Figure 4 Shannon diversity index for the soil arthropod communities at the sites (moss and lichen communities n=12, grass community n=6 and dwarf shrub community n=14). Data based on diversity data from the OTCs and control plots obtained in the 2003-2004 sampling season. Letters indicate significant (p<0.05 Tukey HSD) differences between community types, error bars indicate se.
Figure 5 Total abundance (ind. m\(^{-2}\)) of a) Collembola and b) Acari in the different communities (moss and lichen communities n=12, grass community n=6 and dwarf shrub community n=14). Data based on abundance from the OTCs and control plots obtained in the 2003-2004 sampling season. Letters indicate significant (p<0.05 Tukey HSD) differences between community types. Note the logarithmic scale on the y-axis on part a), error bars indicate se.
Effects of experimental warming by OTCs

The response of soil arthropods to the OTC environmental manipulation was generally low. On the Falkland Islands, warming did not lead to significant changes in the soil arthropod communities over the duration of the study (Figures 6a, b). On Signy Island, the abundance of Collembola was lower (p<0.05) in OTCs relative to control plots during the third study summer, 2005/06 (Figure 6c) in the lichen community, but Acari abundance was not affected (Figure 6d). On Anchorage Island, Collembola and Acari abundance were unaffected in either community (Figures 6e, f). OTCs did not alter arthropod diversity in the experimental plots over the course of the study.
Figure 6 Abundance of Collembolan (left) and Acari (right) (ind. m$^{-2}$) of substrata in control and OTC plots at each study site during the three sampling years. a) At the Falkland Islands, grass community n=3, b) dwarf shrub community n=9 for OTC and control plots. Signy Island c) and d), and Anchorage Island e) and f), moss and lichen communities n=6 for both OTC and control plots. (*) indicate a significant (p<0.05 Tukey HSD) treatment effect. Note the differences in scaling on the y-axis, error bars indicate se.

Discussion

The temperature gradient and consequences of OTC deployment

Even though our three study sites are evenly spaced in terms of absolute latitude, they are not spaced evenly along the gradient in terms of environmental conditions. Thus, in the context of large-scale environmental comparisons, there is a much greater contrast between the Falkland Islands and the two Maritime Antarctic islands than there is between the latter. Temperature and degree days are much higher at the Falkland Islands, while Signy and Anchorage Island have far more comparable ranges in temperature and degree days. We consider the Falklands Islands communities as an analogue for the Maritime Antarctic Islands after they have been exposed to decades of very substantial climatic warming. While environmental differences are present between Signy and Anchorage Islands, these are more subtle. Our
data from the two Antarctic Islands support earlier climatic comparisons
between sites on the Antarctic Peninsula and the South Orkney Islands
(Longton, 1967). These two elements of the Maritime Antarctic showed little
differences between them in terms of longer-term temperature averages, but
there are potentially biologically important differences in terms of average
cloudiness and direct insolation. These differences have consequential
influences on the extent of variation in microhabitat temperatures. As a result,
Signy Island may be considered harsher in a climatic context than Anchorage
Island.

Deployment of OTCs led to a mean summer warming of about 1.0 °C (the
average of the first column in table 2) at the soil surface, comparable with other
studies using this type of methodology (Dorrepaal et al., 2004, Marion et al.,
1997). The increase achieved varied between both season and location. Both
Signy Island and the Falkland Islands experienced the greatest level of increase
during the summer, while on Anchorage Island the largest effect was seen
during the winter. The measure of degree days, which gives a useful measure of
‘physiological time’, also increased in all communities. The Maritime Antarctic
islands had the lowest integrated value under natural conditions while showing
the greatest percentage increase, ±28%, indicating the potential significance of
small temperature increments for ecosystems typically functioning near to
freezing temperature (Convey, 2001b, 2006). OTCs had no significant effect on
relative humidity. Soil moisture was reduced in OTCs, probably as a direct
result of the warming. PAR was marginally affected, with the strongest effect
seen at Signy and Anchorage Islands. This was probably a result of the
accumulation of snow in OTCs. The most important consequences of OTCs on
soil arthropod life cycles are likely to be underlain by the combined effects of
warming experienced during summer months and to the reduction in soil moisture.

The soil arthropod communities along the gradient

There was a general increase in the diversity, but a decrease in the total abundance of soil arthropod communities with decreasing latitude (and thus higher temperatures). This was most clearly seen in the dense (shrub/moss) communities (Fig. 4). Reasons underlying this decrease in abundance are not obvious. Environmentally extreme ecosystems tend to have low species diversity but with very high abundances and high microarthropod population densities are a typical feature of some Antarctic terrestrial ecosystems (Convey, 1996a, 2001a). The abundance gradient found here is probably most strongly influenced by climatic and substrate conditions (Chown et al., 2006, 1998, Greve et al., 2005, Hertzberg et al., 2000, Peck et al., 2006). The more complex dwarf shrub community has a high diversity of vascular plants, which could lead to a diverse mixture of litter types, creating greater niche diversity and giving room for more specialisation between soil arthropods. If the environmental conditions would eventually allow for more vascular plant species to grow in the moss communities of the Maritime Antarctic Islands a more diverse soil arthropod community might be expected. Predation pressure might also be higher at the Falkland Islands as might be concluded from the higher number of potential arthropods predators (Robinson, 1984). Latitudinal species patterns, as seen in above ground studies, are generally not replicated below ground, or are at least not well studied (Wardle, 2002). The Antarctica Peninsula and Scotia Arc provide the opportunity for a detailed study across an increased number of sampling sites, which might provide important new insights on this subject.
The effects of experimental warming on soil arthropods communities

On Signy Island, we found a decrease in Collembola abundance in the lichen community in the OTCs. This may be either a direct effect of warming or an indirect result of increased desiccation stress (Convey et al., 2002a, Hayward et al., 2001) through higher evaporation in response to warming (Table 2). Although, we did find similar changes in microclimate in other communities, no responses of the arthropods were found. The lack of or delayed response of Collembola to warming as seen in the current study is similar to that found by Coulson et al. (1996), in a study using similar warming treatments on Arctic Svalbard. Only after three years of warming did the Collembola abundance decrease under their warming treatment, while, again in parallel with the current study, no responses were detected amongst the Acari. The current study results also parallel those reported by Webb et al. (1998) in a study of soil oribatid mites under a similar manipulation protocol on Arctic Svalbard. They concluded that oribatids have little capacity to respond quickly to short-term environmental changes, but that persistent above-normal temperatures are likely to affect population growth rates. For this taxonomic group, long-term experiments are clearly necessary.

Thus, the (micro) environmental changes achieved through the use of OTCs in this experiment have, at least over the two-year duration of this field experiment, led to little responses of some groups in the soil arthropod communities. Analogous warming experiments, carried out at different Arctic and Antarctic locations, using different chamber designs and/or targeting different taxa, have led to significant changes in arthropod or nematode communities over timescales of 1-8 years (Convey et al., 2002a, Convey et al., 2002b, Coulson et al., 1996, Hodkinson et al., 1998, Kennedy, 1994).
Generally, such studies have found that this type of environmental warming, applied to Antarctic terrestrial habitats, leads to increases in the population density of target taxa over time. However, this is a very simplistic interpretation that summarizes or integrates the interacting responses of several different major groups of biota to several interacting environmental variables. In reality, particularly faunal responses are likely to be dependent on the responses of soil microbiota and cryptogamic and phanerogamic vegetation. Increases in the abundance of these groups, generally seen under warming, then drive changes in the invertebrate populations through the twin routes of providing additional food supplies and altering the three-dimensional structure and interlinked microclimate of the habitat that develops. When examined in more detail, the direction of change achieved can differ between groups. For example, Antarctic Collembola species have been reported to decrease in abundance in manipulated moss and grass communities as warming leads to increased desiccation stress (Convey et al., 2002a) but also to increase in fell field communities due to warming, leading to increased rates of reproduction and growth (Kennedy, 1994). However, application of a warming protocol similar to the current study at continental Antarctic Ross Island also did not lead to large changes in soil arthropod communities (Sinclair, 2002).

Amongst the main challenges in making comparisons between the data obtained using different warming methodologies are the issues of accounting for the different levels and combinations of environmental change they generate, and identifying accurately the environmental changes achieved, including changes in the influence of interactions between variables (Kennedy, 1995a, 1995b). One obvious difference between the current study and those mentioned above lies in the increase of temperature caused by the different
warming treatments, which was more than 2 °C in the latter (Day et al., 1999, Kennedy, 1994). Based on these differences, we would expect to find stronger community responses with greater temperature increases than achieved in the current study.

Implications for ecosystem processes

Collembola and Acari play a key role in nutrient cycling in the soil ecosystem through the twin routes of their ability to fragment larger organic particles and their grazing activity on soil fungi, alga and micro-fauna. Changes, particularly increases, in their diversity or abundance, will alter the rate at which soil organic material can be broken down, potentially removing and certainly altering the importance of this current bottleneck in ecosystem processes. The role of soil arthropods in the decomposition process is also intimately linked with temperature, moisture and litter quality (Aerts 2006, Treonis et al., 2002). Any effects of soil arthropod communities on decomposition rates will be modulated directly by changes in these variables, and indirectly through the vegetation composition. Our data have so far shown limited response of the soil arthropod communities to experimentally increased temperatures. However, the relatively short duration of this experiment renders conclusions about long-term expectations for ecosystem processes premature. Although this study found indications of decreasing abundance under some warming treatments that could have an effect on the rate of decomposition, the observed changes were small, suggesting that immediate effects within the decomposer cycle will also be small. However, from the gradient study it can be inferred that long-term climatic warming may lead to increased species diversity in the Maritime Antarctic sites (cf. Fig. 4). Thus, when climatic warming will continue during the coming decades, the soil arthropod communities may change to more
species-rich communities. The speed with which these community changes may occur will depend on the rate of temperature increase and available water.

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Chapter 5

The effect of environmental change on vascular plant and cryptogam communities along a latitudinal gradient from the Falkland Islands to the Maritime Antarctic

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Submitted
Abstract

1 Antarctic terrestrial vegetation is subject to one of the most extreme climates on Earth. Currently, Antarctica is one of the fastest warming regions on the planet. During 3 growing seasons, we investigated the effect of warming on the diversity and abundance of coastal plant communities in the Maritime Antarctic region (cryptogams only) and the Falkland Islands (vascular plants only). We used a combination of a latitudinal gradient study (as proxy for temperature), ranging from the Falkland Islands (51° S, mean annual temperature 7.9 °C), to Signy Island (60° S, -2.1 °C) and Anchorage Island (67° S, -2.6 °C), and experimental temperature manipulations at each of the three islands using Open Top Chambers (OTCs).

2 Despite the strong difference in plant growth form dominance along the gradient, communities across the gradient did not differ in total diversity and species number.

3 During the summer months, the experimental temperature increase at 5 cm height in the vegetation was similar between the locations (0.9 – 1.0 °C). In general, the response to this experimental warming was low. Total lichen cover showed a decreasing trend at Signy Island (p< 0.06). In the grass community at the Falkland Islands total vegetation cover decreased more in the OTCs than outside and two species disappeared within the OTCs after only two years. This was most likely a combination of a previous dry summer and the increase in temperature caused by the OTCs.

4 These results suggest that the more open plant communities (grass and lichen) are more negatively affected by climate change than dense communities (dwarf shrub and moss). However, species diversity is determined by the balance between extinctions and new colonisations. The isolated position of
Antarctica may prevent the establishment of new plant species. As a result, climate warming may at a local scale lead to an overall decrease in species diversity.

**Introduction**

Antarctica is the coldest, driest, windiest and highest continent on Earth. As a result, plant growth is largely limited to the coastal areas of the sub- and maritime-Antarctic regions. In these regions, there are small areas where vascular plants and cryptogams (mosses and lichens) can grow due to the summer melt of snow and ice. Due to the harsh climate, Antarctic vegetation mainly consists of cryptogams and there are only two vascular plant species (*Deschampsia antarctica* and *Colobanthus quitensis*). The extreme environmental conditions provide one of the main reasons why ecosystems in the Antarctic regions are relatively simple, have a poorly developed trophic structure and are species poor as compared to lower latitude ecosystems (Castello & Nimis, 1997, Convey, 2001).

Recent climate changes documented over the last 50 years along the Antarctic Peninsula have been far greater than seen at lower latitudes. The most conspicuous changes have been an average increase in temperature of about 2 °C over this period (King, 1994, Turner *et al.*, 2005), and changes in patterns of cyclonic activity around the Antarctic continent, along with changes in precipitation intensity (van den Broeke & van Lipzig, 2004, Turner *et al.*, 2005). The warming trends along the Antarctic Peninsula are not constant throughout the year, with higher increases during winter than during the summer (Convey, 2006).

These changes raise the question of whether this (small) apparent reduction in ecological stress through warming will be sufficient to influence the
distribution and abundance of cryptogams and vascular plants in this harsh environment. There are already some indications that this is the case, as climatic changes have been implicated in affecting the local population density and distribution of the two vascular plant species (*Deschampsia antarctica* and *Colobanthus quitensis*) that occur along the Antarctic Peninsula. In addition, their reproductive patterns have also changed, with a greater incidence of successful sexual reproduction and increased seed output (Fowbert & Smith, 1994, Smith, 1994, Convey, 1996, Grobe *et al.*, 1997, Day *et al.*, 1999, Xiong *et al.*, 2000). Invasion of new species and shifts in species composition of communities are also predicted to occur (Kennedy, 1995, Gremmen & Smith, 1999, Stevens & Hogg, 2002, Frenot *et al.*, 2005) but yet to be observed.

Longer periods above biological thresholds are likely to affect the life cycle of cryptogams in the context of growth rates, development and reproduction (Green *et al.*, 1999). Warming of the soil and air may therefore increase the abundance and cover of mosses and lichens due to its influences on these life history traits (Arft *et al.*, 1999, Sonesson *et al.*, 2002, Dorrepaal *et al.*, 2004). Arctic studies have shown that cryptogams can decrease in abundance and biomass due to warming (Chapin *et al.*, 1995, Press *et al.*, 1998, Jonsdottir *et al.*, 2005, Klanderud & Totland, 2005, Wahren *et al.*, 2005), in most cases as a result of increased cover and competition from vascular plants (Cornelissen *et al.* 2001). As vascular plants are very restricted in the Antarctic, the main response here to increased temperatures will be one of the cryptogams alone.

We studied the responses of Antarctic plant communities to temperature change by using two complementary methods: (1) Studies at three field locations, ranging from the cold temperate oceanic Falkland Islands to southern Maritime Antarctic Anchorage Island, spanning a natural latitudinal and
environmental gradient. This ‘climate change by location substitution’ can be seen as a proxy for the possible long-term effect of warming on the Antarctic vegetation. In this context, we consider the Falklands Islands as an analogue for extremely warmed Maritime Antarctic Islands. Working along natural gradients has the advantage of including large spatial and temporal scales, but the disadvantage that it is difficult to separate the effects of different environmental factors. (2) Investigations using multi-year field experiments at each of the three locations, where temperature was experimentally manipulated using Open Top Chambers (OTCs) (Marion et al., 1997). Thus, nested within the natural gradient there was also an experimental temperature increase. This approach has the advantages of standardization of environmental factors and good replication.
Study sites and Methods

Study sites and the latitudinal gradient

The study took place along a latitudinal and environmental gradient between the Falkland Islands (51º76’S 59º03’W), Signy Island (60º71’S 45º59’W) and Anchorage Island (67º61’S 68º22’W) over a period of 3 growing seasons between 2003 and 2006. Experimental manipulations were installed in coastal communities in two dominant vegetation types available at the three locations, although these were inevitably different at the Falklands and the two Maritime Antarctic locations. The sites selected included moss or lichen dominated communities on the Maritime Antarctic islands and grass or dwarf shrub communities on the Falkland Islands (Moore, 1968, Convey, 2001).

The Falkland Islands vegetation is dominated by grasses and dwarf shrubs, due to exposure to typically high winds and low precipitation (Moore, 1968). The study site here was at Saladero Farm, south-west of Brenton Loch, near the settlement of Goose Green on East Falkland (51º7567’S 59º0298’W). The two communities selected for sampling and manipulation were dwarf shrub dominated vegetation (dominance of *Empetrum rubrum* Vahl ex Willd.) and a rocky, grass dominated, vegetation (co-dominance of *Festuca magellanica* Lam., *Poa annua* L. and *P. pratensis* L.). The dwarf shrub community grows on a 30-50 cm layer of peat. A very thin layer of soil on top of the rocky base layer, mainly sandstone, underlies the grass community.

Signy Island is a small (10 km²) island, within the northern Maritime Antarctic South Orkney Islands (60º71’S 45º59’W). The island has an ice cap giving rise to glaciers flowing towards the sea. During the summer months, December –
February, up to c. 50% of the island’s area becomes free of snow and ice, and has a well developed moss or lichen vegetation (Smith, 1972). The study site on Signy Island was on the north facing ‘back slope’ area, near to the British Antarctic Survey (BAS) Signy Research Station. Where moss was present at this site, this community was dominated by *Polytrichum strictum* Brid. and *Chorisodontium aciphyllum* (Hook. f. & Wils.) Broth in Engl. The moss had a depth of approximately 20 cm underlain by a base layer of quartz-mica-schist (Matthews & Maling, 1967). The lichen community was present on a substratum of a similar rock type but did not develop complete vegetation cover while more weathering of the basal layer had occurred. It was dominated by *Usnea antarctica* Du Rietz.

Anchorage Island lies in Marguerite Bay (southern Maritime Antarctic) south of the BAS Rothera Research Station (67°61’S 68°22’W). The island is 2.5 km long and 500 m wide and is partly covered by semi-permanent snow and ice fields, although recently these have been decreasing rapidly in extent (Fox & Cooper, 1998). The island includes several rocky ridges and reaches a maximum height of 57 m asl. On the slopes of these ridges, there are patches of the moss *Sanionia uncinata* (Hedw.) Loeske and the grass *Deschampsia antarctica* Desv. However, the dominant vegetation consists of lichens, with *Usnea antarctica* being most prominent. The communities chosen for sampling and manipulation were dominated by *Sanionia uncinata* or by *Usnea antarctica*. The former consisted of patches (2-4 m$^2$) of complete moss coverage located between rocks. A layer of dead moss of 0-10 cm underlies this vegetation. The lichen-dominated community consisted of bare rock and boulders with a partial coverage of *U. antarctica* and other lichen species.
Experimental warming with Open Top Chambers

At each site, Open Top Chambers (OTCs) were placed on the soil surface to raise the air and soil temperature. The structure was based on the ITEX six sided model used extensively in Arctic climate manipulation studies (Molau & Molgaard, 1996, Marion et al., 1997, Hollister & Webber, 2000). For each community on Signy and Anchorage Islands, 6 plots of 2 x 4 m were chosen based on the visual similarity of vegetation. At the Falkland Islands, 9 plots were selected in the dwarf shrub community and, due to practical constraints, only 3 plots in the grass community. Each of these plots was divided into two sections, one in which the OTC was installed, and a neighbouring section acting as the control plot for that specific OTC, as in a split plot design.

*Environmental data collection*

Environmental monitoring was undertaken at each of the three study locations, with sensors placed in three paired plots of each community. Air temperature at 5 cm, soil moisture (Water Content Reflectometer CS616, Campbell Scientific Uk), air humidity (HMP45C Campbell Scientific UK) and photosynthetically active radiation (PAR) (SKP215 Campbell Scientific UK) were recorded every hour for the duration of the experiment. Due to the nature of the substratum, we were unable to place a Water Content Reflectometer to measure soil moisture in the grass community on the Falkland Islands. Therefore, this was determined gravimetrically. We did not measure this in the lichen community at Anchorage Island as the lichens were growing on rocks. A self registering precipitation gauge (PLUVIO, OTT Hydrometrie) was installed at each location, to compare the yearly amount of precipitation with that of long term means. At the three islands these are: 575, 400 and 500 mm y⁻¹ for the Falkland Islands, Signy and
Anchorage Island respectively (Holdgate, 1967, Turner et al., 2002). We did not obtain a reliable figure due to technical problems with the PLUVIO on Signy and Anchorage Island, so we can not say whether total precipitation differed from the annual mean.

Vegetation recording

The abundance of higher plants, mosses and lichens was estimated using the point-intercept method (Jonasson, 1988). We used a square frame of 30 x 30 cm with holes every 2.5 cm through which a pin (4 mm diameter) could be inserted vertically until it touched the ground. A “hit” was recorded when the pin touched a part of a plant, with a maximum of 10 hits per plant per pin. Moss and lichen species were recorded as present or absent for each point in the frame. These measurements were made during three consecutive field seasons.

The vegetation at the Falkland Islands field sites was identified following Moore (1968), and that of Signy and Anchorage Islands using Ochyra (1998) and Bednarek-Ochyra et al (2000). Lichen identifications were confirmed by D. Øvstedal and R. Lewis Smith.

Logistic practicalities

Although OTCs and environmental monitoring equipment remained in place and were operated year-round, logistic practicalities defined that field activities were restricted to fixed periods at each location. During each season of the study, the Falkland Islands were visited during November, Signy Island during December, and Anchorage Island between late January and early February.
Statistical analysis

*Environmental data analyses*

During the study period between November 2003 and February 2006 there were a number of discontinuities in the data set obtained due to the occurrence of technical problems. Therefore, we used environmental data collected between December 2004 and November 2005, as this was the only year in which the monitoring equipment provided a complete data set at all three locations. The existence of differences in environmental data between communities was examined using a repeated-measures ANOVA between the six communities with treatment (OTC vs. control plots) within a plot as a within-subject factor. Analyses were completed using annual means and seasonal (summer, Dec-Feb, autumn, Mar-May, winter, Jun-Aug and spring, Sep-Nov) means. Log transformations were applied where appropriate to reduce the variance of the residuals. However, for the temperature data, this transformation was inappropriate, and the non-homogeneity of variances could not be resolved. Therefore, data obtained from the Falkland Islands communities was tested separately from that obtained from the four Maritime Antarctic communities. Post-hoc (Tukey HSD) tests were used to test for differences between communities. To identify any relationship between soil moisture and soil temperature a linear regression model was applied. Analyses were completed using the package Brodgar 2.5 (Highland statistics www.brodgar.com).
Diversity was estimated using Shannon’s diversity index (H), calculated as:

\[ H = - \sum_{i=1}^{S} p_i \ln p_i \]

Where \( H \) = Shannon’s diversity index, \( S \) = total number of species in the community (richness) and \( P \) = proportion of \( S \) made up of the \( i \)th species.

Evenness (E) was calculated by dividing the \( H \) by the natural logarithm of the number of species. The diversity indices obtained across community types and treatments were also analysed using repeated measures ANOVA. For the analyses of diversity change after two years, the individual plot diversity index obtained in 2003/04 was subtracted from that obtained in 2005/06 to give a measure of the net change in diversity (if any). Total vegetation cover change was analysed in a similar way for the difference between 2003/04 and 2005/06. However, again there was non-homogeneity of variance in the data that could not be resolved by a mathematical transformation. Therefore, a one-way ANOVA between the control and OTC plots was employed to analyse the change in cover, separately for each community. The differences in total hits per plot obtained for each species between 2003/04 and 2005/06 were also analysed using a repeated measures ANOVA as described above.

**Results**

**Environmental data**

The Falkland Islands was the warmest of the three locations with the highest temperature, measured at 5 cm above the soil surface. Signy and Anchorage
Island had lower and similar annual average temperatures. However, Signy Island had a lower summer temperature than Anchorage Island (Fig. 1).

Figure 1a, b The monthly mean, maximum and minimum temperature at 5 cm above the soil in the control and OTC plots. (a) Falkland Islands dwarf shrub, (b) grass community. A: ambient temperature in control plots, OTC: Temperature in OTC. n= 3 for each monthly value, error bars indicate se.
Figure 1c, d The monthly mean, maximum and minimum temperature at 5 cm above the soil in the control and OTC plots. (c) Signy Island moss, (d) lichen community, A: ambient temperature in control plots, OTC: Temperature in OTC. n= 3 for each monthly value, error bars indicate se.
Figure 1e, f The monthly mean, maximum and minimum temperature at 5 cm above the soil in the control and OTC plots. (e) Anchorage Island moss and (f) lichen community. A: ambient temperature in control plots, OTC: Temperature in OTC. n= 3 for each monthly value, error bars indicate se.
At the Falkland Islands, there was a negative relationship between soil temperature and soil moisture ($r^2 = 0.64$, $P < 0.001$, $n=25$) in the dwarf shrub community. On Signy and Anchorage Island the relation between temperature and soil moisture was non-linear. Therefore, we had to apply a generalised additive model with a Gaussian distribution. When the soil was deep frozen, the measured soil moisture approached zero, but when the temperature rose above -3.0 ºC, there was a linear increase in soil moisture with increasing temperature ($r^2=0.70$, $P < 0.001$, $n=24$).

The total rainfall during the 2004/05 year was 9% lower than the average (575 mm $y^{-1}$) at the Falkland Islands (data obtained from the Falkland Islands Department of Agriculture). The main difference in rainfall occurred during February, with 30 mm less than average.

Effects of OTC deployment

Table 1 summarises the effects of OTC deployment on temperature. Annual mean temperature at 5 cm height was consistently increased by 0.7 ºC ($P < 0.05$) by OTCs in all communities. However, there were differences between seasons and communities in the amount of warming achieved. Maximum and minimum temperatures were differently affected between the communities during summer and winter months as shown in Table 1 and figure 1. Table 2 summarises the effect of OTC deployment on PAR, soil moisture and relative humidity. Gravimetrically determination of soil moisture showed a marginal ($P < 0.06$) lower water value in the OTCs (26.7 ±2.2 vs. 17.9 ±2.5) of the grass community at the Falkland Islands.