**The Cryosphere
Discussions**

Interactive
Comment

Interactive comment on "Evaluation of the ground surface Enthalpy balance from bedrock shallow borehole temperatures (Livingston Island, Maritime Antarctic)" *by* M. Ramos and G. Vieira

M. Ramos and G. Vieira

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Comments on the discussion process of the paper entitled: EVALUATION OF THE GROUND SURFACE ENTHALPY BALANCE FROM BEDROCK SHALLOW BORE-HOLE TEMPERATURES (LIVINGSTON ISLAND, MARITIME ANTARCTIC) Authors: M. Ramos and G. Vieira

Comment 1 The paper discusses and applies a method to study the Enthalpy exchange between the ground surface and the air on a site close to the boundary of continuous permafrost. The borehole has a shallow depth, but allows for the application of a methodology to calculate the heat flux across the ground surface and to characterize the thermodynamical behaviour of the bedrock. The soil temperature records have

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allowed us to know the thermal wave propagation mechanism and we have used it to help us defining other sites to drill deeper boreholes than the one studied here. During the last Antarctic campaign we have drilled two new boreholes, close to the previous one but at higher altitude (275 m asl), with 26 and 15m depth. These will allow us to have information about the thermal state of permafrost in this area and afterwards will enable comparisons with the Incinerador (35 m asl) borehole.

Comment 2 The paper does not focus on issues related to the influence of the active layer in polar ecology or gas emissions. A few general comments on these issues were included to emphasise on the importance of the active layer for those processes. The paper focus in the analysis of the thermal wave propagation in the ground and on the movement of the 0žC isotherm. In the surroundings of the borehole there are places with soil porous media and high moisture content where the existence of the free boundary is controlled by the latent heat of the water. The Incinerador site has been chosen due to the homogeneous conditions of the bedrock and for being a conductive heat transfer site. This allows following a simple modelling approach to estimate and characterize by thermodynamical arguments the Enthalpy balance in the ground surface and its season's evolution in relation with the local climate conditions.

Moderate revisions (changes done by suggestion of the referee 2 recommendations) Pg 154, line 25 changes made according to suggestions.

Pg 155, line 19 .., is a leading factor in the ground thermal regime and active layer thickness (.. In the paper the term soil will be replaced by ground.

Pg 155, line 22-25;..terrain are: (i) thermal soil properties (ii) moisture content in the active layer (iii) thaw effects at the free boundary, and (iv) non-conductive heat transfer effects (variable thermal diffusivity.

Pg 156, line 6-9; Compared to the Arctic where permafrost research developed accompanying engineering needs for regional socio-economic development and natural resource exploitation, very little is....

Pg 156 line 16; Date was corrected from 2001 to 2003.

Pg 157-158, section 2.2 climate. The snow cover in the area is very variable both temporally and spatially, and there is not continuous data for the winter period. However, a sentence will be written explaining this limitation and also that from March to December snow covers the ground with decimetrical to metrical thicknesses, with shallower depths in wind exposed interfluves.

Pg 158, line 24. In December 2003, there is not really zero curtain effect. The slow trend of the upper temperature sensor is due to the air temperature influence. We have studied the apparent thermal diffusivity by means of inverse techniques to confirm that.

Pg 159, line 9. The size of the minilogger casing significantly the possible circulation, since it fills almost completely the PVC tube and don't allow for the convective heat transfer effect. The temperatures are stratified following only a conductive process of heat transfer during all the measured period. A sentence will be added clarifying this issue.

Pg 159, line 20-23. Yes, there are both direct observations and results from electrical resistivity surveying showing the existence of interstitial ice in the slopes near the Incinerador borehole. A sentence will be added explaining this.

Pg 159, line 20-23. This technique allows to calculate the heat balance on the ground surface by dividing the year in two periods: a) when ground temperature is below 0žC; b) when ground temperature is above 0žC. The boundary at 0žC and the isothermal conditions at the start and end of the periods are essential assumptions for the application of the method and therefore, the choice of this boundary. The calculation of the energy exchange in the bedrock with negligible water content provides us information about the ground-air interaction and enables us to evaluate the significance of buffering factors like the snow pack or the air temperature regime. This can be correctly assessed since latent heat effects are not present at the study site.

Pg 160, line 5. In the study area there are sites of bedrock with negligible moisture and also soils with high water content. The terms frost and thaw seasons may, in fact, not be the best ones for the naming of the two periods. This difficulty arises due to translation difficulties between Spanish and English. Therefore, we accept the suggestion and will change these terms into: a) above 0žC season b) below 0žC season

Pg 160, line 8-13. The ground surface refers to the mathematical boundary condition. A semi-infinite system with two boundary conditions one of these on the ground surface is used. The borehole and study site is in fact a bedrock outcrop, without overburden material. This will be clarified in the text.

Pg 161, line 17-27. The two periods are important due to the fact that the temperature cycle is divided at the moment in which the ground thermal gradient is zero. Therefore these dates coincide to the start of a separate period of ground temperatures in the modelling approach. The period when the temperatures are below 0žC at all depths is the frost season (will be changed to below 0žC season); when the temperatures are above 0žC at all depths it is the thaw season (will be changed into above 0žC season). In both of these seasons there is cooling and warming, but the model calculates the energy lost in the cooling period of the frost season, which is equal to the energy gained in the warming in the same season, because the thermodynamics initial and final states are the same, with zero temperature gradient at 0žC, and the Enthalpy is a thermodynamic state function. On the other hand, in the thaw period it is studied the gained energy. We will change looses for loses in line 26.

Pg 165, line 20 to pg 166, line 3; the freezing and thawing indexes presented in table 1 are based in field measurements. We will write the following text to clarify. ..., as well as the other complementary parameters that are calculated from the temperature measurements from the field site, like the air....

Pg 166, line 17-26; We completely agree with you. This was a mistake and the N-factor results will be calculated in table 1 according with the proper definition. Line 17: The

values of the ratio of ground (15 cm) and air freezing indexes (If(-15)/Ia)... Line 23: ...very different (0.70 in 2002 and 0.27 in 2005),....

Pg 165, line 5-7. With the standard definition of N-Factor now the indexes in the thaw seasons are larger than one.

Pg 168, line 1-3. Inverse methods to calculate the apparent thermal diffusivity in summer show that this parameter is more or less constant in this site during this period (unpublished data from the authors). However, measurements of the global solar radiation (direct and diffuse) taken in the field show that the cloud effect is very significant and predominant during, at least the Summer (Ramos M, 1997). Terra Antartica, (ISSN 1122-862), pp.- 5-10. Vol.4, nž1.)

Pg 169 (must be 168), line 23; ...turbulent sensible heat fluxes....

Pg 169, line 3. ...two distinct periods, one of them with daily ground temperature distribution below 0žC (called, in this paper, below 0žC season) and the other with temperatures above 0žC (called above 0žC season&), with...

References, We will add this reference in pg 160, line 16 heat capacity (C) (Ramos and Vieira., 2004).

Figures: - We will delete the figure 3 and rename the figures 4 to 7. - We will try to represent in colour the figures 2 and 4, figure 1 is in black and white. - We draw in figure 2 the records of the temperature at 15 cm depth, to show it on the same graph that air temperature. - We will change the orientation of the figures 7 to plot temperature on the x-axis and depth on the y-axis. We will change the foot note to add the explanation of the last extrapolated points. ..best-fits. The last two points in the graph, below the borehole depth, are extrapolated using the (7) and (8) expressions and correspond to (Df and Dt) that is the reference depth where the soil heat flux is either zero and the temperature is 0žC.

- We consider maintain the orientation of graph 6 because the Enthalpy balance is

related with the area bellow the line and the x-axe, is more clear and coherent this orientation with the model and the formulas (12) to (15) in the text.

Interactive comment on The Cryosphere Discuss., 2, 153, 2008.