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SEASONAL BEHAVIOR OF THE SURFACE FEATURES IN ROSS ISLAND, ANTARCTICA, BY MEANS ASTER' LAND SURFACE TEMPERATURE DATA[1]

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A B S T R A C T

ASTER images from Antarctica taken between 2000 and 2003 in the thermal infrared imaging sensor showed interesting relationship between the land surface temperatures and the surface features. The studied area is the Ross Island, the Ross Ice Shelf at the south and the Antarctic Ocean at the north. The Ross Ice Shelf and icebergs showed to have the lowest surface temperatures, while the sea ice has higher surface temperatures. The open sea has the highest temperatures. The temperature differences are well defined and sharpen, but they are less different on the early and mid-summer and higher on spring and late summer. On land, there is a more irregular temperature pattern. This is due to the relief effects as well the presence of volcanic activity on Mount Erebus, with warm areas possibly heated by the volcanic activity. The surface temperature differences allow study the distribution of ice and sea on the region as well the behavior of the volcanic activity on Mt. Erebus.

Keywords: ASTER, Surface Features, Thermal Images, Ross Island.

Introduction

The discussion about the effects of the so-called global warming, or the intensifying heat of Earth due to the greenhouse effect, caused by the increased emission of gases like CO2, CH4 and CFC´s (mainly products of human activity), led to an increased interest about means of measure and survey all the possible changes on the several terrestrial environments.

A possible consequence of rising global average temperatures is an accelerated melting of the polar ice caps, with serious consequences like flooding of the coastal zones and cities (Oppenheimer 1998). Thus would be interesting a study of the polar ice cover as a way to determine any major variation of the volume, thickness, etc. that could point out for an imminence of a larger melting process of the polar cap.

Among the tools available for such study are the sensors aboard the satellites around the planet Earth. There is a number of sensors available working on many bands, spectral intervals, orbits, etc. that can be usefully used for this kind of research.

The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a sensor that works with the visible, near, shortwave and thermal infrared part of the spectra and is able to produce stereoscopic images. This stereoscopic imaging ability had been exploited for glacier changes analysis, while the infrared imagers have been used for surface temperature analysis (Kargel et al. on press). Its images of the Antarctic ice (Ross Island region) had been selected for a study whose objective, the objective of this paper, is relating the land surface temperature behavior and relate it to the ice thickness. Of course it is not possible determine the specific ice thickness only by the images, but is possible to relate to the more general ice cover types.

With this preliminary data in hand, is possible provide data for a further study that can use the ASTER images to determine the presence of thin or thick ice in order to determine the rate of melting and thinning, which could be used for monitoring the ice cap on Antarctica, specially on its coastal areas. Such monitoring can be used to provide guidelines for specific studies in areas where the ice cap suffered more extensive thinning, helping measure the rate of ice melting.

It was also studied the thermal behavior of the Erebus volcano at Ross island. This volcano is unique for being the southernmost active volcano and also the most active on the Antarctic continent (Rowe et al. 2000). The contrast between the crater and surrounding cone temperatures were subject of preliminary study in this paper. Possible differences between land and ice/sea were also studied for determining thermal patterns.

Materials and Methods

Study area

The studied geographical area was the Ross Island (part of Ross dependency, claimed by New Zealand) and immediate vicinity (Figure 1), which included part of the Ross Ice Shelf and MacMurdo Ice Shelf at the south. It represents a roughly rectangular are limited by the coordinates 166-169°E / 77-78°S. The ASTER images covered the SW quadrant of the island, NW quadrant and NE quadrant.

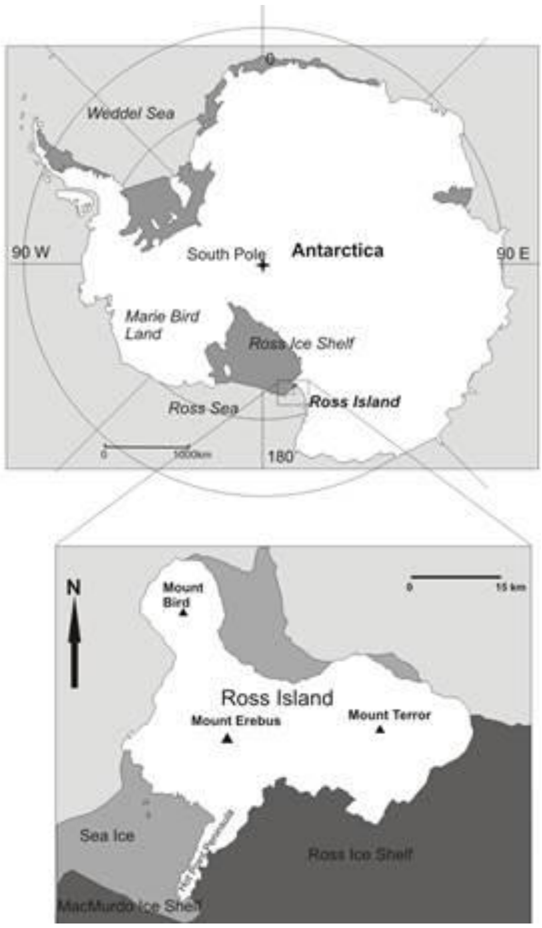

Figure 1 – Location map of Ross Island and Ross Island Map

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Ross Island is almost entirely covered with ice, but rock outcrops showed that geologically the island is composed mainly by alkaline volcanic rocks like phonolites, basanites and trachytes. Erebus mountain is a volcano that presents a lava lake active since the 70´s (Harris et al., 1999, Rowe et al. 2000) composed of anorthoclase phonolite magma with Strombolian-type eruptions that launches considerable quantity of ashes and other gases (specially with Cl and S).

For this work was used a number of images obtained by the ASTER sensor between 2000 and 2003. ASTER is a Japanese-built sensor set in orbit in December 12th, 1999, aboard the satellite EOS (Earth Observing Satellite) AM-1 Terra, a joint venture between USA and Japan. Its orbit is about 750 km altitude, sun synchronous, 98º inclined and 98,88 minutes of orbital period. It crosses the equator everyday at 10:30 AM GMT and every 16 days the orbit pattern repeats again (each 233 orbits). This data was obtained at NASA's Earth Observing System Data Gateway.

ASTER sensor is composed of three subsystems, each one working in a specific region of the specter: near infrared (VNIR, 0.5 – 0.9 µm), shortwave infrared (SWIR, 1.6-2.5 µm) and thermal infrared (TIR, 8-12 µm), totalizing 14 bands and a spatial resolution of 15, 30 and 90 meters, respectively.

The pictures were in a total of 11 (eleven). All were obtained between 2000 and 2003 through the thermal infrared system (TIR) which is composed by 5 bands and have a special resolution of 90 meters per pixel. These data presents 12 bits of radiometric resolution. The dates when they were obtained are October 23rd, 2000 (two pictures); November 8th, 2000; December 26th, 2000; January 27th, 2001; October 20th, 2001; October 29th, 2001; December 7th, 2001; February 15th, 2002; February 3rd, 2003 and December 3rd, 2003. It was used ASTER On-Demand 08 - AST08 - Surface Temperature Product. The lowest values were registered of radiometric temperature was -42° C in spring (October); the highest, 27.8° C in summer (January) in the center of crater of Mt. Erebus summit; the mean was -9.3 ° C, with a standard deviation of 13.2° C.

The ASTER On-Demand Surface Temperature is an on-demand product generated using the 5 thermal infrared (TIR) bands (acquired either during the day or night time) between 8 and 12 µm spectral range. It contains surface temperatures at 90 m spatial resolution for the land areas only. Surface Kinetic Temperature provides a vital input to studies of volcanism, thermal inertia, surface energy, and high-resolution mapping of fires.

The ASTER on demand 08 used an algorithm to atmospheric correction and to convert the TIR images on temperature images that were used in this work. It was convert the 16 bits date to Kelvin degree and finally convert to Celsius degree. Profiles were done in order to get the different patterns on sea, ice and land, looking for recognizes the ice shelf, ice sea and the open sea. In land profiles were done in order to get the "hot spots" on Ross Mtn. volcano. The software ENVI TM 4.1 version was used for visualizes the images and get the temperature profiles presented in this work. The profiles obtained (per image) are indicated on Table 1.

Table 1 – List of the profiles obtained per image.

Image (date)	Profile number:	Area	Profile
October 23th, 2000	1	NE Ross Island	Sea
October 23th, 2000	2	SW Ross Island	Sea / ice shelf
October 23th, 2000	3	SW Ross Island	Island (Mt. Erebus) / ice shelf
November 8th, 2000	4	SW Ross Island	Sea / ice shelf
November 8th, 2000	5	SW Ross Island	Island (Mt. Erebus) / ice shelf
December, 26th, 2000	6	NE Ross Island	Sea
December, 26th, 2000	7	NE Ross Island	Sea / Island
January 27th, 2001	8	SW Ross Island	Sea / Ice Shelf
January 27th, 2001	9	SW Ross Island	Island (Mt. Erebus) / ice shelf

October 20th, 2001	10	NW Ross Island	Sea
October 20th, 2001	11	NW Ross Island	Sea / Island / Sea
October 20th, 2001	12	NW Ross Island	Island (Mt. Erebus) / ice shelf
October 20th, 2001	13	NW Ross Island	Sea / ice shelf
October 29th, 2001	14	SW Ross Island	Sea / Ice shelf
December 7th, 2001	15	NW Ross Island	Sea
December 7th, 2001	16	NW Ross Island	Sea
February 15th, 2002	17	NE Ross Island	Sea
February 15th, 2002	18	NE Ross Island	Sea
February 30th, 2003	19	SW Ross island	Island (Mt. Erebus) / ice shelf

Results

The ASTER images and the respective temperature profiles are presented on Figures 2 and 3. It was observed that images taken in October (spring in southern hemisphere; years 2000, 2001) in the NE area of Ross island (include profiles 1 and 6) that temperature varied in average -23° C in the warmest areas to -41° C in the coldest areas, while ice shelf / sea profiles in SW Ross Island (profile 2) indicated temperature variations of about -42° C to -22° C. Profiles on the NW quadrant (profiles 10 and 13) showed variations between -37° and -22° C.

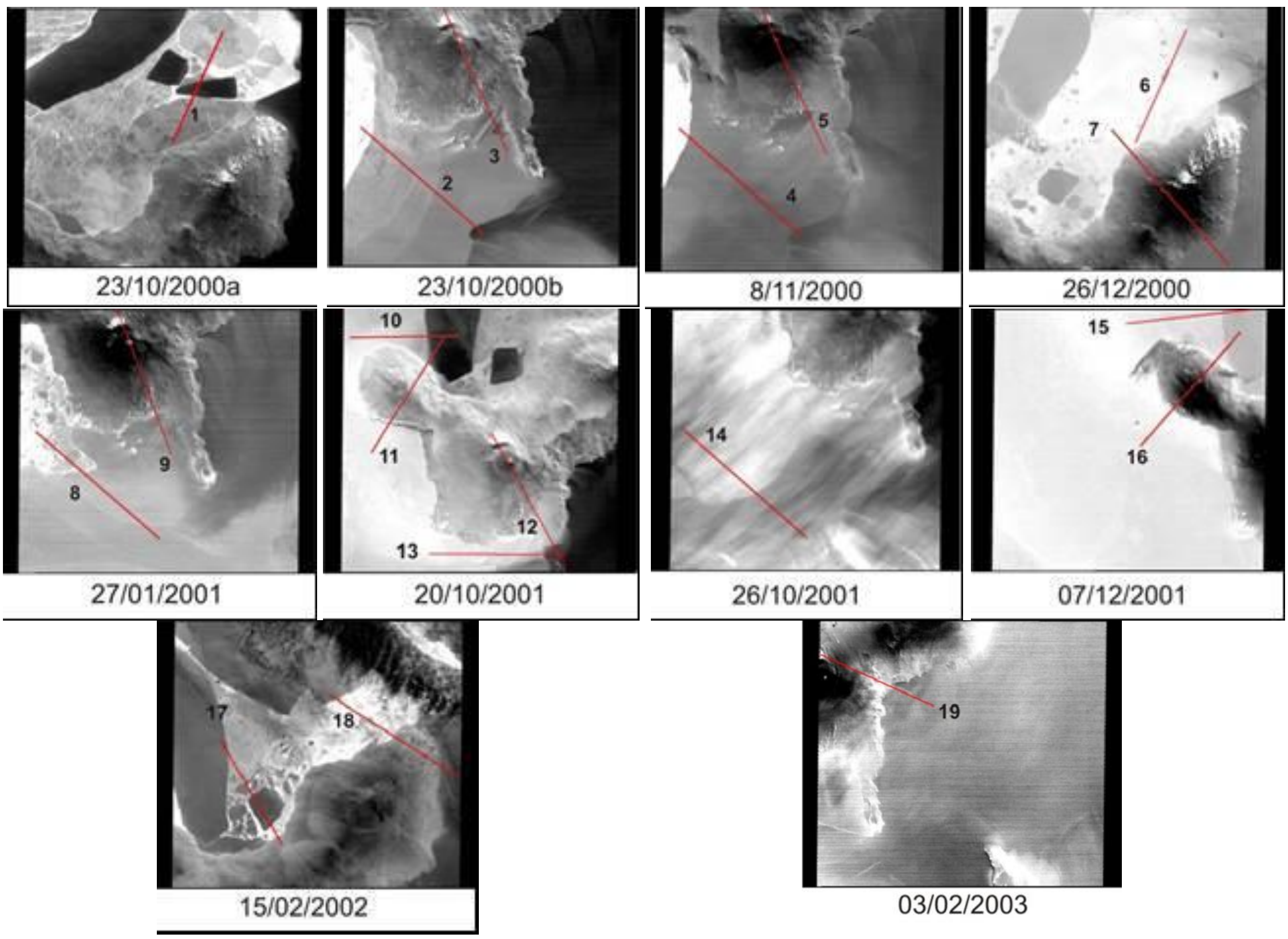


Figure 2 – ASTER TIR images. The lines indicate the profiles.

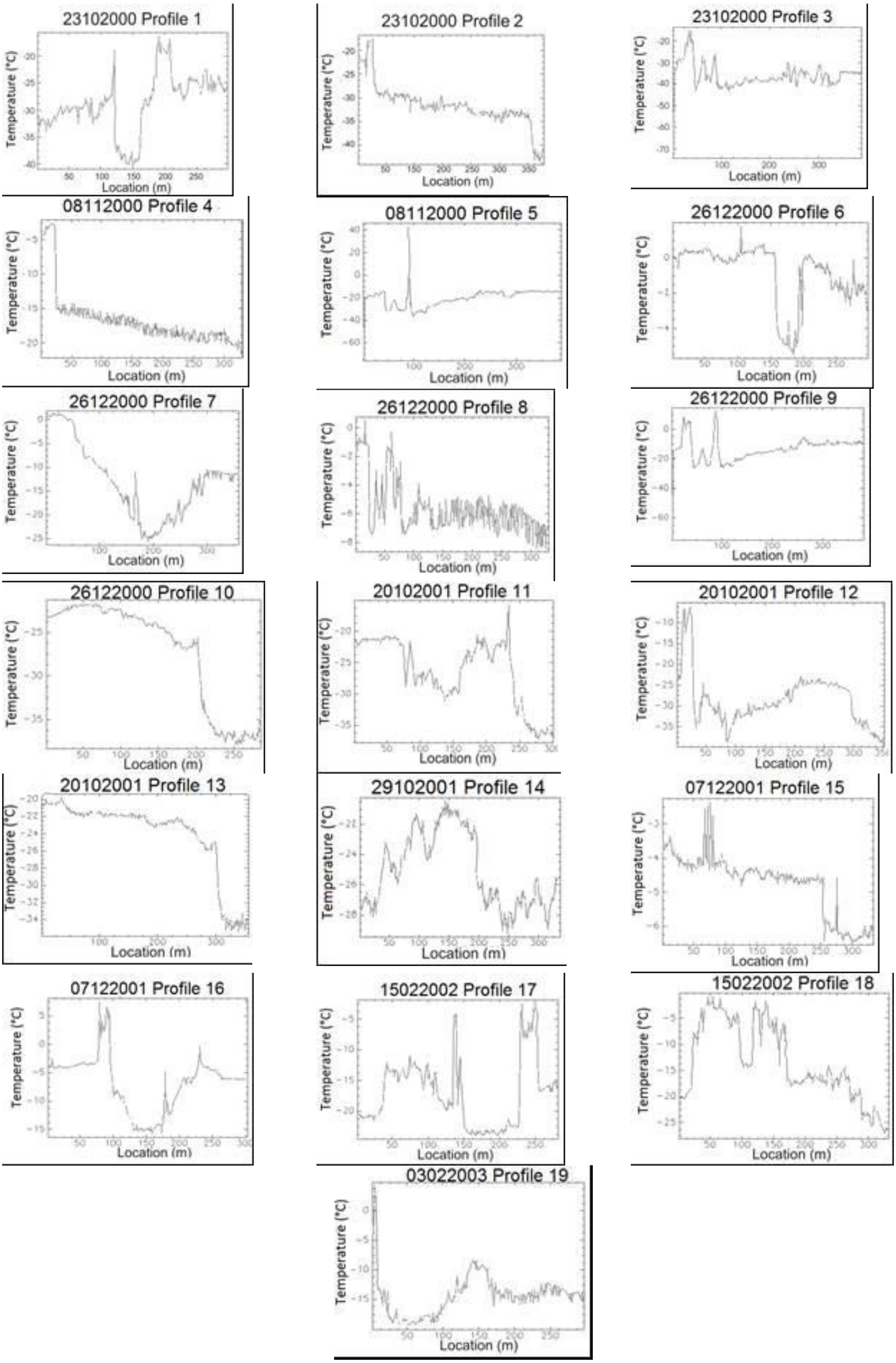


Figure 3 – Temperature profiles obtained with ASTER TIR images.

It was observed that images taken in October (spring in southern hemisphere; years 2000, 2001) in the NE area of Ross island (include profiles 1 and 6) that temperature varied in average -23° C in the warmest areas to -41° C in the coldest areas, while ice shelf / sea profiles in SW Ross Island (profile 2) indicated temperature variations of about -42° C to -22° C. Profiles on the NW quadrant (profiles 10 and 13) showed variations between -37° and -22° C.

In November there is only one image, for the SW area of Ross Island (and profiles 4 and 5) obtained at 2000. The profile 4 runs from the open sea to the ice shelf and the temperature variation was between -5°/-2° C (open sea) to -20°/-15° C (ice shelf). Profile 5 ran from the island, near the summit of Mount Erebus (-14° C), to the low temperatures on the shadowed hillsides (-30° C), and -15°/-13° C on the ice shelf.

Images obtained in December, just before on right the beginning of the summer, covered the NE area (2000; profiles 6 and 7) and NW area (2001; profiles 15 and 16). The Profile 6 showed a small temperature variation in open sea (-2° to 0° C) with lower temperatures in what appears to be an iceberg (-5°/-4° C), while the profile 7 that transected the Ross island, from the open sea to the north to the ice shelf on the south, showed a temperature variation between 0° C (open sea), down to -24° / -3° C on land, and kept stabilized on -11° C on the ice shelf.

Images taken on January (2001, profiles 8 and 9) corresponds to the summer in southern hemisphere, and covers the SW area. Profile 8, which goes from the open sea to the ice shelf showed temperature variation between -1° C (open sea) to -8°/-5° C (ice shelf). The profile 9, which covers part of the island (including mount Erebus) to the ice shelf, showed the slightly lower temperatures on the ice shelf (-10°/-8° C) up to +3°/+8° C on the bright and warm areas on the Mt. Erebus summit, corresponding to the crater.

There are two images obtained on February (2002 and 2003), corresponding on the profiles 17 / 18 (NE area) and 19 (SW area). The profiles 17 and 18 indicated a temperature variation ranging from -6° C on the coldest areas, -4°/-3° C on areas with intermediate temperatures and +1°/+7° C to the warmest areas. The land showed temperature variations between -15° to -5° C. The profile 19, which covers from the Mt. Erebus summit to the ice shelf indicated temperatures -1°/+4° C on the summit (possibly on the crater), and on the land temperatures between -15° to -8° C and -13° C on the ice shelf.

Two main surface patterns can be readily identified, mainly due to the texture, as well by map location, that are the Ross Island itself, as well the ice shelf, an ice cover with up to 200 meters thickness (Giovinetto and Zumberge, 1967).

It must be noted that in the profiles which covers sea or ice shelf (profiles 1, 2, 4, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17 and 18) there are sharp temperature contacts between the several surfaces patterns observed on the image. This can be observed on the Figure 4a and 4b. Can be identified the ice shelf (the thickest ice cover on the sea) in general the colder patterns (and so the darker, see Figure 4b), while non-ice shelf surface (sea) can be observed irregular or polygonal blocks or well defined areas. It is observed that those blocks presents a defined surface temperature, being the darkest (in the image), or the coldest, have a similar temperature behavior of the ice shelf, while the free area among the blocks is in general brighter (it means warmer, see Figure 4a). Between the coldest and the warmest surface patterns there are blocks with an "intermediate" temperature, represented by gray colors (Figure 4a).

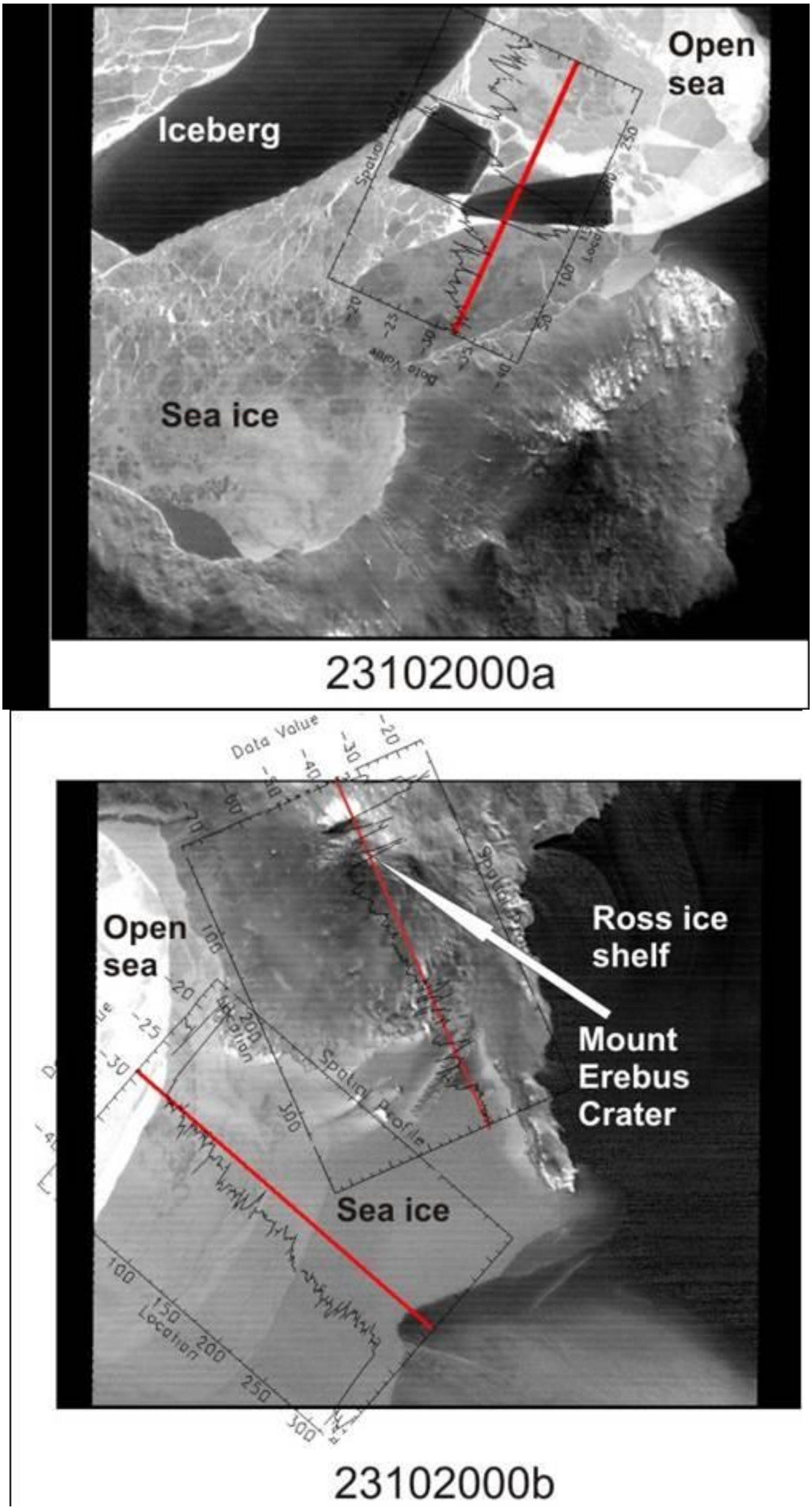
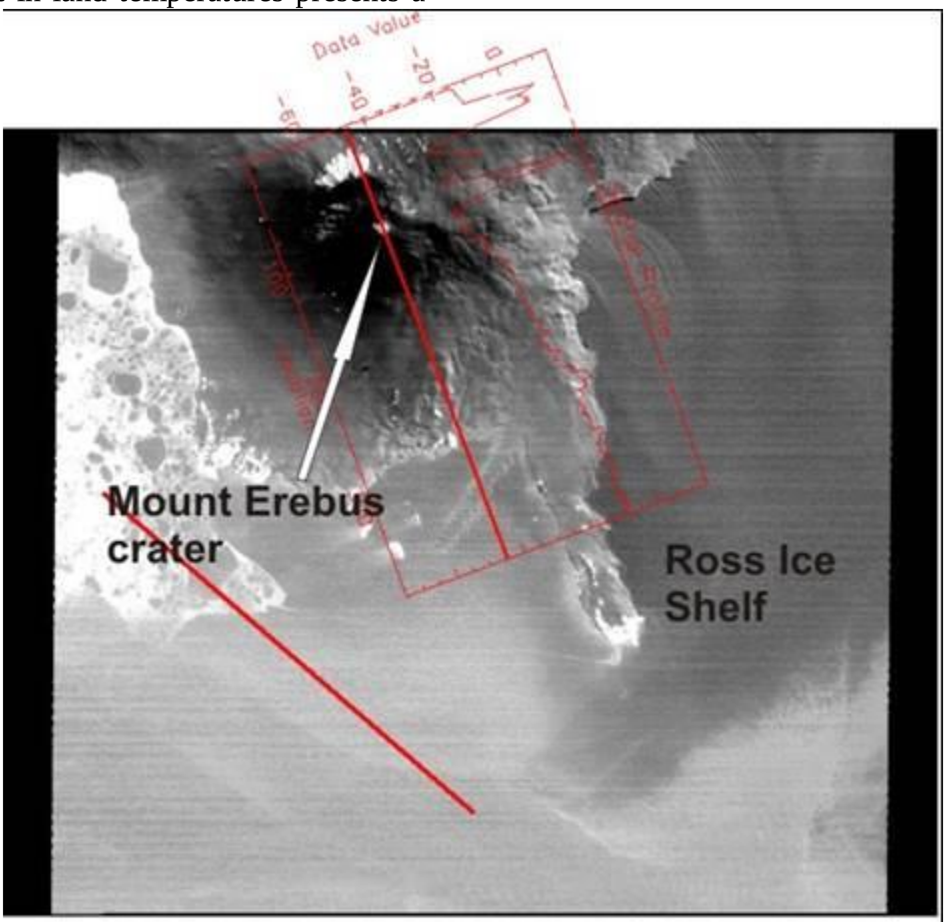


Figure 4a and 4b – Temperature profiles overprinted on ASTER TIR images.

This behavior of the dark, intermediate gray and bright areas, with sharp physical and thermal behavior limits can be observed on the image of October 23th 2000, profile 1 (also Figures 4a and 4b). It must be noted that in some images of the ice shelf on the SW part that presents a smooth, but perceptible, temperature variation from the coldest (southernmost) to the warmest (on the limits of the ice shelf) characterized as a sequence of parallel large strips of progressively different temperature.

The Ross Island land has a rugged relief that allow the presence of shadowing, in contrast with the smoothness of the sea and ice shelf, which can be observed not only as the darkest areas on the land, but also as the coldest (Figure 4b, 4c and 4d). It was observed that in land temperatures presents a more irregular variation than in sea or in the ice shelf, as can be observed on the temperature profiles, and often the land has lower temperatures than in some sea areas, with some isolated brilliant points. However, in the summit of Mt Erebus there is a brilliant area that is related to the crater and lava lake, as observed on the Figure 4b and 4c (Oppenheimer 1998, Rowe et al 2000). In the slopes of the mountain, near to the summit, can be seen irregular, with sharp limits, bright areas. Some are elongated, and positioned in an apparent radial pattern from the mountaintop, with a larger area on the northern slope. All those brilliant areas or spots can be related sunlit areas or thermal activity; this will be discussed in the next topic.



27/01/2001c

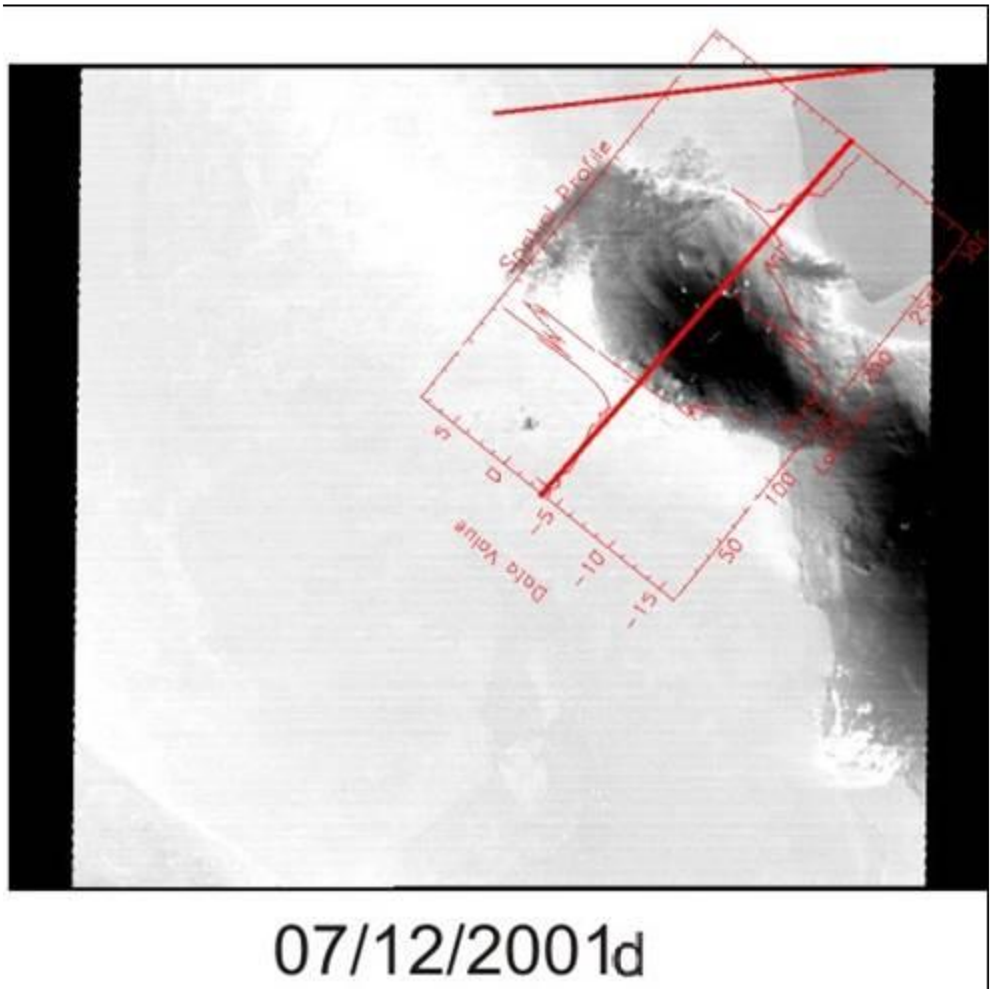


Figure 4c and 4d – Temperature profiles overprinted on ASTER TIR images.

Two images were taken with presence of overall cloud cover, being one left unusable, while in other the surface patterns where recognizable and presented distinctive temperature behavior. However, the clouds left a more irregular temperature profile, where the contacts are less sharpened (see profile 19 and image 30/02/2003).

Discussion

The discussion will be split between the temperatures versus time variation as well the identification of the surface patterns.

Before the time versus temperature variation discussion, it must be stated that is clear that there will be temperatures differences between the many targets on the ground. However, for the considered study, it was observed the temperature differences in the same targets in the same area or targets on the sea. A reason for such is that targets on the sea show low relief, or are actually plain, composed by sea, frozen sea or icebergs, with little or absent shadowing that can produce low temperature areas.

The best examples available are the sea/ice shelf or sea profiles on the SW and NE regions (profiles 1, 2, 4, 6, 8, 14). Profiles obtained on October (mid-spring in Southern hemisphere) indicate temperatures differences of up to 20° C between the coldest areas, which included the ice shelf, and the warmest areas, related to open sea. November profiles suggested also differences of about 15° C.

Must be noted, however, that the profile 19 was partially covered by clouds that reduced the temperature differences for about 2° C. But, as can be observed on the respective profile, that even with the presence of clouds, the temperature differences are still evident. For all the purposes the clouds interfere with the thermal IR radiation reducing the differences between the warmest and coldest areas.

The profiles obtained for January (summer) however, indicated temperature differences of less than 10° C between the ice shelf and the warmest (open sea) areas. Profile 15 (NW area) obtained on December (late spring / early summer) also revealed low temperature differences between the coldest areas (possibly icebergs) which presents similar temperatures to the ice shelf and the open sea (the warmest areas). The profiles 17 and 18 (for February, mid-summer) showed on the sea surface patterns temperature differences of about 16° C.

The temperature differences between the coldest and warmest areas showed up to the largest values in the months immediately before and after the beginning of the summer on the southern hemisphere. October, November and February profile temperatures showed the higher differences than in December and January. The higher temperatures on the early summer also reflected in the surface ice temperatures, warmed up by the warm season, but also the increased incident radiation on a highly reflective surface have translated in higher thermal IR registers, which compounded the smaller thermal differences for this time. The higher differences of temperature in late spring are also related to the fact that liquid water has a great thermal capacity, holding considerable energy and keeping in higher temperatures than the ice (Ayoade, 2004). By the summer, especially in the period of higher temperatures (early summer) solid surface material can absorb easily the increased solar radiation and show up higher temperatures.

It can also point out to warmer atmosphere temperatures, warmed both by the increased incident and ice-reflected solar radiation, which can add to the surface temperatures. It means that temperature analysis by satellite sensors must take in account the season to avoid possible abnormal high-temperature lectures that could be interpreted as an effect of the global warming.

The region covered by the images can be said that is composed by snow- or ice-covered land (Ross Island), with occasional strips of snow / ice-uncovered land, the ice shelf (called Ross Ice Shelf), icebergs, open sea and thinner sea ice. On the Ross Island itself there are two mountains, one of them is an active volcano (Mount Erebus), with a lava lake on its crater.

The open sea areas show up the highest temperatures (except the Mt. Erebus crater), and during the summer temperatures can be over 0° C. In some cases they appear as bright areas, almost grading for medium-gray areas, that suggest be ice-covered sea (an ice cover with few meters thick; Zwally et al. 2002, Tin et al. 2003). Those ice-covered sea patches have sometimes a “mottled” texture, indicating subtle temperature variations.

They also do not have the smoothness and well-defined shape and limits of large tracts that can be identified as icebergs, which can be compared with satellite images showing icebergs from other works (e.g. McAyeal et al. 2001 for submission). Those icebergs also have a temperature behavior similar to the thick ice shelf. It suggests that the considerable thickness of icebergs mean lower surface temperatures in a similar fashion of the ice shelves, thus suggesting a thickness / surface temperature relationship. Higher temperatures from the open waters, followed by the lower temperatures of the ice sea, and then the lowest temperatures for the icebergs. The mottled texture pattern of the ice sea can be related to different thickness due to surface irregularities (possibly due to snowfall or deformation due to tide or wave movement) that can appear.

Is important highlight that the temperature profiles indicate a sharp contact among those patterns (ice, sea ice and iceberg / ice shelf; see Figures 4a and 4b) that suggests also considerable differences of thickness, if taken in account the relationship temperature / thickness.

The Ross ice shelf has, as stated before, lower surface temperature and has also a smoother texture, even though must be observed that on its surfaces there are, for example, the ice flows coming from Ross Island (for example, see 20/10/2001 image on figure 2). In this image the darkest areas limited to the west by Hot Point Peninsula (SW Ross Island, where is located Scott Base and MacMurdo Station) may suggest thickest areas, while the middle gray areas suggest a thinner ice coverage, thicker than the ice sea, but in the 08/11/2000 image there is a more homogeneous color (temperature) pattern. It may be due to a homogeneous surface heating, indicating that snow coverage or surface ice heating affect surface temperatures. But there is still a slightly dark area limited by the peninsula that is visible.

The Ross Island showed to have a more irregular temperature pattern as result of the relief effect and the shadowing. In general presents lower temperature on the lit areas than in the open sea areas, but sometimes is warmer than the ice shelf areas. However, areas of warmer surface temperatures can be seen on the sunlit slopes of the hills and mountains (for example, as seen on Figure 4d, image 07/12/2001) that possibly are related to rock exposed outcrops warmed by the sunlight. Possible exceptions are the bright areas on the northern slopes of the Mt. Erebus as near to the top (see pictures 23/10/2000b, 08/11/2000, 27/01/2001, 20/10/2001, Figures 4b and 4c). The small and bright area in the top is obviously related to the volcanic activity, and resembles Landsat TM images from Harris et al. (1999) temperatures obtained where above 0° C, but not too warm as could be first imagined. Probably this is related to period of quiescent activity as well the fast freezing of any magma that reaches the surface. However, it keeps warm enough to be quite contrasting with the surrounding hills. No sign of smoke emission or any lava emission through the mountains hills were detected.

The bright areas on the slopes near to the mountaintop could be also related to areas warmed by the sun when the images were taken, as quoted for the Figure 4d, but this is not applied for the case in study. They appear as well defined areas, with sharp limits, and they are alongside the northern and western slopes, near to shaded areas, and do not change positions even in different images taken in different time periods. Due to the characteristics described, it is more possible that they are related to underground warming due to volcanic activity (as they are nearby the crater) and fumaroles activity as well, as Harris et al. (1999) suggested; they also pointed out for series of fumaroles oriented in radial patterns from the crater.

Conclusion

The concluding remarks of the study done on the ASTER images show that the surface temperature patterns are related to different ice thickness of the different targets. Icebergs and the ice shelf are the thickest ice targets (several tenths of ice) and showed up lower temperatures. The sea ice (few meters to less than one meter) has intermediate temperature patters while the open sea has the highest surface temperatures. The differences are well defined and can be sharply observed on temperature profiles.

Differences on the surface gray scale indicate differences on thickness, higher or lesser degrees if smoothness or differences of the surface materials (ice, snow or water). The overall differences on temperature appear to be smaller on the peak of summer (December-January) while are larger during the end of spring or late summer (October/November and February). This variation does not affect the overall thermal differences of the surface targets. Cloud coverage affects the thermal register, reducing the temperature contrast.

Land targets (on Ross Island) are less regular thermal surface behavior than the sea targets, being this variation related to relief patterns. However, Mt. Erebus summit, with its crater and still active volcanism, presented to be a warm surface target.

Considering the importance of the study on the ice thickness of the ice shelf on the monitoring of the possible effects of the global warming, the monitoring of the Antarctica (as well other polar regions) ice cover using the surface temperatures is a possibility that deserves more detailed studies in the future. Besides it, the control and study of the development of sea ice, especially its thickness and covered area, are of interest in the study of the biological en physical environment (Jeffries and Adolphs 1997), as it has important consequences in the phytoplankton growth, as well on the ocean-atmosphere interaction.

The study of the volcanic behavior of the Mt. Erebus is also another good possibility using the TI ASTER images, defining warmed areas that can be related to vents or fumaroles, and even the differences can be monitored to preview possible activity as eruptions.

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