ALMA Memo 334
Atmospheric Transparency at 225 GHz over Chajnantor, Mauna Kea, and the South Pole

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Abstract

Measurements of the 225 GHz atmospheric transparency with functionally identical tipping radiometers at Mauna Kea, the South Pole, and Chajnantor indicate periods of excellent observing conditions at all three sites. Conditions at Chajnantor and the South Pole are better than at Mauna Kea. The first quartile zenith transparency at Chajnantor and the South Pole are roughly equal. During the best conditions at Chajnantor, however, the zenith transparency is better than during the best conditions at the South Pole. Median conditions at Chajnantor and the South Pole are similar for observations near meridian transit when observing geometry is considered.

Introduction

Three premier sites for millimeter and submillimeter wavelength astronomy are Mauna Kea, the South Pole, and the ALMA site near Cerro Chajnantor, Chile. Functionally identical 225 GHz tipping radiometers have been operated at all three sites to gauge observing conditions. This memo compares the results from these measurements.

Instruments

The NRAO tipping radiometers (Memos 40 & 41) are DSB heterodyne receivers operating at 225 GHz. An internal chopper continuously switches the receiver input between two calibration loads (45°C and 65°C) and an offset parabolic mirror that scans the sky. The atmospheric transparency is determined by measuring the sky brightness at different zenith angles. Several tippers were constructed in the mid-1980s and operated at various sites under consideration for the Millimeter Array project (Memos 19, 45, 49, 51, 68, 79, & 118). Although different computers and software have been used to control the tippers at different sites, the radiometers are functionally identical and the measurements are directly comparable.

One tipper been in service at the Caltech Submillimeter Observatory on Mauna Kea (4100 m altitude) since 1989 August with only brief interruptions. Transparency measurements are made every 10 minutes. For the period considered in this memo, 1997 January to 2000 October, data are available 76% of the time. These data are consistent with previously reported data from 1989–1993 (Memos 79 & 118; Masson 1992).

Another tipper was deployed to the South Pole (2835 m) in 1992 (Chamberlin & Bally 1994, 1995), where it operated about 75% of the time. The interval between successive transparency measurements alternated between 8 and 36 min.

Since 1995 April, NRAO has operated a radiometer at the ALMA site (5060 m) near Cerro Chajnantor, Chile (Radford & Holdaway 1998). Transparency measurements are made every 10 min, but every 4.5 h, these are suspended for one hour while the receiver measures fluctuations in the sky brightness. Through 2000 September, this instrument has operated 81% of the time. Because of Y2K jitters and various instrument failures, however, data are sparser in 2000 than in earlier years.

Geometry

At the Earth's poles, the observing geometry is naturally different than at lower latitudes (Figure 1). Two factors are affected: the overall sky coverage, or visible fraction of the sky, and the typical zenith angle during an observation. As a result, the relative merits of particular sites will depend on the observing goals and strategy as well as atmospheric conditions. Sometimes maximum sky coverage might favor a tropical site; at other times a polar site might be preferred because observing at constant zenith angle is advantageous.

All sites view equal instantaneous fractions of the sky. At the poles, sources circle the sky at constant zenith angle so the sky coverage never changes. At lower latitudes, on the other hand, the Earth's daily rotation brings different parts of the sky into view. For a maximum zenith angle $z_{\rm max} < 60^\circ$, corresponding to an upper airmass limit $A_{\rm max} = \sec(z_{\rm max}) < 2$, one quarter of the sky is visible from the poles. For the same maximum zenith angle, over three times more sky is visible from the tropics (latitude $\leq 30^\circ$) than from the poles (Figure 2).

Consider also the median zenith angle (airmass), defined so half of the visible sources from a uniform distribution are observed at zenith angles less than the median zenith angle and the other half at zenith angles between the median and the maximum zenith angles. Then for sources observed near meridian transit (upper culmination) from tropical sites, the median airmass is 1.1 for $z_{\rm max} < 60^\circ$, with a weak sensitivity to the maximum zenith angle. At the poles, $A_{\rm med} = 1.33$ for $z_{\rm max} < 60^\circ$, with a stronger dependence on the maximum zenith angle (Figure 2).

Data

It comes as no surprise that all three sites have periods of excellent observing conditions. The cumulative distributions of the measured 225 GHz zenith optical depths, τ_{225}, show significant differences (Figure 3). Chajnantor and the South Pole are clearly superior to Mauna Kea. The comparison between Chajnantor and the South Pole is more complex. The distributions cross near the fortieth percentile. During the best conditions at Chajnantor, the transparency is better than during the best conditions at the South Pole. The distribution at the South Pole, however, is far sharper than at the other sites.

Because Chajnantor (23° S) and Mauna Kea (19° N) have similar latitudes, they are directly comparable. Comparison of the South Pole with the tropical sites, on the other hand, is affected by consideration of the different observing geometries (Figure 4). For observations near meridian transit, the distribution for the South Pole crosses the Mauna Kea distribution near the fifteenth percentile and crosses the Chajnantor distribution just above the median level.

Conclusions

Mauna Kea, Chajnantor, and the South Pole all have periods of excellent observing conditions for millimeter and submillimeter wavelength astronomy. At 225 GHz, the atmospheric transparency over Chajnantor and the South Pole is better than over Mauna Kea. The first quartile zenith transparency at Chajnantor and the South Pole are roughly equal. During the best conditions at Chajnantor, however, the zenith transparency is better than during the best conditions at the South Pole. Median conditions at Chajnantor and the South Pole are similar for observations near meridian transit when observing geometry is considered.

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Table 1: 225 GHz optical depths (τ_{225})

		Chajnantor	Mauna Kea (CSO)	South Pole
	start	1995 Apr	1997 Jan	1992 Jan
	stop	2000 Jul	2000 Oct	1992 Dec
	25 %	0.036	0.058	0.043
at zenith	50 %	0.061	0.091	0.053
	75 %	0.115	0.153	0.066
	z_{med}	25.7°	25.7°	41.4°
at median	A_{med}	1.1	1.1	1.33
airmass	25 %	0.040	0.064	0.057
($\tau_{225}\ A_{\mathrm{med}}$)	50 %	0.067	0.100	0.070
	75 %	0.127	0.168	0.087

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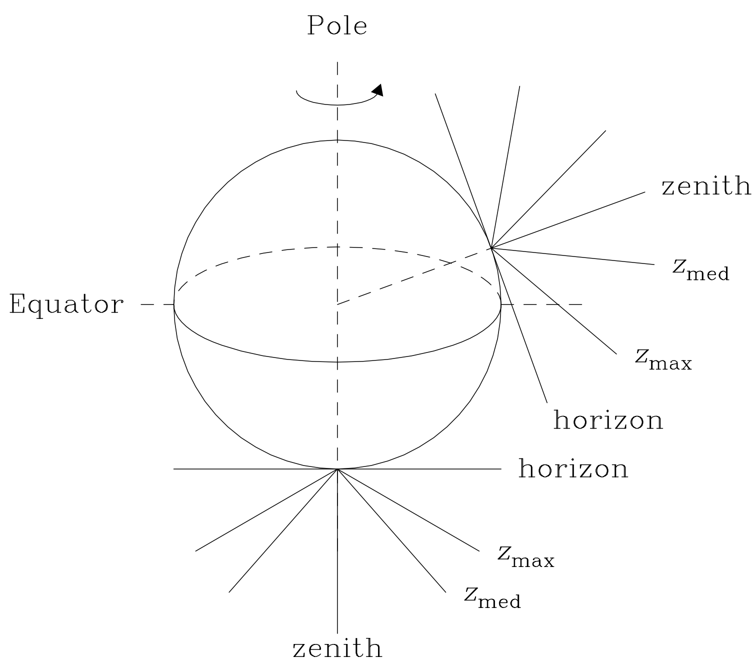

Figure 1: Observing geometry at tropical ($20°$ latitude) and polar sites. The median zenith angle ($z_{\rm med}$) is shown for observations near meridian transit with $z_{\rm max} = 60°$.

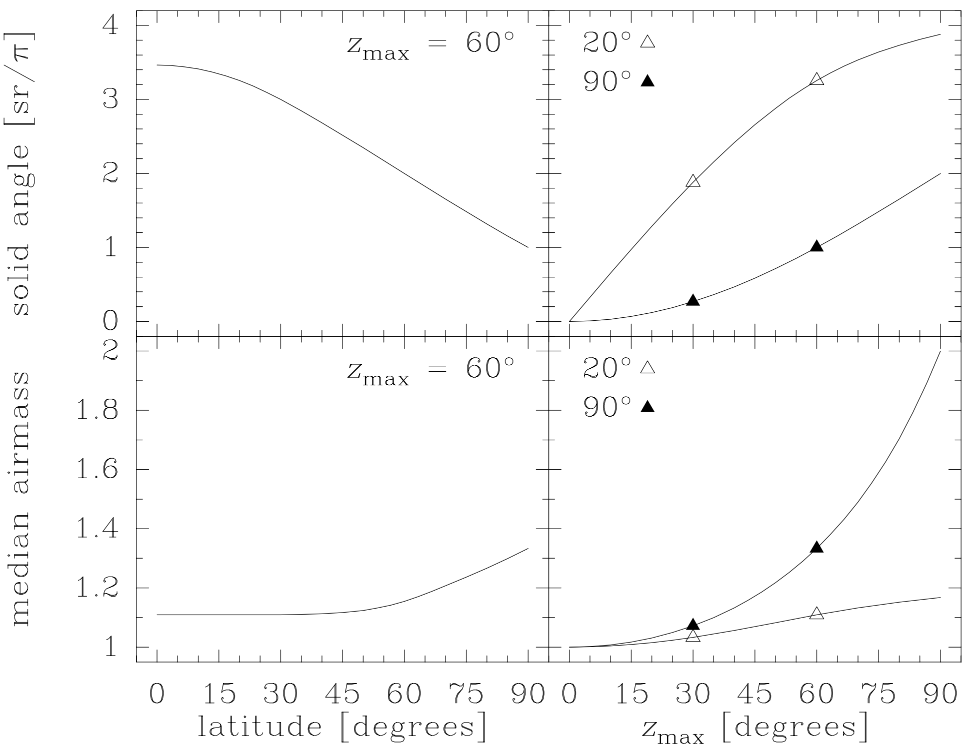

Figure 2: Visible solid angle *(top panels)* and median airmass for observations near meridian transit *(bottom panels)* at different latitudes *(left panels)* and with different maximum zenith angles *(right panels)* at 20° *(open symbols)* and 90° *(solid symbols)* latitudes.

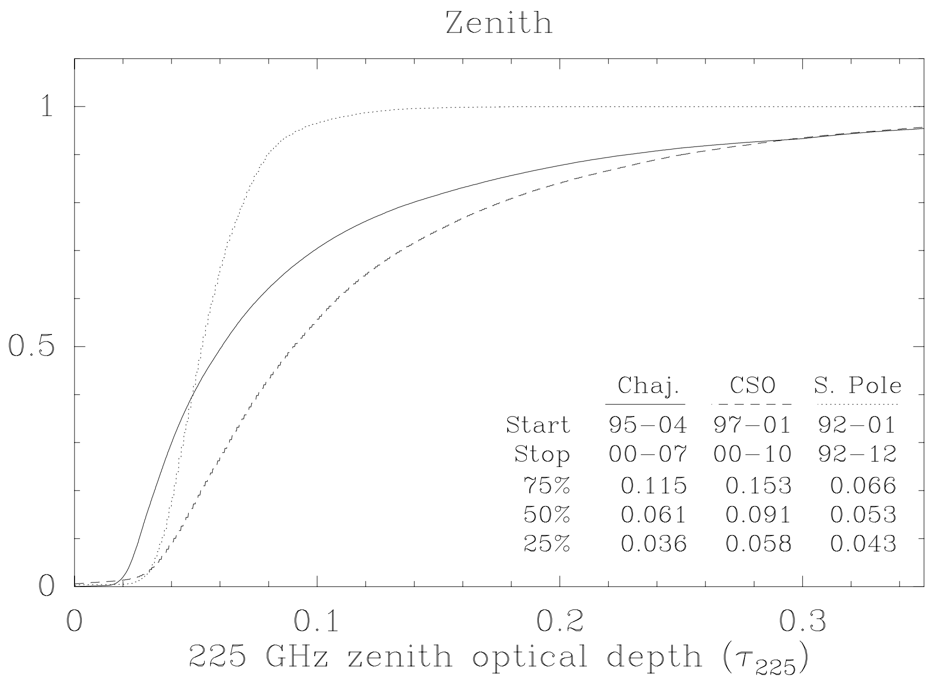

Figure 3: Cumulative distributions of the 225 GHz zenith optical depth (τ_{225}) measured at Chajnantor, at the CSO, and at the South Pole.

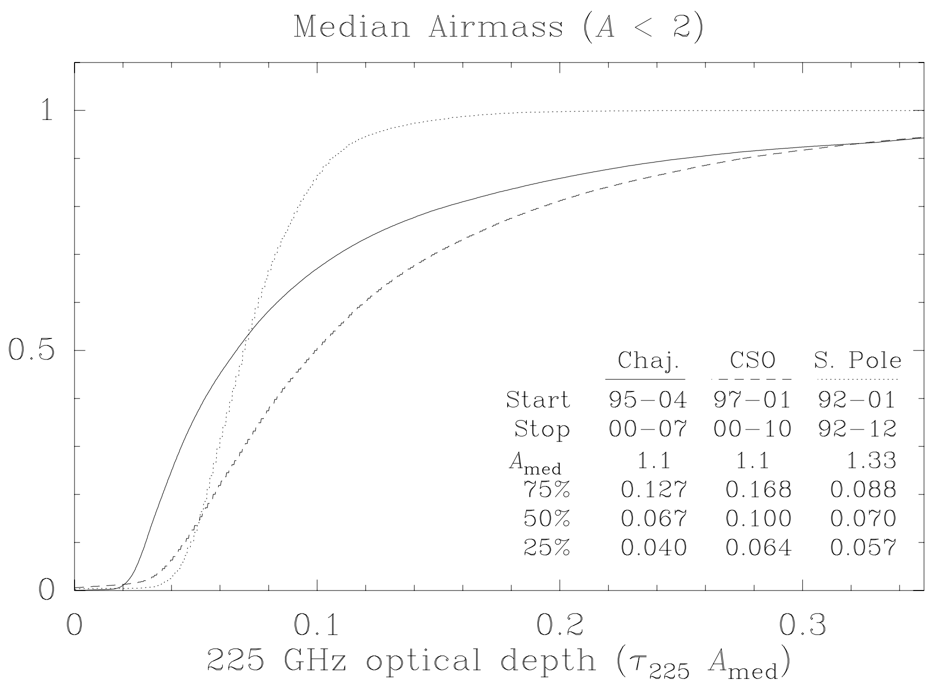

Figure 4: Cumulative distributions for Chajnantor, the CSO, and the South Pole of the 225 GHz optical depth at the median airmass ($\tau_{225}\ A_{\mathrm{med}}$) for observations near meridian transit and $z < 60°$ ($A < 2$).