Preliminary result of Site Testing in Northern Chile with a Portable 220 GHz Radiometer

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ABSTRACT

A 220 GHz radiometer has been developed at the Nobeyama Radio Observatory to evaluate possible sites for LMSA (Large Millimeter and Submillimeter Array). The radiometer is designed to achieve high sensitivity (receiver noise temperature < 1800 K) to measure the atmospheric opacity and fluctuations of the atmospheric emissions. We started a cooperative site testing activities in northern Chile using this radiometer in July 1994. Atmospheric opacities were measured at five sites for eight days. The zenith opacity at 220 GHz was ranging from 0.03 (at the 4700 m site, it was fine) to 0.5 (at the 4300 m site, it was snowing) during our measurements. The measurement of zenith opacity at Paranal is still being continued together with the monitoring of radio seeing.

1 INTRODUCTION

Atmospheric opacity is the most principal parameter to evaluate astronomical sites. As the aperture synthesis observations at submillimeter wavelengths (including 490GHz, 690GHz and 820GHz bands) are limited by the atmospheric absorption and atmospheric phase fluctuations ("radio seeing"), the LMSA(Ishiguro *et al.*1993, Ishiguro 1994) site should be one of the best sites in the world. The opacity in millimeter and submillimeter wave lengths is dependent on the amount of atmospheric water vapor, so the potential LMSA site will be a very dry site at very high altitude (3500 m $\sim$ 4500 m).

There are two possibilities for the LMSA site, the summit of Mauna Kea in Hawaii for the northern hemisphere and the Atacama desert in northern Chile for the southern hemisphere. The Mauna Kea site has been studied extensively from various points of view (atmospheric opacity(Hogg 1992, Shwab 1994) and radio seeing(Masson 1993)). On the other hand, opacity measurements for northern Chile is very limited (Martin 1990) and the measurements of radio seeing is not available. There is also a plan of Southern Hemisphere Millimeter Array in

European Countries(Booth 1993). Therefore we decided to do site testing in northern Chile under the collaboration of Nobeyama Radio Observatory with SEST/ESO and University of Chile. There exists very arid region where the annual precipitation is less than 10 millimeter, indicating the area is expected to be a very good site for astronomical observatories.

With this report we will present a technical description of the instruments and a preliminary summary of the opacities obtained in northern Chile. The measurement of zenith opacity at Paranal is still being continued and a more complete report will be prepared after collecting the long term data.

2 INSTRUMENT

This radiometer has high sensitivity (receiver noise temperature $T_{RX} < 1800$ K at room temperature) which enables the precise measurements of atmospheric transmission and its fluctuation with high accuracy even in the condition when the opacities is very low (*i.e.*the brightness temperature of atmosphere is very low).

The receiver uses a Schottky diode harmonic mixer (Millitech Model MXH-05-2F) operating at 220 GHz in room temperature. The local oscillator signal is supplied from a 110 GHz Gunn oscillator which is designed at Nobeyama Radio Observatory. The emission from atmosphere is collected with an 83 mm diameter primary mirror and is fed into the mixer through a corrugated feed horn. The primary mirror is strongly tapered (the edge level is -20 dB) and spill over loss is less than 0.05 dB. System properties are summarized in Table 1.

To study spatial structure of atmospheric emission, azimuthal drive is incorporated in addition to the elevation drive of the radiometer (see Figure 1). With the help of this motor drives we can measure atmospheric emission at any direction. There is a radio absorber with temperature sensor (see Figure 1). They are observed at every scans and we use assumption that the atmospheric temperature is equal to the temperature of the absorber when we calculate the zenith opacities. Figure 2 shows the block diagram of the radiometer.

Zenith opacities are measured with a tipping scan method. The principle of the measurement is summarized in Appendix. The measurement of the zenith opacity consisted of a series of nine observations between zenith angles $Z = 70.5$ degree ($\sec Z = 3.0$) and $Z = 0.0$ degree ($\sec Z = 1.0$). The system itself is very stable, but the system gain drifts due to the changes in ambient temperature. To reduce the effect of gain drift, two tipping scan data (first scan : from $Z = 70.5$ to $Z = 0.0$ degree , second scan : from $Z = 0.0$ to $Z = 70.5$ degree) are averaged in calculating a opacity. The antenna temperature is measured 6 times at each elevation and the net integration time is 3 seconds. The data which have substantially large deviations in the integration sequence are not used in calculating the zenith opacity. Fitting residuals are also evaluated and the opacities that has very large residuals are discarded.

3 MEASUREMENTS

The measurements of opacities were carried out from 27th June to 9th July, and from 19th July to 24th August 1994. In the latter testing period, we went to higher sites near the Andes and measured atmospheric opacities there. The measured sites were listed in Table 2 with other information. The map of the region we tested is also shown in Figure 3.

Opacity was measured with the tipping scan method with a time interval of about 100 seconds. A portable power generator was used to operate the radiometer system except at the

Escondida site where line power was available.

Considering the difficulty in working at very high elevations such as 4000 m, we gave up the continuous measurements. We usually arrived at the site at 5 o'clock in the morning, set up the radiometer, and started the measurements at 6 o'clock. The measurement was continued typically for 6 hours in a day.

Monitoring of meteorological parameters was made at the same time. Temperature, humidity and dew point were measured every ten minutes with a weather monitor and recorded in a small personal computer.

4 RESULTS

Paranal

Figure 4 shows the 220 GHz zenith opacity measured at Paranal(18 days). We could not measure opacities in September due to troubles in line power. Although it is dangerous to evaluate the site performance with a very limited data, this site might be suitable for observations at millimeter wavelengths but not for submillimeter wavelengths, because there was little time when the opacity became smaller than 0.06, that corresponds to the opacity of 1 at 490, 690 and 820 GHz bands (Masson 1993).

Sites near San Pedro de Atacama

The measured zenith opacities are plotted in Figure 5 through 6. Compared to the opacities at Paranal, we can see the large daily variation of opacity that is probably due to the variation of weather conditions (see weather conditions listed in Table 2). The fraction of time that the opacity is less than a certain value is displayed in Figure 7.

Site near Est. Imilac (Escondida)

We made measurements at the site in Escondida where there is a mining company near the Imilac Station. Operational support was provided by the staff of Escondida, and measurements were carried out for 8 days, but due to the trouble in the harddisk of our small computer the data were lost except only one night (August 11–12). The environment of the computer was so dusty that the harddisk might be damaged.

The measured zenith opacities are shown in the lower-right corner of Figure 6. This site seems to be a good site in spite of their relatively lower elevations (3000 m) and further observations will be made at this site.

Acknowledgements

We thank Jørg Eschwey and Robelto Alvarez for permitting us to use the Paranal site for our site testing activities and for giving a great support for us. The other staff of VLT site were also very helpful for us.

It was very difficult for us to imagine the testing in Chile without their help. We also thank Mario Parada Meyer who helped the operation of our radiometer at the Escondida site.

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Appendix : Measurement of Atmospheric Opacity

The emission characteristics of the atmosphere is well represented by those of a blackbody radiation at the same temperature. Therefore, the atmospheric emission is often expressed in terms of the absorption coefficient. Using Kirchhoff's law, one can derive the radiative transfer equation which describes the absorption and emission in the atmosphere.

The brightness temperature of sky, T_{SKY}, can be expressed as

$$T_{SKY} = \int_0^\infty T(\tau)\exp(-\tau)d\tau \simeq T_{atm}(1 - \exp(-\tau)) \tag{1}$$

where T_{atm} is effective physical temperature of atmosphere (assuming isothermal atmosphere) and optical depth (opacity) τ is defined using absorption coefficient of atmosphere κ;

$$\tau \equiv \int_0^\infty \kappa(s)ds \tag{2}$$

where s is the distance along path length from the radiometer.

Genenally, one can represent the effects of atmospheric attenuation with plane parallel assumption which ignore the curvature of the atmosphere. In this case, opacity of the atmosphere is described as $\tau = \tau_0 \sec Z$, where τ_0 is the zenith opacity and Z is zenith angle. In practical measurements, the noise power received consists of radiation from the atmosphere and the receiver system when the radiometer is pointed to the sky.

$$V(Z) = kGB\,(T_{atm}\,(1 - \exp(-\tau_0 \sec Z)) + T_{RX}) \tag{3}$$

where $V(Z)$ is the output voltage when the radiometer is pointed at zenith angle Z, k is the Boltzmann's constant, G is the gain of the system, B is the post detection band width, and T_{RX} is the receiver noise temperature including the antenna noise temperature.

To subtract the contribution of receiver noise an absorber is also observed;

$$V_{cal} = kGB\,(T_{cal} + T_{RX}) \tag{4}$$

where T_{cal} is the physical temperature of absorber we call calibrator.
Then one can derive the relation between τ_0 and the output of radiometer assuming $T_{cal} \simeq T_{atm}$.

$$\begin{aligned} V_{cal} - V(Z) &= kGB\,(T_{cal} - T_{atm} + T_{atm}\exp(-\tau_0 \sec Z)) \\ &\simeq kGBT_{atm}\exp(-\tau_0 \sec Z) \end{aligned}$$

$$\ln(V_{cal} - V(Z)) = \ln(kGBT_{atm}) - \tau_0 \sec Z \tag{5}$$

By plotting the output of radiometer $\ln(V_{cal} - V(Z))$ as a function of $\sec Z$, the proportional constant of the fitting line corresponds to the value of τ_0.

The atmospheric transmission is expressed using τ as $\exp(-\tau)$.

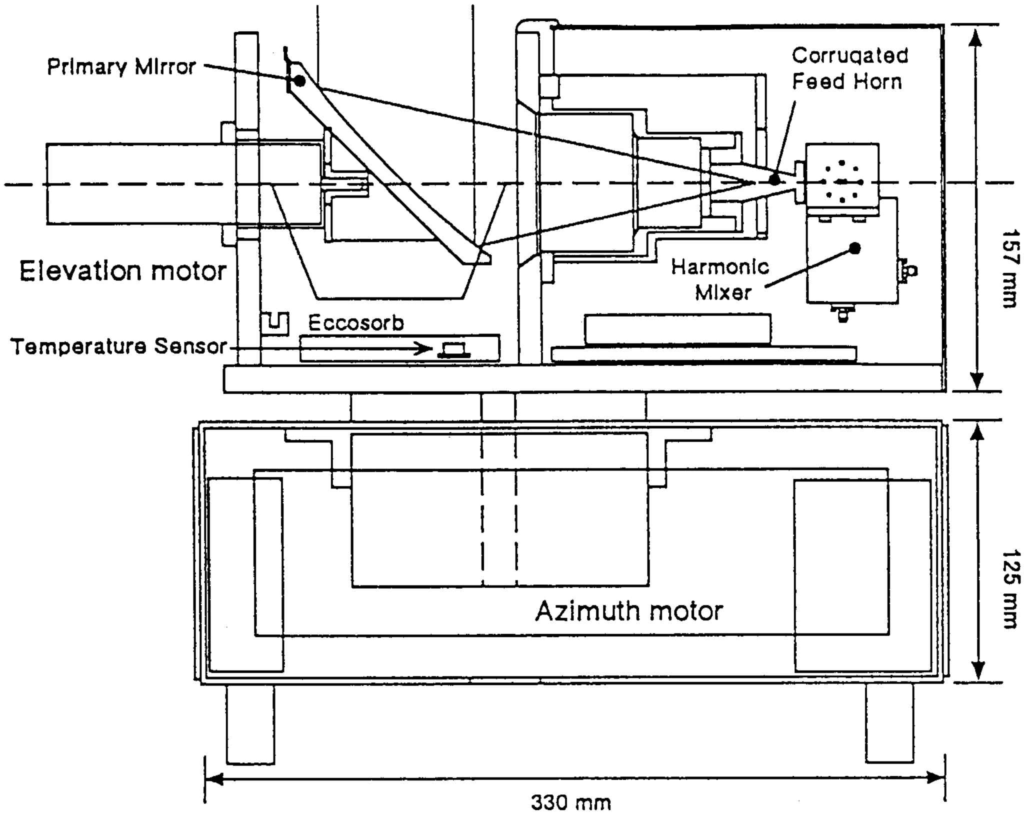

Figure 1: **220 GHz Portable Radiometer**

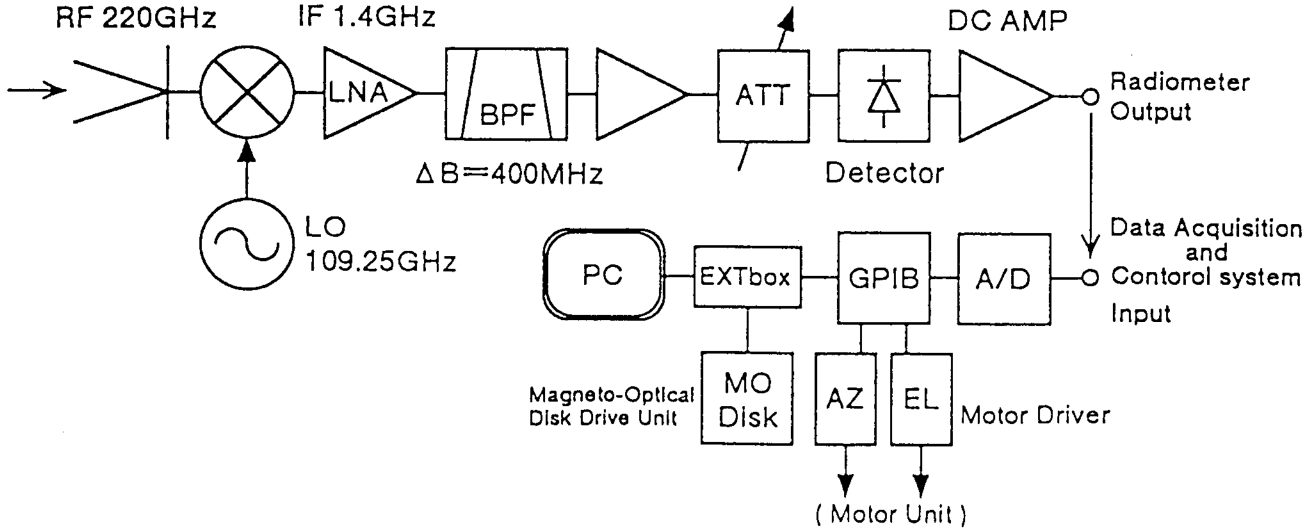

Figure 2: **Block Diagram of the Radiometer**

Table 1: **Specifications**

PRIMARY MIRROR		
optics		off set paraboloid
diameter	D	83 mm
surface accuracy	ε	$< 5\ \mu m$ (rms)
beam width	θ	$\simeq$ 63arcmin (at 220GHz)
feed horn		corrugated feed horn
MIXER		
type		Schottoky diode mixer
noise figure	NF	7.5dB
conversion loss	L	9.2dB (DSB)
harmonics		second
LOCAL OSCILLATOR		
diode		InP Gunn diode
frequency	f_{LO}	109.25 GHz
IF		
frequency	f_{IF}	1.4 GHz
band width	B	400 MHz
noise temperature of preamplifier	T_{LNA}	51 K
time constant of detector out	τ_{integ}	$0.5 \sim 1.0$ sec (variable)
receiver noise temperature	T_{RX}	< 1800 K

Table 2: **The list of measured sites**

latitude	longitude	elevation	date	weather	remarks
22°55′16″	67°46′43″	4700 m	Aug. 3	fine	
22°40′28″	67°57′08″	4300 m	Jul. 31	snow	
			Aug. 4	fine	
			Aug. 5	fine	
			Aug. 6	cloudy	
22°34′52″	68°20′46″	3500 m	Aug. 2	fine	
24°15′11″	69°03′26″	3000 m	Aug. 11-12	fine	Escondida
22°54′22″	68°15′20″	2500 m	Aug. 1	fine	
24°37′24″	70°24′05″	2400 m	18 days (*)	fine	Paranal

* The measurement at Paranal is still being continued.

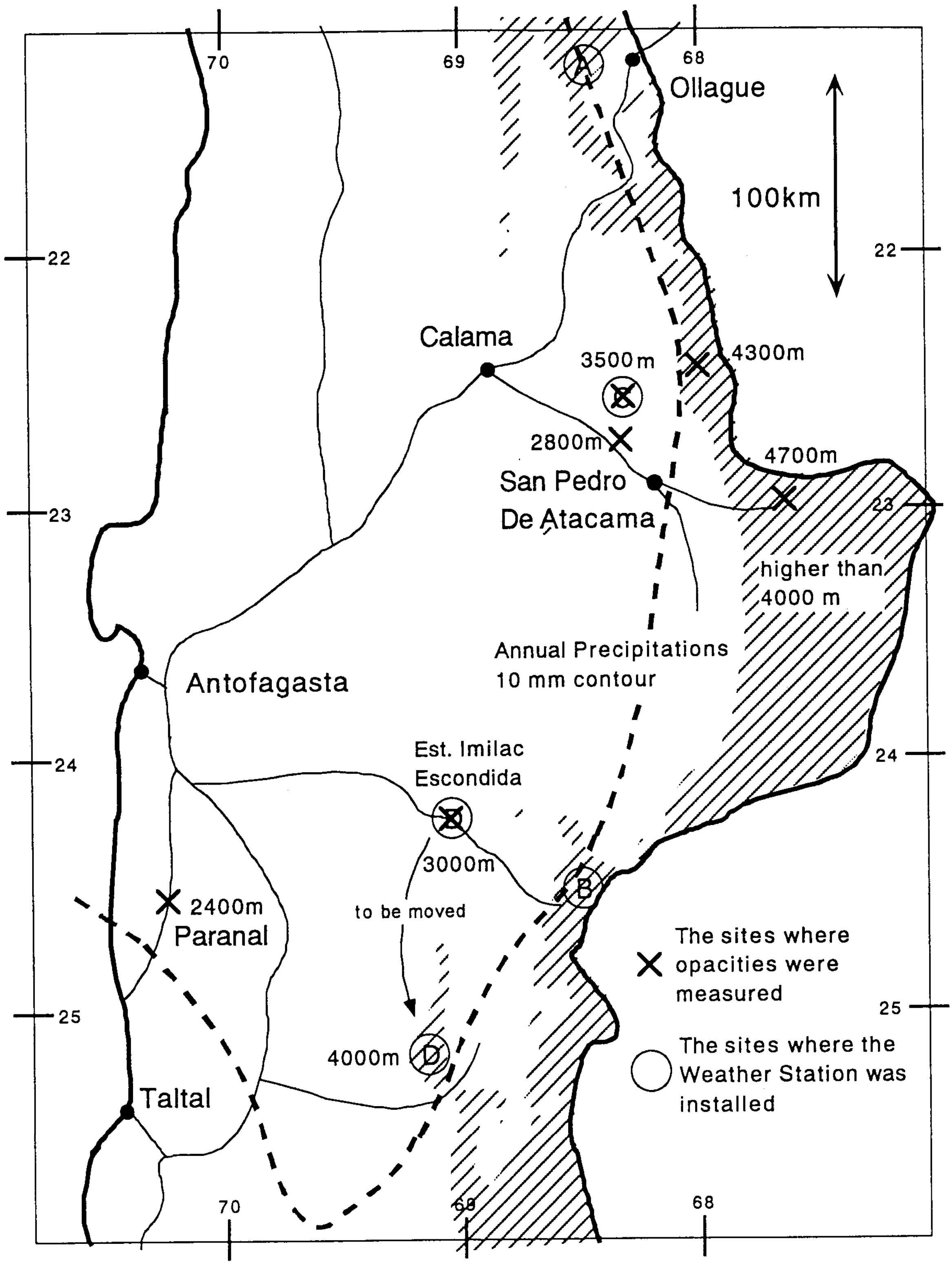

Figure 3: Map of Northern Chile

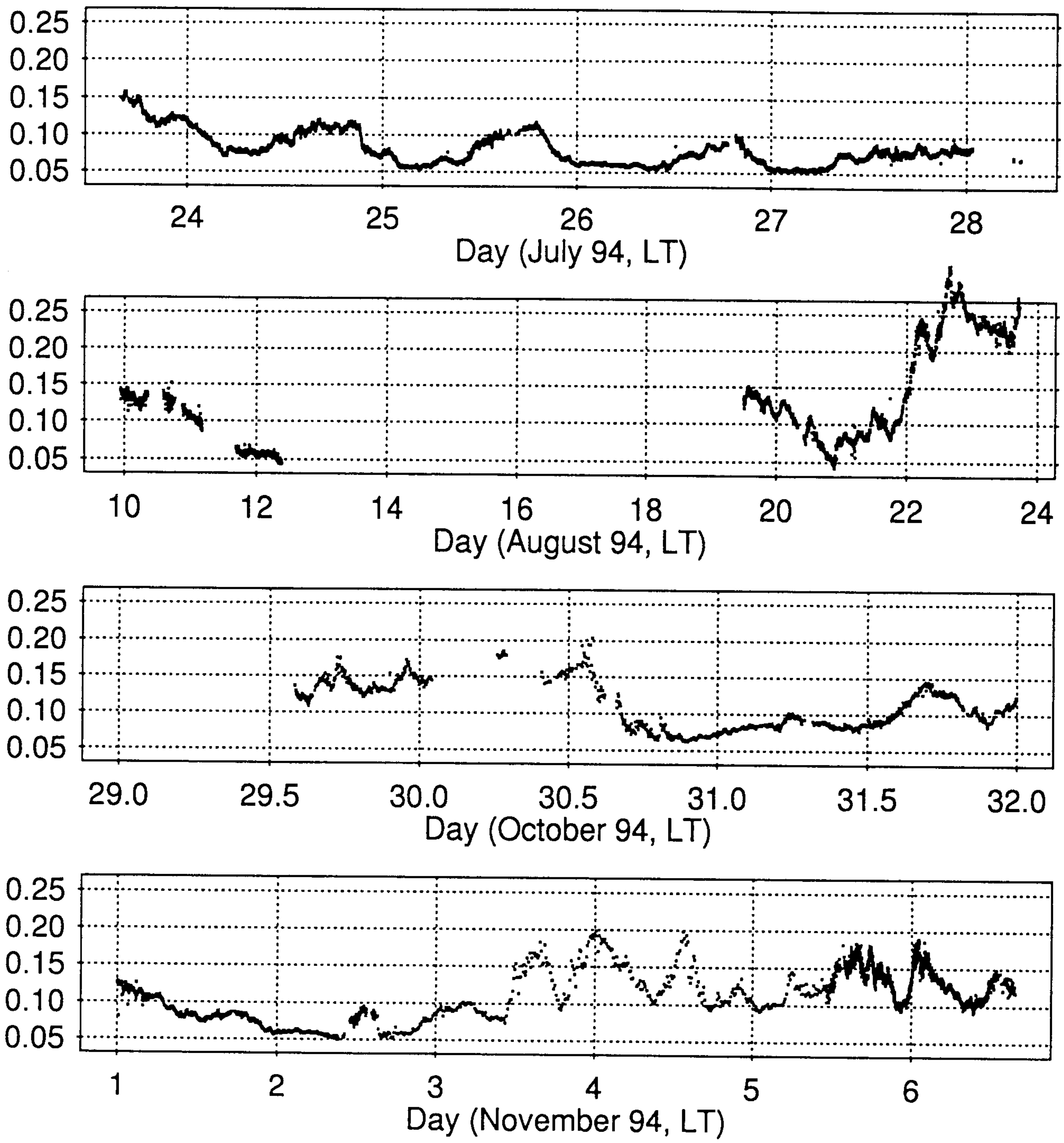

Figure 4: **Zenith oapcity(220 GHz) at Paranal**

LT = UT - 4 hours (Winter Local Time)

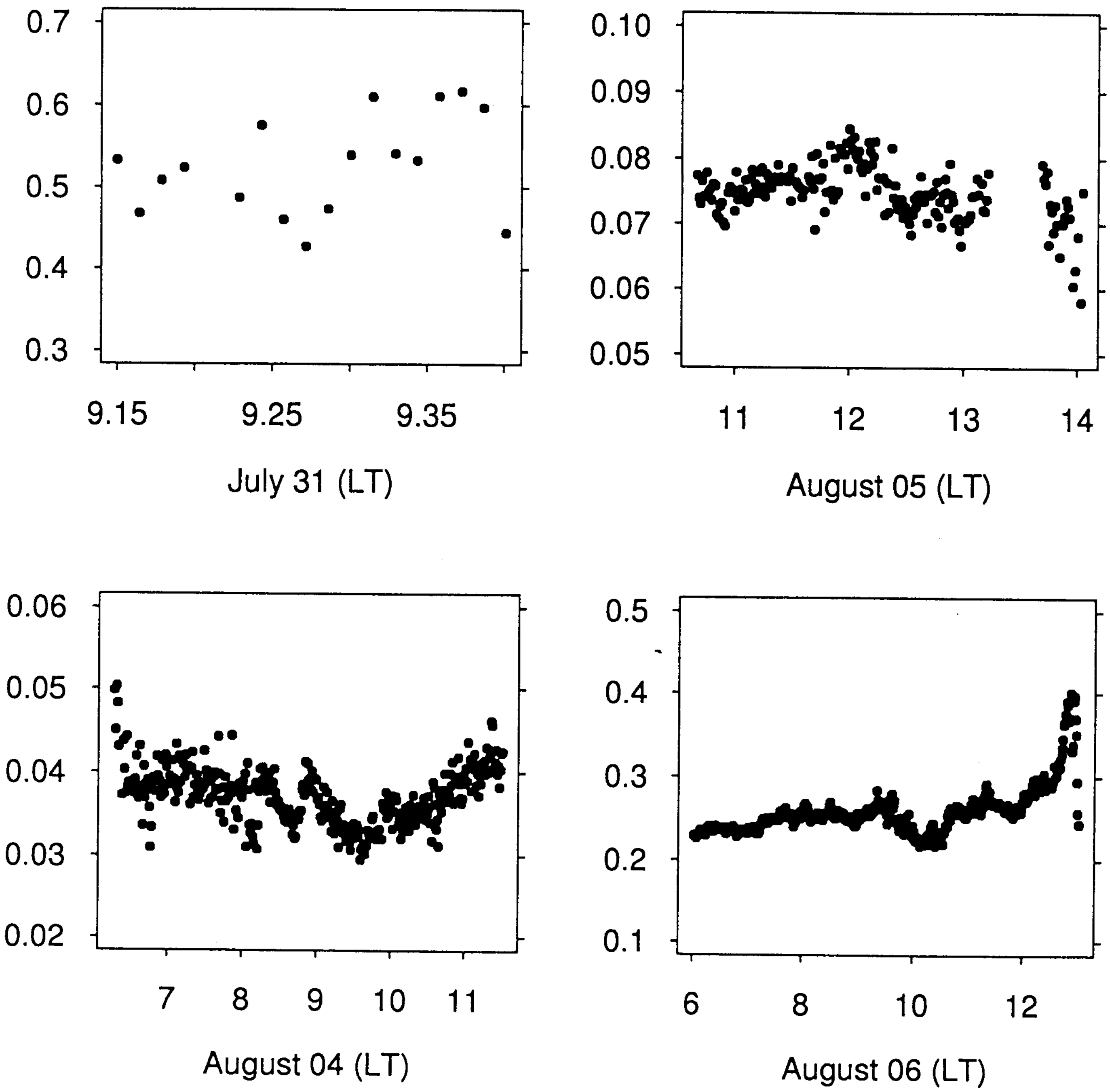

Figure 5: **Zenith oapcity(220 GHz) at the 4300 m site near San Pedro de Atacama**

LT = UT - 4 hours (Winter Local Time)

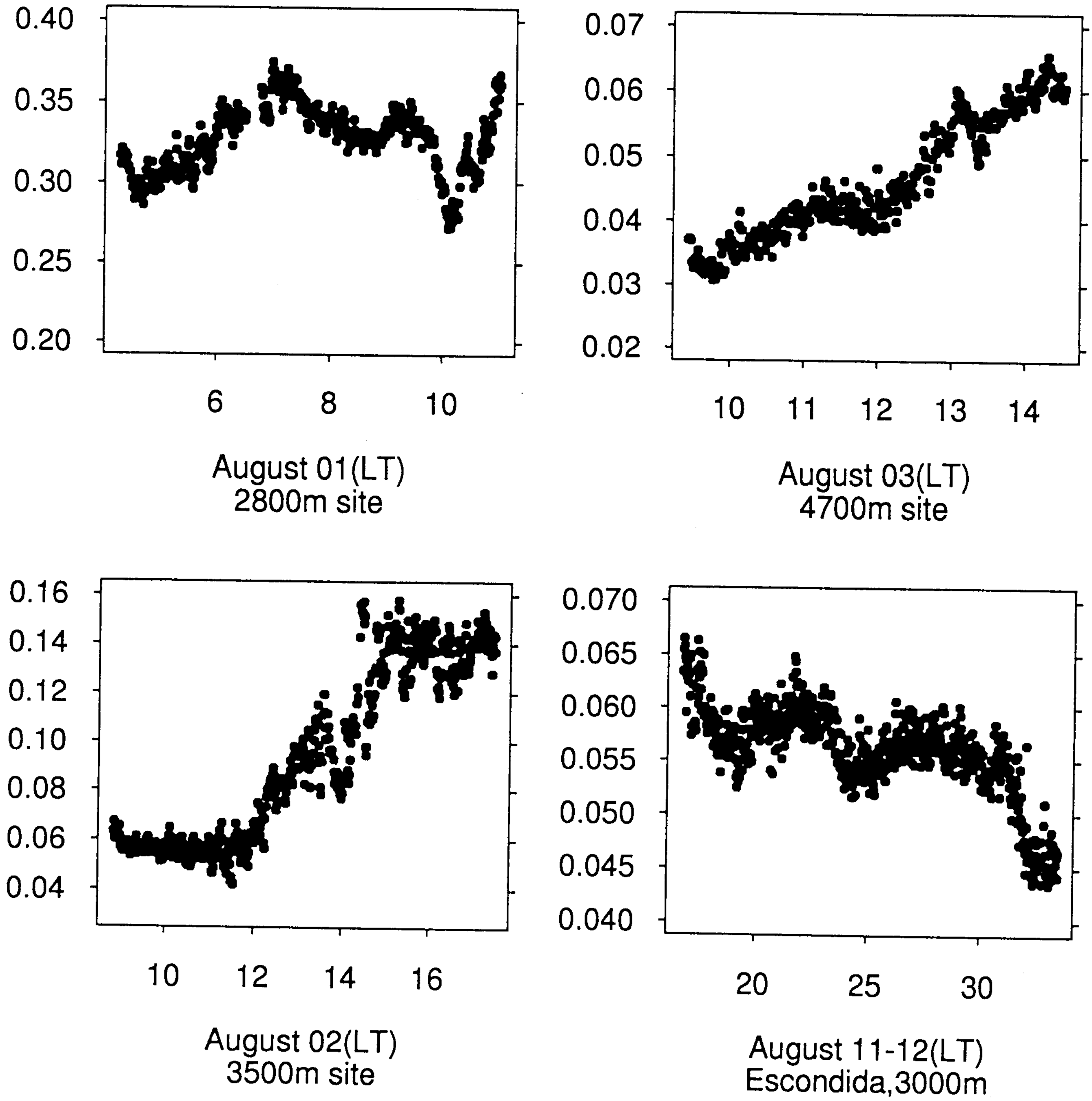

Figure 6: **Zenith oapcity(220 GHz) at the other sites**

LT = UT - 4 hours (Winter Local Time)