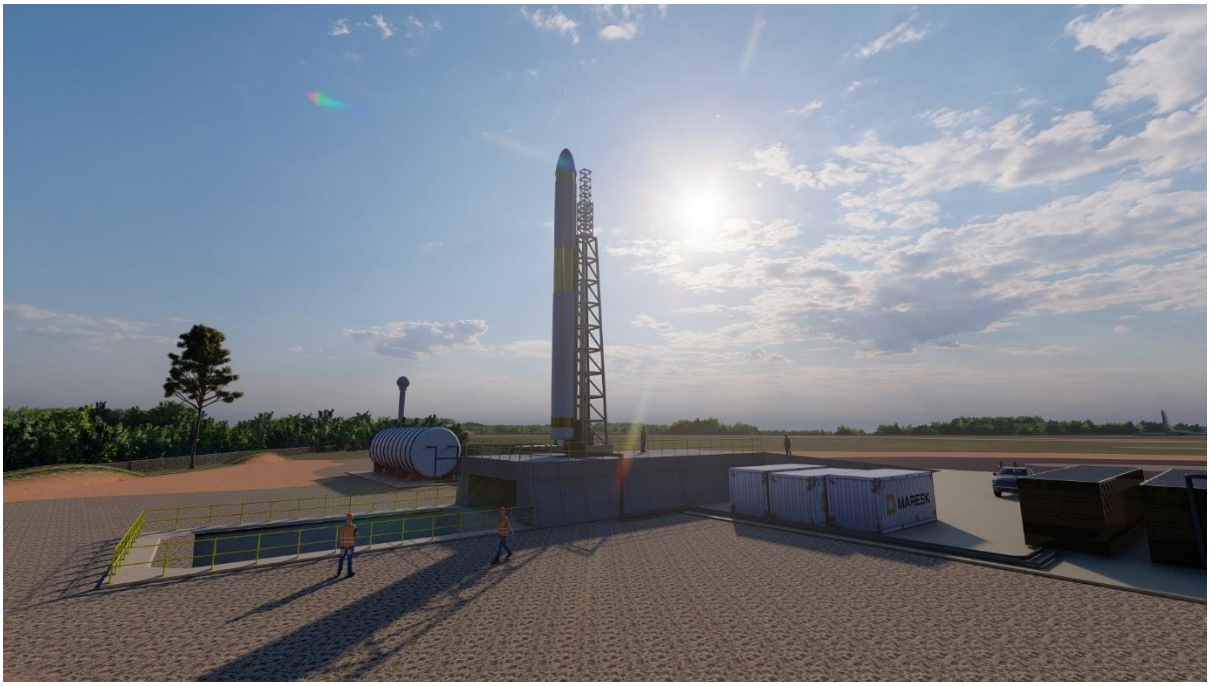


Figure 3 **Conceptual rocket launch pad (image supplied by ELA)**

The launch facility will initially be equipped with three launch pads (e.g., Figure 3) to accommodate sub-orbital and small orbital satellite launch vehicles, with the design allowing scaling to support all current and future launch and recovery technologies, fuel storage and pumping facilities, and water storage for the deluge system.

2.3.2 Operations

Orbital launch related activities are expected to commence in 2024 with a range of different rockets and fuel types projected between 2024 and 2027 (Table 1). Under the Project, the site will also be used for static firing tests of rocket engines.

Table 1 Frequency of launches for each fuel type

Fuel	Fuel Type	FY22/23	FY23/24	FY24/25	FY25/26	FY26/27	Total
LOX/RP1	Liquid	0	0	10	18	22	**50**
LOX/H_2		0	1	1	1	2	**5**
N_2O/SBR	Hybrid	0	2	4	5	5	**16**
LOX/Paraffin		0	0	2	3	6	**11**
NO_X/HRF-1AL		0	0	1	2	2	**5**
HTPB	Solid	0	2	5	8	13	**28**
Total Launches		**0**	**5**	**23**	**37**	**50**	

Key:
LOX – liquid oxygen
RP1 – “refined petroleum” or “rocket propellant” – highly refined form of kerosene
H_2 – hydrogen
N_2O/SBR – nitrous oxide and styrene-butadiene rubber
NOX/HRF-1AL – nitrous oxide, aluminized hybrid rocket fuel
HTPB – Hydroxyl-terminated polybutadiene

3. POLICY AND LEGISLATIVE CONTEXT

3.1 National policy

The Australian Government has committed that Australia will reduce GHG emissions by 43% below 2005 levels by 2030 and will achieve net zero GHG emissions by 2050. It is developing new policies to drive the transition to net zero and will build on existing programs such as the Emissions Reduction Fund.

The Australian Government is also reviewing the Safeguard Mechanism, which requires Australia's largest emitters to keep net emissions within baseline levels, to ensure that it will conform to Australia's climate targets. The Safeguard Mechanism has been put in place to ensure that emissions reductions purchased by the Government through the ERF are not offset by significant increases in emissions by large emitters elsewhere in the economy.

The Safeguard Mechanism commenced on 1 July 2016 and requires Australia's largest emitters to keep emissions within baseline levels. It applies to around 140 large businesses that have facilities with direct emissions of more than 100,000 tonnes of carbon dioxide equivalent (tCO_2-e) a year and is expected to cover approximately half of Australia's emissions.

3.2 Climate Change Act 2022

The Climate Change Act 2022 (CC Act) provides the legislative framework to implement Australia's net-zero commitments and codifies Australia's 2030 and 2050 net GHG emissions reductions targets under the Paris Agreement. The legislated targets are to reduce net GHG emissions to 43% below 2005 levels by 2030, and to reduce net GHG emissions to zero by 2050.

The CC Act establishes that 2030 GHG emissions reduction target as a national point target and an emissions budget. The CC Act does not impose obligations directly on companies, but it does signal sector-based reforms to achieve the GHG emissions reduction targets.

3.3 Climate Change (Consequential Amendments) Act 2022

The Climate Change (Consequential Amendments) Act 2022 (CCCA Act) embeds the GHG emissions reduction targets into fourteen Commonwealth Acts, including the Clean Energy Regulator Act 2011, Infrastructure Australia Act 2008, National Greenhouse and Energy Reporting Act 2007, and the Renewable Energy (Electricity) Act 2000.

3.4 National Greenhouse and Energy Reporting (NGER)

The National Greenhouse and Energy Reporting Act 2007 (NGER Act) established a national framework for corporations to report GHG emissions and energy consumption. The NGER Act 2007 is administered by the Clean Energy Regulator with details of the scheme and allowable calculation methodologies contained in the:

- *National Greenhouse and Energy Reporting Regulations 2008 (NGER Regulation);* and
- *National Greenhouse and Energy Reporting Determination 2008 (NGER Determination).*

The NGER Regulation recognises Scope 1 and Scope 2 emissions as follows:

- Scope 1 emissions – in relation to a facility, means the release of GHG into the atmosphere as a direct result of an activity or series of activities (including ancillary activities) that constitute the facility. GHG emissions associated with land clearing are not covered by the NGER scheme; and
- Scope 2 emissions – in relation to a facility, means the release of GHG into the atmosphere as a direct result of one or more activities that generate electricity, heating, cooling or steam that is consumed by the facility but that do not form part of the facility.

NGER registration and reporting are mandatory for corporations that have energy production, energy use or GHG emissions that exceed specified thresholds. GHG emission thresholds include Scope 1 and Scope 2 emissions. NGER reporting thresholds are summarised in Table 2. GHG emissions from land clearing activities associated with a project do not contribute towards the NGER reporting thresholds.

Table 2 NGER annual reporting thresholds – greenhouse gas emissions and energy use

Threshold level	Threshold type	
	GHG ($ktCO_2$-e)	Energy consumption (TJ)
Facility	25	100
Corporate	50	200

$ktCO_2$-e = kilotonnes of carbon dioxide equivalent. TJ = terajoules

3.5 Northern Territory Policy

3.5.1 Climate Response Plan

The Northern Territory Government (NT Government) released a Climate Response Plan in 2020 that details their ambitions to achieve net zero GHG emissions by 2050. This includes a Three-Year Action Plan and reforms for environmental offsets. Currently, the NT Government is working towards developing an Emissions Reduction Strategy that will set timeframes and interim targets and identify potential approaches to achieve their goal of net zero by 2050. Part of the Climate Response Plan also involves a 50% renewable energy target across the territory.

While these policy frameworks are not yet in legislation, it is expected that during the proposed development of ASC significant changes will come into effect. Therefore, it is crucial that the proposed policy is well-understood so that changes to legislation will not impact planned operations of the facility.

3.5.2 Greenhouse Gas Emissions Management for New and Expanding Large Emitters

The Northern Territory (NT) Government's 'Greenhouse Gas Emissions Management for New and Expanding Large Emitters' policy identifies the NT Government's minimum requirements for the management of greenhouse gas emissions from new or expanding industrial and land use development projects. It has been established in recognition of the Northern Territory's target of net zero greenhouse gas emissions by 2050. The policy commenced on and is in effect from 1 September 2021.

Under the policy an industrial project is classified as a 'large greenhouse gas emitters', should it meet the following emissions thresholds:

Industrial project threshold: Estimated scope 1 emissions of 100 000 tCO2-e in any financial year over the life cycle of a project, not counting emissions generated from land clearing directly associated with the project.

Proponents of all new projects and expansions of existing projects subject to this policy must develop and implement a greenhouse gas abatement plan (GGAP) that has been tailored specifically for their project. A project's GGAP should be submitted for assessment as part of the usual process for a project to obtain an environmental authorisation.

4. GREENHOUSE GAS ASSESSMENT

This greenhouse gas (GHG) assessment considers the potential contribution of the Project to the GHG emissions of the Northern Territory and Australia. GHG emissions are classified into three scopes for assessment (NGER Act). Scope 1 emissions are direct emissions from sources controlled or owned by an organisation. Scope 2 emissions are indirect emissions from the generation of grid electricity purchased and used by an organisation. Scope 3 emissions are other indirect emissions that are produced by an organisation's supply and/or value chain.

This assessment considers Scope 1 and Scope 3 emissions associated with the construction and operation of the ASC with data provided by ELA. There are no Scope 2 emissions associated with the Project as it is not connected to an electricity grid due to its remote location.

4.1 Greenhouse gas emission estimation method

GHG emissions associated with the Project have been estimated for each year of operations until Financial Year 2026/2027 based on projected activity data provided by ELA.

The methods used to estimate the GHG emissions resulting from the Project are consistent with:

- The National Greenhouse Accounts, August 2021 (Commonwealth Department of the Environment and Energy, 2021)
- National Greenhouse and Energy Reporting (Measurement) Determination 2008 (NGER Determination)
- The Greenhouse Gas Protocol.

Method 1 as outlined in the *NGER Determination* was used for all emission calculations where emission factors from the *NGER Determination* are available. In general, the formula applied is:

$$E = Q \times ECF \times EF$$

Where:

E represents the total emissions

Q is the quantity of the emission source (e.g., quantity of diesel)

ECF is the energy content factor of the emission source

EF is the emission factor that describes the total amount of equivalent carbon dioxide emissions associated with the emission source.

Where emission factors from the *NGER Determination* are not available, mass fractions of exhaust fumes have been derived from published data in academic literature to determine the GHG emissions from a particular fuel type. In this case, the CO_2 emissions from a given launch are calculated by taking a fraction of the total fuel used in that launch. It is, therefore, assumed that 100% of the fuel is burned. For example, consider a mass of propellant m_{prop} where the exhaust gases comprise of 47% CO_2. The GHG emissions from this launch would as follows.

$$E = m_{prop} \times 0.47$$

4.1.1 Activity data

Operations at the ASC commenced in financial year (FY) 2021-22 and continued into FY2022-23, providing a base case. The site is likely to stay under maintenance into the first half of FY2023-24 with little activity or fuel consumption occurring during this time. Construction of Stage 2 will begin in the first half of FY2023-24 and launches should recommence during this time.

It has been projected that diesel combustion for onsite electricity generation will increase 25% per annum FY2023/24 and FY2026/27 (Table 3). This is based on increasing operations onsite, which includes more people using more electricity. This projected estimate is highly conservative and will be closely monitored year-on-year. A fraction of total diesel is also used for vehicles, with projections based on increasing activity per year. Again, forecasting vehicle diesel usage is conservative and continuous monitoring will be undertaken to ensure GHG estimates are not underpredicting site activities. Several assumptions have been made in line with increasing activity onsite. Final projections have considered that approximately 200 people will be onsite at any time and approximately 50 vehicles will be used onsite (approximately 10 will be operated by ELA).

A range of solid, liquid, or hybrid rocket fuels, including liquid oxygen-refined petroleum1 (LOX/RP1) will be transported to site, temporarily stored if necessary, and will fuel a range of rockets. The quantities in Table 3 are projected for FY2023/24 – FY2026/27 based on anticipated rocket launches but this may change. The hybrid NO_X/HRF-1AL is likely to be the least used fuel at 300 – 600 kg/year while 370,000 – 700,000 litres of liquid LOX/RP1 are likely to be the most used fuel.

The quantities of diesel and avgas (gasoline for aviation purposes) used for rocket retrieval by barge and helicopter are projected to be 800 – 8,000 L/year and 200 – 2,000 L/year, respectively. This will depend on the number of rockets launched, their trajectory over sea or land, and whether they are retrieved individually or collectively. Several assumptions have been used to estimate these fuel usages. The barge is assumed to use 40L/hr of diesel, travelling on average 20km/hr, completing a 200km round trip to pick up debris. On average, it is assumed two rockets can be collected in one trip. The helicopter is assumed to consume 100L/hr of avgas and complete a two-hour journey. For all rocket debris to be collected, 80% are projected to be collected with a barge and the remaining 20% are to be collected with a helicopter.

Scope 3 emissions include the use of construction materials for the expansion of facilities at the ASC, as well as company travel that includes both domestic flights as well as international flights. Diesel used for the barging and trucking of diesel and rocket fuel to site is unknown at this stage. Similarly, Scope 3 emissions will include diesel usage for the transport of water to site. ELA has identified that the increasing water usage over time will require a lake to be constructed onsite as procurement of water from external sources will become damaging both economically and environmentally.

4.1.2 Emissions factors

Emissions factors for standard fuels such as diesel are derived from the NGER Determination (Table 4). Some compounds expected to be used at ASC, such as the high energy fuel (HRF-1, Table 3) are proprietary. As such, the exact composition and emissions related to the combustion of the fuel are unknown. Furthermore, hybrid rocket engines and their environmental impact, including emissions, are an emerging study area. Consequently, determining their GHG emissions is difficult due to limited information. Where information was scarce (particularly with hybrid engine fuels), emission factors have been assigned as recommended by ELA. These will be adjusted over time as more data becomes available.

Table 3 Summary of actual (FY 2021/22 – FY 2022/23) and projected activity data (2023/24 – 2026/27)

Activity	Description	Scope	Units	FY21/22	FY22/23	FY23/24	FY24/25	FY25/26	FY26/27
Diesel usage	Generators	1	L	56,900	62,840	77,301	96,626	120,783	150,978
	Vehicles (on-site)	1	L	2,536	1,268	2536	5072	10,145	20,290
Rocket fuels	LOX/RP1	1	kg	-	-	-	372,400	600,000	696,400
	N_2O/SBR	1	kg	-	-	43,700	45,300	67,100	67,100
	LOX/Paraffin	1	kg	-	-	-	19,900	31,300	62,600
	NO_X/HRF-1AL	1	kg	-	-	-	300	600	600
	HTPB*	1	kg	-	-	31,300	107,100	107,100	143,400
Rocket retrieval	Barge (diesel)	1	L	-	-	800	3,600	6,000	8,000
	Helicopter (avgas)	1	L	-	-	200	1,000	1,400	2,000

Table notes:
*HTPB is assumed to use oxygen as the oxidiser (while ammonium perchlorate is most common, oxygen has the highest emission factor so is used as a worst-case scenario).
Highlighted cells make predictions about usage: assume that dormant generators increase by 25% per annum; assume diesel for vehicles increases by 100% per annum

Table 4 Emission factors

Emission source	Note	Energy content	Units	Emission factor	Units
Biodiesel	Stationary purposes[1]	34.6	GJ/kL	0.28	$kgCO_2$-e/GJ
Gasoline	Aviation purposes[1]	33.1	GJ/kL	67.66	$kgCO_2$-e/GJ
Kerosene	Aviation purposes[1]	36.8	GJ/kL	69.82	$kgCO_2$-e/GJ
Diesel	Stationary purposes[1]	38.6	GJ/kL	70.2	$kgCO_2$-e/GJ
	Transport purposes[1]	38.6	GJ/kL	70.4	$kgCO_2$-e/GJ
Rocket fuel	LOX/RP1[1,2]	36.8	GJ/kL	69.82	$kgCO_2$-e/GJ
	N_2O/SBR[3]	-	-	14.4	%*
	LOX/Paraffin[3]	-	-	28.7	%*
	NO_X/HRF-1AL[3]	-	-	14.4	%*
	HTPB[3]	-	-	31.3	%*
Concrete	-	-	-	250.6	$kgCO_2$-e/t
Steel	-	-	-	1547	$kgCO_2$-e/t

Table notes:
*% represents a total mass fraction of the fuel
[1]NGER Determination, Compilation 14
[2]Kerosene values have been used for LOX/RP1, where it's assumed a 1:2.56 fuel to oxidizer ratio.
[3]Figure 6, Galfetti, et al., (2014).

4.2 Greenhouse gas emission results

GHG emissions are projected to increase year-on-year due to the increased frequency of launches.

Diesel combustion for electricity generation produced 154,191 and 167,571 kg CO_2-e/y in FY2021/22 and FY2022/23, respectively, and is projected to produce approximately 410,000 $kgCO_2$-e in FY2026/27 (Table 5). Electricity generation contributes approximately 90% of total Scope 1 emissions between FY2021/22 – FY2023/24, before frequent launching takes plane.

The combustion of rocket fuel then becomes the dominant source of Scope 1 emissions particularly as rocket launches fueled by LOX/RP1 commence in FY24/25. This highly refined kerosene-based liquid fuel is projected to be used significantly more than other fuels and it is assumed to have a higher emission factor than the other rocket fuels (Table 4). There remains a large degree of uncertainty around the emission factors of rocket fuels as there is little data available to quantify their emissions.

Scope 3 emissions arise from the construction of new concrete launch pads, earth works, and development of laterite roads. There will be significant Scope 3 emissions associated with bringing materials to site, including rocket fuel, diesel, and water. Additionally, company travel (both domestic and international) contributes to Scope 3 emissions. Given the ASC's remote location, staff frequently fly across Australia to visit the site.

At this point there is uncertainty around diesel use and the Scope 3 emissions associated with fuel transport to the site. This can be monitored, and projections revised over time.

Table 5 Summary of projected emissions (kgCO_2-e)

Activity	Description	Scope	FY21/22	FY22/23	FY23/24	FY24/25	FY25/26	FY26/27
Diesel usage	Generators	1	154,191	167,571	209,464	261,830	327,287	409,109
	Vehicles (on-site)	1	6,892	3,446	6,892	13,784	27,568	55,136
Rocket fuels	LOX/RP1	1	-	-	-	335,968	541,301	628,270
	N_2O/SBR	1	-	-	6,293	6,523	9,662	9,662
	LOX/Paraffin	1	-	-	-	5,711	8,983	17,966
	NO_X/HRF-1AL	1	-	-	-	43	86	86
	HTPB*	1	-	-	9,797	20,251	33,522	44,884
Rocket retrieval	Barge (diesel)	1	-	-	2,174	9,783	16,305	21,740
	Helicopter (kerosene)	1	-	-	2,240	11,198	15,677	22,395
Total Scope 1 Project Emissions			**161,083**	**171,017**	**236,859**	**665,091**	**980,392**	**1,209,250**

Table notes:
*HTPB is assumed to use oxygen as the oxidiser (while ammonium perchlorate is most common, oxygen has the highest emission factor so is used as a worst-case scenario).
Highlighted cells assume that dormant generators use 1.5kL of diesel per week

The contribution of the ASC to the Northern Territory's and Australian emissions is shown in Table 6. The total emissions from the Project have limited impact upon both territory and national emissions, totalling a contribution of 0.0002% and 0.007%, respectively.

Table 6 Contribution of Project's Scope 1 emissions to current GHG emissions ($MtCO_2$-e) for Australia and the Northern Territory

Inventory total	Australia[1]	Northern Territory[2]	Arnhem Space Centre	
	Emissions ($MtCO_2$-e)	Emissions (Mt CO_2-e)	National Contribution[3]	Territory Contribution[3]
Excluding LULUCF	490.5	17.3	0.0002%	0.007%

[1]Value based on 2022 estimates included in Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2022
[2]Value based on 2020 estimates included in State and Territory Greenhouse Gas Inventories 2020
[3]Derived using annual maximum Scope 1 excluding land clearing

4.3 Reporting obligations

4.3.1 NGER

ELA does not currently have NGER reporting obligations and will not have NGER reporting obligations under projected operations, as they are significantly less than the NGER emissions threshold (Table 2). Nevertheless, emissions and energy usage associated with the Project should be monitored regularly to ensure exceedances of these thresholds do not occur in accordance with the NGER Act 2007 and supporting legislation.

4.3.2 Greenhouse gas emissions management for new and expanding large emitters

The total estimated Scope 1 emissions from the Project do not trigger the industrial projects threshold of 100,000 tCO2-e in any financial year over the life of the project. As a result of the Project not triggering the industrial threshold, it does not require a greenhouse gas abatement plan.

4.4 Greenhouse gas mitigation strategies

The ASC has limited options for reducing or mitigating GHG emissions and continuing operations given its remote location.

Direct emissions from diesel combustion for electricity can be minimised through actions such as:

- Generator control systems to match supply with load
- Load management and energy efficiency
- Back up batteries to store excess generator supply
- Solar PV and batteries
- Use of biodiesel.

Direct emissions may be offset through actions such as:

- Land use change

- Investment in certified carbon sequestration projects in the Northern Territory.

Direct and indirect emissions may be offset through sealing the road between Nhulunbuy and the ASC with cold emulsion containing a high proportion of biochar.

ELA and its clients may also support research into and monitoring of the pollutants including GHGs released by the combustion of different types of rocket fuels in different types of engines.

5. CLIMATE CHANGE ASSESSMENT METHOD

Climate is the long-term pattern of weather in a region (averaged over 30 years), whereas weather is the state of the atmosphere at a particular point in time. Key weather variables of interest are temperature, rainfall, wind speed, and humidity.

Climate change, i.e., change in previously characteristic weather patterns, is a consequence of global warming. Global warming is occurring because the increased concentration of GHG in the atmosphere slows the rate of heat loss from earth into space. This heat energy accumulates in the oceans and atmosphere. Sea level rise is also a response to global warming, driven by thermal expansion of water and the addition of water from melting land-based ice sheets. This is also a variable of interest in this assessment.

A Climate Change Assessment is a critical feature of environmental risk management. The Climate Change Assessment for the ASC has been conducted based on guidance provided in:

- Australian Standard AS 5334-2013 – Climate change adaptation for settlements and infrastructure – A risk-based approach
- ISO 31000:2009 Risk management principles and guidelines
- ISO 14091-2021 Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment.

The assessment involves the following steps:

1. Climate screening, i.e., a description of current climate
2. Climate change, i.e., description of likely future climate
3. Climate hazard screening, i.e., a description hazards/risks the ASC may face because of climate change
4. Adapting to climate change, i.e., steps the ASC can take to mitigate impacts of climate change at their site.

Climate screening involves consideration of historical weather and climate, coupled with identifying vulnerabilities specific to the ASC to determine the physical hazards that are most likely to cause adverse impacts. The hazards identified for further assessment are:

- Annual rainfall
- Temperature
- Wind speed
- Humidity
- Extreme conditions (temperature, rainfall, flooding, storms, bush fires)
- Sea level rise.

The key climate risks variables and their potential impacts are summarised in Table 7.

Table 7 Climate variable identification

Climate Hazard	Climate variable	Project exposure
Rainfall	Average annual rainfall	Water supply for the ASC is partially sourced from rainfall. Other water sources are unknown. Water runoff for the site.
	Extreme rainfall events	Stormwater management and erosion/runoff.
		Flooding, limiting site accessibility.
Temperature	Average annual temperature	Equipment and machinery efficiency.
		Changes to operational power requirements to maintain equipment at constant temperatures.
	Extreme temperature events	Launch operations cannot proceed in periods of high temperature.
		Incidence of heat stress in workers and clients.
Wind	Gales and extreme wind events / cyclones and or storms	Damage to equipment and structures.
		Launch operations cannot proceed in high wind conditions.
Relative humidity	Average annual	Equipment and machinery efficiency.
		Heat stress in workers and clients.
Bush fire weather	Fire danger index	Fuel combustion.
		Damage to infrastructure.
		Site/infrastructure accessibility.
		Launch operations cannot proceed when smoke plumes are present in the area.

6. CURRENT WEATHER AND CLIMATE

6.1 Overview

East Arnhem Land of the Northern Territory is classified as Am, i.e., tropical (monsoonal) with rainforest vegetation according to the Köppen classification system, which is defined as having monthly mean temperatures greater than 18ºC and a dry season.

Meteorological data that is representative of the region surrounding the ASC site has been acquired from the Scientific Information for Land Owners (SILO) climate database (interpolated grid cell, Stone et al, 2019) and from the nearest long-term BOM weather station (Table 8). The nearest meteorological station operated by the Bureau of Meteorology (BoM) weather station at Gove Airport (Site ID: 014508; Figure 4), 13.5 km north-northeast of the ASC. The station has been operational since 1944; however, the observational data set does not approach 100% completeness until the 1990s.

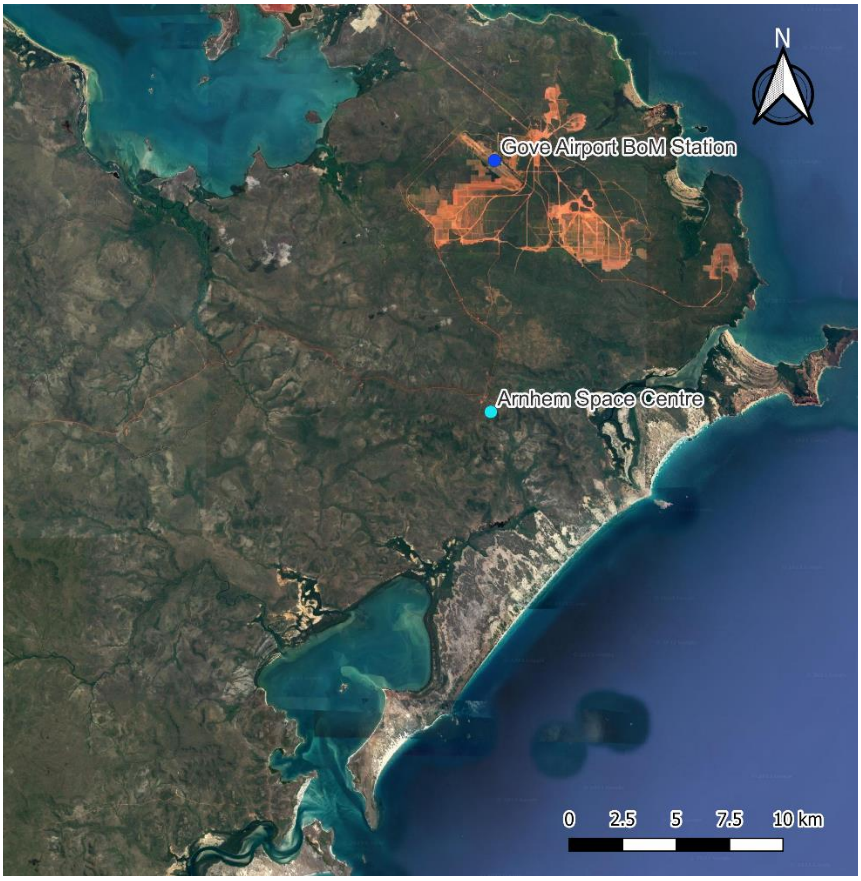


Figure 4 Nearest Bureau of Meteorology station to the Arnhem Space Centre

The data obtained from the SILO climate database and the weather station have been used to collectively describe the climatic trends within the vicinity of the Project. Historical data is presented as a basis from which future climatic trends, patterns, cycles, and extremes can be framed. A baseline period of 1986 – 2005 has been used, consistent with climate change projections. In addition, data from 2000 – present has also been considered where relevant or if earlier data is incomplete or unavailable.

Table 8 **Sources of historical climate data and availability**

Parameter	SILO Climate Database Grid Cell	Gove Airport Bureau station
Locality	On ASC, same cell as BOM station	~13.5 km NNE of ASC
Data availability		
Temperature	1958 - 2022	1966 - 2022
Rainfall	1958 - 2022	1944 - 2022
Wind Speed and Direction	N/A	1972 - 2022
Humidity	N/A	1969 - 2012

6.2 Climatic Drivers

Australia's weather patterns are dictated by several climate drivers, which can have varying levels of influence depending on their relative strength at the time. These drivers include the Indian Ocean Dipole (IOD), Madden-Julian Oscillation (MJO), El Niño/Southern Oscillation (ENSO), and the Indo-Australian monsoon. Of these drivers, the monsoon, ENSO, and the MJO have the strongest influence on this region of the Northern Territory.

6.2.1 Indo-Australian monsoon

The Indo-Australian monsoon is the primary climate driver between the months of December and April. Colloquially known as "the wet", the monsoon brings heavy rainfall across the far north of the continent. Throughout most of the year, the prevailing wind is from the east or southeast. As summer approaches, winds shift to the northeast. This causes the formation of a low-pressure system and a trough that stretches across the Australian continent. Moist air moves in from the oceans, creating conditions that facilitate widespread heavy rainfall. The trough sometimes moves back out to sea during the season, which provides a break in the rain.

6.2.2 El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) is an oceanic-atmospheric coupling that describes an oscillation in the difference in sea surface temperatures between the eastern and western Pacific Ocean and the strength of the Southern Oscillation Index (SOI). The SOI is a measure of the long-term difference in surface air pressure between Tahiti and Darwin (long-term refers to a period of around a month), which is indicative of the Walker circulation. The Walker circulation is caused by a pressure gradient force resulting from a high-pressure system over the eastern Pacific and a low-pressure system over Indonesia.

During an El Niño event, there is warming across the central and eastern Pacific, off the coast of Peru, and relatively cooler temperatures in the western Pacific. This leads to a drier than average wet season in this region of the Northern Territory during the summer months and a later onset of the wet season. During a La Niña event, the inverse occurs. The central and eastern Pacific Ocean experiences cooler than average temperatures and higher rains can be expected, with an earlier onset of the wet season. Events are separated by neutral years where the difference in sea surface temperatures is not significant enough to have a substantial impact on weather patterns.

6.2.3 Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is a global feature of the tropics and affects the intraseasonal variability in the tropical atmosphere. Because it has an interaction with ocean-atmosphere processes, there is some indication it may contribute to the evolution of ENSO. A distinct feature of an active MJO is a strong westerly wind, which runs counter to the easterly trade winds that typically dominate the region's wind pattern. At the surface, it features a large centre of strong, deep convection (the 'active phase'), flanked to the east and west with weak, deep convection (the 'inactive' or 'supressed' phases). Globally, the active phases are easiest to identify in the eastern Indian and western Pacific Oceans, where there is a large 'warm pool' to facilitate convection.

The MJO is like ENSO in that although it is named as an oscillation, the occurrence is not regular. Active periods typically occur every 30-60 days, though the time between periods can be as long as 100 days. The MJO can also be influenced by ENSO, since ENSO affects the size and location of the 'warm pool'.

6.2.4 Indian Ocean Dipole

The Indian Ocean Dipole (IOD) describes the difference in sea surface temperature (SST) between the eastern and western Indian Ocean in the tropical latitudes. Events typically begin in May to June, peak between August and October, and end when the monsoon arrives in late spring. Events are classified as positive, negative, or neutral. It impacts water temperatures in the Gulf of Carpentaria, which may affect cyclone development but has little impact on rainfall in the region.

6.3 Seasonality and rainfall

The ASC is located within the wet-dry tropics and experiences a dry season (approximately June to October) and a wet season (November to May). The seasons can be identified through changes in monthly rainfall, as presented in Figure 5.

During the wet season (January-March), rainfall is high, with high temperatures and humidity. Cyclones may also occur during this time. The wet-to-dry (WtD) transition occurs during April and May. During the WtD transition, rainfall begins to ease, though heavy rainfall is possible, particularly in April. The Dry season occurs from June-October, and is characterised by sunny days, cool nights, and low humidity. The dry-to-wet (DtW) transition occurs in November-December. The DtW transition is characterised by increasing humidity and the return of thunderstorms.

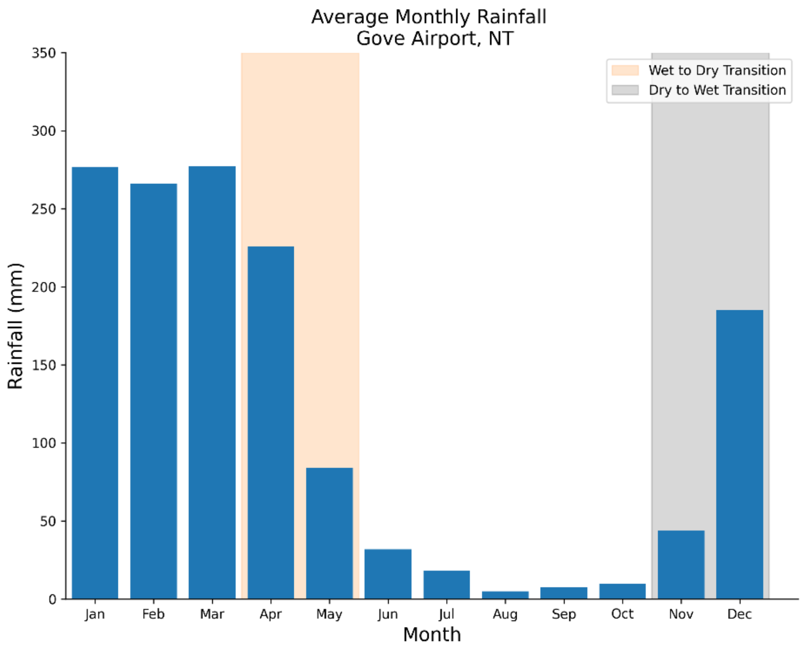


Figure 5 Annual rainfall and seasonality of the ASC and surrounding region

A timeseries showing the annual rainfall from 1960-2020 as a percent difference from the 1986-2005 annual mean (1465 mm) is presented in Figure 6 for the ASC region. The plot also indicates El Niño and La Niña events with red and blue shading, respectively. ENSO event records are not available from the Bureau prior to 1980, which is indicated by the grey shading. Years with no shading indicate neutral years in which climatic indicators were not sufficiently strong to declare an El Niño or La Niña event.

The plot indicates that in years where a La Niña event occurs, rainfall is likely to be heavier than average and in years where an El Niño or neutral conditions prevail, rainfall is likely to be lower than average. However, there are some El Niño years where rainfall is higher than average, likely due to cyclones. There are some La Niña years where rainfall is lower than average, but it is very close to average (less than 10% lower).

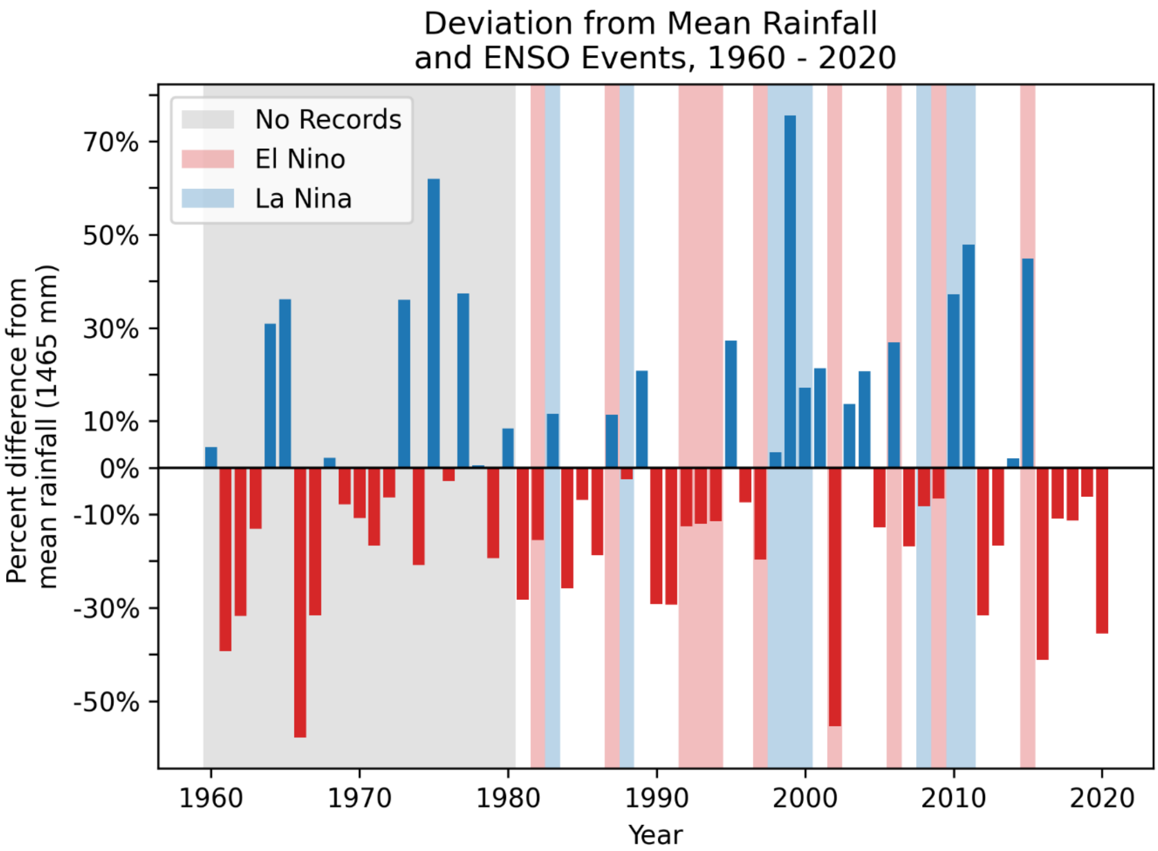


Figure 6 Deviation from mean rainfall and ENSO events for ASC region, 1960 – 2020

6.4 Temperature

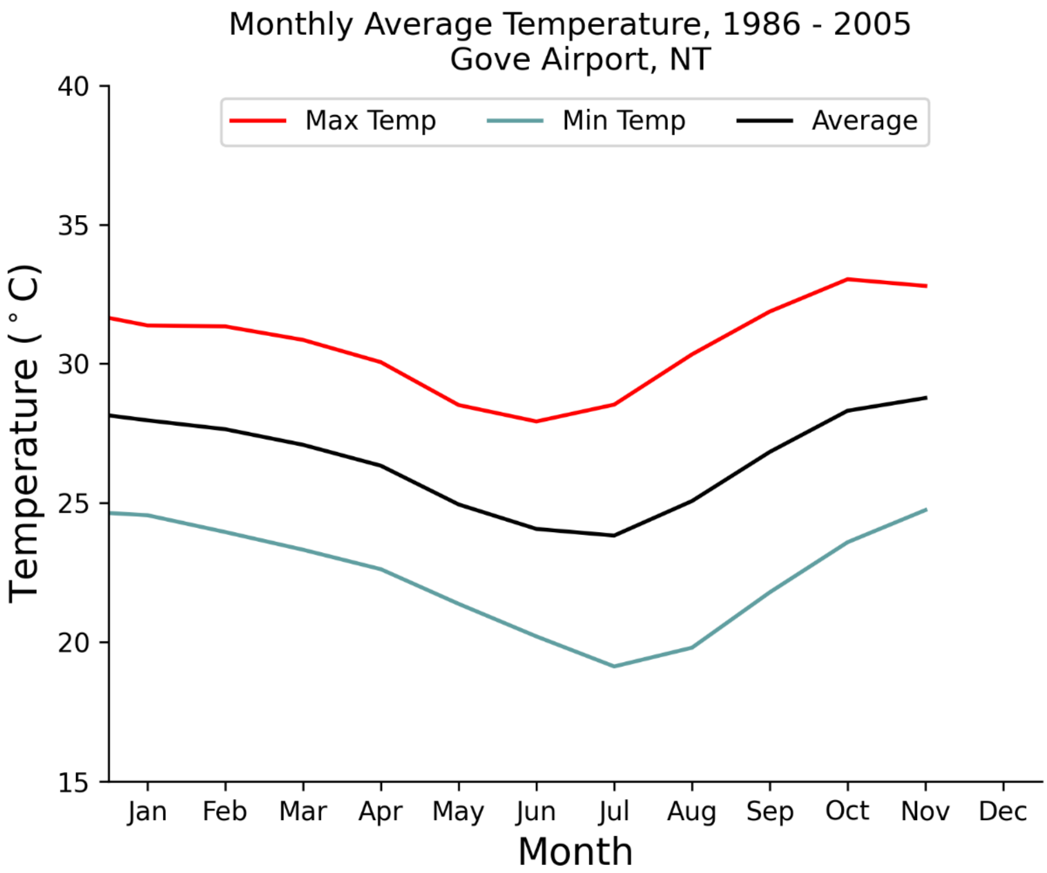
This section provides a summary of historical temperatures followed by analysis of key temperature parameters against a background of relevant climate drivers. Extreme temperature events are considered separately in Section 6.7.1.

A comparison of historical temperature data from the 1986 – 2005 from the SILO climate database and representative of the ASC region is presented in Figure 7. These range from a mean low of 19.1 to a mean high of 33.0°C, with the highest temperature recorded in the period being 34.6°C.

The data shows:

- High temperatures range from 27.9 to 33.0°C temperatures, which is well below the maximum temperature requirements for launch operations.

- Low temperatures range from 19.1 to 24.7°C, which is well above the minimum temperature requirements for launch operations.
- The proximity of the ocean plays a large role in moderating the temperatures at this site.
- There is a lag between the lowest high and lowest low temperatures. This is likely due to the proximity of the site to the ocean and the differential rate of heating between ocean and land.



Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SILO Climate Database (1986 – 2005)													
Mean Max (ºC)	31.9	31.4	31.3	30.9	30.1	28.5	27.9	28.5	30.3	31.9	33.0	32.8	30.7
Mean Min (ºC)	24.7	24.6	24.0	23.3	22.6	21.4	20.2	19.1	19.8	21.8	23.6	24.7	22.5
Mean Temp (ºC)	28.3	28.0	27.7	27.1	26.4	25.0	24.1	23.8	25.1	26.85	28.3	28.8	26.6

Figure 7 Monthly mean maximum and minimum temperatures from the SILO Climate Database (Gove Airport, NT)

6.5 Wind speed

This section provides a summary of historical wind speed and wind direction with an analysis of wind patterns near the ASC. Extreme wind speed events (cyclones) are considered separately in Section 6.7.4.1. Historical wind speed and wind direction observations are not provided by SILO data, so this discussion relies on data from the Gove Airport station.

The surface wind climate is driven by the large-scale circulation patterns of the atmosphere. The Space Centre is in the Monsoonal North (West) NRM sub-cluster, approximately 7.5 km from the Gulf of Carpentaria, on a high ridge. Winds in this area are primarily influenced by synoptic level Trade Winds, which are predominantly east-southeasterly in direction.

The annual, seasonal, and diurnal distribution of winds based on the Gove Airport Bureau site are presented in Figure 8, Figure 9, and Figure 10 for the period spanning 2016 – 2022. These years were selected over previous years as the observational record is more complete and wind patterns have a relatively low interannual variability. The annual distribution (Figure 8) shows a predominance of winds from the southeast, and speeds low enough to not impede a launch. The seasonal distribution presented in Figure 9 shows the distinct shift in winds with the change of seasons. In the wet season, winds are primarily from the northwest quadrant as monsoon wind patterns dominate. During the WtD transition, winds shift to the come from the southeast. This wind pattern persists through the dry season, then during the DtW transition the winds are primarily from the northeast, but there are also winds from the northwest, signaling that the prevailing wind is shifting in that direction.

Wind speeds are the primary focus for consideration for the diurnal winds, presented in Figure 10. Winds are calmest during the overnight hours. They begin to increase in the morning and reach a maxima in the afternoon hours. The high winds decrease after sunset and the percentage of calms increase.

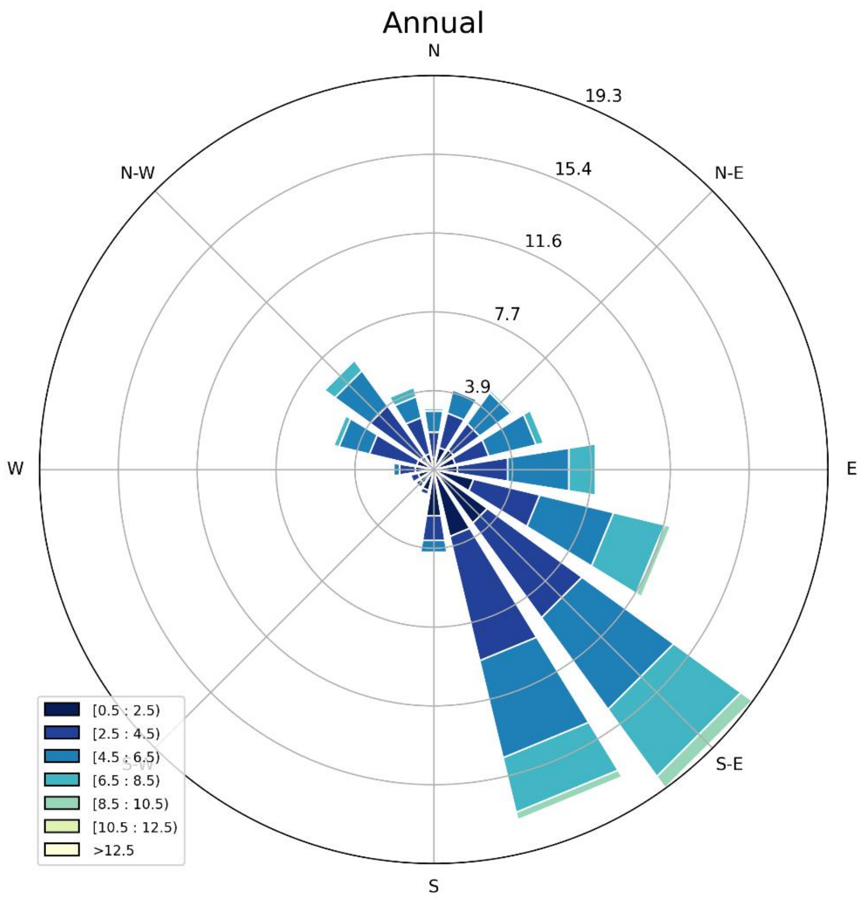
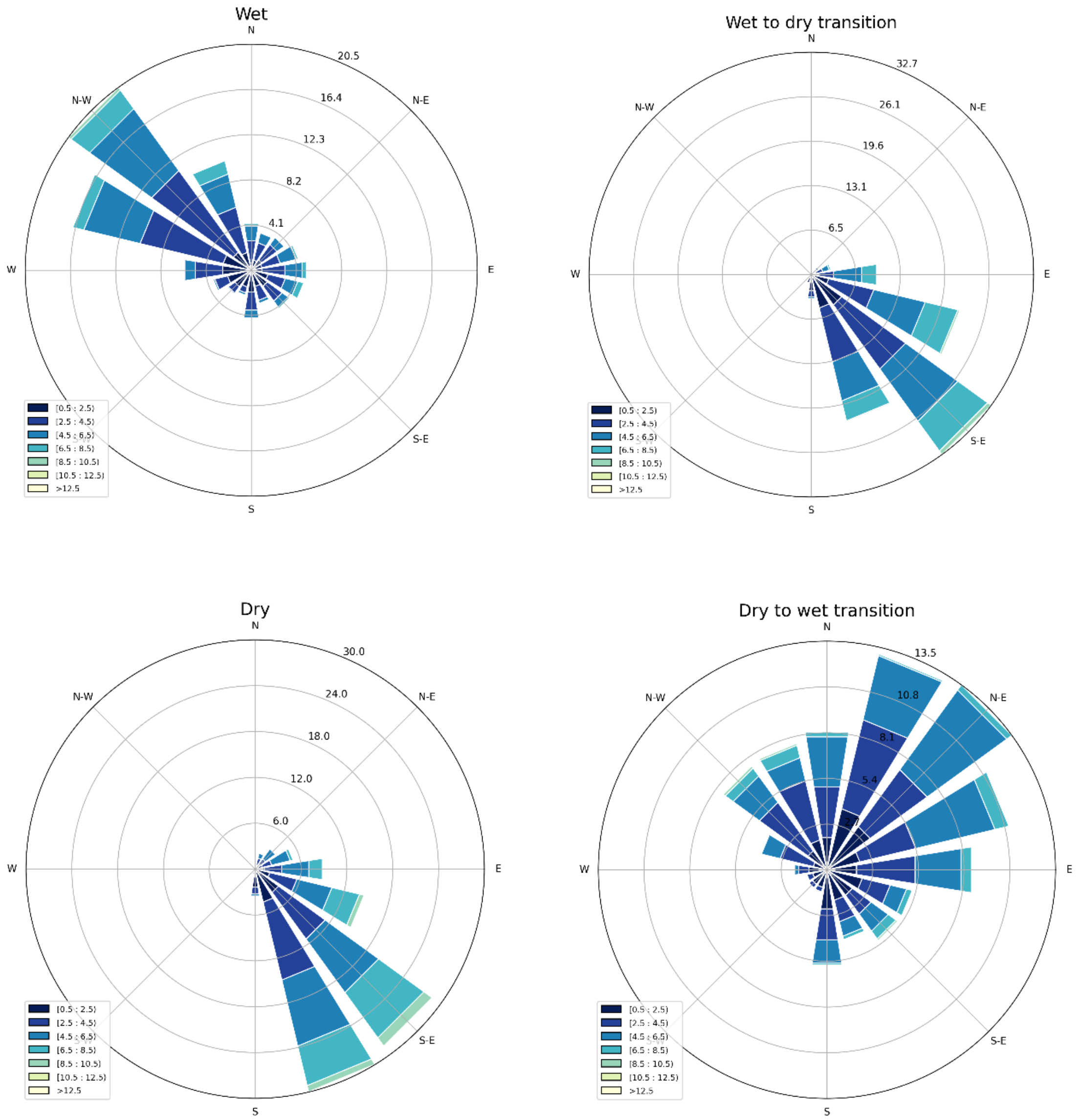
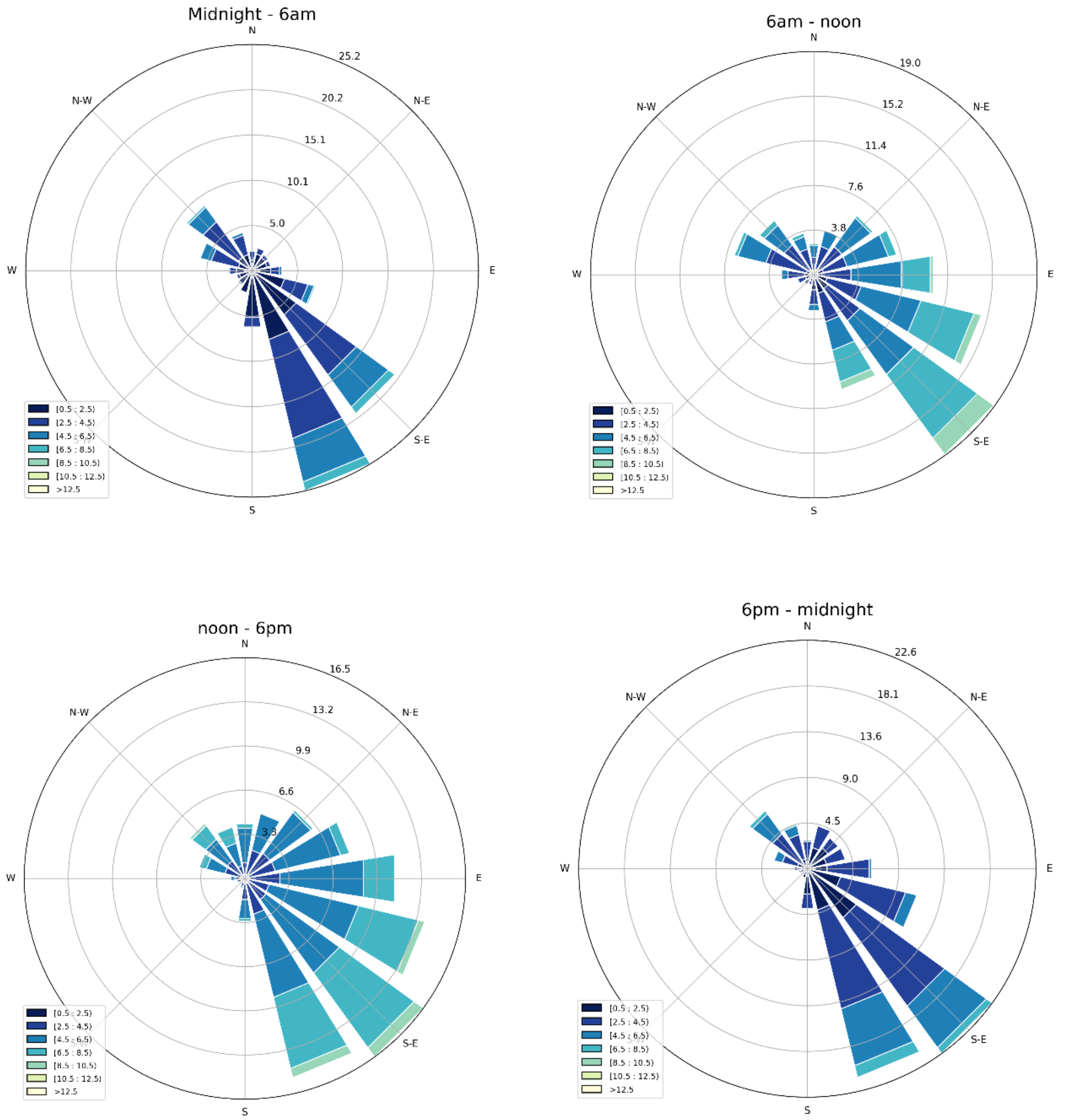


Figure 8 **Annual average wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)**



Speed category (m/s)	Season (percentage)			
	Wet	WtD transition	Dry	DtW transition
calms (0 – 0.5)	9.3 %	6.9 %	7.0 %	14.9 %
0.5 – 2.49	23.6 %	19.1 %	16.3 %	24.5 %
2.5 – 4.49	37.7 %	30.9 %	27.1 %	30.9 %
4.5 – 6.49	23.3 %	27.1 %	29.3 %	25.1 %
6.50 – 8.49	5.6 %	14.9 %	17.5 %	4.2 %
8.50 – 10.49	0.4 %	1.2 %	2.7 %	0.4 %
10.50 – 12.85	0.007 %	0 %	0.1 %	0 %
< 12.86 (25 kts)	0 %	0 %	0 %	0 %

Figure 9 Seasonal wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)



Speed category (m/s)	Time			
	midnight – 06:00	06:00 – 12:00	13:00 – 18:00	19:00 - midnight
calms (0 – 0.5)	24.0 %	3.1 %	0.04 %	5.6 %
0.5 – 2.49	33.7 %	12.3 %	3.5 %	30.1 %
2.5 – 4.49	29.3 %	30.1 %	22.0 %	45.8 %
4.5 – 6.49	11.0 %	32.7 %	47.1 %	16.0 %
6.50 – 8.49	1.9 %	18.3 %	24.0 %	2.5 %
8.50 – 10.49	0.1 %	3.3 %	2.4 %	0.01 %
10.50 – 12.85	0 %	0.16 %	0.1 %	0 %
< 12.86 (25 kts)	0 %	0 %	0 %	0 %

Figure 10 **Diurnal wind speeds and wind directions recorded at Gove Airport Bureau of Meteorology monitoring station (2016 - 2022)**

6.6 Humidity

Dew point temperature and relative humidity indicate the moisture content of air. Dew point temperature reflects the minimum temperature that air can reach before it is completely saturated, after which condensation will occur. A high relative humidity indicates that the dew point temperature is close to the ambient temperature. SILO data does not maintain records on relative humidity. Humidity data from the Gove Airport monitoring station has been used to characterise humidity at the ASC.

Table 9 shows the monthly average fluctuations and annual average relative humidity for the Gove Airport monitoring station over the period 2000 – 2010.

Table 9 Monthly and annual average fluctuations in relative humidity (%) for the Gove Airport Bureau monitoring station for the period 2000 - 2010

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2000	81.5	86.0	86.1	88.6	79.0	78.0	75.2	75.1	76.5	76.0	77.9	81.8	**80.2**
2001	85.9	85.6	85.2	84.4	71.1	76.8	76.0	72.5	77.2	74.5	75.9	77.0	**78.5**
2002	80.3	82.8	79.7	81.0	71.3	68.7	71.6	71.6	74.8	74.2	73.7	72.3	**75.1**
2003	85.4	83.1	83.2	77.0	72.8	74.3	72.0	74.8	74.9	73.1	72.4	78.9	**76.8**
2004	80.8	86.8	84.7	76.5	80.9	68.3	75.3	72.7	72.9	74.6	76.6	77.7	**77.3**
2005	80.9	80.0	84.5	75.4	66.9	74.4	74.0	75.5	75.1	74.2	76.1	74.8	**76.0**
2006	83.4	80.6	87.8	87.1	77.9	75.1	76.5	71.2	72.8	71.7	73.4	77.7	**77.9**
2007	82.8	83.9	86.8	78.9	80.4	78.5	74.7	78.0	74.8	76.1	74.5	76.2	**78.8**
2008	81.0	84.5	83.8	73.4	66.9	75.1	75.7	72.8	75.9	75.8	73.8	79.8	**76.5**
2009	85.3	84.5	81.0	78.9	83.1	74.2	71.7	75.2	73.3	70.0	73.9	73.3	**77.0**
2010	83.8	81.6	83.0	85.6	79.9	74.7	80.6	75.0	80.4	82.6	79.4	80.8	**80.6**

6.7 Extreme weather events

Key factors influencing weather events in the ASC region revolve around the influences of the climatic drivers detailed in Section 6.2 and tropical cyclones, particularly:

- The development and onset of the Indo-Australian monsoon, which drives wind and rainfall patterns in the region.
- El Niño/Southern Oscillation, which influences the amount of annual rainfall the region is likely to receive.

The following sections characterise the status of these extreme weather events for the ASC.

6.7.1 Extreme temperatures

Extreme temperatures have been assessed on an annual basis for the SILO climate data extracted at Gove Airport covering the period 1986 to 2005, inclusive. Annual maximum and minimum temperatures for each month of the year are presented in Table 10. Values are based on 24-hour average data.

The ASC has indicated that temperatures must be between 0ºC and 37ºC for launch operations to proceed. The information provided in the table indicates that these criteria are unlikely to be exceeded in the current climatic conditions.

Table 10 Summary of temperature extremes from the Gove Airport SILO Climate Data

Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SILO Climate Database (1986 – 2005)												
Max Recorded (ºC)	33.3	33.7	32.7	32.0	31.5	29.4	29.1	29.8	31.5	33.1	33.7	34.6
Min Recorded (ºC)	24.3	23.4	23.3	22.5	20.8	20.2	18.4	17.0	18.3	19.9	22.1	23.6

6.7.2 Extreme rainfall

The Gove Airport BoM monitoring station has been used to characterise trends in historical rainfall for the ASC area due to its proximity and long-term coverage. This analysis covers the years 1986 – 2005, in line with the other baseline analyses in this section. The highest rainfall recorded in a single day was 437 mm and the maximum monthly rainfall was 1080.2 mm.

Table 11 shows the highest amount of rain to fall in one month for the periods 1986 – 2005, as extracted from the SILO Climate Database for Gove Airport.

Table 11 Summary of rainfall extremes from the Gove Airport SILO Climate Data

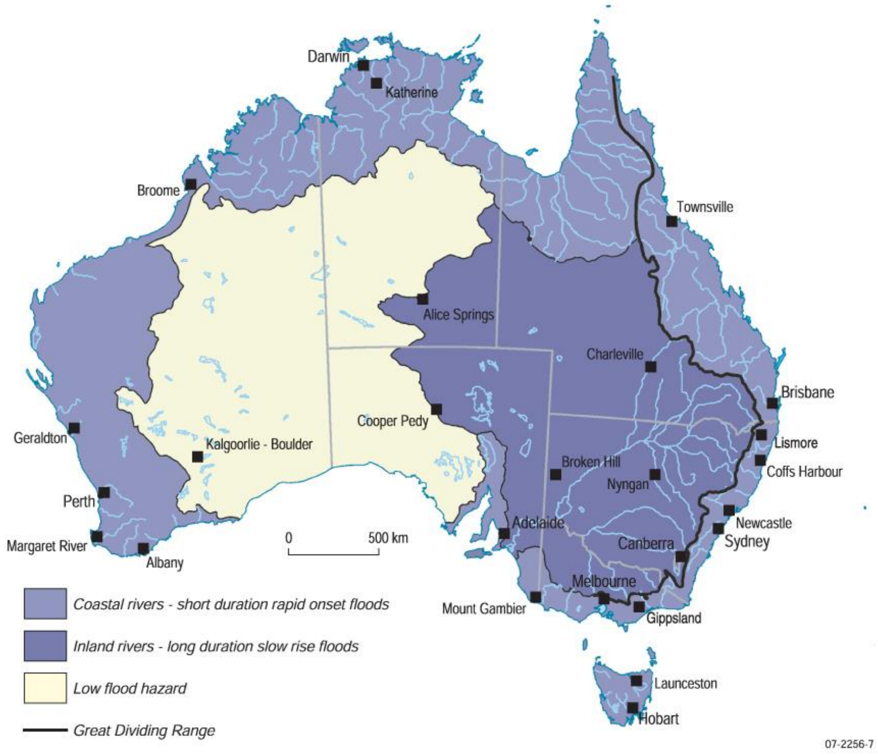
Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SILO Climate Database (1986 – 2005)												
Max Recorded (mm)	740	571	514.6	1080.2	373.4	76	67.8	28	32.6	81.4	190.2	372.6

6.7.3 Flood potential

As depicted in Figure 11, approximately two thirds of Australia is exposed to significant flood risk. While the ASC itself is located at a higher elevation and is unlikely to be directly impacted by flooding, indirect impacts may occur. While weather forecasts can provide advance warning of a flood and seasonal forecasts can be used to determine the likelihood of flooding in coming months, forecasting flood extent is a complex process.

Floods occur when the amount of water flowing from a catchment exceeds the capacity of its drains, creeks, and rivers. Some rainfall is absorbed by soil and vegetation and what remains is classified as run-off and enters waterways as water flow. Rainfall is the most important factor in creating a flood; however, there are many other factors that contribute to the extent and severity of flooding. These factors include the geometry of the catchment and land use within the catchment.

Localised flood mapping, based on historical records and flood studies that have been conducted over the area, can be used to understand the exposure of the site and surrounds to flood events. The vulnerability of the site and surrounds will also be affected by the capacity of the storm water drainage systems. Effective drain systems can both assist with erosion from the site and incoming water to lower-elevation locations.



Source: Geoscience Australia, 2007

Figure 11 Map of flood potential in Australia (Geoscience Australia, 2007)

6.7.4 Storms and extreme winds

6.7.4.1 Extreme wind speeds

Maximum wind gusts are based on windspeeds measured over 10-minute intervals. Wind data is not maintained in the SILO dataset but it is recorded at the Gove Airport Bureau station. However, the data set is incomplete prior to 1997 and after 2010. The highest recorded wind gust recorded in each month between 2000 and 2010 is presented in Table 12.

On average, high winds are possible any time of year and gusts that exceeded the wind criteria for safe launch operations (25 kts, 12.8 m/s) occurred in all but three months of the 10-year period that was studied. However, the months with the lowest wind gusts are November and December, in the Dry to Wet Transition season. In general, gusty conditions can occur at any time at the site and will likely need to be considered for operational planning purposes.

Table 12 Monthly and annual maximum wind gusts (m/s) recorded at the Gove Airport Bureau monitoring station for the period 2000 - 2010

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max
2000	19	13.9	15.9	17.5	15.9	16.5	16.5	12.9	14.4	14.4	11.8	14.9	**19**
2001	11.3	19	13.9	15.9	13.9	15.9	14.9	14.9	12.9	12.9	13.4	14.9	**19**
2002	13.9	18.5	12.9	13.4	17	14.9	14.9	15.9	15.9	11.8	12.3	14.9	**18.5**
2003	20.1	17	23.7	14.9	14.4	14.4	15.4	15.9	14.9	13.4	14.4	15.9	**23.7**
2004	18	13.4	12.9	12.9	18	16.5	14.4	13.9	15.9	12.3	13.4	14.4	**18**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max
2005	16.5	14.9	28.3	14.4	12.9	14.9	15.9	14.4	11.8	13.4	13.4	14.4	**28.3**
2006	19.5	13.4	15.4	21.1	14.9	15.4	13.9	16.5	15.9	14.9	13.9	13.9	**21.1**
2007	18	14.9	18	15.4	18	14.9	13.9	18	13.9	12.9	13.9	13.4	**18**
2008	20.1	18.5	13.4	12.9	15.9	14.9	17	17	15.9	13.4	12.9	13.4	**20.1**
2009	15.9	14.9	13.9	15.4	13.4	14.4	15.4	13.9	14.9	15.9	11.8	13.4	**15.9**
2010	19	14.9	18.5	13.9	14.9	14.9	14.9	17	14.4	15.4	13.9	14.4	**19**
Max	**20.1**	**19**	**28.3**	**21.1**	**18**	**16.5**	**17**	**18**	**15.9**	**15.9**	**14.4**	**15.9**	

6.7.4.2 Tropical Cyclones

The International Best Track Archive for Climate Stewardship (IBTrACS: Knapp et al, 2010, 2008) is a global archive of all cyclone tracks from 1897 to 2021. It is updated annually with the best estimate of each individual storm track across all ocean basins. The analysis presented here uses a subset of the IBTrACS archive for the South Pacific Basin and the East Australian sub basin. The dataset was refined to eliminate those events that would not have a direct impact on the weather and climate of the Project site and surrounding region; the dataset was constrained to identify tropical cyclones whose eye approached within a 400km radius of the ASC. The analysis identified 58 tropical cyclones covering the 1984/85 to 2019/20 storm seasons, shown in Figure 12.

On average, approximately 1.5 tropical cyclones can be expected to pass within 400km of the project site per year. However, this has ranged from zero to 4, as presented in Figure 13. The number of storms experienced in each month of the cyclone season is shown in Figure 14. Most tropical cyclones occur during the tropical cyclone season (1 November to 30 April); however, tropical cyclones have also occurred in May.

The time elapsed between a storm being named and entering a 400 km radius of the site for the cyclones in the 1984/85 to 2019/20 storm seasons is presented in Table 13. Fifty percent of the storms analysed became sufficiently organised to be named within 400 km of the ASC. Ten percent moved into the radius either within 24 or 48 hours, and 19% of the time, the storm arrived after 2-7 days. Another 10% of the storms entered the radius after 7 days or more. However, it should be noted that three of those storms formed within the basin, moved out of the analysis area, then made a 180° turn, and returned along a similar track.

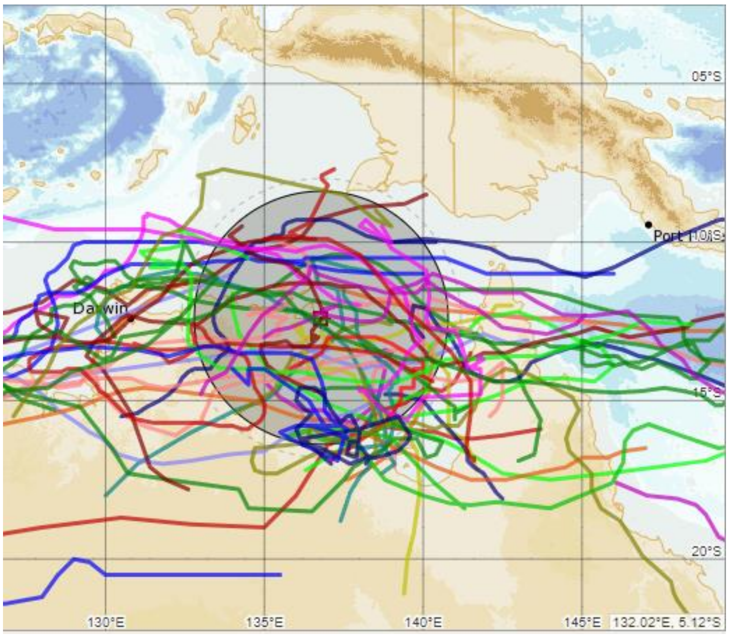


Figure 12 Map of named cyclones crossing within 400 km of the ASC, 1984/85 - 2019/20 seasons

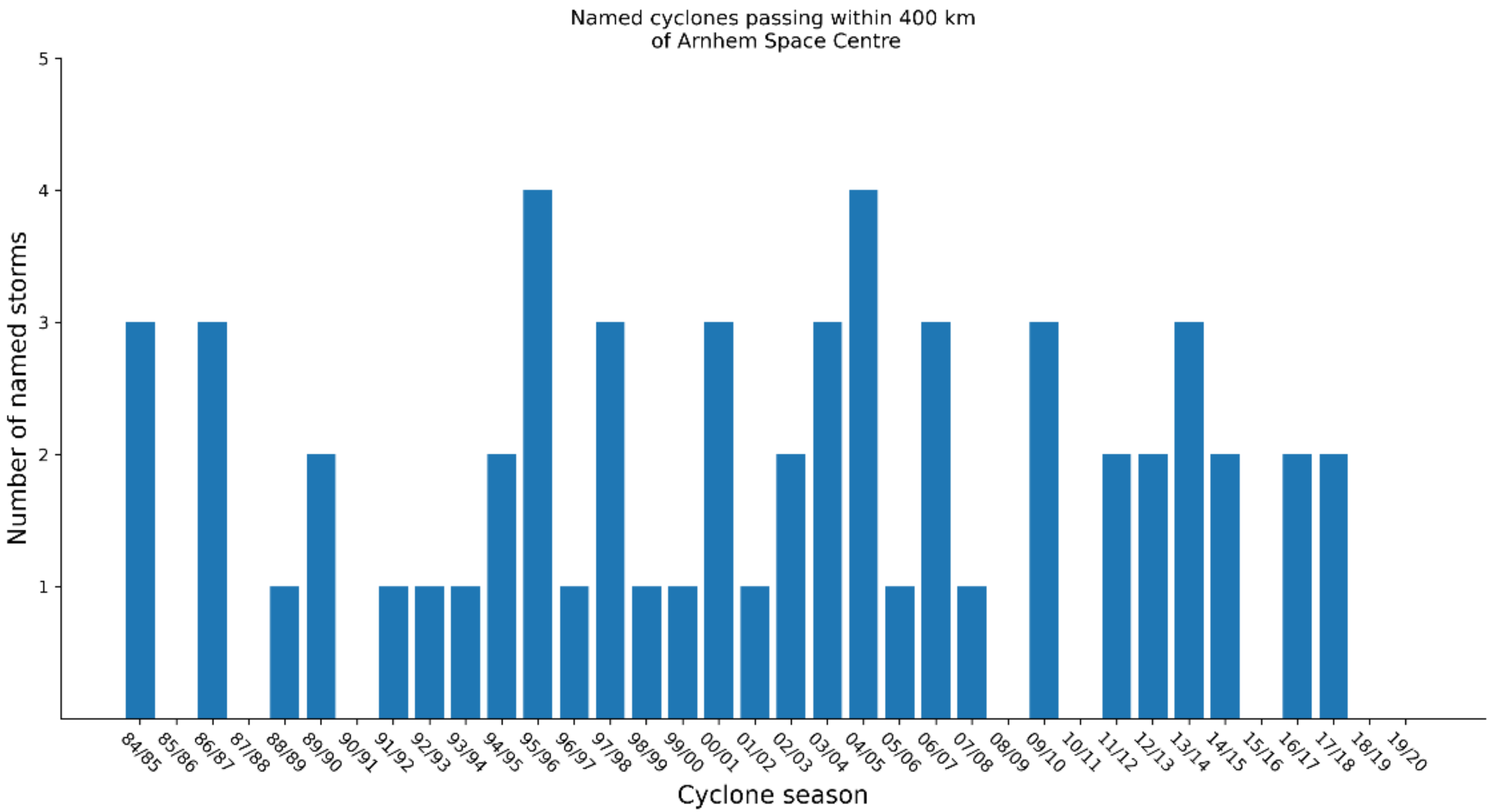


Figure 13 **Annual total number of tropical cyclones that passed within 400km of the ASC during the 1984/85 to 2019/20 storm seasons**

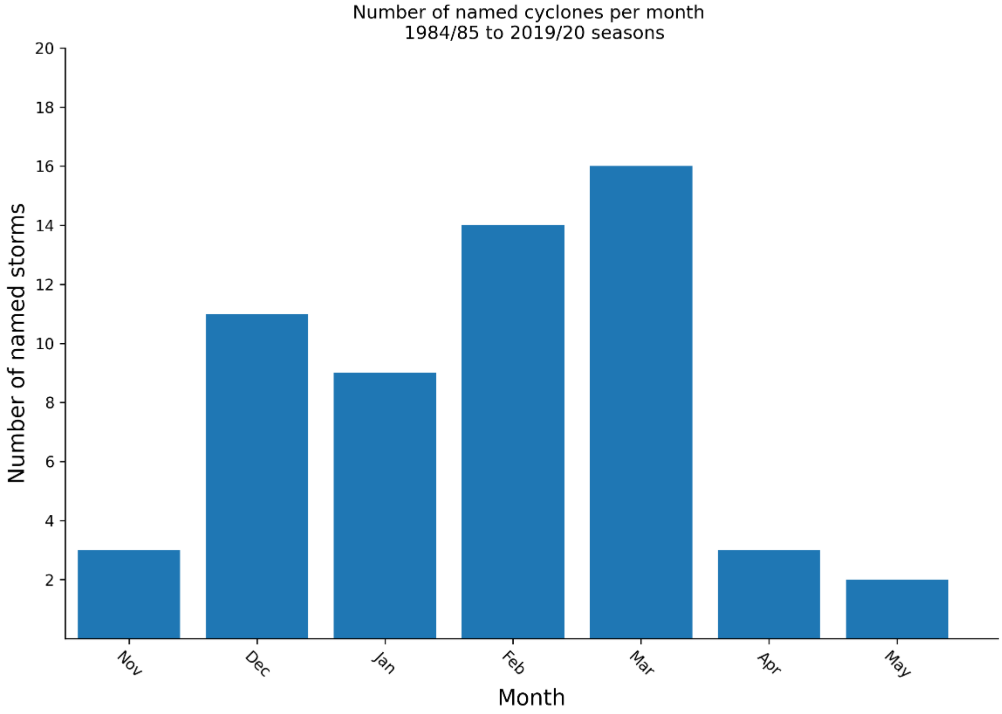


Figure 14 **Number of named cyclones per month, 1984/85 to 2019/20 seasons**

Table 13 **Time elapsed between naming of cyclone and moving within 400 km radius of ASC**

Time since storm named	Number of Storms	Percentage
formed in radius	29	50%
< 24 hours	6	10.3%
1-2 days	6	10.3%
2-7 days	11	19.0%
> 7 days	6	10.3%

6.7.5 Bush fires

Bushfire prone areas are prominent throughout the Northern Territory. Figure 15 presents the number of historical bushfires (recorded as fire scars) that have occurred during the years 2000-2020. The area that the ASC is located in has had few bushfires (less than 4 in the 20-year span); however, areas surrounding ASC have experienced bushfires in as many as 16 of the 20 years in question. The months in which fires occurred in 2020 and 2021, as recorded by North Australia and Rangelands Fire Information (NAFI) is presented in Figure 16. Only two years are presented here for image clarity, though the pattern is typical of the region. The figure shows that fires in the area typically occur during the dry season (July-October). This may have an impact on launch operations if the fires are sufficiently close to the ASC.

In addition, while the site may be reasonably protected from fires, access to and from ASC, either to Darwin or to the Gove peninsula, may be restricted due to bushfires.

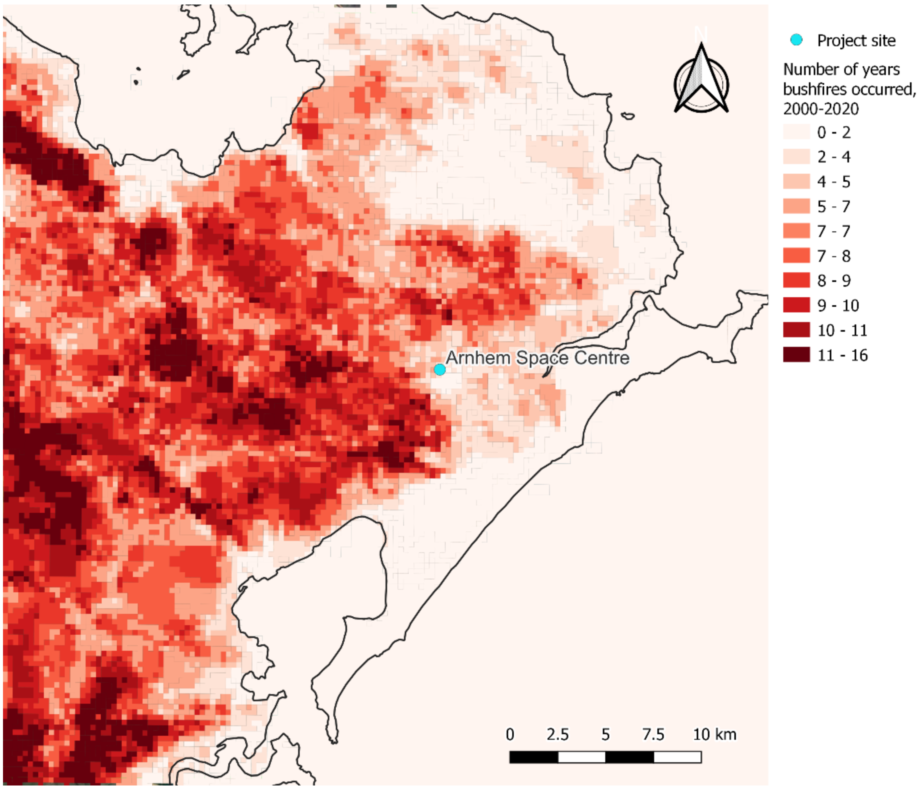


Figure 15 Number of bushfires recorded, 2000-2020

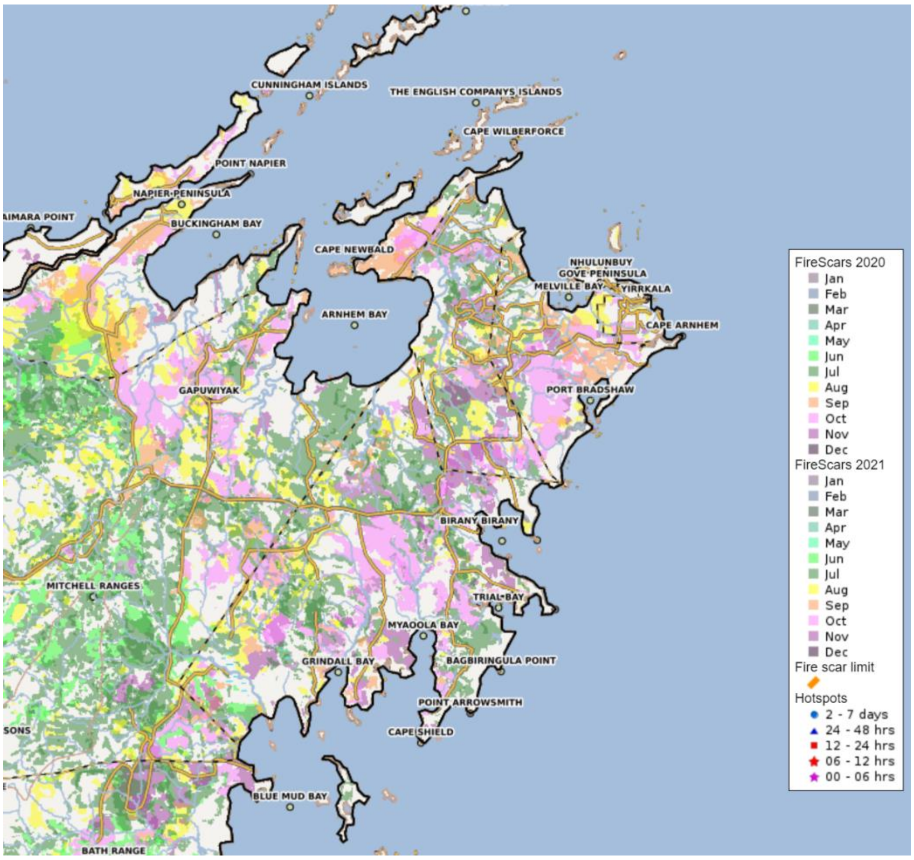


Figure 16 Months in which bushfires occurred, 2020 - 2021

7. CLIMATE CHANGE

Climate change projections of Australia's future climate are delivered at a national level through the Climate Change in Australia (CCiA) website (CSIRO and BOM, 2015; Moise et al, 2015). In addition, state-based climate policy statements are delivered by Climate Change NT. These have been reviewed to provide an understanding of the climate drivers of the region to determine the climate change considerations of relevance to the ASC. Climate change projections provided by CCiA have been based on the Monsoonal North (West) sub-cluster of Australia's NRM regions (CSIRO and BoM, 2015; Figure 17).

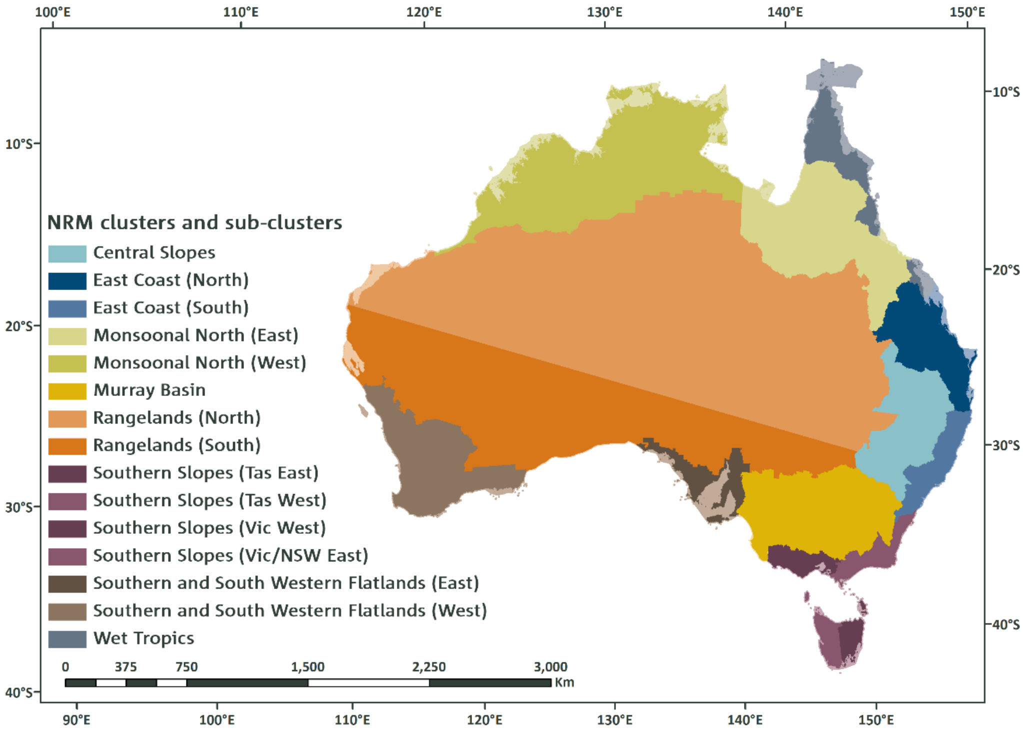


Figure 17 **NRM Cluster Map (CSIRO and BoM, 2015)**

The global climate model (GCM) simulations provided by CSIRO and BoM (2015) represent a range of emission scenarios, defined by the IPCC as Representative Concentration Pathways (RCPs). Each RCP represents a different trajectory for greenhouse gas concentrations in the atmosphere, and each reflects varying levels of GHG emissions, aerosols, and land-use change. Given the current trajectory of GHG emissions we apply the highest emission scenario, RCP8.5.

7.1 Climate change data

Data in this assessment were sourced from multiple locations. A summary is provided in Table 14 and includes:

- Gridded data from the SILO database of Australian climate data from 1889 to present. SILO is a collaboration between the Queensland government and the Bureau of Meteorology.
- Data sourced from the Bureau of Meteorology Australian Water Outlook website
- Data sourced from the CSIRO Climate Change in Australia (CCiA) website
- Elevations were sourced from 1-second STRM data.

Dozens of climate models are available for use in climate studies, each with their own strengths and weaknesses. There is no single "best" model. The specific models chosen for use in this study were those identified by CSIRO as performing particularly well over Australia. Where relevant, a "worst case" model was selected. That is, the model selected for rainfall projections represents a "wet" scenario, and that for bushfires is a "hot" scenario. The model selected for temperature represents a balanced scenario. Runoff projections are from the Australian Water Resource Assessment Landscape (AWRA-L) hydrological model, which is developed from an ensemble (average) of four global climate models.

Table 14 Data indicators and sources used in this analysis

Weather Event	Indicator	Baseline		Future			
		Period	Data	Period	Scenario	Model	Data
Extreme Temperature	Count of days >35°C	2000-2020	SILO	2040-2059	RCP 8.5	ACCESS	CSIRO
Extreme Rainfall	1 in 20 ARI (5% AEP)	1986-2005	CSIRO	2040-2059	RCP 8.5	NorESM GFDL-ESM2M	CSIRO
Bush Fire	FFDI >50	1986-2005	CSIRO	2040-2059	RCP 8.5	CANESM2-NARCLIMJ	CSIRO
Flood	Runoff + extreme rainfall	1976-2005[a]	Bureau	2036-2065	RCP 8.5	Bureau	Bureau
Sea Level Rise	<15m elevation + proximity to coast	current	GIS	-	-	-	-
Cyclone	Storm tracks	1984-2020	Bureau	-	-	-	-

[a] Note: baseline data not available for download

7.2 Data presentation

The results of the assessment are presented as regional maps, with additional plots and tables to support more in-depth analysis.

Map contours were generated from the gridded data sets (with 5km resolution) with contours selected in such a way as to appropriately encompass the range of values found in the region. These contours are then held constant across all maps of the same type to facilitate comparisons of change between the baseline and future scenarios. In both the baseline and future scenario maps, the values presented represent a temporal average over the period stated. For example, the number of days over 35°C was counted for each year in the projection period and the mean of the counts was taken for each grid cell and the results are presented on the map as the average number of days over 35°C per year for the period.

It should be noted that some maps have areas of missing data in remote regions. These data points were removed by the publishing body, usually due to insufficient observations from the baseline period and subsequent lack of confidence in the future scenario model outputs. These areas have a value of "NA" (not available) and are not included in any statistical calculations of the area in which they occur.

7.3 Temperature

Surface air temperatures in the Monsoonal North (West) sub-cluster have been increasing since national records began in 1910. Daily maximum temperatures increased by 1.0°C and overnight minimum temperatures have increased by 0.9°C between 1910 and 2013. This increase in temperature has occurred despite increased cloudiness which can drive a cooling effect.

Current mean temperature and climate change projections are presented in Figure 18 over the current period (2000-2020), Figure 19 presents a near future hot scenario (2036 – 2065) and Figure 20 presents a scenario later in the century (2056 – 2085). All three plots are presented on the same scale to facilitate comparisons. The most notable finding from these figures is that the observed mean temperatures over the past 20 years have already exceeded the climate projections from the 2015 RCP8.5 scenario. While the lower estimates in the near future scenario could be attributed to several factors, such as maritime synoptic conditions, or grid placement and statistical downscaling, these issues are unlikely to hold true for the entire region. Thus, it is more likely that the temperature regime in the region will continue to increase, and the late century projections may be realised sooner in the century than originally projected.

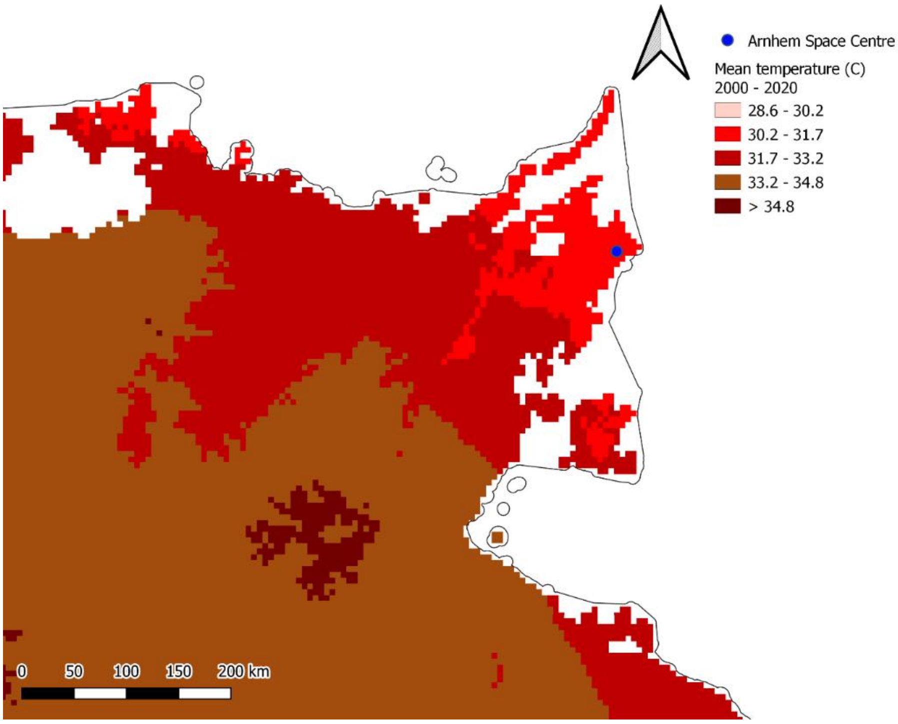


Figure 18 **Observed mean temperature for the ASC and surrounding region for the period 2000 – 2020 (SILO)**

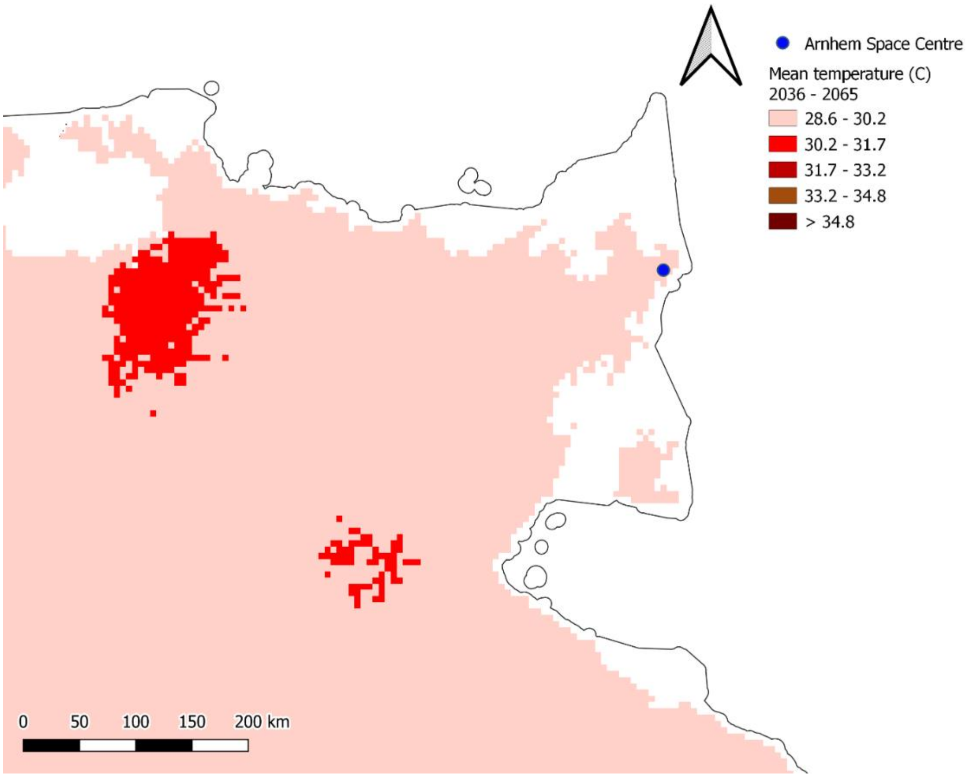


Figure 19 **Projected mean temperature for the ASC and surrounding region for the period 2036 – 2065 (CSIRO ACCESS model RCP8.5)**

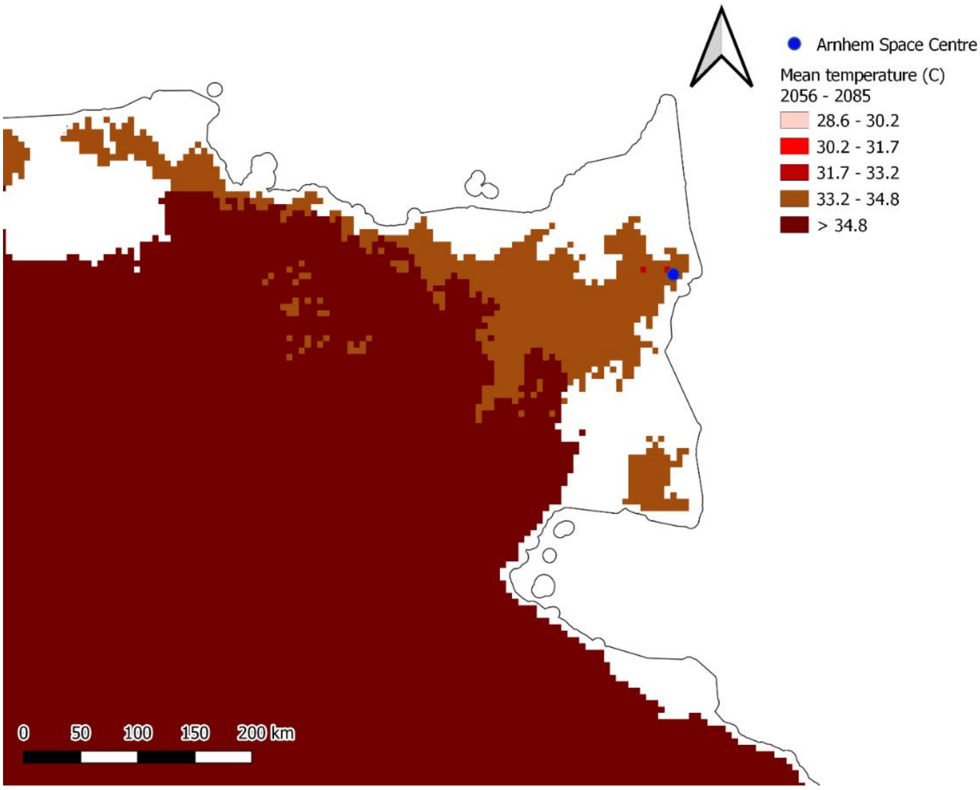


Figure 20 **Projected mean temperature for the ASC and surrounding region for the period 2056 – 2085 (CSIRO ACCESS model RCP8.5)**

7.4 Rainfall

Over the past century, total annual rainfall has increased in the Monsoonal North region (NESP, 2020). Wet season rainfall has increased in the Top End, and the seasonal distribution has changed further south. It is predicted that natural variability will cause greater interannual changes to rainfall than climate change. Near future projections for the dry season range from 35% drier to 29% wetter than the 1986-2005 average, and projected wet season change ranges from 7% drier to 8% wetter, compared to the same period. The large ranges and unclear direction indicate that both drier and wetter future scenarios should be considered.

Climate change projections for the average annual rainfall across the region are illustrated in Figure 21 and Figure 22. Given a baseline annual average rainfall for 1465 mm, the figures reflect the predictions, indicating that there is little change in average annual rainfall projections for 2050 (2036-2065) and 2070 (2056-2085), compared to the baseline period. However, interannual (single year) changes may depart substantially from the climatological average. In addition, there is little information regarding any changes to the onset of the Indo-Australian monsoon or the timing of the wet and dry seasons.

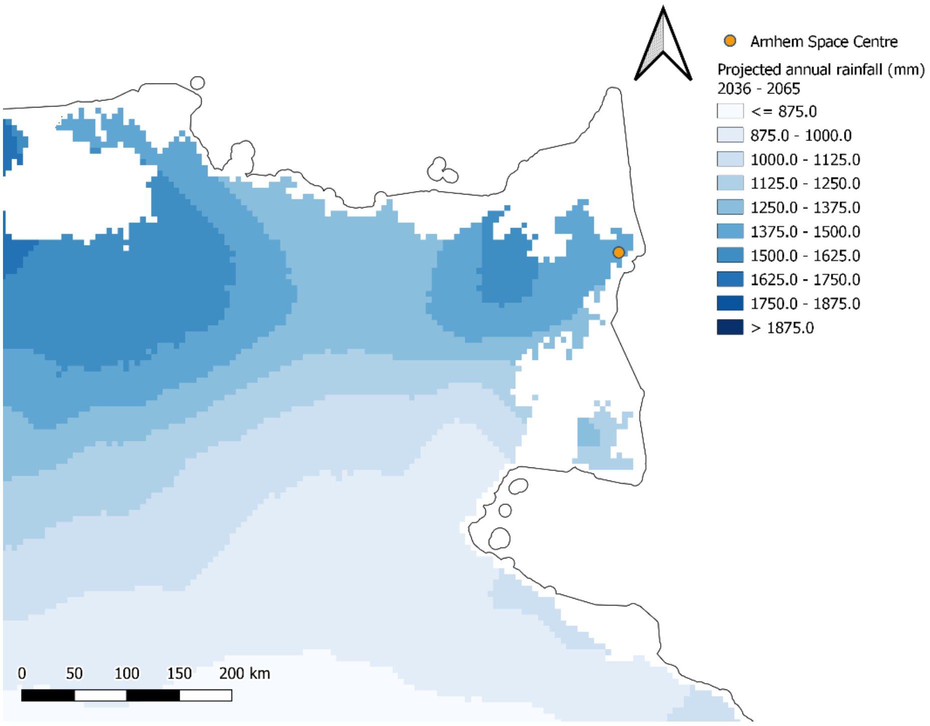


Figure 21 Projected annual rainfall (mm) for the ASC and surrounding region for the period 2036 – 2065 NorESM model RCP8.5

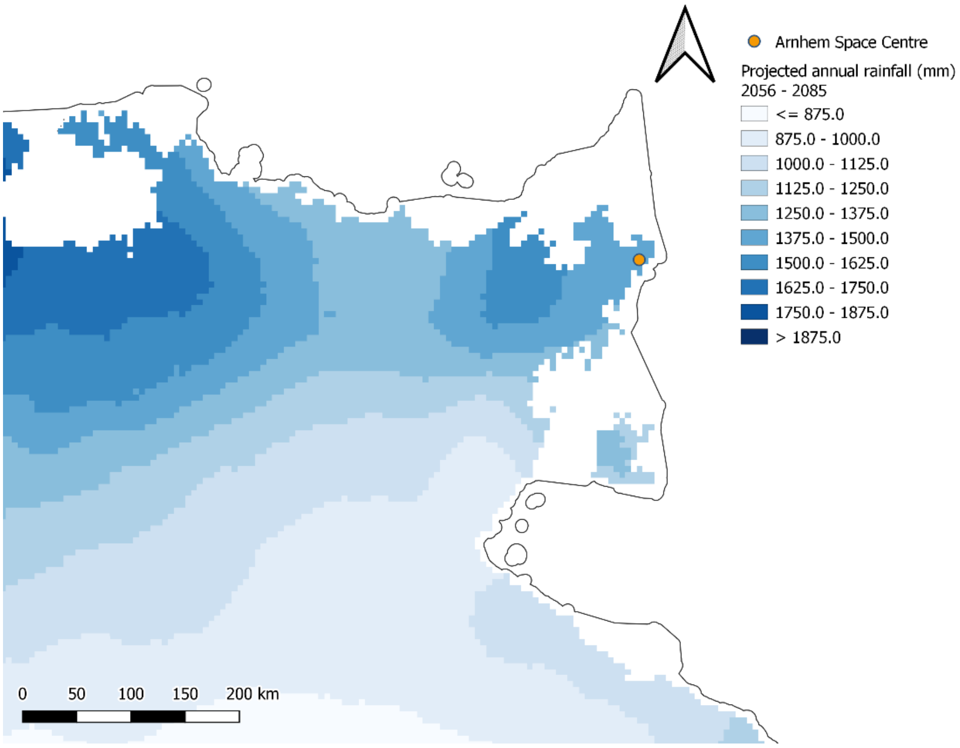


Figure 22 **Projected annual rainfall (mm) for the ASC and surrounding region for the period 2056 – 2085 NorESM model RCP8.5**

7.5 Wind Speed

Climate change projections for mean wind speed are provided by the CCiA. There is high confidence in little change through 2050 throughout the Monsoonal North (West) sub-cluster. Predicted wind speed changes for the region, expressed as a percentage, are presented in Table 15. On average, wind speeds are predicted to undergo little change, though there may be some increases in speed in the Dry to Wet Transition, with the arrival of the monsoon.

Table 15 **Summary of average wind speed variation (%) for RCP8.5 in the Monsoonal North region**

Season	2030		2090	
	Median	Range	Median	Range
Annual	0.2	-0.9 to 1.4	0.8	-3.7 to 5.1
Wet	1	-1.1 to 2.8	1.9	-3.9 to 8.3
Wet to Dry Transition	-0.6	-2.9 to 1	-3.3	-7.6 to 2.5
Dry	-0.2	-1.5 to 3.1	0.4	-2.6 to 6
Dry to Wet Transition	0.6	-1.1 to 2.4	2.1	-0.5 to 8.4

7.6 Extreme weather events

7.6.1 Extreme temperatures

Using hot days (>35°C) as an indicator of extreme heat, Figure 23 provides a summary of the average number of hot days experienced in the region's current climate compared to hot days projected under climate change for 2050 (Figure 24). The map shows the average number of days per year across the period. Some years will experience more events than others. The figures indicate that the number of hot days is expected to increase substantially, from <5 per year in the current climate to 30-50 in 2050.

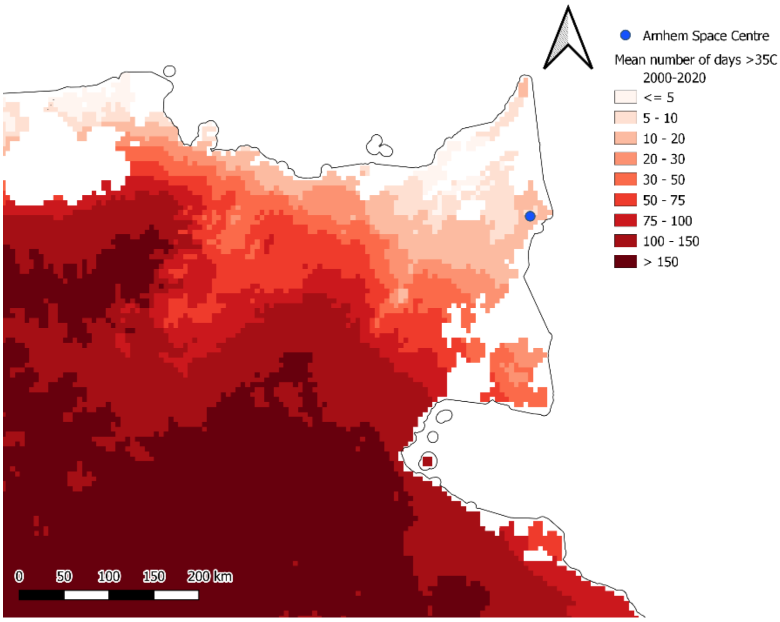


Figure 23 Average number of days per year above 35°C observed in the region for the period 2000 - 2020

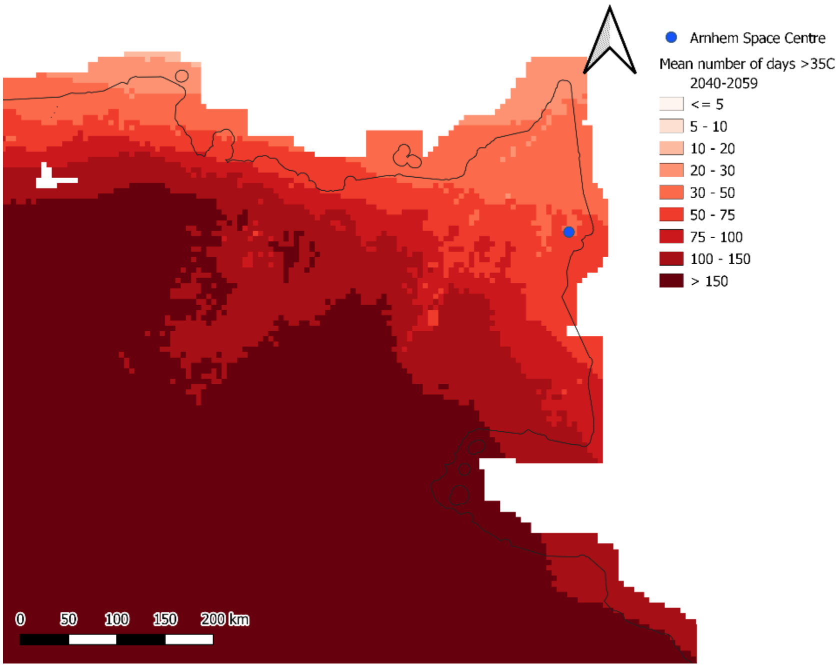


Figure 24 **Average number of days per year above 35°C observed in the region for the period 2040 - 2059**

7.6.2 Bushfire weather

The Forest Fire Danger Index (FFDI) has been selected as the most useful indicator of fire weather hazard at a regional scale. The FFDI is used to provide an indication of fire weather conditions, with higher values representing more dangerous conditions under which fires are more likely to start, spread, be more difficult to suppress, and have higher impacts and consequences. Values are grouped into the following categories: Low/Moderate (0-11), High (12-24), Very High (25-49), Severe (50-74), Extreme (75-99), and Catastrophic (100+). Fire weather is considered ‘severe’ when the FFDI exceeds 50. Bushfires have potentially greater human impacts at this level (Blanchi et al, 2010).

Bushfire occurrence depends on four ‘switches’ (Bradstock, 2010):

1. Ignition, either human-caused or from natural sources such as lighting;
2. Fuel abundance or load;
3. Fuel dryness, where lower moisture contents are required for fire, and
4. Suitable weather conditions for fire spread, generally hot, dry, and windy.

FFDI captures two of the four switches, fuel dryness and suitable weather conditions. Fuel abundance is a consideration that needs to be made at a more localised level.

The average number of days with severe fire danger, FFDI > 50, has been selected as the weather indicator to consider the existing and future risk of fire weather for ASC operations. Given the relatively low proportion of forested areas in the Northern Territory, this metric is not as accurate in the Northern Territory as it is in other locations, but it is still a useful indicator for potential changes in fire weather.

Figure 25 provides a summary of severe fire danger days for the baseline period of 1986 -2005. High rainfall rates on an annual basis contribute to the low number of average days with a severe rating. The future climate scenario, presented in Figure 26 indicates little change for the region.

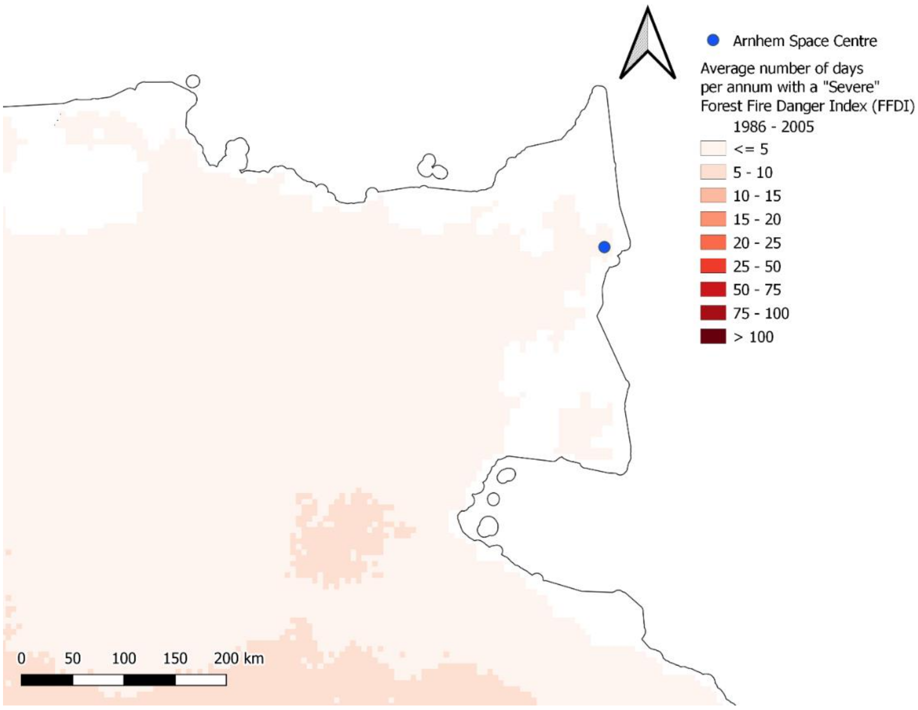


Figure 25 **Average number of days per year with severe fire danger (FFDI>50) observed in the region for the period 1986 - 2005**

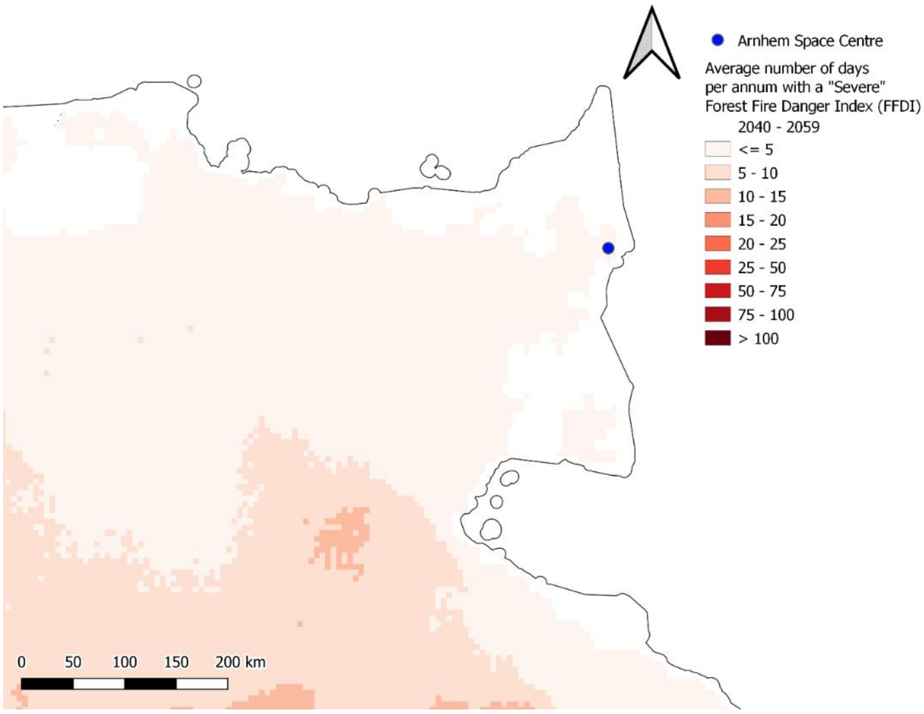


Figure 26 **Average number of days per year with severe fire danger (FFDI>50) observed across Australia for the period 2040 – 2059 RCP 8.5 CSIRO ACCESS**

7.6.3 Extreme rainfall

In Australia there is high variability in both annual average rainfall and the occurrence of intense rainfall events. Rainfall patterns are strongly influenced by climate drivers such as El Niño (hot and dry) and La Niña (warm and wet). Despite this natural variability, long-term trends are evident in the rainfall records:

- Heavy rainfall events in the region are generally associated with weather systems such as localised convective thunderstorms, cyclones and the Indo-Australian monsoon
- An increase in the intensity of heavy rainfall events have been observed nationally, with an increase of around 10% in short-duration (hourly) extreme rainfall observed in recent decades. Daily rainfall totals associated with thunderstorms has also increased.

A warmer atmosphere can hold more water vapour. For every degree of temperature change, the atmosphere's moisture content can increase by 7%. Australia's warming climate will lead to a greater number of intense, short-duration heavy rainfall events. In addition, heavy rainfall events will become more intense.

Using the maximum 1-day rainfall with a 5% AEP as an indicator of extreme rainfall, Figure 27 provides a summary of maximum 1-day rainfall with a 5% AEP experienced during the baseline period in the region (1986 – 2005) compared to the expected 5% AEP projected under a warm wet scenario for 2050 (Figure 28). During this period, the 5% AEP 1-day rainfall is expected to increase up to 50 mm.

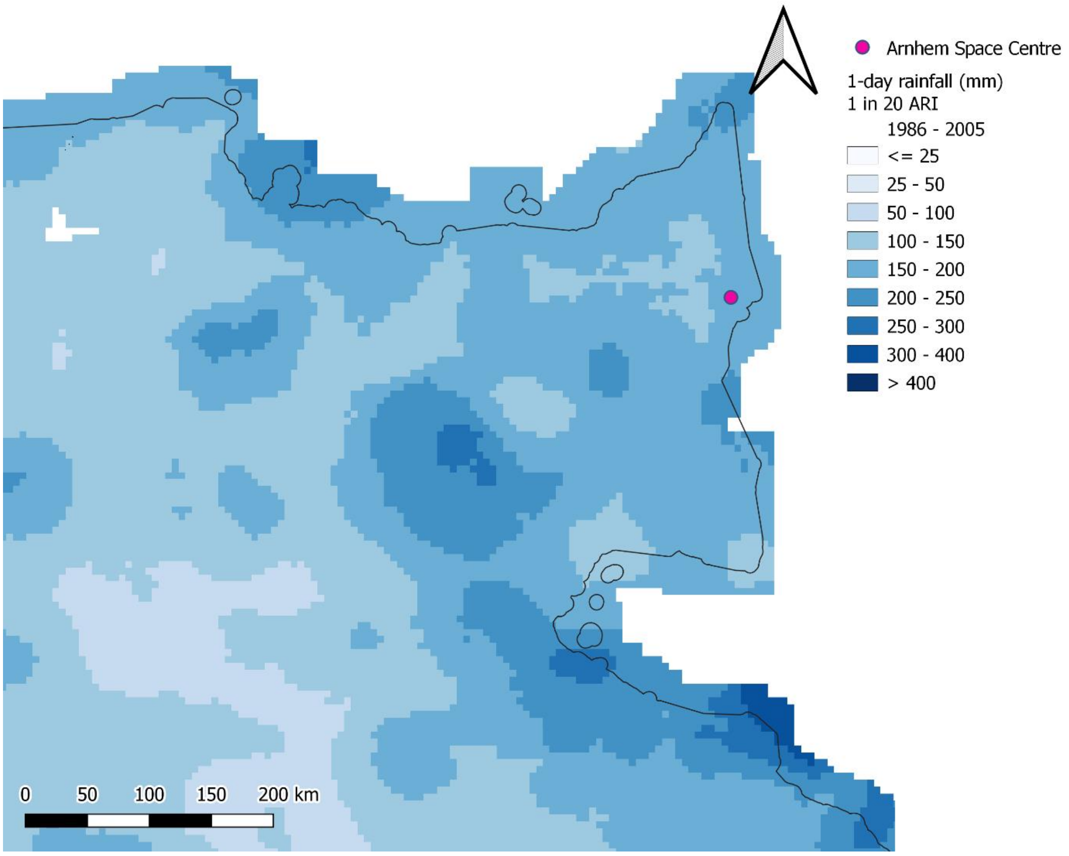


Figure 27 Maximum 1 day rainfall (mm) with 5% AEP for the baseline period (1986 - 2005)

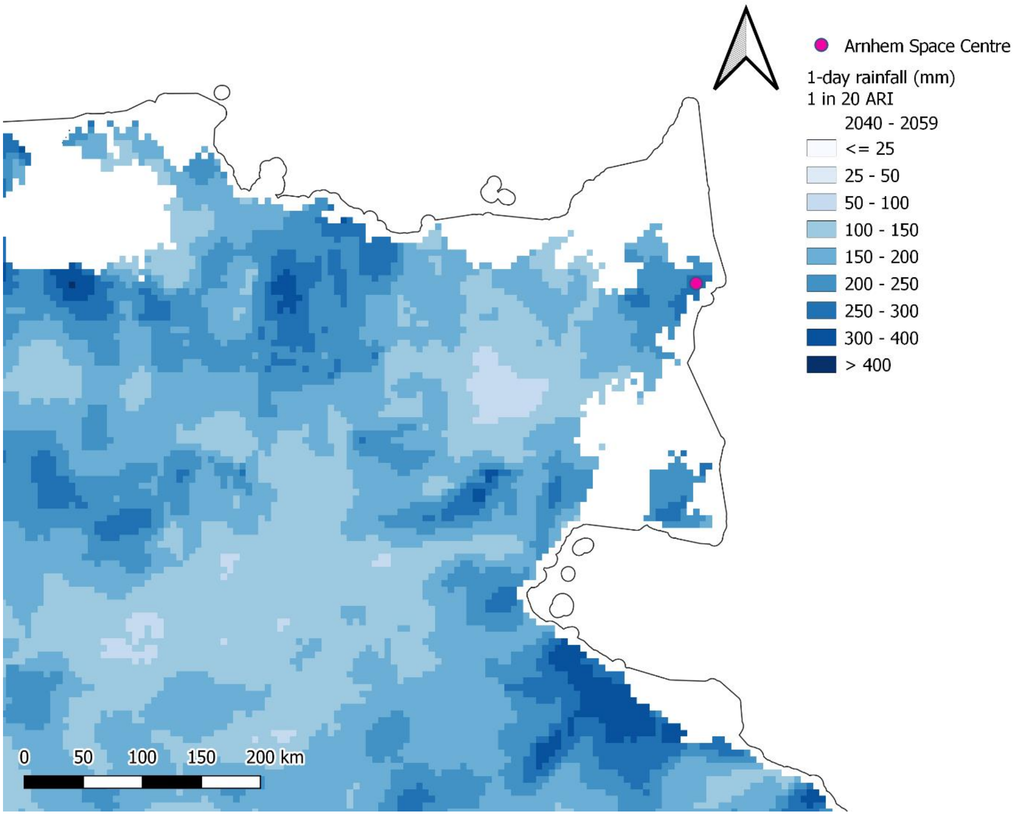


Figure 28 **Maximum 1 day rainfall (mm) with 5% AEP for the period 2040 - 2059 (RCP 8.5 Warm Wet)**

7.6.3.1 Surface run-off

In addition to the assessment of extreme 1-day rainfall, surface run off is another contributing factor that can be considered for the ASC and surrounding regions. Average surface run-off is a combination of average temperature and average rainfall. Areas where average surface run-off has decreased can act as a buffer to flood events by absorbing rainfall during extreme events.

The occurrence of a flood event can be attributed to a complex mix of contributing factors. Figure 29 presents the annual run off (in mm) for the region in 2021. It is currently low, with an annual run-off of less than 50mm per year. This indicates that water flow in the catchment is handled well through natural process, such as flow towards creeks and streams and substantial ground cover to absorb water. The near-future climate change scenario (2036-2065), as shown in Figure 30, indicates that surface run-off will increase by 10-30 mm per annum in an RCP 8.5 change scenario. This could pose issues for the ASC with regards to groundwater management, access due to road washout, and possibly land erosion of the nearby escarpment.

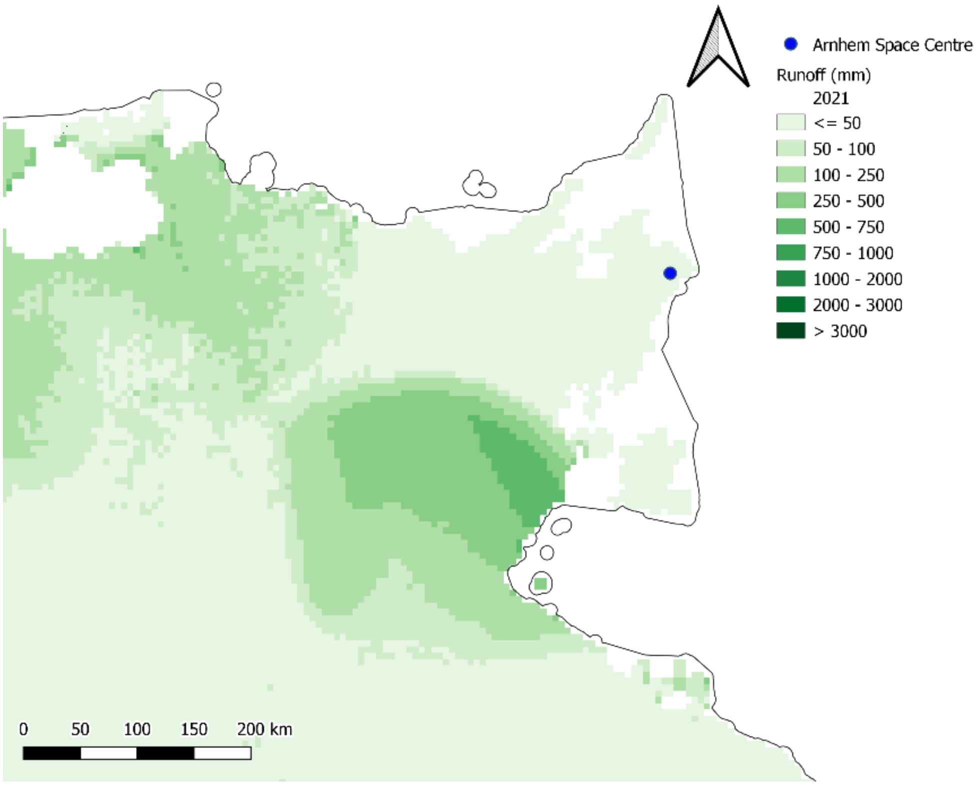


Figure 29 Annual mean run-off in the current climate (2021)

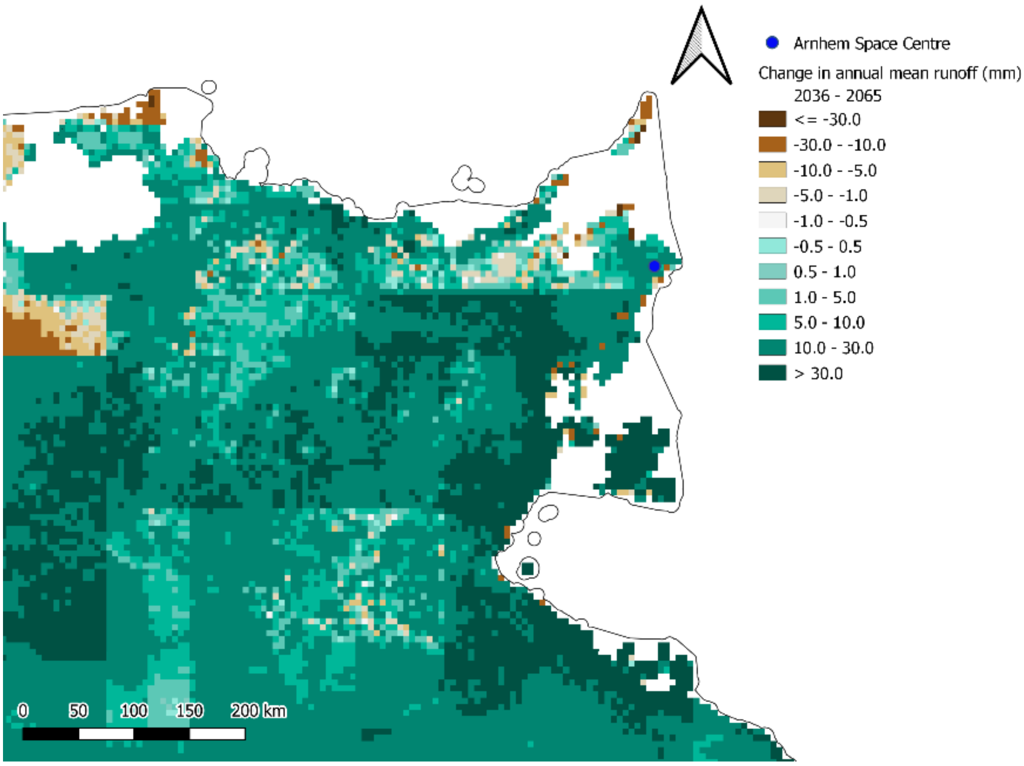


Figure 30 Change in the annual mean run-off in 2036 - 2065 compared to the baseline period of 1990 (RCP 8.5)

7.6.4 Extreme wind speed

Extreme wind speed projections for the region are less certain than projections for other meteorological parameters, due to the inability of global climate models to resolve the small-scale meteorological phenomena that contribute to extreme wind conditions (e.g., cyclones). Current projections for the Monsoonal North (West) sub-cluster indicate that the annual maximum 1-day wind speed and the 2-=year return values for 1-day wind speed are projected to increase. However, there is low certainty in this projection and the predictions of individual models have a large range.

7.7 Climate change summary

A summary of climate projections against existing conditions for each of the key climate variables with the potential to impact the ASC is provided in Table 16.

Table 16 Summary of climate projections for key climate variables associated with the ASC

Parameter	Statistic	Existing Climate	Climate Change Projections	Comments
Temperature	Daily mean temperature	22.5 to 30.7°C	2050: +1.8°C 2090: +3.7°C	There is consensus that temperatures will increase at a rate that is strongly connected to global GHG emissions rates. There is very high confidence in projections.
	Daily maximum temperature	34.6°C	2050: + 2090: +	Hot days will become more intense (higher temperatures) and more frequent. Heatwaves will last longer in duration. There is very high confidence in projections.
Rainfall	Average annual rainfall	1450 mm	dry: -35% to +25% wet: -7% to +8%	There may be greater year-to-year changes in rainfall. Both wetter and drier futures are possible, depending on greenhouse gas concentrations. There is low confidence in projections.
Extreme rainfall	Highest daily rainfall	437 mm	Increase	Heavy rainfall events are predicted to become more intense. The confidence in this prediction is high. However, the degree of intensity change is not clear, with a low confidence in that projection.
	Highest monthly rainfall	1080.2 mm	Increase	
Evapotranspiration	Runoff	< 50 mm/annum	Increase	Evaporation is predicted to increase, with high confidence in that prediction. However, the size of the increase has more uncertainty. Changes in soil moisture and evapotranspiration. However, this has low confidence.
Extreme weather conditions	Bushfire weather	< 5 days/annum	<5 days/annum	High confidence in projections of little change to fire frequency due to reliable annual rainfall and availability of fuel.
	Tropical cyclones	~1.5 storms / annum		Overall, the number of cyclones is projected to decrease, with an increase in intensity for the cyclones that do form. There is medium confidence in this

Parameter	Statistic	Existing Climate	Climate Change Projections	Comments
				prediction. However, there has been no discernable trend to date in the Northern Territory.

8. CLIMATE HAZARD SCREENING

Climate hazard screening is used to focus the Climate Change Assessment on the physical hazards that are likely to be of significance to the Project.

The Project may be vulnerable to the effects of extreme weather and climate change at several points:

- Landing and transfer of fuels, rockets, and other materials at the port
- Transport of fuels, rockets, and other materials to the ASC from the port
- Storage of fuels, rockets, and other materials at the ASC
- Operational and communications infrastructure.

Weather and climate impacts to these may lead to:

- Operational failure
- Environmental damage
- Health and safety concerns.

These scenarios and the impacts that may cause them are discussed in the following sections.

Climate change scenarios play an integral role in climate-related risk management and strategy formulation processes (TCFD, 2020). Scenario analyses are intended to assist a business with assessing the implications of climate change by allowing them to understand how they might perform under different hypothetical climate futures. Scenario analysis contributes to resilience by:

- Identifying potential future threats and opportunities
- Identifying trigger points to set contingency plans in motion
- Serve as a basis for monitoring and strategy adjustments.

The GCM simulations described in Section 7.1 represent one type of scenario, intended to describe plausible representations of future climate. Other publicly available scenarios provide models of emissions and vulnerabilities, including economic, policy, and cultural, and socio-economic scenarios.

In addition to publicly available scenarios, scenarios may be customised to suit particular business needs. This has been done for this assessment, as the area of concern is localised in nature and the up-stream and down-stream impacts are restricted to a regional area.

Several climate change scenarios have been developed for the site and are intended as thought experiments for ASC to consider as they develop their infrastructure and business model moving forward. They may be thought of as stress tests, focusing on “tail risks”, which appear to have a low probability of occurrence, but that could have significant to catastrophic impacts. ASC should use these scenarios to determine whether it has plans and sufficient resources to withstand the impact of such events. Alternatively, ASC may determine that such circumstances as described in the scenarios may render their operational plans unworkable or expose a fatal flaw in the business model. Thus, contingency plans may be developed as the business moves forward.

The climate change scenario analysis was applied to the potential impacts of climate change on the infrastructure, operations, and environment surrounding the ASC. Climate change due to continued global warming has implications for the ASC through:

- Occurrence and frequency of extreme heat days
- Frequency and intensity of tropical storms and
- Coastal erosion and inundation.

These may individually or in combination have a negative impact, at various times in the lifetime of the Space Centre, on the capacity of ASC to conduct regular operations, host clients, and securely store and maintain plant and consumables (e.g., fuel). This may pose a range of financial and reputational risks to the ASC.

The risks and potential mitigations to infrastructure, operations, and the environment are described below for specific scenarios.

8.1 Scenario 1: Extreme heat days

Extreme heat days have the potential to impact ASC operations by limiting the ability to conduct launches, contribute to fire weather risk, and present human health risks to staff and visiting clients. While the site currently only experiences an average 5-10 days > 35ºC in an average year, this is projected to increase to an average of 30-50 days per year by 2050. ASC has identified that launches do not proceed if the temperature is greater than 37ºC due to potential risk to human health.

The risk scenario is as follows:

> *The ASC is conducting a series of launches in late November and early December, prior to the wet season. Clients from overseas are planning to stay on site while the launches occur. A heat wave occurs (3+ days of highs >37ºC) occur, disrupting launch operations.*

8.1.1 Infrastructure

Fuel storage tanks typically do not encounter safety issues at ambient temperatures. However, given the presence of special fuels and boutique blends, care should be exercised in this area. Diesel is not a volatile fuel and therefore is not as affected by issues of evaporation as other liquid fuels, such as gas (petrol). However, liquid oxygen should be protected from extremes in temperatures. Solid fuels follow a zero-order change in burning rate with increasing age and increasing temperatures (Kishore et al, 1977). Kishore et al demonstrate an ~18% decrease in burning rate for solid fuel stored for 40 days in 63ºC. Thus, it would be beneficial to erect a canopy or other shade over solid and liquid oxygen fuel storage tanks.

Generators and electrical infrastructure become less efficient with increasing temperature, and additional fuel may be required to ensure consistent provision of electricity. Running out of fuel (e.g., for a generator) during a heat wave would have substantial consequences for other site infrastructure and the people who are on site.

Computers and other sensitive electronic devices may fail in high temperatures; it may be necessary to develop a heat protocol for the use of computers and other sensitive electronic devices during periods of extreme temperatures.

8.1.2 Operations

The ASC has indicated that launch operations cannot proceed when the temperature is greater than 37ºC if outdoor work must be undertaken. If operations can be carried out from inside with suitable cooling facilities, operations are then contingent on rocket-specific temperature thresholds. An increase in extreme temperature conditions is likely to impact launch operations, particularly those that occur in the DtW transition season (Nov-Dec), when temperatures have begun to rise but the wet season has not yet commenced.

8.1.3 Surrounding environment

The primary risk to the surrounding environment in a heatwave is to human health. This is particularly relevant given the high humidity of the site, as the apparent temperature increases (on average) by 1ºC for every 5% increase in relative humidity.

While the effects of the apparent temperature on humans is subjective, clients from the northern hemisphere may be particularly at risk, as they will not be acclimatised to the heat, may not be as aware of their hydration needs, and would have arrived from winter temperatures. For these clients, there is a risk for heat exhaustion and heat stroke. Visitor education is recommended, and first aid or medical attention may be required.

The fire weather risk is also increased with increasing heat. However, the predominant fire seasons in the top end are winter and spring, which is when extreme temperatures are less likely to occur. In addition, high humidity mitigates the fire danger somewhat.

8.2 Scenario 2: Tropical storms

Tropical storms and cyclones have the potential to impact ASC operations in several ways. As discussed in Section 6.7.4, there is currently a 50% chance of any storm forming within 400 km of the ASC and another 10% chance it will pass within 24 hours of being named. While it is acknowledged that a storm that is only just named is typically a Category 1 storm, individual storms can undergo rapid intensification in the first 24 hours and storms are predicted to become more intense under all climate change scenarios. ASC has indicated that they do not plan to conduct launches during cyclone season, but late- and out-of-season storms have already been demonstrated to occur (see Figure 14).

The risk scenario is as follows:

> *The ASC is conducting a series of launches, scheduled for April. The clients are planning to stay on site while the launches occur. A cyclone forms within the Gulf of Carpentaria during the launch series and is forecast to make landfall near the site within 24 hours.*

8.2.1 Infrastructure

The ASC has indicated the buildings have been constructed to withstand tropical cyclones and as such, are likely to not be damaged beyond repair. However, flying debris (e.g., unsecured equipment or tree branches) may break windows or puncture roofs or walls, thus causing damage to building interiors and interrupting regular operations, even after the cyclone has passed. Many buildings will also be mounded and have ballistic proofing in their construction (e.g., double brick walls, earth mounds next to fuel storage) to mitigate against effects from flying debris (whether that be caused from from adverse weather events or from fuel explosive (debris) risks).

Fuel tanks are also likely to withstand the winds from a cyclone and are unlikely to be flooded given the site terrain. However, fuel may become damaged or degrade if seals are not complete and water is driven into the tanks. As such, fuel quality should likely be tested before further use.

8.2.2 Operations

ASC has indicated that launch operations cease during periods of inclement weather. However, there are no plans in place regarding cyclone preparation procedures, specifically surrounding rocket de-fuelling, safe storage, and other necessary actions. Failing to develop a plan may lead to sensitive client equipment being damaged or fuel spills/losses.

Logistically, ASC should also consider the presence of clients. Clients may have no previous experience with sheltering in place during a tropical storm and as such, may feel unprepared to do so. Several weeks of supplies (food and water) should be sufficient for staff and all clients as depending on the storm’s intensity, access to and evacuation from the site may become impossible should roads be damaged during a storm. This may impact clients’ travel arrangements, or the ability of the launch series to complete as planned.

8.2.3 Surrounding environment

Impacts to the surrounding environment are most likely to impact logistics surrounding the site. Roads may become impassable, transport in and out of Gove (both the port and the air strip) may also cease for a period, both during and after the storm. There may be other damage to the surrounding area and infrastructure.

8.3 Scenario 3: Coastal infrastructure and sea level rise

Supplies and fuel for the ASC are transported through the Port of Gove, which has an elevation of 4m above sea level. Sea level is predicted to rise by approximately 1m by the year 2100, however this will be a non-linear increase. Tidal dynamics and storm surges, both amplified by sea level rise, are likely to add stress to coastal infrastructure and require increased maintenance.

The risk scenario is as follows:

> *The Port of Gove is progressively damaged by storm surges and access areas of the Port become inundated during high tides. Local mining operations have ceased, and the Port has scaled down operations. The Government has ranked the Port as a low priority for maintenance and financial support.*

8.3.1 Infrastructure

On-site infrastructure will not be directly affected in this scenario; however, the cost of transporting materials may lead to deferred maintenance and repair, resulting in reputational risk, challenges in retaining staff, and potential human health issues.

8.3.2 Operations

Should there be a disruption of the delivery of fuel and supplies to the site, all operations would be suspended. Changes to Port activities are beyond the control of the ASC and secondary methods of fuel and supply deliveries would need to be explored.

8.3.3 Surrounding environment

The surrounding environment will experience substantial change, as the Port of Gove or other areas may become inaccessible due to sea level rise. Alternative access routes may be required to be developed. However, this would likely be done in conjunction with the NT Government, as both residents and the ASC would be impacted.

9. CLIMATE CHANGE RISK MANAGEMENT

ELA is advised to conduct a scenario analysis process to stress test its planned operations to ensure that it can maintain business continuity in the event of direct impacts of extreme weather events on its infrastructure and operations and indirect impacts arising from the effect of extreme weather events on supply chain infrastructure and operations. Risk management measures identified through this provisional analysis are identified in Table 17.

The climate risk scenarios presented in Section 8 highlight examples of the direct, indirect, and compounding risks that may be faced by the ASC through the life of the business, and that require consideration in development of a site risk register and risk management plan. Some of the potential impacts to operation can be mitigated through improved design measures, such as increased engineering tolerances and inbuilt redundancy, and following construction and other technical standards that have been updated to include climate change, e.g., *AS/NZS 1170.2:2021 Structural design actions, Part 2: Wind actions*.

A site risk management plan should include the capacity to respond to challenging weather events:

- Warning systems for extreme weather events and identified thresholds triggering action.
- Standard operating procedures for application in extreme weather events.
- Capacity for repair of site or infrastructure following extreme weather events, including stockpiling, insurances, and arrangements with Dhimurru Aboriginal Corporation and the NT Government.
- Training for rapid response, e.g., rocket defueling and pack down.

Table 17 Provisional climate change risk management measures for the ASC

Climate Change Hazard	Potential impact on site operations (Risk Statement)	Risk control measures
Higher average and maximum temperatures	Operations: Reduced capacity of electricity supply equipment	Ensure that generator, line, and other electricity capacities exceed projected maximum load under high temperature conditions. Ensure that cooling systems can effectively transfer heat under high ambient temperatures and high humidity.
	Operations: Higher temperatures and changes in water vapour leading to increase corrosion rates of metal infrastructure.	Procurement specification for materials with greater corrosion resistance (refer to *AS/NZS 2312.2 2014 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings)* Regular inspection and repair of affected buildings and infrastructure.
	Operations: Launch operations cannot proceed when temperatures are >37°C	This temperature threshold may increase in the future as new fuel and rocketry technologies are developed. Planning launch operations during months with cooler temperatures will reduce the risk of operations being delayed.
	Operations: Fuel quality may degrade when stored in elevated ambient temperatures	Sensitive fuel storage infrastructure should be out of direct sunlight.
	Operation: Temperatures > 35°C can lead to heat stress in workers and clients.	Implement and follow guidance for managing risks of working in heat produced by Safe Work Australia and NT WorkSafe. Provide education and guidance to clients both prior to their arrival and on-site about how to manage risks of heat-related illness.
An increase in the intensity of tropical storms and cyclones	Construction: Infrastructure may be damaged if construction works are not completed before the onset of cyclone season.	Plan works to occur during the dry season. Stay abreast of construction codes as they change to reflect a change in climate and consult with engineers on an as-needed basis to ensure buildings are not vulnerable to cyclone damage.
	Operations: Launches cannot be conducted in inclement weather	Launch operations should be scheduled outside of tropical storm season, where possible. Care should be exercised when scheduling launches during the WtD transition season, as late-season storms are possible.

Climate Change Hazard	Potential impact on site operations (Risk Statement)	Risk control measures
	Operations: Cyclones may form or make landfall near the ASC within 24 hours, requiring swift storm preparations which may include rocket defueling and storage.	Devise a cyclone response plan, including rocket defueling and storage as well as consideration of clients who may be staying on-site.
	Operations: Cyclone damage may prevent access to or evacuation from the site for an unknown period.	Ensure supplies (food, water, fuel) are sufficient for staff and all clients who may be sheltering in place for the duration of a storm. Consider purchase, rental, or loan of machinery to remove downed trees (e.g., skid steer loader) or an all-terrain vehicle suitable to transport staff and clients through rough terrain/washed out roads. Grade or pave access road and monitor for erosion and general road maintenance.
Coastal erosion and inundation	Construction: Erosion may require the re-location of some buildings or critical infrastructure.	Monitor for erosion on the ASC land through the life cycle of the Centre.
	Operations: Changes to Port of Gove activities or deliveries may disrupt deliveries of fuel, supplies, or rocketry, halting operations.	Consider identification of reliable alternative delivery routes (e.g., road). This may occur in conjunction with the NT government.

10. CONCLUSION

Katestone was commissioned by ELA to complete a GHG and Climate Risk Assessment of the Project.

Based on current projections, ELA will not have NGER or NT Government GHG reporting obligations. However, continual monitoring of GHG emissions should still occur ensure that reporting thresholds are not breached and to understand GHG emissions as the activity evolves so that there is an ongoing focus on minimising emissions where possible.

There are limited options for ELA to reduce its GHG emissions given the remoteness of the site and the key activity being rocket launches. Direct emissions from diesel combustion for electricity can be minimised through actions such as:

- Generator control systems to match supply with load
- Load management and energy efficiency measures
- Back up batteries to store excess generator supply
- Solar PV and batteries
- Use of biodiesel.

Direct emissions may be offset through actions such as:

- Land use change
- Investment in certified carbon sequestration projects in the Northern Territory.

Research and monitoring will be required to determine the actual GHG and other pollutant emissions from rocket fuel combustion, given the lack of available data, and/or promote research into the development of low GHG fuels.

Current and projected weather patterns and the increased likelihood of extreme conditions may pose a material risk to the successful and safe operation of the ASC. The site is in a tropical monsoonal area of Australia and has a defined wet season and dry season. Tropical cyclones are common during the wet season and transitions to and from the wet season, and many have formed and tracked within 400 km of the ASC in recent history. Material risks that may need to be managed include:

- The number of hot days >35°C is projected to increase from < 5 per year to 30 – 50 per year by 2050. This may have an adverse effect on human health, infrastructure condition, and fuel conditions.
- The magnitude of short duration intense rainfall events may increase by up to 50mm in any one day, which may exceed infrastructure drainage capacity and cause damage to roads.
- Extreme wind gust speed may increase, although there is less certainty around this projection
- The number of cyclones that form is projected to decrease; however, the intensity of those cyclones that do form is expected to increase. Cyclones of greater intensity will potentially result in the delay of site activities, may affect site infrastructure as well as off-site critical infrastructure (e.g., the Port) and have an may impact on supply lines.

It is recommended that ELA integrate this understanding of potential climate risks into its processes for site risk identification and risk management.

11. REFERENCES

Blanchi, R, Lucas C., Leonard J., and Finkele, K. (2010). Meteorological conditions and wildfire-related house loss in Australia. *International Journal of Wildland Fire*, 19(7): 914-926.

Bradstock, R. A. (2010). A biogeographic model of fire regimes in Australia: current and future implications. *Global Ecology and Biogeography*. 19: 145-148.

Commonwealth Department of Environment and Energy (DEE) (2021). National Greenhouse Accounts (NGA) Factors, Australia National Greenhouse Accounts, Australian Government.

CSIRO and Bureau of Meteorology (2015). Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia

DEPWS (2021). Environmental impact assessment and environmental approval in the Northern Territory. Environmental impact assessment guidance. Environment Division, Department of Environment, Parks, and Water Security (DEPWS), Darwin. NTEPA2019/0141-002.

https://depws.nt.gov.au/__data/assets/pdf_file/0003/816906/Guide-to-the-NT-environmental-impact-assessment-and-approval-process.pdf

Galfetti, et al., (2014). *An Italian network to improve hybrid rocket performance: Strategy and results.* Acta Astronautica, 96, 246.

Kishore, Kaushal, Pai Verneker, V.R., and Prasad, G. (1977). Storage stability of solid rocket fuels. 1. Effect of temperature. *Fuel* 56: 292–294.

Moise, A. et al. (2015). *Monsoonal North Cluster Report.* Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster reports, eds. Ekström, M. et al. CSIRO and Bureau of Meteorology, Australia.

NESP Earth Systems and Climate Change Hub. (2020). Climate change in the Northern Territory: state of the science and climate change impacts. NESP ESCC Hub, Melbourne.

Stone, G., Dalla Pozza, R., Carter, J., and McKeon, G. (2019). Long paddock: climate risk and grazing information for Australian rangelands and grazing communities. *The Rangeland Journal*, 41, 225-232. DOI: doi.org/10.1071/RJ18036.

Task Force on Climate-related Financial Disclosures. (2020). Guidance on Scenario Analysis for Non-Financial Companies. https://assets.bbhub.io/company/sites/60/2020/09/2020-TCFD_Guidance-Scenario-Analysis-Guidance.pdf