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Seasonal and Diurnal Variation of Upper Soil Resistivity in the Cerro Chascón Science Preserve

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Abstract

We monitored seasonal and diurnal variation of upper soil resistivity in the Cerro Chascón Science Preserve in the Wenner method with a fixed electrode spacing of 2 m. The resistivity shows a factor ~ 3 seasonal variation with the lowest values during austral summer. The resistivity in summer is $\sim 300\ \Omega$ m in the Pampa La Bola area while it is $\sim 1000\ \Omega$ m in the Llano de Chajnantor area. Throughout the year, the resistivity at Pampa La Bola is systematically a factor ~ 3 lower than at Llano de Chajnantor. This means that worked area needed to realize a certain ground resistance will be a factor ~ 10 smaller at Pampa La Bola than at Llano de Chajnantor. Although diurnal variation also exists with the lowest values near the sunsets, the peak-to-peak variation is less than 3% of the mean value of the day.

1 Introduction

Soil resistivity is not only a useful measurable that reflects subsurface structure but also a basic parameter to the design of effective grounding and lightning prevention/protection system. In our previous work on the resistivity sounding of eight locations in the Cerro Chascón science preserve area, we obtained thickness of the upper layer at each location consistent with that of the weathered layer measured with a borehole [1]. This result was important in that it demonstrated the feasibility of sounding the thickness of the weathered layer in more convenient and inexpensive way than excavation. Through our subsequent resistivity measurements at twenty-one locations during austral winter, we also noted that the resistivity of the upper layer significantly varied from a point to another, probably reflecting difference in water content in the upper soil layer due to local topography and drainage [2]. What is missing now is how the resistivity varies as functions of the day of year and the time of day. In particular, the upper soil resistivity during austral summer when lightning hazard is concerned is important for the design of lightning prevention/protection system. In this work we present results of monitoring of upper soil resistivity at eight locations in the Cerro Chascón science preserve area.

2 Measurements and Analysis

The measurements were conducted during selected periods from 2000 June 25 to 2001 May 5 with Yokogawa Type 3244 earth resistivity tester. Methodology of the measurements is the same to our previous report on resistivity mapping [2]. The electrode spacing was set to be 2 m so that the measured apparent soil resistivity represents that of the weathered layer near the surface (down to a few meters), which is crucial to the practical design of effective grounding and lightning prevention/protection system.

Monitored points included all six locations examined with our previous excavation [3] and also one at Pampa La Bola near the NRO containers and another at Llano de Chajnantor near the NRAO/ESO containers. Except for the resistivity monitoring campaign held at Pampa La Bola near the NRO containers during 2001 March 4–14 and April 29–May 5, the measured points were not exactly the same. The results will, however, provide us with basic ideas on seasonal variation of the soil resistivity.

3 Results and Discussion

3.1 Diurnal Variation of Upper Soil Resistivity

Summarized in Figure 1 is a diurnal variation of apparent soil resistivity, which primarily reflects resistivity of the upper weathered layer, measured near the NRO containers at Pampa La Bola during 2001 March 4–14 with a fixed electrode spacing of 2 m. During the March run, we observed a small but significant diurnal variation of the soil resistivity, though the diurnal variation was negligibly small in the succeeding April–May run. Peak-to-peak variation of the soil resistivity in a day was 10 Ω m and was equivalent to only 3% of the mean value of the day. The value decreases during daytime (UT = 13–21h. Note that the local solar time is UT − 4h31m) and increases during nighttime. Daytime decrease was steeper than nighttime increase.

Of several parameters that control soil resistivity — e.g., porosity, permeability, and mineralization of soils, and fraction, ionic content, and temperature of pore fluids — only water content and temperature of soils may vary in measurable timescales. One might wonder if this trend reflects precipitation that preferably occurs in the afternoons during summer. However, the 24 hours' cycle was observed also on clear days and is unlikely due to the precipitation. Minor precipitation events observed during the measurements had apparently negligible contribution to the short timescale variation. On the other hand, good anti-correlation is found between the slope of the time curve of upper soil temperature and that of upper soil resistivity as illustrated in Figure 1. We thus conclude that diurnal variation of upper soil resistivity is chiefly attributed to the variation of upper soil temperature, rather than precipitation. Because the diurnal variation in the April–May run was found to be very small, we may conclude that the soil should be wet enough to have significant ($\sim 3\%$) amount of diurnal variation.

We synthesized in Figure 2 a time profile of the upper soil resistivity, normalized to an assumed mean value of each day. Through comparison of this time profile with that of soil temperature, we conclude that temperature variation of surface layers (< 20 cm) contribute largely to the diurnal variation of the soil resistivity.

Besides this diurnal variation, we also note that there exists longer timescale (several days) variation, or shifts of mean resistivity value of each day. The mean value was about 365 Ω m on March 4–6 when severe storms were observed, recovered to about 372 Ω m during March 7–13, and dropped again down to about 365 Ω m on March 14 when severe storms were observed. Although this longer timescale variation seems to correlate the amount of precipitation of the day, we do not have appropriate data to confirm this argument yet.

3.2 Seasonal Variation of Upper Soil Resistivity

Because we measured eight common locations in 2000 June–July, 2000 September, 2001 March, and 2001 May, we may evaluate seasonal variation of the upper soil resistivity. Although the measurements were not simultaneous, the errors introduced by this effect will be less than 3% as we saw in the previous subsection. Summarized in Figure 3 and Table 1 is a comparison of the values measured in these four different periods. The values in June–July were estimated via interpolation of our previous sounding data taken with various electrode spacings and were rounded by 10 Ω m. The location IDs correspond to those in our previous report [2]. The resistivity in austral summer was ∼ 300 Ω m at three locations (ID 01, 03, 04) in the Pampa La Bola area, while it was ∼ 1000 Ω m at the three locations (ID 19, 20, 21) in the Llano de Chajnantor area.

The resistivity had a factor ∼ 3 seasonal variation with the lowest values during austral summer. Controlling factor of this seasonal variation still remains unresolved. One possibility is a seasonal variation of precipitation with a peak in summer. Because the resistivity of normal soil is a sensitive function of the water content — 220 Ω m, 130 Ω m, and 90 Ω m with the water content of 10%, 16%, and 20%, respectively [5] — moderate change of the water content at very low level may account for the seasonal variation of the soil resistivity. The other possibility is a seasonal variation of soil temperature. Unlike diurnal variation of the soil temperature that can reach ∼ 40°C (peak-to-peak) at the surface but is suppressed to ∼ 0.1°C at the depth of 100 cm, seasonal variation of subsurface temperature is ∼ 10°C virtually irrespective of depth, with the highest value at ∼ 10°C and the lowest value at ∼ −0°C [4]. Therefore very thin uppermost layer contributes to the diurnal variation of the soil resistivity whereas a bulk of the upper layer contributes to the seasonal variation of the soil resistivity. Because normal soil with a 15% water content, for example, will have a specific resistivity of 99 Ω m at +10°C, 130 Ω m at +0°C, 300 Ω m at −0°C, and 790 Ω m at −5°C [5], expected seasonal variation of the resistivity due to the 10°C temperature variation can reach ∼ 3 if the soil at the site has similar characteristics to the normal soil. Both of these mechanisms may contribute to the seasonal variation of the soil resistivity, and laboratory measurements will be needed to resolve this issue.

Throughout the year, the upper soil resistivity at Pampa La Bola was systematically a factor ∼ 3 lower than at Llano de Chajnantor[1]. This means that worked area per antenna pad needed to realize a certain ground resistance will be a factor ∼ 10 smaller at Pampa La Bola than at Llano de Chajnantor.

We thank Tomohiko Sekiguchi and Jin Koda who helped the measurements at high altitude.

References

[1] Sakamoto, S., Ezawa, H., Takahashi, T., & Yamaguchi, N. 2000, "Vertical Profile of Soil Resistivity at Pampa La Bola and Llano de Chajnantor Locations," LMSA Memo 2000-010 (also ALMA Memo 326)

[2] Sakamoto, S., & Sekiguchi, T. 2001, "Spatial Distribution of Near-Surface Soil Resistivity in the Cerro Chascón Science Preserve," ALMA Memo 346

[3] NRO-NRAO 2000, "Geotechnical Study, Chajnantor Site, II Region," LMSA Memo 2000-004

[4] Sakamoto, S. 2001, "Thermal Properties of Subsurface Layer at Pampa La Bola," ALMA Memo, in preparation

[1] Exception is the borehole site #1 (ID 02) where the values comparable to those at Llano de Chajnantor were recorded. Because this site was selected as an area whose slope is locally near 0° midst the mildly-tilted pampa, this location corresponds to the top of a small hill. It is thus naturally explained that this location shows exceptionally high resistivity value in the Pampa La Bola area because of locally efficient water drainage. Exceptionally high soil resistivity at the borehole site #1 will not introduce much difficulties in locating the array in the Pampa La Bola area since there are many other locations in the Pampa La Bola area that meet the criteria of local slope and roughness at very satisfactory level [6].

[5] Takahashi, T. 1986, "Setchi-Gijutsu-Nyūmon (Grounding Technique Primer)," (Ohmsha) [Text in Japanese]

[6] Butler, B., Radford, S. J. E., & Otarola, A. 2000, "The Best Sites for the Compact ALMA Configuration," ALMA Memo 338

Table 1: Seasonal Variation of Upper Soil Resistivity

ID	Resistivity (Ω m)				Description
	2000 June–July	2000 September	2001 March	2001 May	
01	830	811	396	470	Borehole site #6 (Chascón E.).
02	...	2036	943	1131	Borehole site #1 (Pampa La Bola).
03	1200	943	376	439	NRO testing site.
04	740	748	351	402	Borehole site #2 (ASTE).
10	1120	1634	251	1015	Borehole site #5 (Saddle point).
19	> 4100	> 4398	1074	1318	Borehole site #3 (Chajnantor N.).
20	2750	> 4398	999	1697	NRAO/ESO testing site.
21	3380	> 4398	1194	1487	Borehole site #4 (Chajnantor S.).

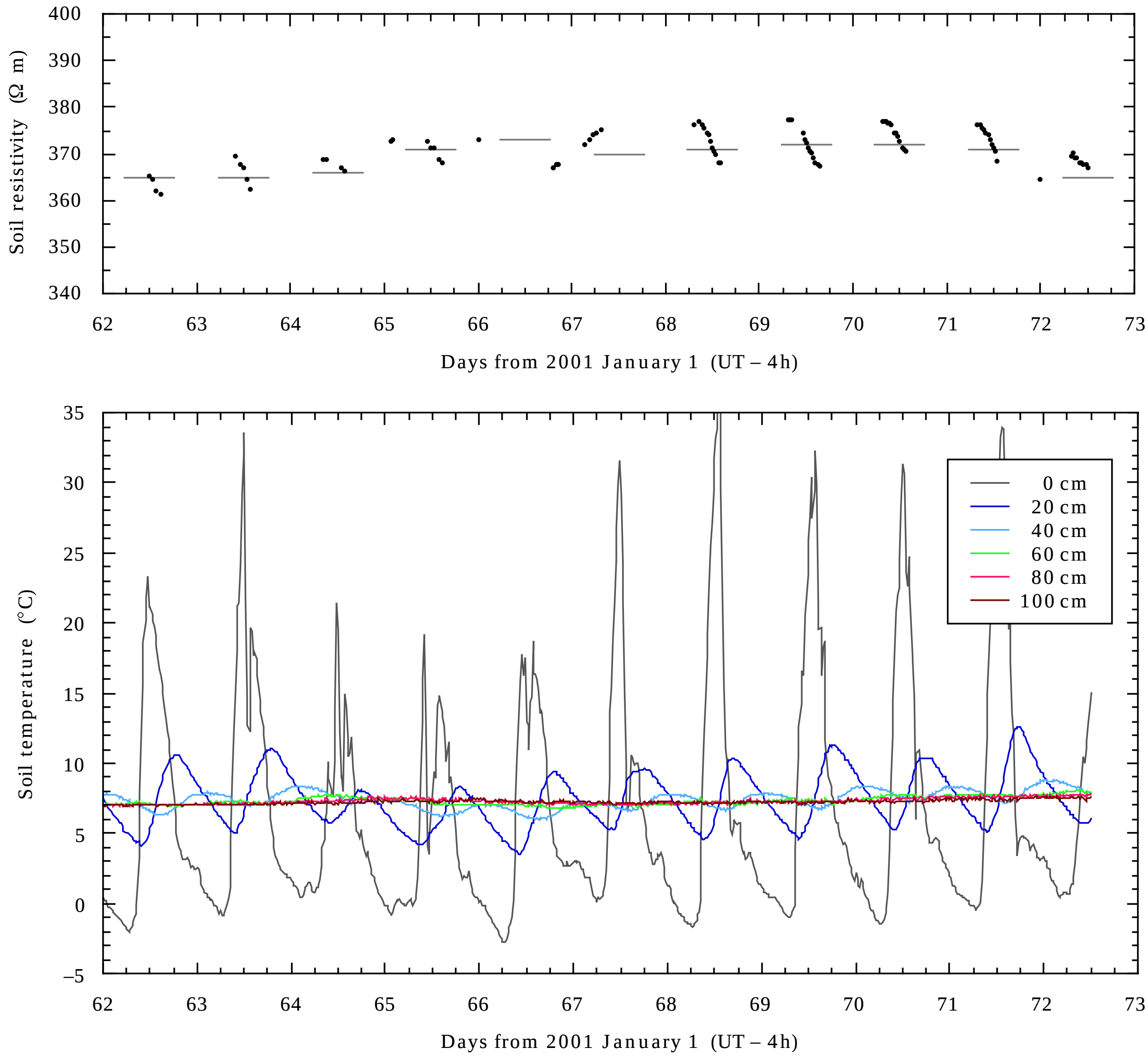

Figure 1: (*Top*) Time variation of apparent soil resistivity measured during 2001 March 4–14 near the NRO containers at Pampa La Bola (ID 03). The electrode spacing of the Wenner method was fixed at 2 m, so that the measured resistivity primarily reflects that near the surface (down to $\sim$ 2 m). Mean values assumed to synthesize the time profile in Figure 2 were also indicated with horizontal bars. (*Bottom*) Time variation of soil temperature at 0, 20, 40, 60, 80, and 100 cm from the surface [4]. Note that specific resistivity of wet soils decreases as temperature increases.

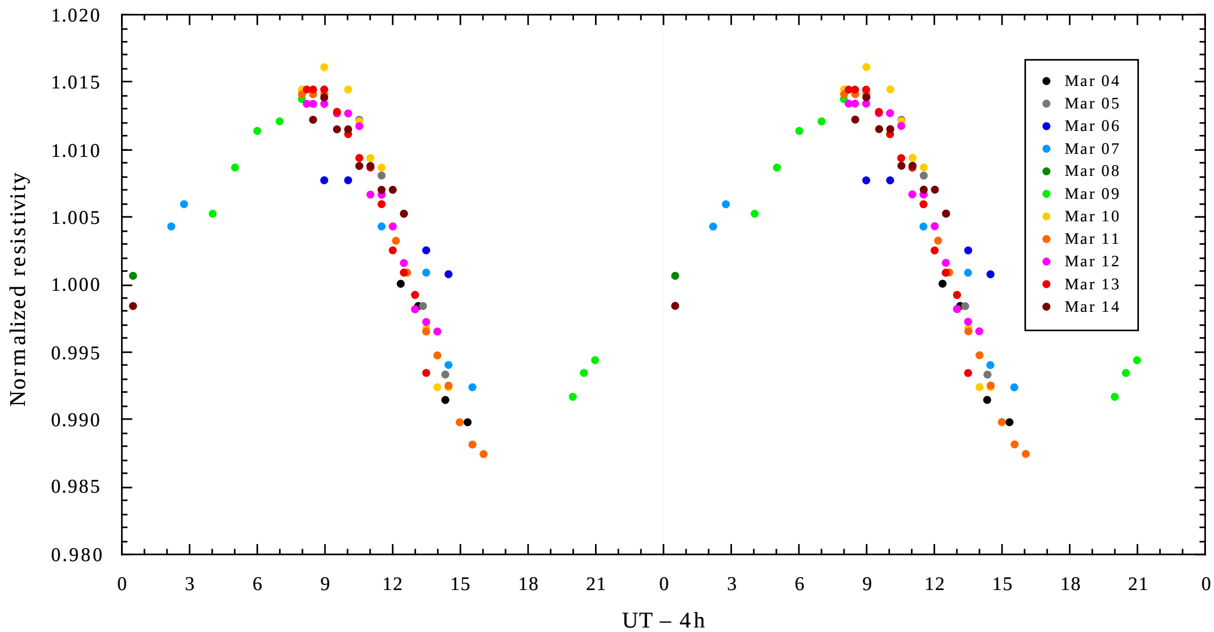

Figure 2: Time profile of apparent soil resistivity measured during 2001 March 4–14 near the NRO containers at Pampa La Bola (ID 03), synthesized after normalization by assumed daily mean values shown in the top panel of Figure 1.

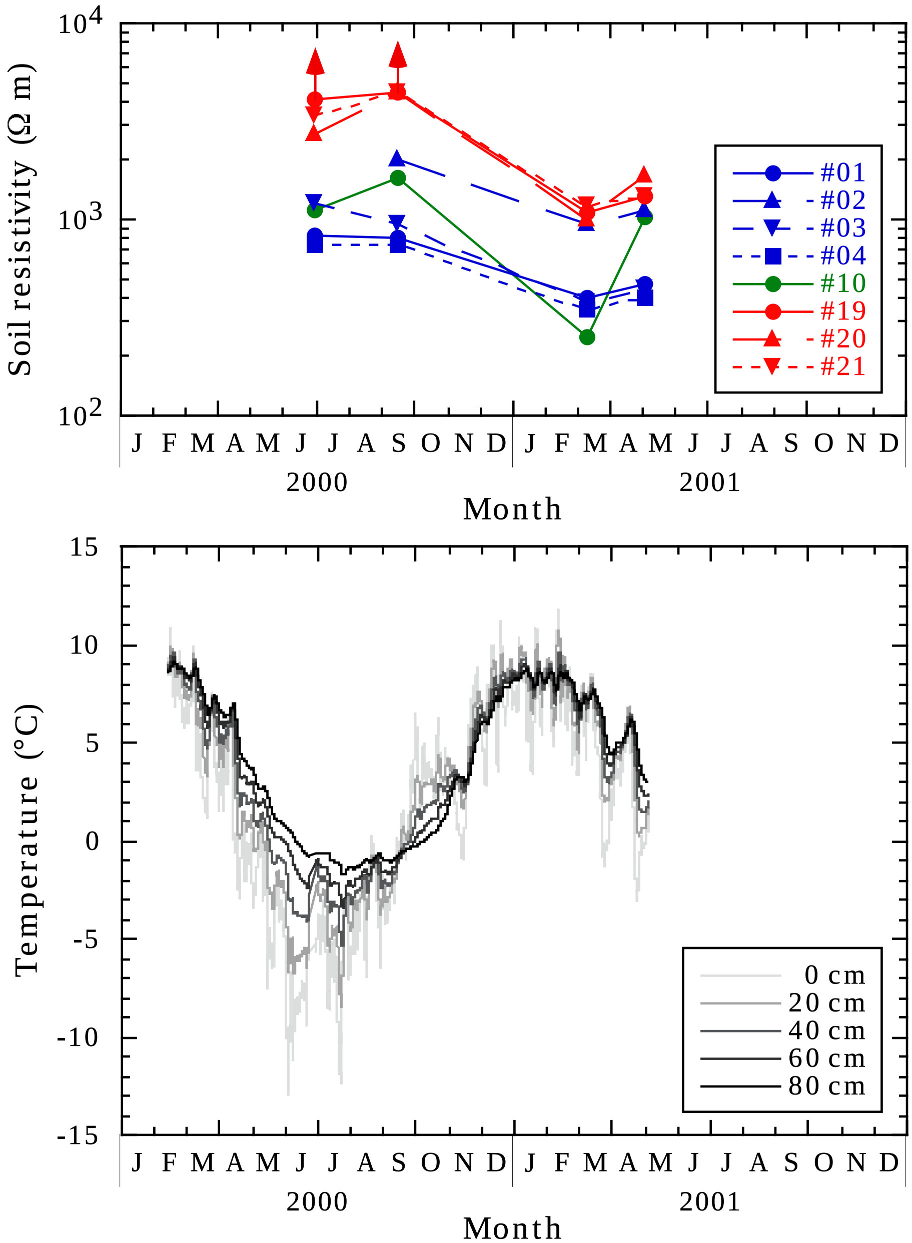

Figure 3: (*Top*) Semi-log plot of seasonal variation of apparent soil resistivity measured at eight locations spreading over the Cerro Chascón science preserve. Lower limits are marked with arrows. The electrode spacing of the Wenner method was fixed at 2 m, so that the measured resistivity primarily reflects that near the surface (down to $\sim$ 2 m). (*Bottom*) Seasonal variation of daily mean soil temperature at 0, 20, 40, 60, and 80 cm from the surface [4]. Note that specific resistivity of wet soils decreases as temperature increases.