THERMAL AND SPECTRAL MAPPING OF DECEPTION ISLAND, ANTARCTICA

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Abstract: *Deception Island, located in the South Shetland Islands archipelago, Antarctica, is a unique volcanic territory characterized by complex relief, geothermal activity, diverse surface substrates and specific climatic conditions. The spatial heterogeneity of the earth's surface and the presence of sparse vegetation, represented mainly by mosses and lichens, create prerequisites for the formation of various thermal and spectral characteristics.*

The aim of this study is to analyze the spatial distribution of the Earth's surface temperature and the spectral characteristics of different types of surfaces on Deception Island by integrating satellite data and ground-based measurements. Data from Sentinel-2 MSI were used to calculate the spectral indices NDVI (Normalized Difference Vegetation Index), MCARI2 (Modified Chlorophyll Absorption Ratio Index 2), SAVI (Soil Adjusted Vegetation Index), NDWI (Normalized Difference Water Index) and NDSI (Normalized Difference Snow Index). Land Surface Temperature (LST) data from Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) were used to assess thermal performance. Satellite observations are complemented by field measurements carried out with the HT-19 infrared thermal camera to determine the local surface temperature and with the Sekonic C-800 spectrometer to characterize light conditions in the visible spectral range (380–780 nm).

The methodological approach includes spatial analysis of the thermal and spectral characteristics of volcanic substrates, areas with sparse vegetation cover, and surfaces occupied by mosses and lichens. Particular attention is paid to the possibilities for distinguishing vegetation from bare volcanic surfaces by means of spectral indices, as well as to the assessment of local temperature variability by field infrared thermography. The analysis takes into account the differences in the spatial resolution of satellite and ground-based observations and the limitations in their comparison.

The study proposes an integrated approach for thermal and spectral characterization of Antarctic volcanic territories and for evaluating the applicability of satellite and field methods in monitoring surface characteristics and vegetation cover in polar regions.

ТЕРМАЛНО И СПЕКТРАЛНО КАРТОГРАФИРАНЕ НА ОСТРОВ ДИСЕПШЪН, АНТАРКТИКА

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Ключови думи: *остров Дисепшън, Антарктика, дистанционни изследвания, Sentinel-2, Sentinel-3, LST, мъхове, лишеи*

Резюме: *Остров Дисепшън, разположен в архипелага Южни Шетландски острови, Антарктика, представлява уникална вулканична територия, характеризираща се със сложен релеф, геотермална активност, разнообразни повърхностни субстрати и специфични климатични условия. Пространствената неоднородност на земната повърхност и наличието на оскъдна растителност, представена основно от мъхове и лишеи, създават предпоставки за формиране на различни термални и спектрални характеристики.*

Целта на настоящото изследване е да се анализират пространственото разпределение на температурата на земната повърхност и спектралните характеристики на различни типове повърхности на остров Дисепшън чрез интегриране на спътникови данни и наземни измервания.

Използвани са данни от Sentinel-2 MSI за изчисляване на спектралните индекси NDVI (Normalized Difference Vegetation Index), MCARI2 (Modified Chlorophyll Absorption Ratio Index 2), SAVI (Soil Adjusted Vegetation Index), NDWI (Normalized Difference Water Index) и NDSI (Normalized Difference Snow Index). За оценка на термалните характеристики са използвани данни за температурата на земната повърхност (Land Surface Temperature – LST) от Sentinel-3 Радиометър за температура на морската и земната повърхност (SLSTR). Спътниковите наблюдения са допълнени с теренни измервания, извършени с инфрачервена термокамера HT-19 за определяне на локалната повърхностна температура и със спектрометър Sekonic C-800 за характеризиране на светлинните условия във видимия спектрален диапазон (380–780 nm).

Методологичният подход включва пространствен анализ на термалните и спектралните характеристики на вулканичните субстрати, участъците с оскъдно растително покритие и повърхностите, заети от мъхове и лишеи. Особено внимание се отделя на възможностите за разграничаване на растителността от оголените вулканични повърхности чрез спектрални индекси, както и на оценката на локалната температурна изменчивост чрез теренна инфрачервена термография. Анализът отчита различията в пространствената разделителна способност на спътниковите и наземните наблюдения и ограниченията при тяхното съпоставяне.

Изследването предлага интегриран подход за термално и спектрално характеризиране на антарктически вулканични територии и за оценка на приложимостта на спътниковите и теренните методи при мониторинг на повърхностните характеристики и растителното покритие в полярните области.

Introduction

Deception Island is a volcanically active, horseshoe-shaped island enclosing Port Foster in the Bransfield Strait. Its most recent historical eruptions occurred in 1967, 1969 and 1970. The combination of volcanic deposits, geothermal manifestations, snow and ice, and highly variable maritime weather produces a complex surface thermal environment. Prior field work has demonstrated that geothermal influence can strongly affect near-surface ground conditions over limited distances [1], while geological and photogrammetric studies provide an important spatial framework for interpreting volcanic landforms [2].

Satellite observations offer spatial context for regional mapping, whereas handheld thermal instruments can resolve fine-scale heterogeneity that is not visible at satellite thermal resolution. However, an apparent thermal hotspot may also reflect differences in insolation, substrate emissivity, wetness, topographic orientation or acquisition time. Likewise, optical spectral contrasts can reflect lithology, grain size, weathering, snow and moisture rather than thermal activity alone. Integrating both sources with terrain information therefore requires careful co-registration and explicit uncertainty assessment.

The aim of this study is to analyze the spatial distribution of the Earth's surface temperature and spectral characteristics of Deception Island through the integrated use of data from Sentinel-2 MSI, Sentinel-3 SLSTR [3] and field measurements. The study includes the calculation and analysis of the spectral indices Normalized Difference Vegetation Index (NDVI), Modified Chlorophyll Absorption Ratio Index 2 (MCARI2), Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Water Index (NDWI), characterization of regional temperature conditions by Land Surface Temperature (LST), and assessment of local temperature variability by infrared thermography with HT-19 [4]. Additional measurements with the Sekonic C-800 [5] are used to describe the recorded light conditions in the visible spectral range. The main attention is paid to the spatial differences between volcanic substrates, vegetation-cover areas and snow surfaces, as well as to the possibilities and limitations of the integrated spectral-thermal approach for monitoring Antarctic volcanic territories.

Materials and Methods

Study Area

The study was conducted in Whalers Bay, Port Foster, Deception Island, located in the South Shetland Islands, Maritime Antarctica. Deception Island is an active volcanic caldera characterized by a distinctive horseshoe shape, with its central depression occupied by Port Foster. The area is characterized by diverse volcanic substrates, including volcanic ash, pyroclastic deposits, and rock formations, as well as localized geothermal activity (Fig. 1, 2).

Whalers Bay is situated within the volcanic caldera and exhibits distinctive thermal and spectral surface characteristics influenced by volcanic substrates, coastal environmental conditions, and heterogeneous land cover. Local vegetation communities, including mosses and lichens, occur on suitable natural and anthropogenic substrates.



Fig. 1. Deception Island, Antarctica, 17 March 2023 [6]

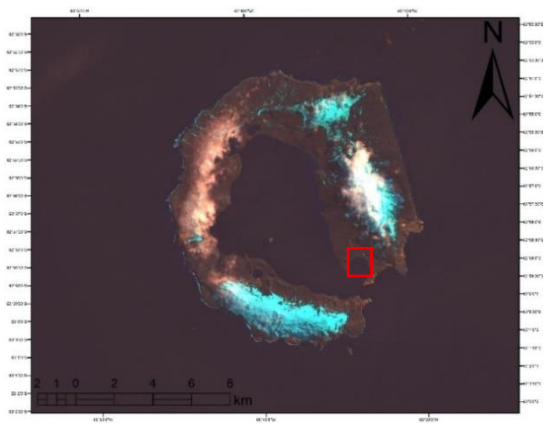


Fig. 2. Whaler's Bay, Port Foster, Deception Island, bands:11,8,3;ESA [3]

Field observations included surface temperature measurements using an HT-19 infrared thermal camera and visible-light measurements performed with a Sekonic C-800 spectrometer. The investigated sites were used to characterize local thermal and light variability and to complement the spatial analysis of Sentinel-2 MSI and Sentinel-3 SLSTR satellite data.

Data and Methods

The satellite data used in the study are from the Sentinel -2B and Sentinel-3B satellites of the European Space Agency (ESA) [3], (Table 1).

Table 1. Satellite image and mobile thermal camera acquisition dates

Satellite	Date	Spectral Band, wavelength	Band	GSD*, m
Sentinel-2B	30 January 2026	0.56 μm	3	10
		0.665 μm	4	10
		0.842 μm	8	10
		0.865 μm	8a	20
		1.61 μm	11	20
Sentinel-3B	30 January 2026	3.74 μm	S7	1000
		10.85 μm	S8	1000
		12 μm	S9	1000
HT-19 thermal camera	04 February 2026	8 to 14 μm	Infrared	320 x 240 pixels
Sekonic C-800	04 February 2026	380 to 780 nm	visible	1 nm

**Ground sample distance (GSD)*

The HT-19 mobile thermal camera was used during field measurements. Operating in the 8–14 μm spectral range with a measurement accuracy of ±2°C, it offers five color palette options (Rainbow, Iron Red, Cold Color, Black & White, White & Black). This enhances the visualization and interpretation of data by effectively integrating surface temperature readings with real-time thermal imaging. The Iron Red color scale palette was selected for the study and the measured parameters are the maximum and minimum values of the ground temperature. The display also displays the Central point temperature, which was taken into account when assessing the snow condition [7], Table 1.

The field spectral surveys were performed using a spectrometer in the visible range (Sekonic Spectrometer C-800), a full-spectrum color meter that can accurately measure any type of light. The data from the spectrometer is with the following parameters: Color temperature, CCT (Correlated Color Temperature), Δuv (Deviation) between the correlated color temperature and the place of emission of the black body, Hue (in degrees), Sat – Saturation is the index to express the intensity or chroma.

Using these data, a study of the color characteristics of the objects was conducted. For each spectral reflectance characteristic (SRC), the color characteristics (color coordinates (x, y) and dominant wavelength) in the spectral range 380–780 nm were calculated relative to CIE 1931 and a standard source of electromagnetic radiation [7, 8].

To map and characterize the spectral properties of the land surface on Deception Island, Antarctica, several spectral indices were calculated using Sentinel-2 MSI optical data. These indices were applied to distinguish vegetation-covered areas, exposed volcanic substrates, and snow-covered surfaces, as well as to assess spatial variations in surface characteristics. The selected spectral indices and their corresponding mathematical formulas are presented in Table 2.

Table 2. Calculation formulas and description of the optical indices used in the study

Spectral index	Formula	Sentinel-2 bands	Reference
NDVI	(1) NDVI = (B8 − B4) / (B8 + B4)	B8, B4	Rouse et al. (1974) [9]
MCARI2	(2) MCARI2 = 1.5 × [2.5 × (B8 − B4) − 1.3 × (B8 − B3)] / √[(2 × B8 + 1)² − (6 × B8 − 5 × √B4) − 0.5]	B8, B4, B3	Haboudane et al. (2004) [10]
SAVI	(3) SAVI = (1 + L) × (B8 − B4) / (B8 + B4 + L); L = 0.5	B8, B4	Huete (1988) [11]
NDWI	(4) NDWI = (B8A − B11) / (B8A + B11)	B8A, B11	Gao (1996) [12]

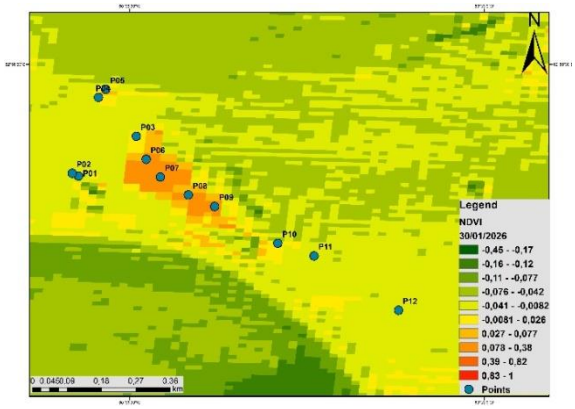
Results

At points 6 to 9, the highest values are observed in the spectral indices NDVI, MCARI2, SAVI and NDWI (Fig. 3). The rectangular area highlighted on the map indicates the common area of interest used for extracting the surface profiles (Fig. 2).

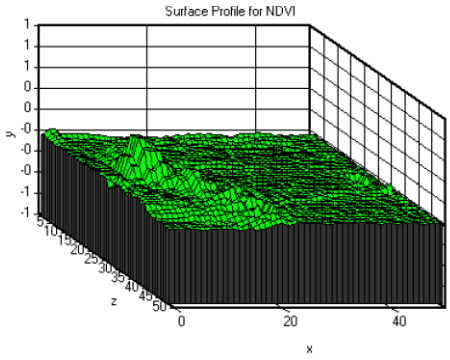
Sampling point P07 exhibited the highest MCARI2 value (0.459) among the investigated locations, accompanied by elevated NDVI (0,26), SAVI (0.390), and NDWI (0.123) values. The agreement among these four spectral indices suggests a comparatively strong vegetation-related spectral response associated with potentially higher surface moisture.

This pattern is consistent with the possible presence of a relatively well-developed moss-covered microsite within the volcanic landscape of Whalers Bay, Deception Island. The elevated MCARI2 value further supports the vegetation-related interpretation, although it cannot independently establish chlorophyll concentration or photosynthetic activity.

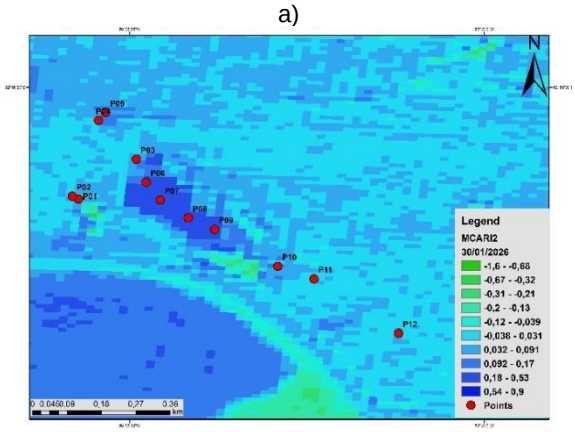
The combined spectral response identifies P07 as a priority location for further investigation of moss cover, moisture conditions, and vegetation physiological status.



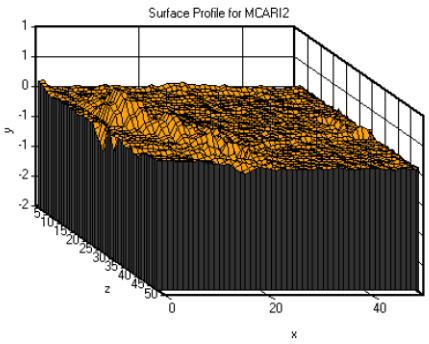
a)



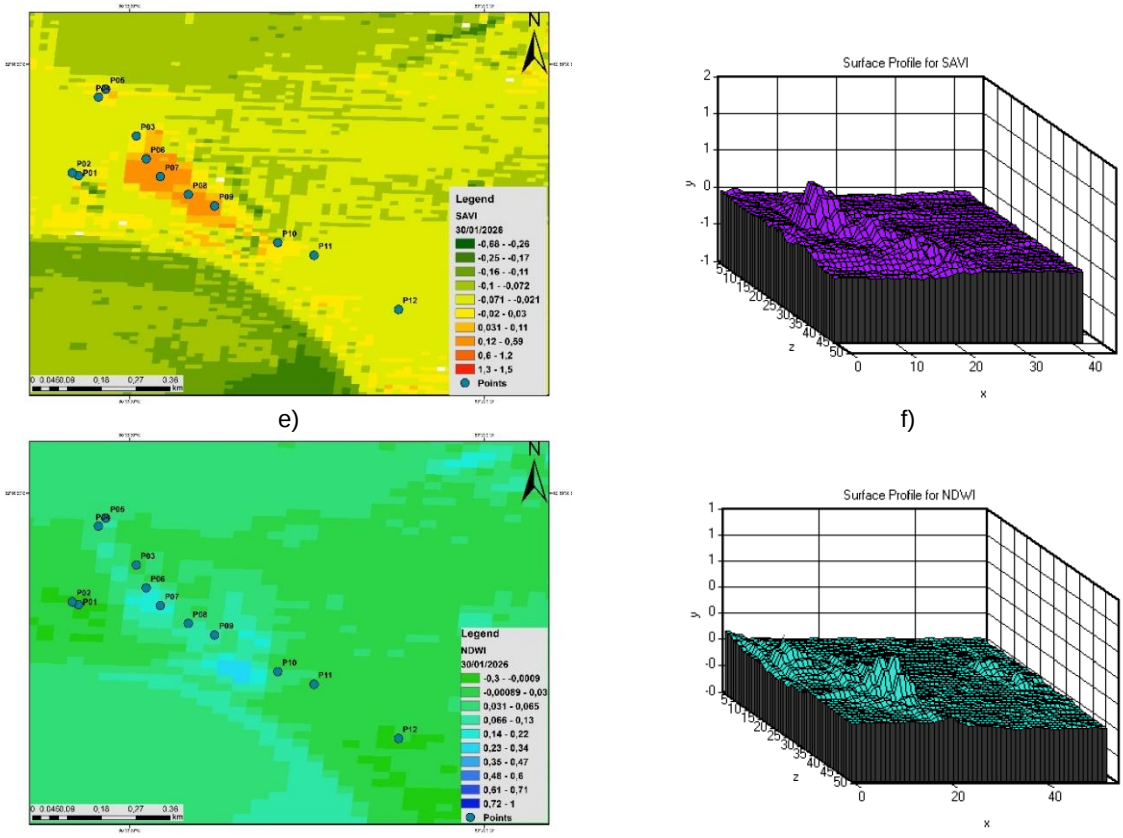
b)



c)



d)

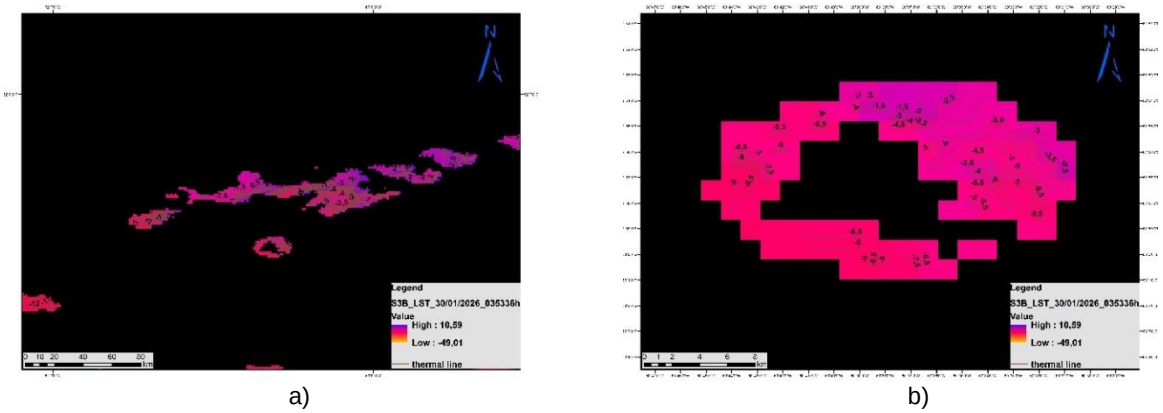


e) f)

g) h)

Fig. 3 (a–h). Spatial distribution with field points and corresponding three-dimensional surface profiles of (a) NDVI, (b) surface profile for NDVI, (c) MCARI2, (d) surface profile for MCARI2, (e) SAVI, (f) surface profile for SAVI, (g) NDWI and (h) surface profile for NDWI in Whalers Bay, Deception Island, derived from Sentinel-2 MSI imagery acquired on 30 January 2026

Sentinel-3 LST data acquired on 30 January 2026 indicated temperatures ranging from −5°C to −3,5°C in the area containing P7 (Fig. 4). Sentinel-2 spectral indices were derived from imagery acquired on the same date, enabling a temporally consistent comparison of optical and thermal satellite observations, although their acquisition times and spatial resolutions differ.

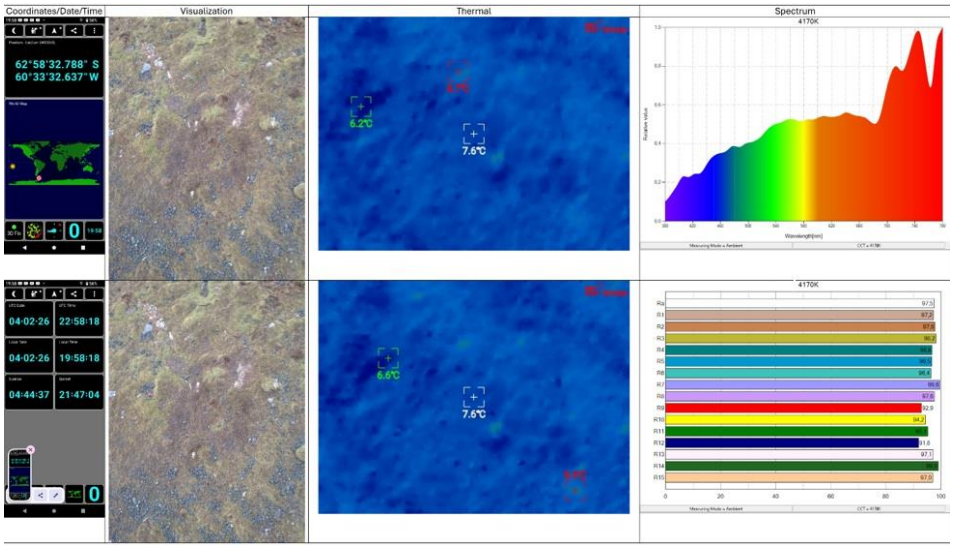


a) b)

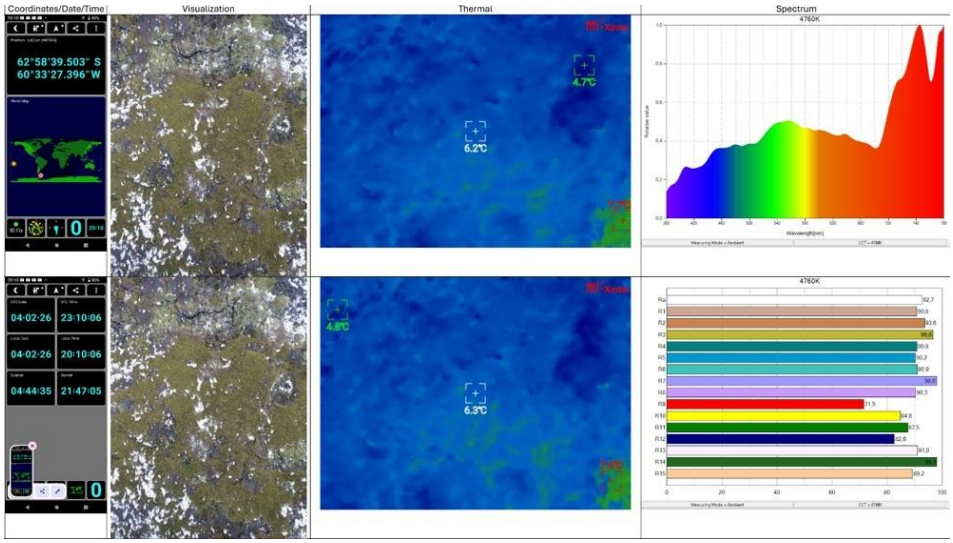
Fig. 4. (a)Thermal map of South Shetland Islands, Sentinel 3B, 30/01/2026, (b)Thermal map of Deception Island Sentinel 3B, 30/01/2026

The Fig. 5 presents GPS coordinates and acquisition metadata (left), visible-light images of the investigated surface (centre-left), corresponding thermal images with selected temperature readings (centre), and the measured spectral power distribution and colour-rendering parameters of ambient illumination (right) and the recorded correlated colour temperature (CCT) in Kelvin [K].

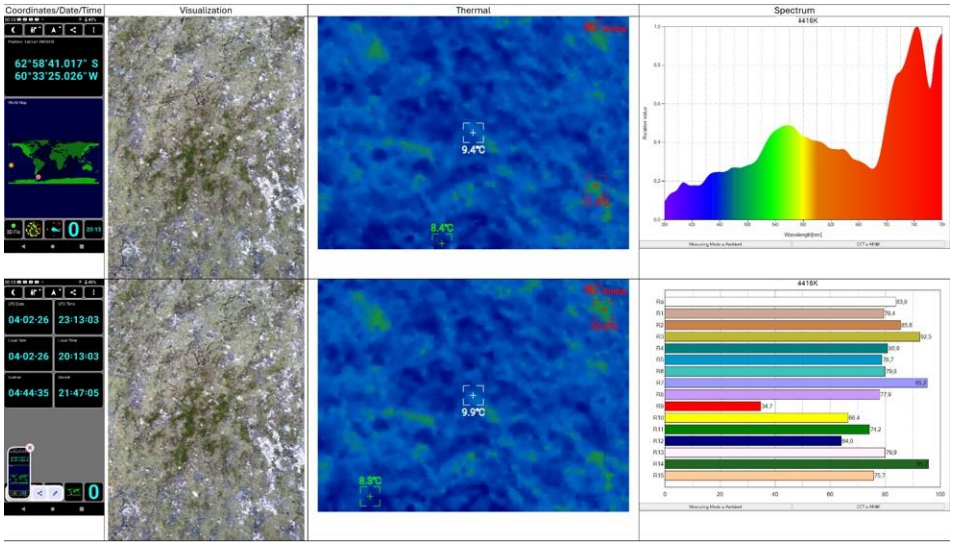
Field-based thermal measurements conducted on 4 February 2026 indicated local temperature readings of approximately 7–8°C (Fig. 5, Table 3). These observations suggest substantial differences between the regional satellite-derived thermal conditions and the localized field measurements.



a) Field profile 04



b) Field profile 07



c) Field profile 08

Fig. 5 (a–c). Field observations of moss-covered volcanic terrain at Whalers Bay, Deception Island, Antarctica (4 February 2026). Autor: prof. Miroslav Tsvetkov.

Table 3. Geographic coordinates of the investigated sampling profiles and results of thermal camera measurements (surface temperature, °C) and spectrometric measurements (Correlated colour temperature, CCT, K) at Whalers Bay, Deception Island, Antarctica (4 February 2026). Autor: prof. Miroslav Tsvetkov

Points	Time	Latitude (S)	Longitude (W)	Termal camera, [°C]	CCT, [K]
P01	19:42	62°58′39.425″	60°33′34.322″	8.7	5825
P02	19:46	62°58′39.196″	60°33′34.858″	9.3	4815
P03	19:51	62°58′36.068″	60°33′29.428″	6.1	4424
P04	19:58	62°58′32.788″	60°33′32.637″	7.6	4479
P05	20:02	62°58′32.110″	60°33′32.022″	7.9	4355
P06	20:07	62°58′38.016″	60°33′28.599″	7.9	4334
P07	20:10	62°58′39.503″	60°33′27.396″	6.2	4760
P08	20:13	62°58′41.017″	60°33′25.026″	9.4	4416
P09	20:15	62°58′41.986″	60°33′22.800″	8.7	4550
P10	20:20	62°58′45.089″	60°33′17.458″	7.3	4058
P11	20:25	62°58′46.155″	60°33′14.386″	7	5088
P12	20:35	62°58′50.742″	60°33′07.247″	7.5	4825

Spectral curves show a relatively low intensity in the blue part, a gradual increase towards the green and yellow parts, and pronounced fluctuations in the red part of the visible spectrum (Fig. 5).

The Correlated Color Temperature (CCT) is approximately 4660 K on average for the 12 points (Table 3). It characterizes the color of the recorded lighting, not the temperature of the plant or the volcanic surface. These values are measured at the end of the day, which can be seen from the GPS data. Although the survey was done in February, when the so-called white nights are observed for the area. The field spectrometer data provides important information that complements and enriches the satellite data [13]. The Color Rendering Index (CRI) and the data for the 15 colors (R1 to R15) show low values mostly for P08. The data for R9 (red) from the selected three profiles show values below 35. This means that there are no colors close to the real colors of the examined objects. The values presented in profile P08 for color rendering are no exception to the rest, but they are one of the lowest, and it is there that some of the highest values with P07 for spectral indices are available.

All the parameters examined by the spectrometer can complement and upgrade the information not only about mosses and lichens, but also about any other object, as long as we know the spectral curve of the object under study well enough. Information from spectrometric data does not replace the use of satellite data (optical or radar), as it is about different spatial resolutions. This information helps with the integrated approach, as it enriches the momentary information, which may not coincide with the temporal and spatial resolution of the satellites [13].

Chlorophyll strongly absorbs light in the blue and red areas. These areas are present in the measured curve, but it does not prove chlorophyll absorption because the Sekonic C-800 measures the spectral distribution of light and not directly the reflection or fluorescence of the plant.

The combined findings identify P07 as a potentially important moss-covered microsite for investigating relationships between vegetation-related spectral responses, surface moisture and thermal conditions in the volcanic environment of Deception Island.

Conclusions

The integration of Sentinel-2 spectral indices, Sentinel-3 land surface temperature data, and ground-based thermal and spectral observations provides complementary information on the environmental characteristics of Whalers Bay, Deception Island, Antarctica.

Among the twelve investigated sampling locations, point P07 was characterized by elevated NDVI, SAVI, and NDWI values and the highest MCARI2 value. This combined spectral response is consistent with the potential presence of a relatively well-developed moss-covered surface associated with increased moisture availability.

Sentinel-3 observations acquired on 30 January 2026 indicated regional land surface temperatures ranging from −5°C to −3,5°C, while localized thermal measurements conducted on 4 February 2026 recorded temperatures of approximately 7–8°C. These differences highlight the spatial and temporal variability of thermal conditions in the investigated volcanic environment. However, they cannot independently establish geothermal influence or persistent surface warming.

Field spectrometric measurements provided additional information on illumination conditions, including spectral regions relevant to chlorophyll light absorption. Nevertheless, these observations do not directly quantify chlorophyll concentration or photosynthetic activity.

Overall, the results identify P07 as a potentially important moss-covered microsite and demonstrate the value of combining optical satellite indices, regional thermal observations, and field measurements for investigating environmental heterogeneity in Antarctic volcanic landscapes. Further high-resolution spectral measurements and chlorophyll fluorescence observations are required to establish the physiological condition of the vegetation and its relationship with moisture and temperature.

Acknowledgements

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