ALMA Project Book, Chapter 14

SITE CHARACTERIZATION AND MONITORING

Simon Radford
Last revised 2000 September 6

View south from Cerro Chajnantor of MMA site.
Photo: S. Radford, 1994 November.

Revision History:
2000 September 6: Updated, removed WBS numbers.
1999 February 4: Updated URLs.
1998 October 16: Reorganized to match WBS, added section numbers.
1998 July 15: Original version.

14.1 Goals

During the project's prehistory, NRAO conducted extensive measurements to characterize several candidate sites for the Millimeter Array. These studies culminated in the recommendation of an array site on the high (5000 m) plateau southwest of Cerro Chajnantor, Chile, about 40 km east of the village of San Pedro de Atacama. The goals of further site characterization and monitoring are:

- to identify and quantify site conditions and their influence the instrument design or operations concepts,
- to provide a historical record of site conditions to guide priorities for instrument development and operation,
- to maintain a continuous presence on the site through development and construction to the start of operations, and
- to maintain contact and coordinate efforts with other groups working on or near the site.

14.2 Areas of interest

At millimeter and submillimeter wavelengths, pressure broadened molecular spectral lines make the atmosphere a natural limitation to the sensitivity and resolution of astronomical observations. Tropospheric water vapor is the principal culprit. The translucent atmosphere both decreases the signal, by attenuating incoming radiation, and increases the noise, by radiating thermally. Furthermore, inhomogeneities in the water vapor distribution cause variations in the electrical path length through the atmosphere. These variations result in phase errors that degrade the sensitivity and resolution of images made with both interferometers and filled aperture telescopes. The site characterization effort addresses these areas:

- Radiometric properties of the atmosphere
  - stability
  - transparency
- Physical structure of the atmosphere
  - meteorology
  - stratification
  - turbulence
- Physical characteristics of the site
  - topology
  - geology

14.3 Site Infrastructure

The ALMA operations base on Chajnantor are two 20 foot (6 m) long ocean shipping containers. These provides shelter for personnel and physical support for the instruments. In 1995, NRAO installed the first container and in 1998 June ESO installed a second container 15 m north of the NRAO equipment. In 1998 October, a third container was installed 1 km west of the ALMA containers as a launch base for radiosondes.

14.3.1 Safety program

Site inspections (every six months? year?); inventory, inspection, and, if necessary, repair or replacement of safety supplies and equipment; identification, and, if necessary, remediation of safety hazards; training (first aid, high altitude illness, oxygen therapy, fire safety, industrial safety). Note NRAO safety rules.

14.3.2 Solar power system

All three containers have arrays of solar panels and battery banks to supply electrical power. The system on the NRAO container can supply about 500 W continuously (24 VDC and 110 VAC 60 Hz), with sufficient reserve capacity to weather a storm of a few days. With current instrumentation, this system operates near capacity. The ESO container has a slightly smaller system (24 VDC and 220 VAC 50 Hz), also near capacity. A wind turbine has been installed on two occasions to augment the NRAO system, but it broke quickly. System maintenance includes a periodic (yearly) check and refill of battery water.

14.3.3 Communications

Voice and low-speed (<= 9600 baud) data are transmitted by cellular and satellite (Inmarsat A) telephones. In 2000 October, an Inmarsat M4 satellite terminal will be deployed to provide voice and ISDN (64 kbaud) data communications. The Inmarsat A terminal then will be decommissioned. Handheld radios will be used for communications on and around the site.

14.3.4 Transportation

Four wheel drive vehicles are required to access to Chajnantor, especially during inclement weather.

14.3.5 High resolution digital elevation model

1n 1996, contour maps and digital elevation models were prepared from aerial photographs (Maps of the Chajnantor Zone). These cover two 8×8 km regions of the Chajnantor and Pampa la Bola areas at 5-10 m resolution. In 1999, these maps were extended to the entire science reserve (18×19 km). They will be used for hydrodynamic studies of airflow over the site, for planning the array configurations, and for planning civil works.

14.3.6 Computers and network

All NRAO and ESO instruments are controlled by PCs running Windows 95. They are interlinked with ethernet, which extends to the LSA container. The PC clocks are synchronized to a GPS receiver that provides an absolute time reference good to about 1 s. The GPS receiver was used to determine the position of the container (Memos 261 and 312)>

14.3.7 Auxiliary instruments

- A surveillance camera, installed on 1997 June 15, takes pictures of the southwest horizon every two hours. Data are retrieved about once a month and the images posted.
- A subsurface temperature probe was operated 1997 June - October and 1998 March - May. Data are analyzed in Memo 314.
- A seismometer was installed in 1995. Data are analyzed by Chilean group (K. Bataille). Firmware was updated in 2000 July to accomodate GPS date rollover.

14.3.8 Physiology studies

John West, MD (UCSD) is investigating strategies for improving worker comfort and performance at high altitude. These include enhancing the oxygen concentration of the air in working and living quarters (Memos 191 and 302).

14.4 Atmospheric stability

Inhomogeneities in the distribution of water vapor cause variations in the electrical path length through the atmosphere. The resulting phase errors degrade the sensitivity and resolution of observations with both interferometers and filled aperture telescopes.

14.4.1 *12 GHz interferometer*

The site test interferometers directly measure the tropospheric phase stability. They observe unmodulated 11.5 GHz beacons broadcast from geostationary satellites and measure the phase difference between the signals received by two 1.8 m diameter antennas 300 m apart. Because the atmosphere is non-dispersive away from line centers, the results can be scaled to millimeter and submillimeter wavelengths.

Four instruments have been constructed by NRAO's Tucson office. The first was operated near the VLBA antenna (3720 m) on Mauna Kea, Hawaii, from 1994 September to 1996 June, then installed at the VLA in in 1997 May. The second has been operating on Chajnantor (5000 m) near San Pedro de Atacama, Chile, since 1995 May. A third was built for the LSA project. ESO installed it at Pajonales in 1997 April and moved it to Chajnantor in 1998 June. A fourth instrument, with a 100 m baseline, was installed at Green Bank in 2000 March.

The design and operation of these instruments are described in Site Test Interferometer (Radford, Reiland, & Shillue 1996, PASP 108, 441). From the phase time series, we obtain the r. m. s. path fluctuations on a 300 m baseline, the power law exponent of the phase structure function, and the velocity at which the turbulent water vapor moves over the array. Memo 129 describes the site test interferometer data reduction in detail, and Memo 130 illustrates the agreement between two different methods of deriving the mean velocity of the turbulent water vapor flow in the atmosphere.

In 1998 June, the ESO interferometer was set up alongside the NRAO interferometer. They share essentially the same baseline, but observe different satellites about 5° apart on the sky. Lag correlation of the data from the two interferometers will indicate the height of the turbulent layer (see Memo 196).

The interferometers operate autonomously. Status reports are received daily and data are retrieved about once a month. The data are analyzed in Tucson and monthly summaries are posted. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis.

14.5 Atmospheric transparency

Pressure broadened molecular spectral lines, principally of tropospheric water vapor, make the atmosphere semi-opaque at millimeter and submillimeter wavelengths. The translucent atmosphere radiates thermally, which increases the system noise, and attenuates incoming radiation, which decreases the signal.

14.5.1 *225 GHz tipper [11.1.3.1]*

The 225 GHz tipping radiometer is the benchmark instrument for site characterization. It measures the atmospheric transparency every 10 minutes and the stability of atmospheric emission every fifth hour. Operation is automatic. Daily and monthly data summaries are posted. The data are made available to interested parties in machine readable form. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis.

14.5.1 Submm tipper

A tipping photometer was been developed in collaboration with Carnegie Mellon University to directly measure the atmospheric transparency at 350 µm wavelength. This instrument is based on an ambient temperature, pyroelectric detector. The spectral response is defined by a resonant metal mesh. A compound parabolic (Winston) cone and offset parabolic scanning mirror together define the 6° beam on the sky. The detector is internally calibrated with two temperature controlled loads and views the sky through a woven Gore-tex window. Identical instruments have been deployed on Chajnantor (1997 October), at the CSO on Mauna Kea (1997 December), and at the South Pole (1998 January). An incomplete fourth unit was supplied to the University of New South Wales in 1999 July for modification prior to remote Antarctic deployment. In 2000 June, a fifth instrument equipped with a filter wheel and 200, 260, 350, and 1300 µm filters was deployed at Chajnantor. In 2000 October, this will be redeployed to 5700 m on Sairecabur to investigate the dependence of transparency with altitude in the area of Chajnantor.

The instruments operate autonomously. Status reports are received daily and data are retrieved about once a month. The data from these instruments are being analyzed with the aim of making an unbiased comparison of the three sites. Current activity includes operation and maintenance, including sporadic repair as required, data retrieval, and data analysis. Further work includes cross calibration between the submm tipper and other instruments, namely the 225 GHz tippers, SCUBA, CSO, and AST/RO,

14.5.2 Fourier Transform Spectrometer

To measure the atmospheric emission spectrum at Chajnantor, the Smithsonian Observatory has deployed a Fourier transform (polarizing Martin-Pupplet) spectrometer. This cryogenic instrument covers 350 - 3000 GHz with 3 GHz resolution and a 3° beam. The instrument recorded data for most of the 1998 winter season. NRAO provides the base for field operations.

14.6 Physical structure of atmosphere

The vertical profiles of atmospheric water vapor and turbulence may affect the success of radiometric phase calibration schemes.

14.6.1 Radiosonde campaign

Radiosondes carried by weather balloons provide *in situ* measurements of pressure, temperature, humidity, and wind speed and direction over the launch site. From these data we learn about the stratification of the water vapor over Chajnantor and about shear layers that may generate turbulence. A surplus radiotheodolite was acquired, upgraded by the manufacturer, tested in Tucson, and deployed at Chajnantor. Beginning in 1998 October, balloon flights have been made whenever appropriate personnel are at the site. This campaign is a collaboration between NRAO, Cornell, ESO, and SAO. The balloons are launched from a container placed 1 km west of the main site.

14.6.2 Hydrodynamic models

Calculations of airflow over Chajnantor, with emphasis on turbulence generated by local topography. Collaboration with NOAO.

14.6.3 Sodar

Acoustic sounding, or sodar, senses thermal turbulence in the lower atmosphere. Engineering tests of an ESO sodar unit were made in 1999 November. We are evaluating our interest we have in pursuing further measurements.

14.6.3 Weather stations

Additional weather stations will be deployed to measure the variation of meteorological parameters over the site.

14.7 Technical planning with collaborators and neighbors

Several groups are carrying out site characterization studies or astronomical experiments nearby. NRAO encourages these groups and takes interest in their results. As needed, NRAO and the other groups coordinate activities.

14.7.1 ESO

In 1998 June, ESO redeployed its site characterization equipment to Chajnantor. The ESO equipment, located 15 m north of the NRAO equipment, includes:

- Several weather stations. These are currently deployed adjacent to the containers, but will be deployed across the site in the last quarter of 1998.
- A 12 GHz interferometer. This is set up alongside the NRAO interferometer, sharing essentially the same baseline, but observing different satellites about 5° apart on the sky. Lag correlation of the data from the two interferometers will indicate the height of the turbulent layer (see MMA Memo 196).
- Dual three channel 183 GHz radiometers. These (instruments, designed and constructed by MRAO, OSO, and ESO, measure the H_2O line shape. They are installed at the ends of the LSA interferometer and look in the same direction as the interferometer. Variations in the line shape will then be compared to the phase fluctuations measured with the interferometers. See Memo 271.
- A single channel 22 GHz radiometer (deployment uncertain).

ESO provides field support for the ALMA site characterization program.

14.7.2 NRO/LMSA

At Pampa la Bola, about 7 km northeast of the MMA equipment, the LMSA project has installed:

- Weather stations (Memo 322),
- Dual 220 GHz tipping radiometers,
- A 12 GHz interferometer, and
- A Fourier Transform Spectrometer (temporary deployments).

14.7.3 Cornell

The CAT project is making optical seeing (DIMM) measurements. Campaigns in 1998 May, July, October, etc.

14.7.3 MAT

Observations of fluctuations in the Cosmic Background Radiation by a Princeton/Pennsylvania group. Campaigns in 1997 and 1998.

14.7.3 CBI

Observations of fluctuations in the Cosmic Background Radiation by a Caltech group. Deployment occurred in late 1999, with observations throughout 2000.

14.8 Site Characterization Reviews

Scientific reviews of site characterization data obtained by all groups.

14.8.1 USNC/URSI meeting

At the USNC/URSI National Radio Science Meetingin 1999 January in Boulder, there was be a session on Atmospheric Transmission at Millimeter and Submillimeter Wavelengths. Results from the NRAO site characterization program will be presented.

14.8.2 Mid-term Review

2000 March 22

14.8.3 Final Review

2001 March

References

ALMA Site Studies at NRAO ALMA Site Studies at ESO

MMA site NRAO safety rules

NRAO 1998 May, Recommended Site for the Millimeter Array [also ps]

Delgado, G., Otárola, A., Belitsky, V., & Urbain, D., The Determination of Precipitable Water Vapour at Llano de Chajnantor from Observations of the 183 GHz Water Line, MMA Memo 271

Gerard, A. B., McElroy, M. K., Taylor, M. J.,Grant, I., Powell, F. L., Holverda, S., Sentse, N., &West, J. B., 2000, Six Percent Oxygen Enrichment of Room Air at Simulated 5000 m Altitude Improves Neuropsychological Function, High Altitude Medicine & Biology 1, 51; ALMA Memo 302

Holdaway, M. A., & Radford, S. J. E., 1998, Options for Placement of a Second Site Test Interferometer on Chajnantor, MMA Memo 196

Holdaway, M. A., Gordon, M. A., Foster, S. M., Schwab, F. R., and Bustos, H., 1996, Digital Elevation Models for the Chajnantor Site, MMA Memo 160

Holdaway, M. A., 1995, Velocity of Winds Aloft from Site Test Interferometer Data, MMA Memo 130

Holdaway, M. A., Radford, S. J. E., Owen, F. N., & Foster, S. M., 1995, Data Processing for Site Test Interferometers, MMA Memo 129

Radford, S. J. E., Reiland, G., & Shillue, B., 1996, Site Test Interferometer, PASP 108, 441

Radford, S. J. E., 1999, Position of MMA Equipment on Chajnantor, MMA Memo 261

Radford, S. J. E., 2000, Refined Position of ALMA Equipment on Chajnantor, ALMA Memo 312

Sakamoto, S., Handa, K., Kohno, K., Nakai, N., Otárola, A., Radford, S. J. E., Butler, B., & Bronfman, L., 2000, Comparison of Meteorological Data at the Pampa La Bola and Llano de Chajnantor Sites, ALMA Memo 322

Snyder, L. A., Radford, S. J. E., & Holdaway, M. A., 2000, Underground Temperature Fluctuations and Water Drainage at Chajnantor, ALMA Memo 314

West, J. B., Powell, F. L., Luks, A. M., 1997, Feasibility Study of the Use of the White Mountain Research Station (WMRS) Laboratory to Measure the Effects of 27% Oxygen Enrichment at 5000 m Altitude on Human Cognitive Function, MMA Memo 191
