A Comparison of the Frost Environment of Three Disparate Climatic Locations

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Landscape Processes in Antarctic Ecosystems

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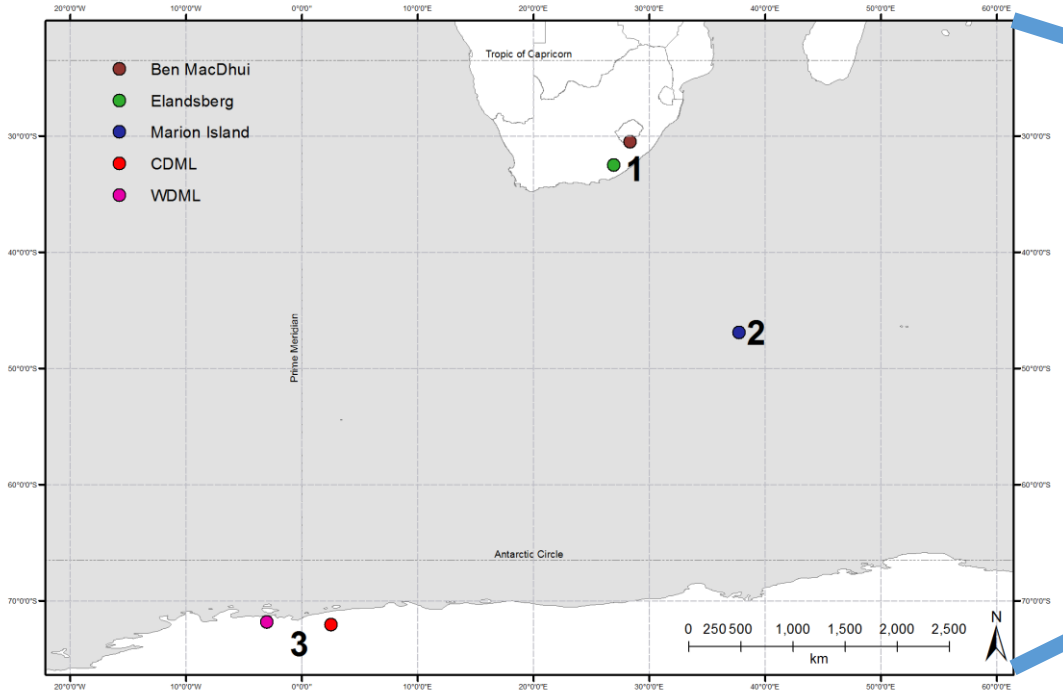
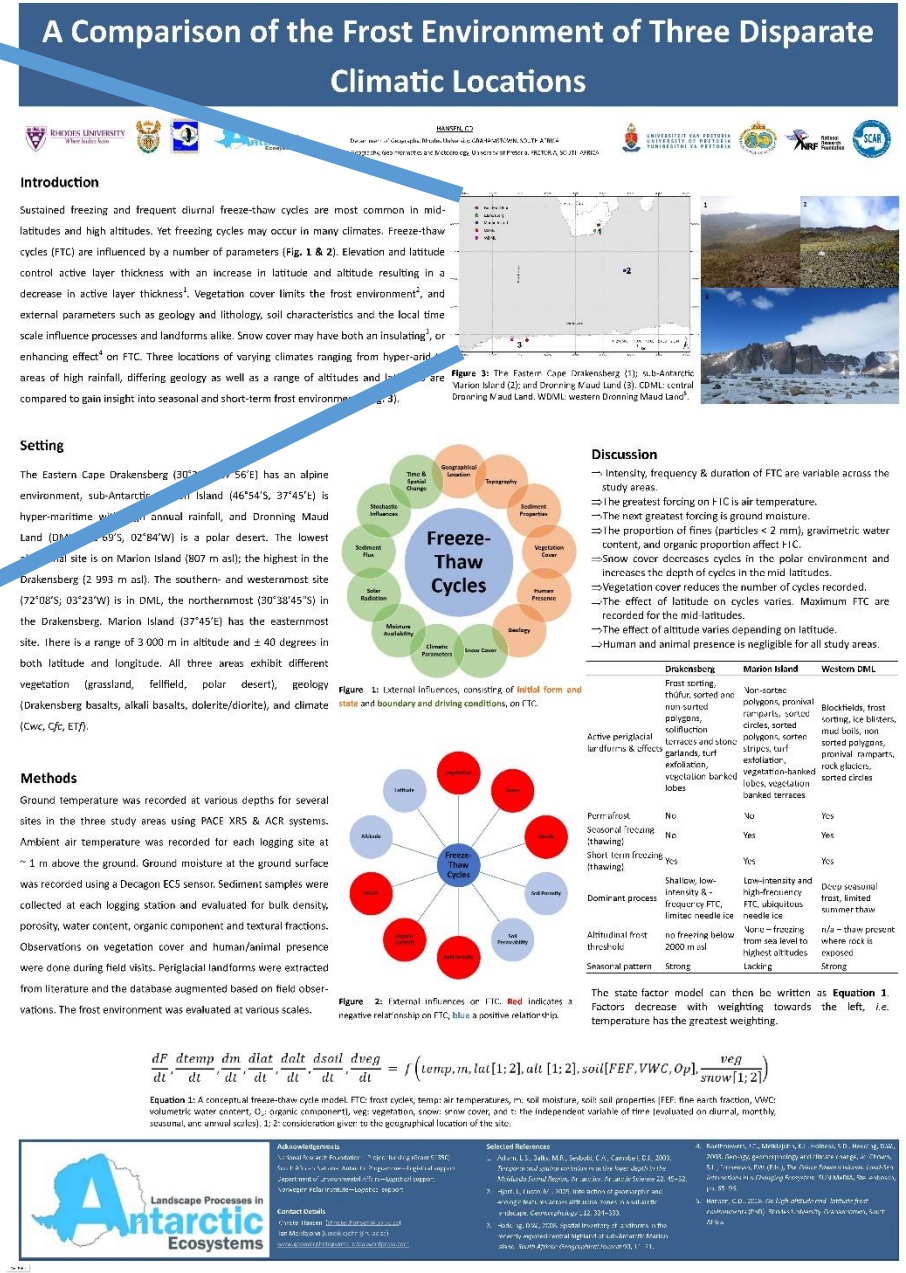


- Alt range ~ 3 000m
- Lat/Long range ~ 40 degrees
- Vegetation
  - Grassland, fellfield, polar desert
- Geology
  - Drakensberg basalts, alkali basalts, dolerite/diorite
- Climate
  - C*wc:* winter drought; C*fc*: warm(ish) and rainy; Et*f*: snow and ice



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Introduction

Sustained freezing and frequent diurnal freeze-thaw cycles are most common in mid-latitudes and high altitudes. Yet freezing cycles may occur in many climates. Freeze-thaw cycles (FTC) are influenced by a number of parameters (Fig. 1 & 2). Elevation and latitude control active layer thickness with an increase in latitude and altitude resulting in a decrease in active layer thickness[1]. Vegetation cover limits the frost environment[2], and external parameters such as geology and lithology, soil characteristics and the local time scale influence processes and landforms alike. Snow cover may have both an insulating[3], or enhancing effect[4] on FTC. Three locations of varying climates ranging from hyper-arid areas of high rainfall, differing geology as well as a range of altitudes and latitudes are compared to gain insight into seasonal and short-term frost environments (Fig. 3).

Figure 3: The Eastern Cape Drakensberg (1); sub-Antarctic Marion Island (2); and Dronning Maud Land (3). CDML: central Dronning Maud Land. WDML: western Dronning Maud Land.

Setting

The Eastern Cape Drakensberg (30° 56'E) has an alpine environment, sub-Antarctic Marion Island (46°54'S, 37°45'E) is hyper-maritime with high annual rainfall, and Dronning Maud Land (DML; 69'S, 02°84'W) is a polar desert. The lowest altitudinal site is on Marion Island (807 m asl); the highest in the Drakensberg (2 993 m asl). The southern- and westernmost site (72°08'S; 03°23'W) is in DML, the northernmost (30°38'45"S) in the Drakensberg. Marion Island (37°45'E) has the easternmost site. There is a range of 3 000 m in altitude and ± 40 degrees in both latitude and longitude. All three areas exhibit different vegetation (grassland, fellfield, polar desert), geology (Drakensberg basalts, alkali basalts, dolerite/diorite), and climate (C*wc*, C*fc*, Et*f*).

Figure 1: External influences, consisting of initial form and state and boundary and driving conditions, on FTC.

Methods

Ground temperature was recorded at various depths for several sites in the three study areas using PACE XRS & ACR systems. Ambient air temperature was recorded for each logging site at ~ 1 m above the ground. Ground moisture at the ground surface was recorded using a Decagon EC5 sensor. Sediment samples were collected at each logging station and evaluated for bulk density, porosity, water content, organic component and textural fractions. Observations on vegetation cover and human/animal presence were done during field visits. Periglacial landforms were extracted from literature and the database augmented based on field observations. The frost environment was evaluated at various scales.

Figure 2: External influences on FTC. Red indicates a negative relationship on FTC, blue a positive relationship.

Discussion

- Intensity, frequency & duration of FTC are variable across the study areas.
- ⇒The greatest forcing on FTC is air temperature.
- →The next greatest forcing is ground moisture.
- ⇒The proportion of fines (particles < 2 mm), gravimetric water content, and organic proportion affect FTC.
- ⇒Snow cover decreases cycles in the polar environment and increases the depth of cycles in the mid latitudes.
- ⇒Vegetation cover reduces the number of cycles recorded.
- →The effect of latitude on cycles varies. Maximum FTC are recorded for the mid-latitudes.
- →The effect of altitude varies depending on latitude.
- →Human and animal presence is negligible for all study areas.

	Drakensberg	Marion Island	Western DML
Active periglacial landforms & effects	Frost sorting, thúfur, sorted and non-sorted polygons, solifluction terraces and stone garlands, turf exfoliation, vegetation banked lobes	Non-sortec polygons, pronival ramparts, sorted circles, sorted polygons, sorted stripes, turf exfoliation, vegetation-banked lobes, vegetation banked terraces	Blockfields, frost sorting, ice blisters, mud boils, non sorted polygons, pronival ramparts, rock glaciers, sorted circles
Permafrost	No	No	Yes
Seasonal freezing (thawing)	No	Yes	Yes
Short term freezing (thawing)	Yes	Yes	Yes
Dominant process	Shallow, low-intensity & -frequency FTC, limitac needle ice	Low-intensity and high-frequency FTC, ubiquitous needle ice	Deep seasonal frost, limited summer thaw
Altitudinal frost threshold	no freezing below 2000 m asl	None – freezing from sea level to highest altitudes	n/a – where present where rock is exposed
Seasonal pattern	Strong	Lacking	Strong

The state factor model can then be written as Equation 1. Factors decrease with weighting towards the left, i.e. temperature has the greatest weighting.

$$\frac{dF}{dt}, \frac{dtemp}{dt}, \frac{dm}{dt}, \frac{dlat}{dt}, \frac{dalt}{dt}, \frac{dsoil}{dt}, \frac{dveg}{dt} = f\left(temp, m, lat[1;2], alt\ [1;2], soil[FEF, VWC, Op], \frac{veg}{snow[1;2]}\right)$$

Equation 1: A conceptual freeze-thaw cycle model. FTC: frost cycles; temp: air temperatures; m: soil moisture, soil: soil properties (FEF: fine earth fraction, VWC: volumetric water content, O_p: organic component), veg: vegetation, snow: snow cover, and t: the independent variable of time (evaluated on diurnal, monthly, seasonal, and annual scales). 1; 2: consideration given to the geographical location of the site.

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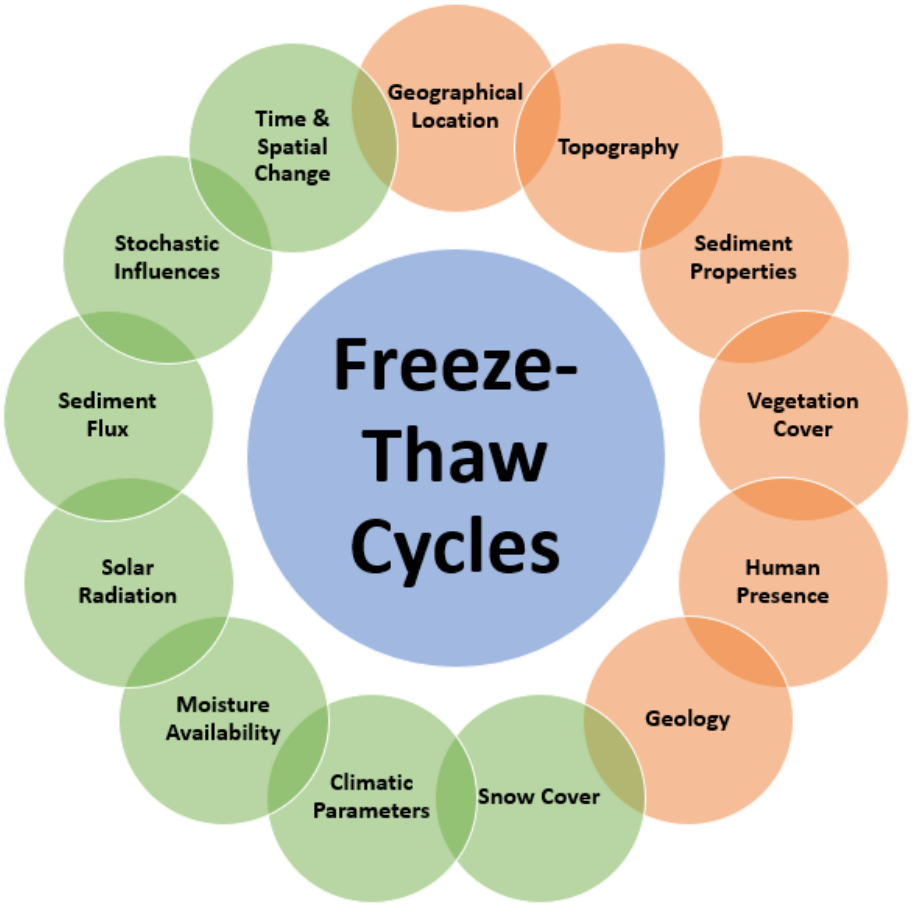

External influences, consisting of **initial form and state** and **boundary and driving conditions**, on FTC.

External influences on FTC. **Red** indicates a negative relationship on FTC; **blue** a positive relationship.






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Seasonal pattern	Strong	Lacking	Strong
T extrapolation	Winter: colder by ~-2.5°C (standard rate)	Winter/spring/autumn: warmer ~1°C (moist rate)	n/a

$$\frac{dF}{dt}, \frac{dtemp}{dt}, \frac{dm}{dt}, \frac{dlat}{dt}, \frac{dalt}{dt}, \frac{dsoil}{dt}, \frac{dveg}{dt} = f\left(temp, m, lat[1;2], alt\ [1;2], soil[FEF, VWC, Op], \frac{veg}{snow[1;2]}\right)$$

A conceptual state-factor (FTC) model. FTC: frost cycles; temp: air temperatures, m: soil moisture, soil: soil properties [FEF: fine earth fraction, VWC: volumetric water content, Op: organic component), veg: vegetation, snow: snow cover, and t: the independent variable of time (evaluated on diurnal, monthly, seasonal, and annual scales). 1; 2: consideration given to the geographical location of the site.

Global vs. Local | Modelling vs. Experimental | The 3rd Pole