PWV, temperature and wind statistics at sites suitable for mm and sub-mm wavelengths astronomy in northern Chile

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Introduction

Atmospheric water vapor is the main limiting factor of atmospheric transparency in the mm and sub-mm wavelength spectral windows. Thus, dry sites are needed for the installation and successful operation of radio astronomy observatories exploiting those spectral windows. Other parameters that play an important role in the mechanical response of radio telescopes exposed to the environmental conditions are: temperature, and in particular temperature gradients that induce thermal deformation of mechanical structures, as well as wind magnitude that induce pointing jitter affecting this way the required accuracy in the ability to point to a cosmic source and track the source during the observations. Temperature and wind are variables of special consideration when planning the installation and operations of large aperture radio telescopes.

Goals

This work summarizes the statistics of precipitable water vapor (PWV), temperature and wind monitored at sites by the costal mountain range, as well as on the west slope of the Andes mountain range in the region of Antofagasta, Chile. This information could prove useful for the planning of the Atacama Large-Aperture Submm/mm Telescope (AtLast).

Specifically the sites are:

- **Armazones**: as a representative of the atmospheric conditions shared by the sites in the coastal mountain range. The main sites found nearby Armazones are, Cerro Paranal, Cerro Ventarrones and Cerro Mackenna. All these sites have been studied in the context of the VLT, E-ELT and TMT, site testing efforts. These sites are about 301 km SW from the ALMA site.
- **Tolonchar**: This is a site located on the west slope of the Andes Mountain and about 103 km south from the ALMA site. Tolonchar was studied in the period 2004-2008 as an option for the TMT.
- **The Chajnantor plateau and surrounding peaks**: Various sites have been monitored in the context of the ALMA, APEX, TAO and C-CAT projects, among others.

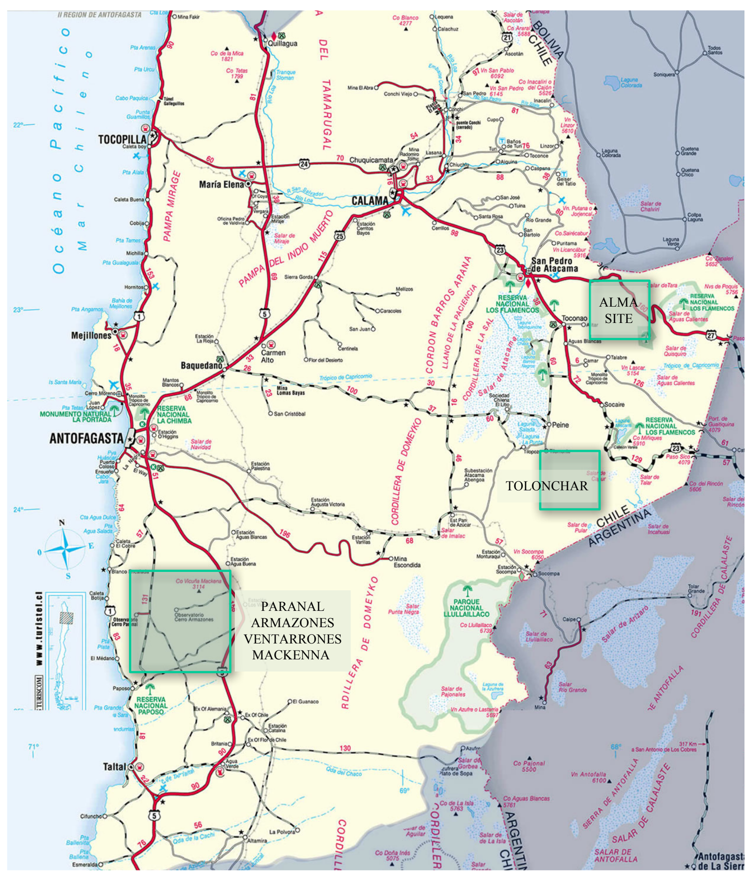

Figure 1 helps to show the relative location of the sites considered in this study, and is useful to show the location of existing facilities on the Chajnantor and Pampa La Bola complex. These region offer various sites, at varying geographic altitude that are suitable for the deployment of new astronomical facilities such as the AtLast project.

Fig. 1: Map of the Region of Antofagasta – Chile.

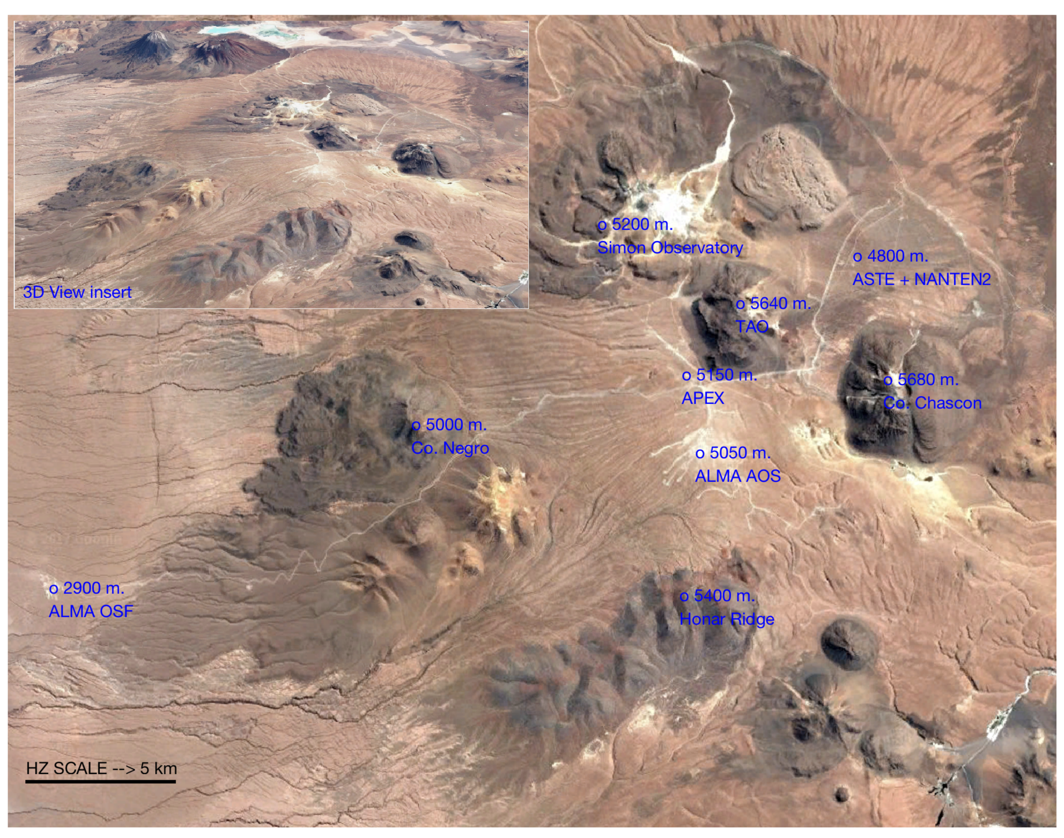

Fig. 2: Satellite Image of the Chajnantor / Pampa La Bola complex. The location of existing facilities and nearby peaks and their altitudes are shown.

Acknowledgments

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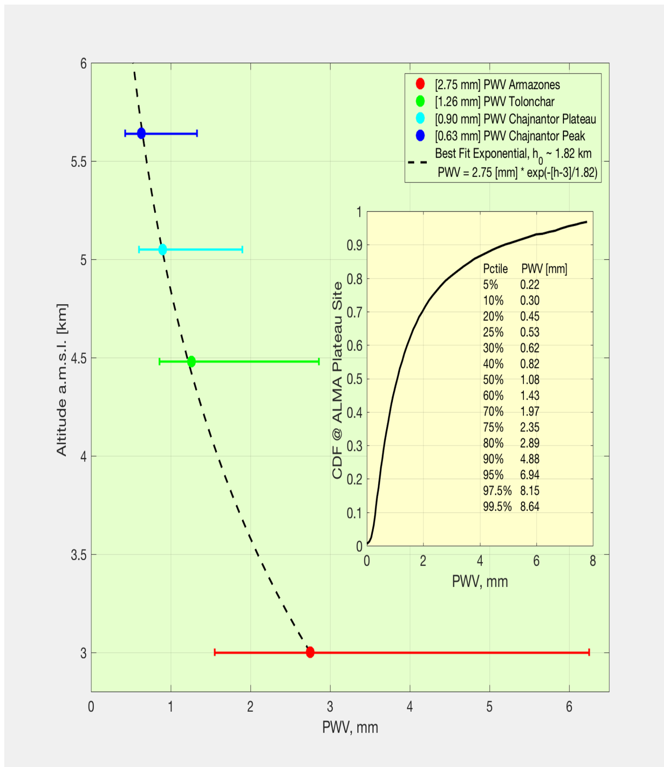
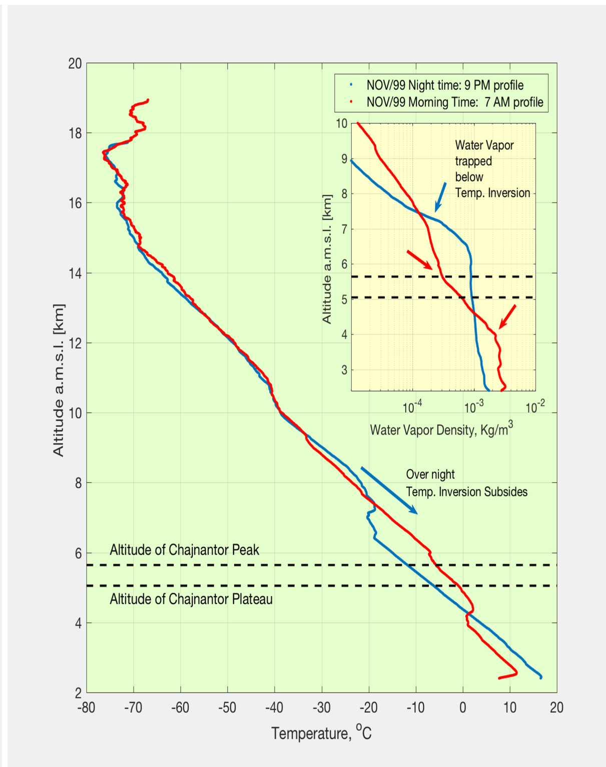
Precipitable Water Vapor





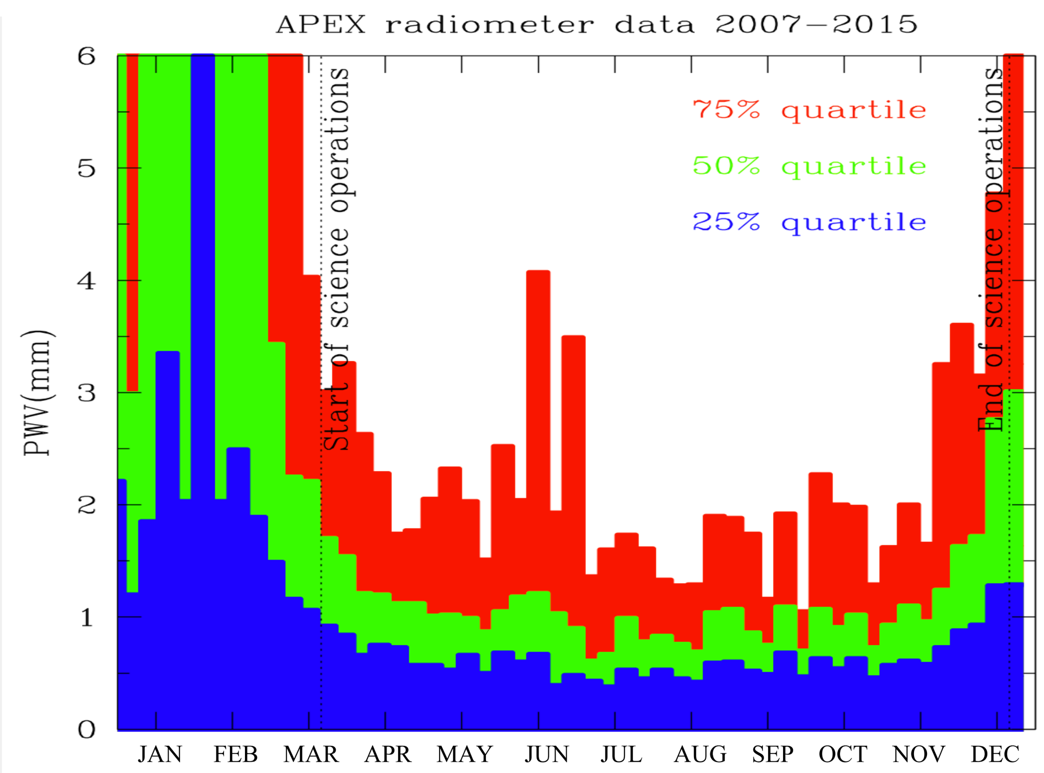
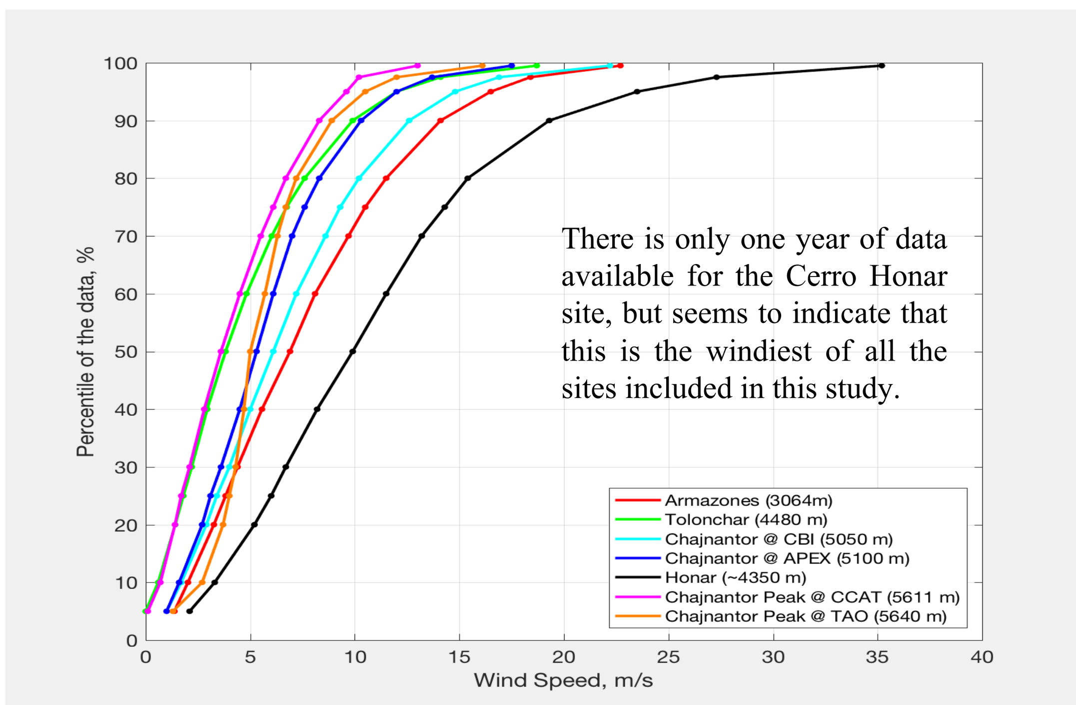


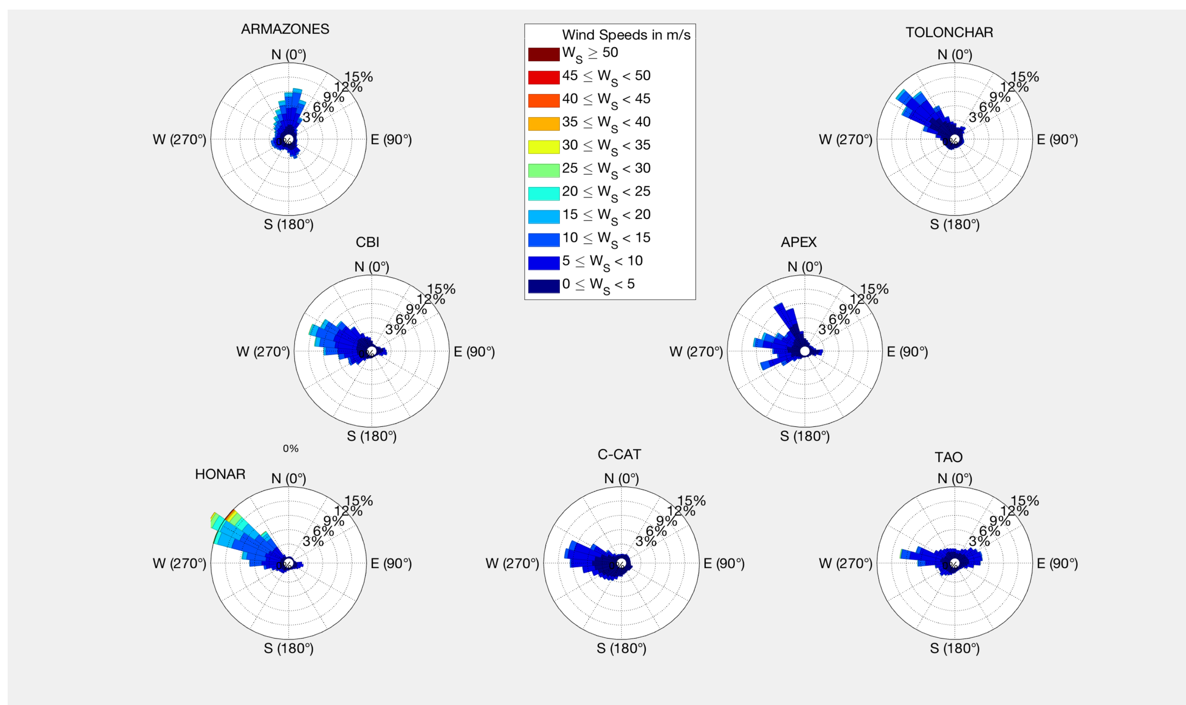
Fig. 3 (left): PWV as a function of altitude from the analysis of 762 soundings launched from the Antofagasta station. The humidity profiles were corrected from known dry bias effects effecting the Väisälä RS-92 sensors. The plot shows the mean PWV at each altitude level as well as the interquartile range. The mean PWV decreases with a scale height of 1.82 km. Fig. 3 (insert) Cumulative function of PWV for the ALMA site obtained from the long-term site testing study done for the ALMA project. Water vapor radiometers operating at 183 GHz as well a 225 GHz tipper were operated between 1995 and 2005.

Fig. 4 (center): Vertical profile of temperature and water vapor density (insert) from two radio soundings launched from the town of San Pedro de Atacama on November 1999 by the ALMA site testing team. A night launched (9 PM – Blue) and an early morning sounding (7 AM – Red). The segmented lines show the altitude of the Chajnantor plateau and Chajnantor peak. This illustrate the important effect of temperature inversion layers that keep water vapor at altitudes below the inversions. This implies sites at nearby peaks spend more time above the temperature inversions and are therefore relatively dryer.

Fig. 5 (right): Monthly variability of PWV at the Chajnantor area (data obtained at the APEX site in the period 2007-2015). This monthly variability is representative of the conditions in the northern Chile by the Antofagasta region. The drier seasons are Fall, Winter and Spring. Summer gets affected by the summer storms typical of the South-American Monsoon.

Wind Speed, Prevailing Wind Direction & Temperature Gradients





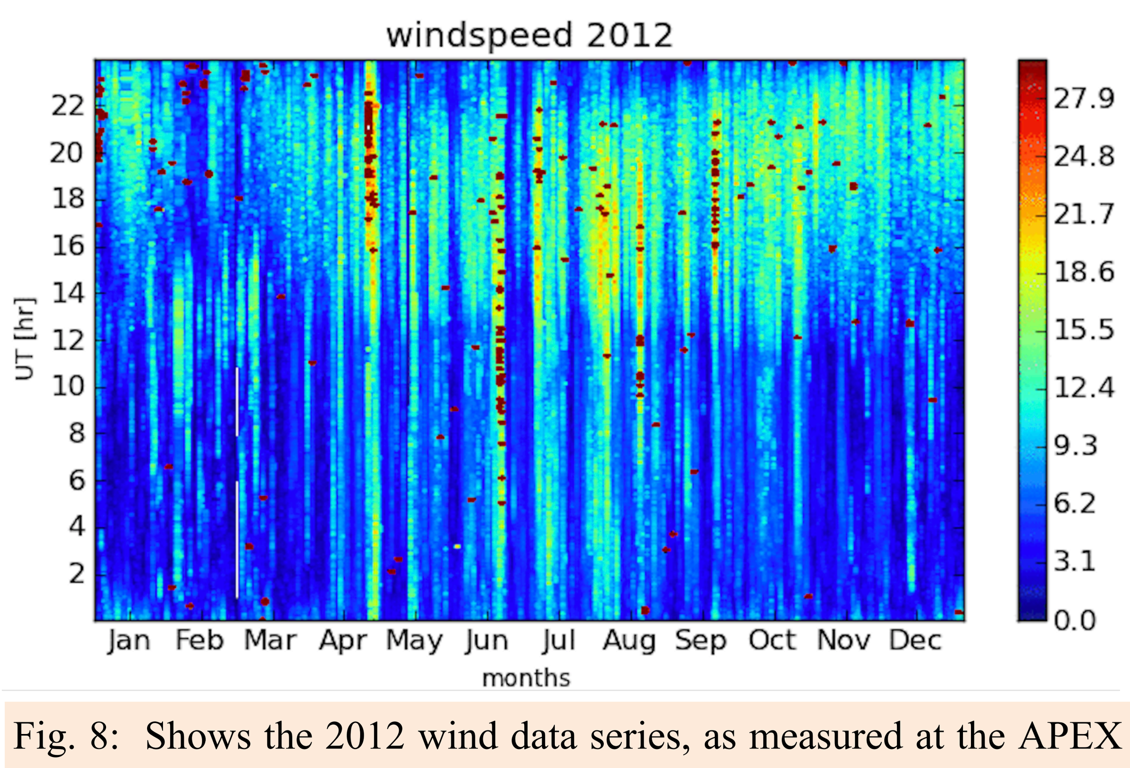


Fig. 8: Shows the 2012 wind data series, as measured at the APEX site, through the year and as a function of time of day (UT). This clearly shows the higher afternoon winds, but also illustrate the occasional periods of relatively higher winds at night time (most likely associated with particularly active periods of the jet stream).

Fig. 6 (top-left): Cumulative function for wind speed at various potential sites for astronomy projects. AtLast consists of a large aperture single dish radio telescope intended to operate in the mm and sub-mm wavelength regime, well into the THz spectral windows. High pointing and tracking stability is required, and consequently wind plays an important role. The analysis of wind data at the various sites seems to indicate that lower magnitude wind are possible at the peak of Chajnantor nearby the area tested by the former C-CAT project team.

Fig. 7 (top-right) shows wind directions. The sites by the coastal mountain range have prevailing winds from about the north direction, while the sites by the west slope of the Andes, are high sites exposed to the free atmosphere westerly winds.

Interestingly enough the APEX site shows a very distinct pattern in the wind direction. We found that the prevailing winds change through the day: The NNW component is characteristic of night time, the W component correspond to the day time and is the typical pattern for the area, and the SW component shows up in the late afternoon.

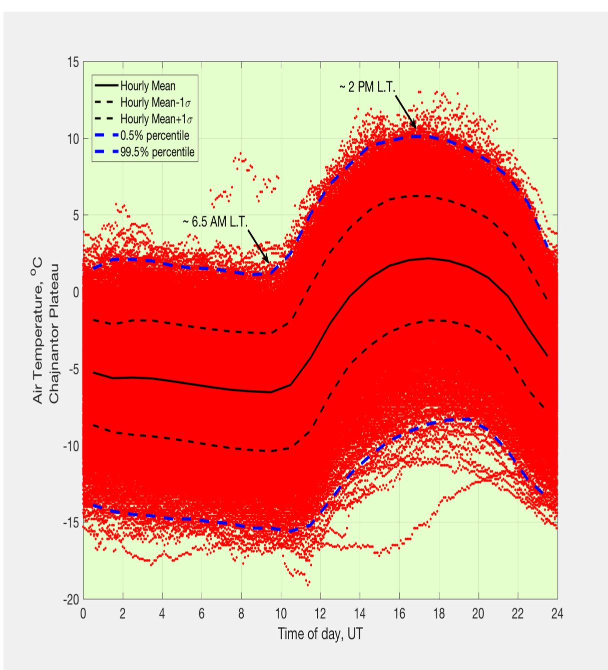


Fig. 9: Shows the annual daily temperature range at the Chajnantor plateau. The daily and annual temperature range are comparable and of order 20 °C range.

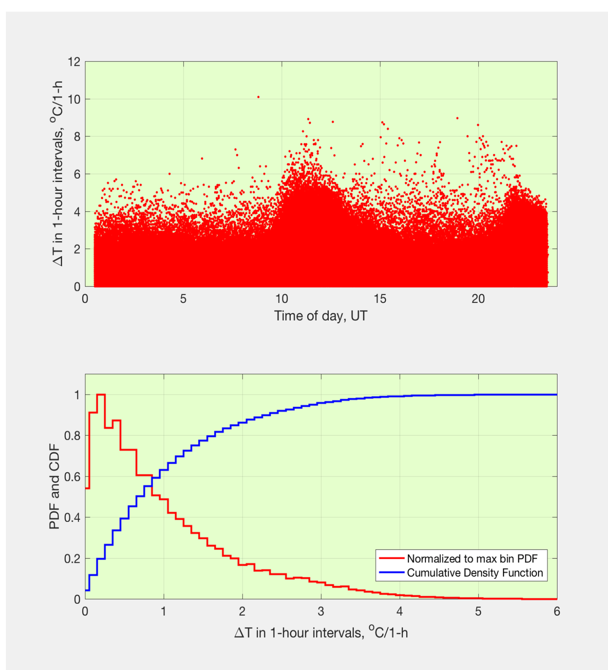
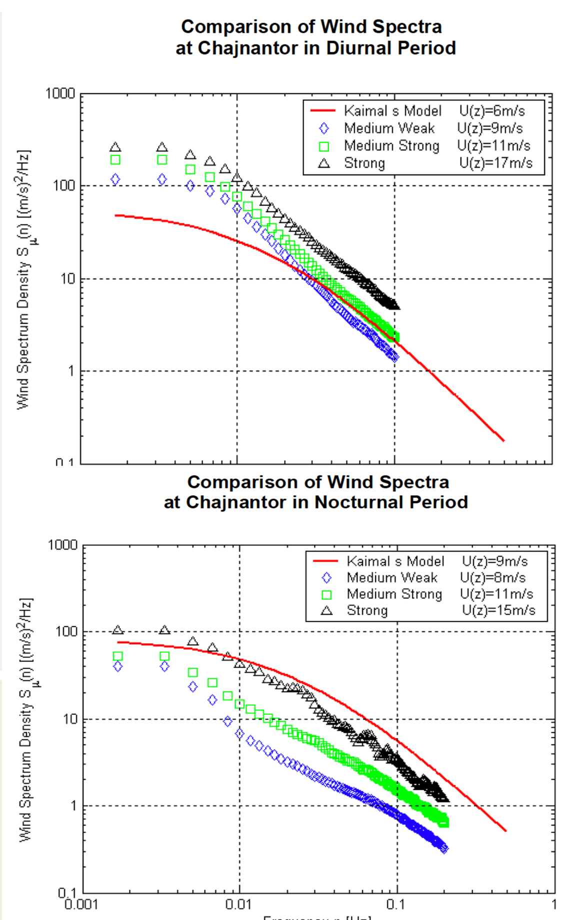


Fig. 10: This is the 1-hour absolute temperature gradients. **The 95% percentile is 2.9 °C/1-hour**. The 10-min temperature gradients (not shown) is about 0.9 °C/10-min.



Regarding the power spectral density of the wind at Chajnantor a study was conducted in the context of the ALMA project (see Pérez-Beaupuits et al., ALMA Memo 497, 2004. Figures 7.1 (a) and (b) are shown here for completeness). The red line corresponds to the Kaimal model used for modelling of the ALMA antennas (that was designed to perform under the power of a nighttime wind of 9 m/s). However, it was found, at Chajnantor the 9 m/s nighttime wind has less energy than the model.