This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 951815

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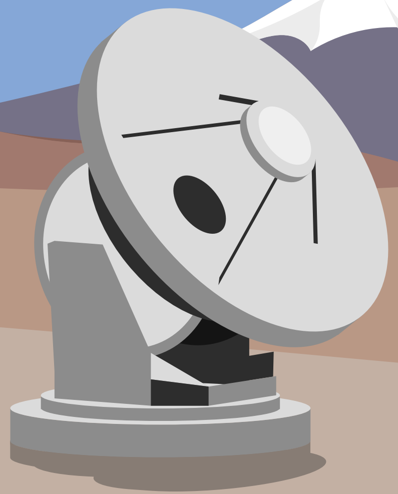


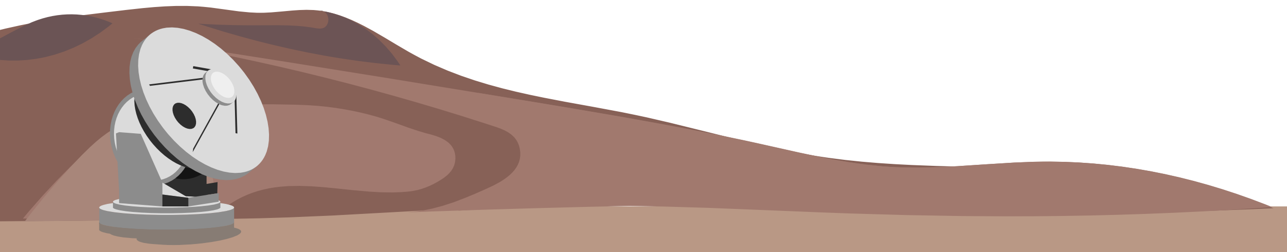
First results from site measurements

AtLAST Conference, Mainz-Germany, 21-24 of May

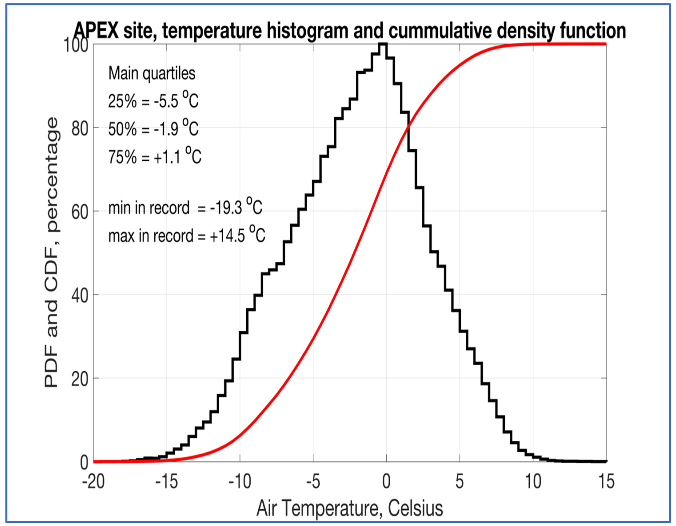
Main topics

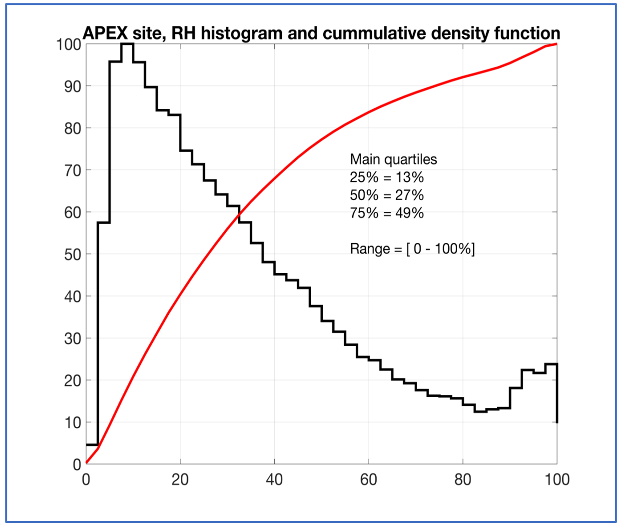
- Summary of long-term meteorological conditions of the Chajnantor plateau area
  - Air temperature
  - Relative Humidity
  - Wind Speed & wind direction
  - PWV
- **The AtLAST potential sites: Site I and Site II**
  - **Wind speed & direction statistics**
  - **Wind conditions nighttime & daytime**
  - **Site I: the vertical profile of the horizontal wind**
  - **The wind power spectrum**
- **Summary of the first results**

Long-term meteorological and PWV conditions at the Chajnantor plateau

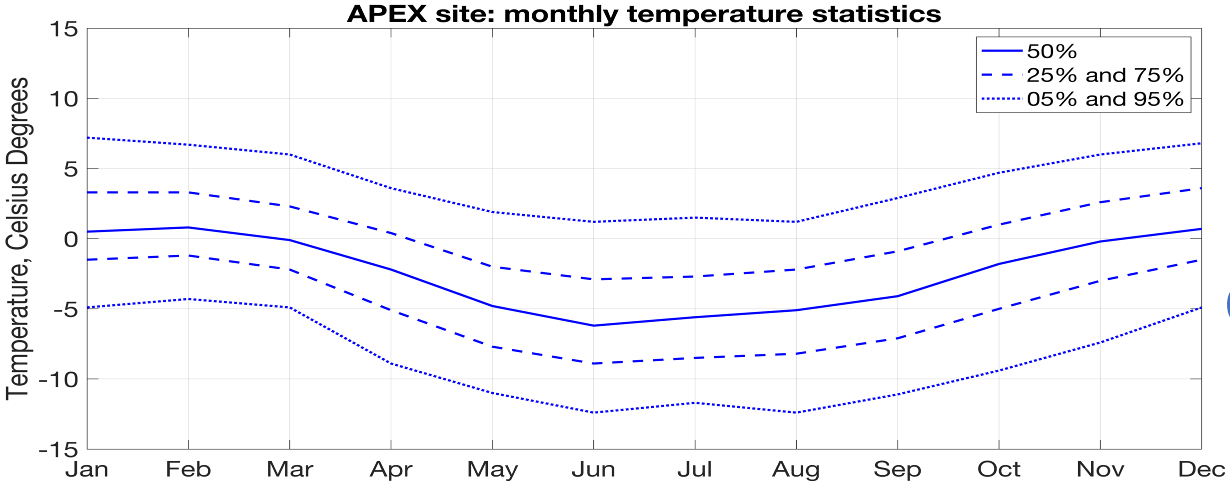


Temperature & RH from APEX data (2019-2024)





Air temperature range: -19.3 - +14.5 Celsius
25% quartile = -5.5 Celsius
50% quartile = -1.9 Celsus
75% quartile = +1.1 Celsius



There are periods of high relative humidity
Under very cold temperature in winter
Under high absolute humidity periods in summer

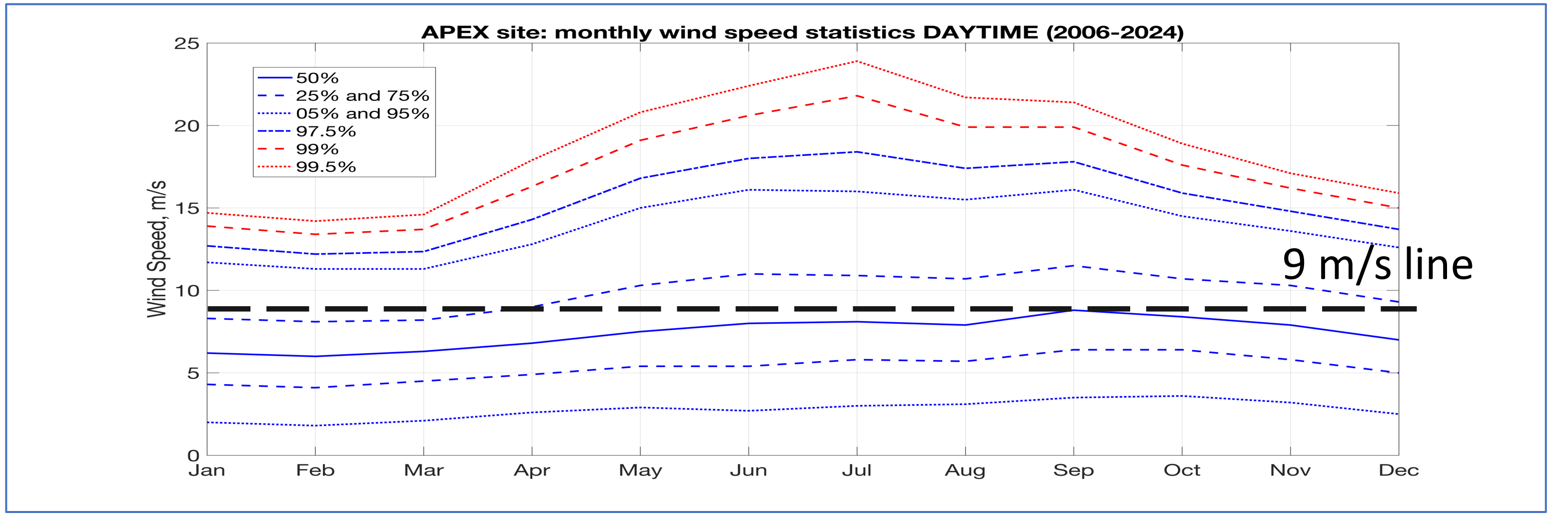
Coldest period is June thru August

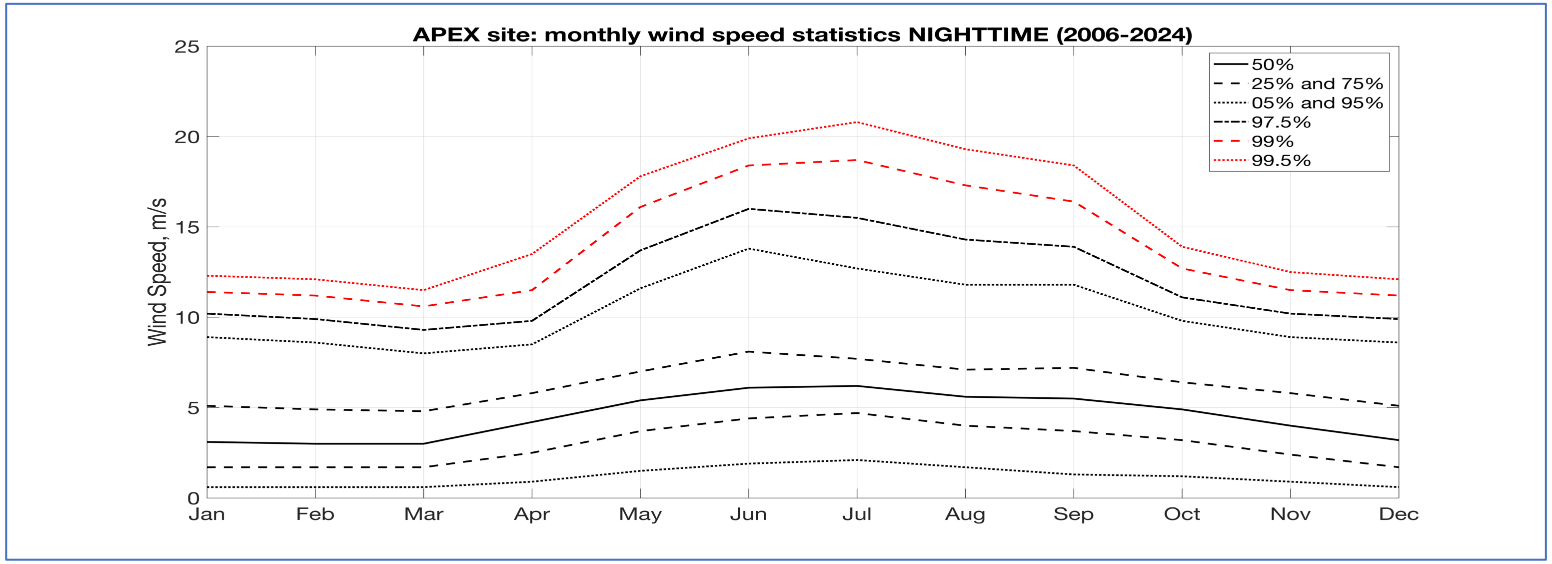
Wind Speed from APEX data (2006-2024)

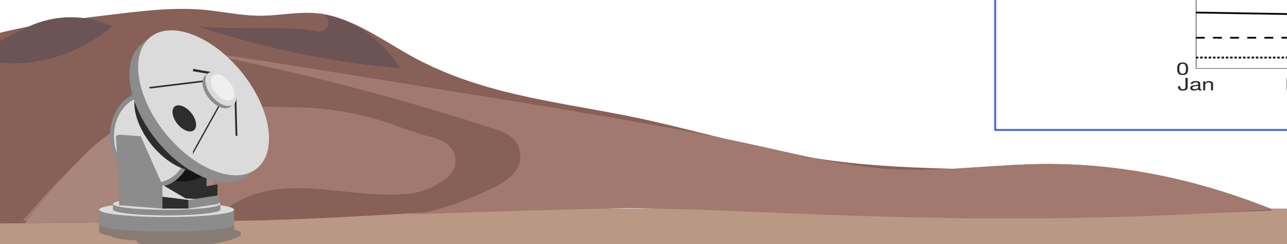
- **Data consists of 1-minute averages**
- **Daytime wind speed is larger**
- **Windiest period MAY thru SEPTEMBER**
- **Windiest month JULY**

Percentile	Wind Speed	Wind Speed
50	8.1 m/s	29.2 **km/h**
75	10.9 m/s	39.2 **km/h**
95	16.0 m/s	57.6 **km/h**
99	21.8 m/s	78.48 **km/h**
99.5	23.9 m/s	86.0 **km/k**
99.95	29.2 m/s	105.1 **km/h**

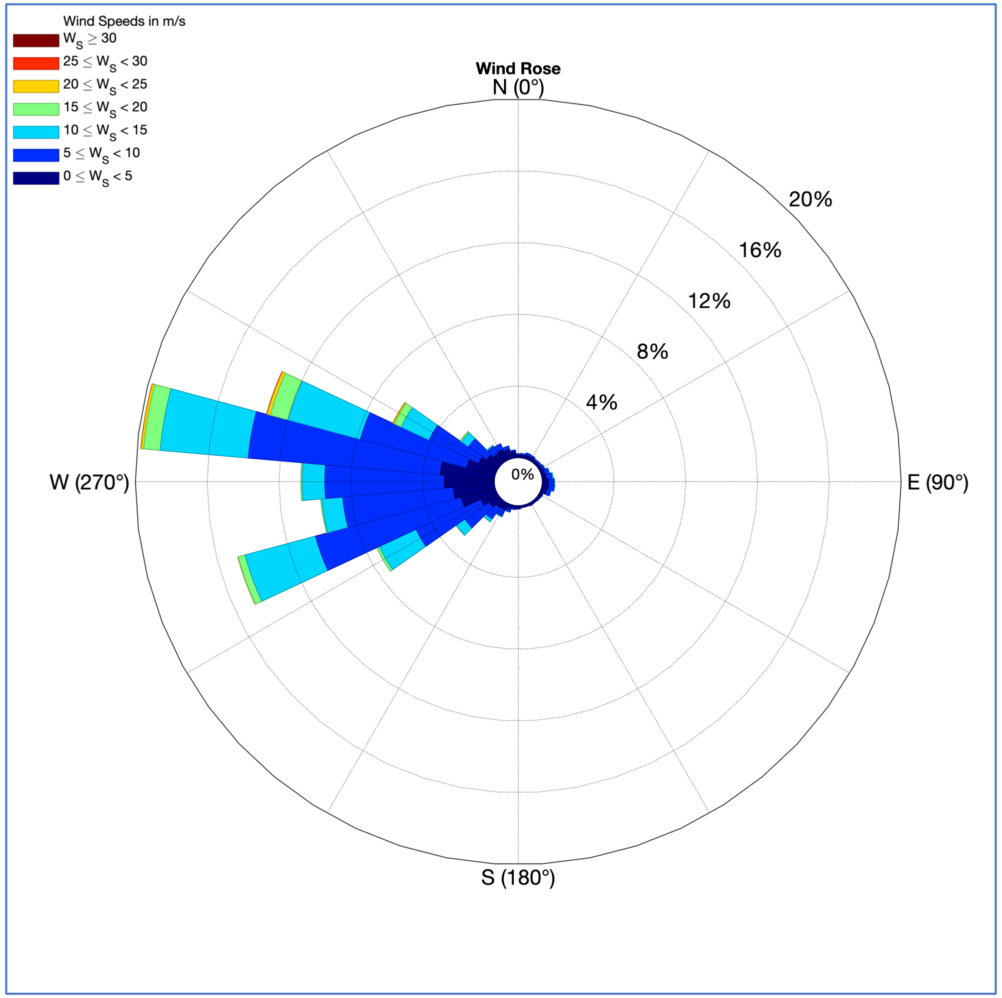
Table shows windiest month and daytime wind



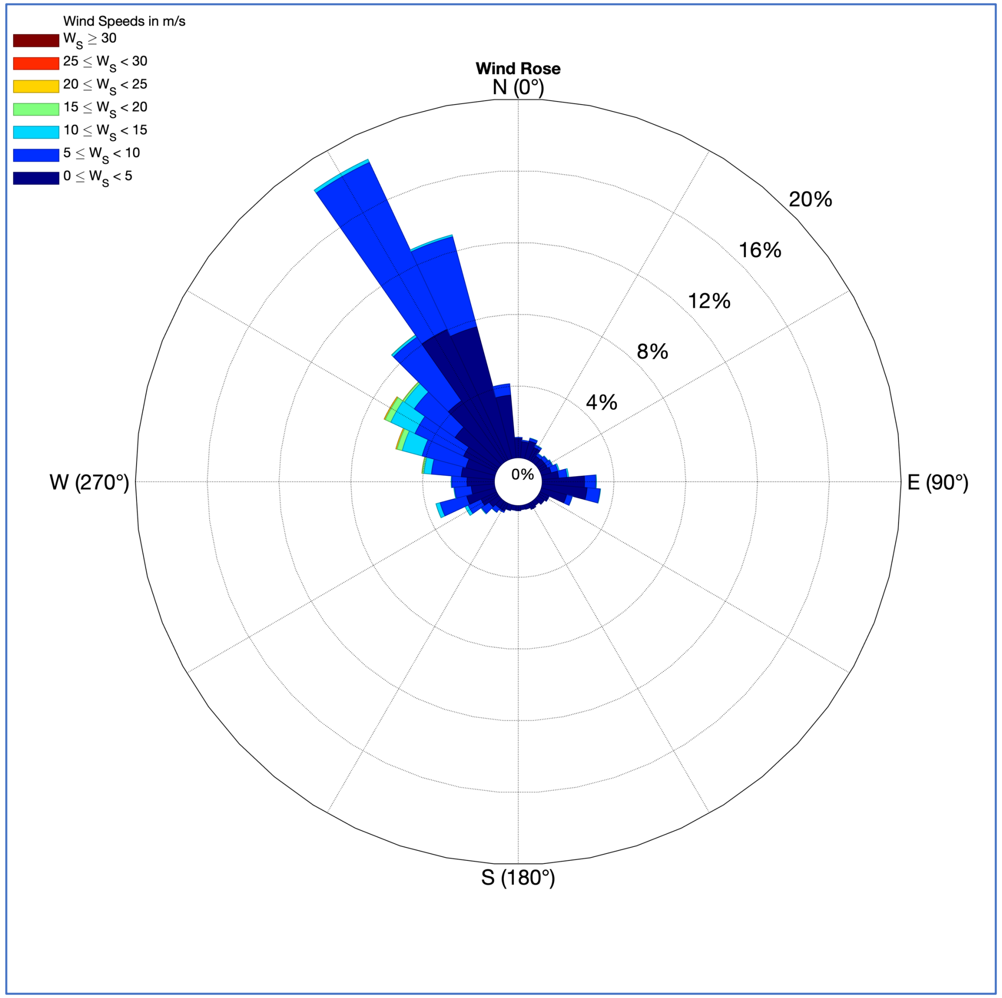




Wind Direction from APEX data (2006-2024)



Prevailing wind direction is from WEST
With higher wind speeds



Prevailing wind direction is from NNW
With lower wind speeds

Precipitable Water Vapoir from APEX data (2006-2017)

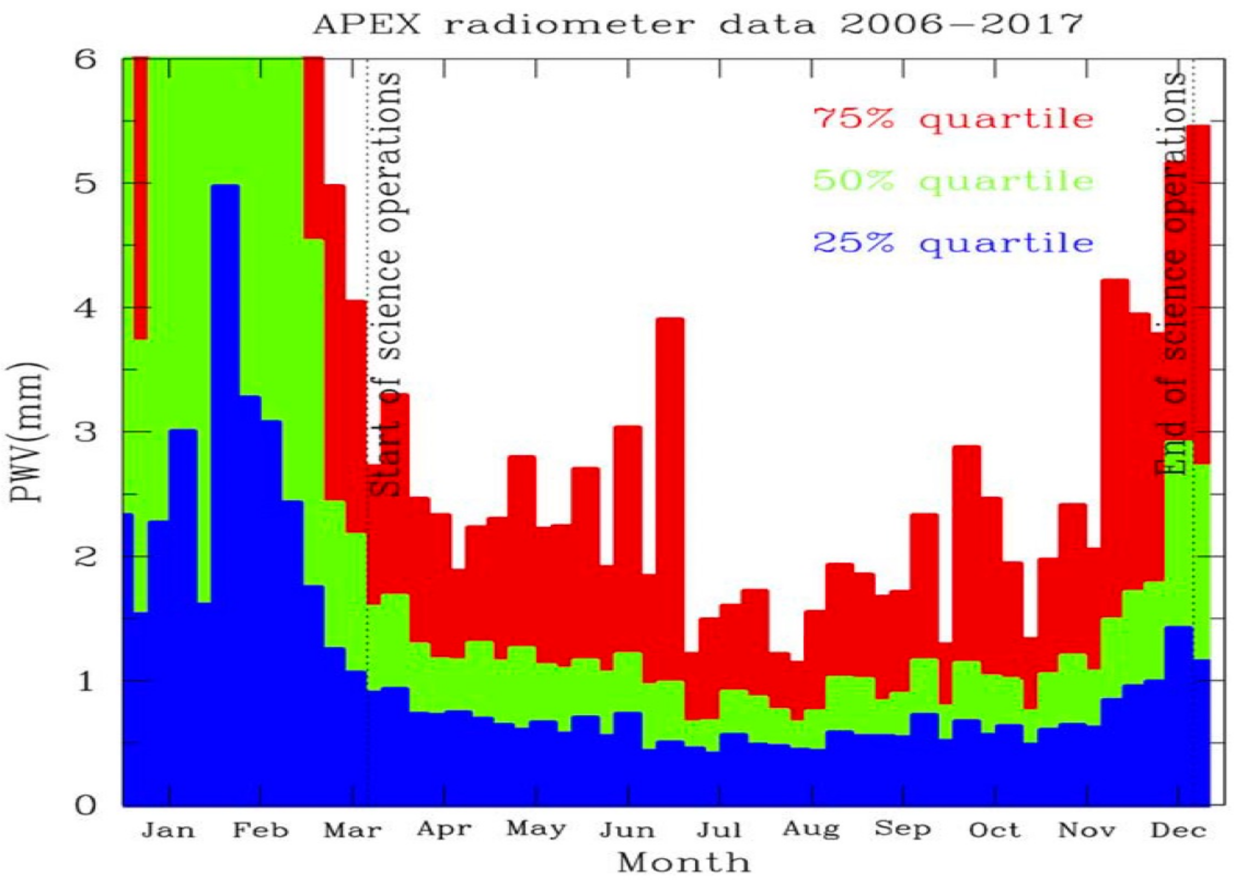


Figure 3. PWV statistics as a function of month at the Chajnantor plateau, as measured using a 183 GHz radiometer at the location of the APEX telescope.

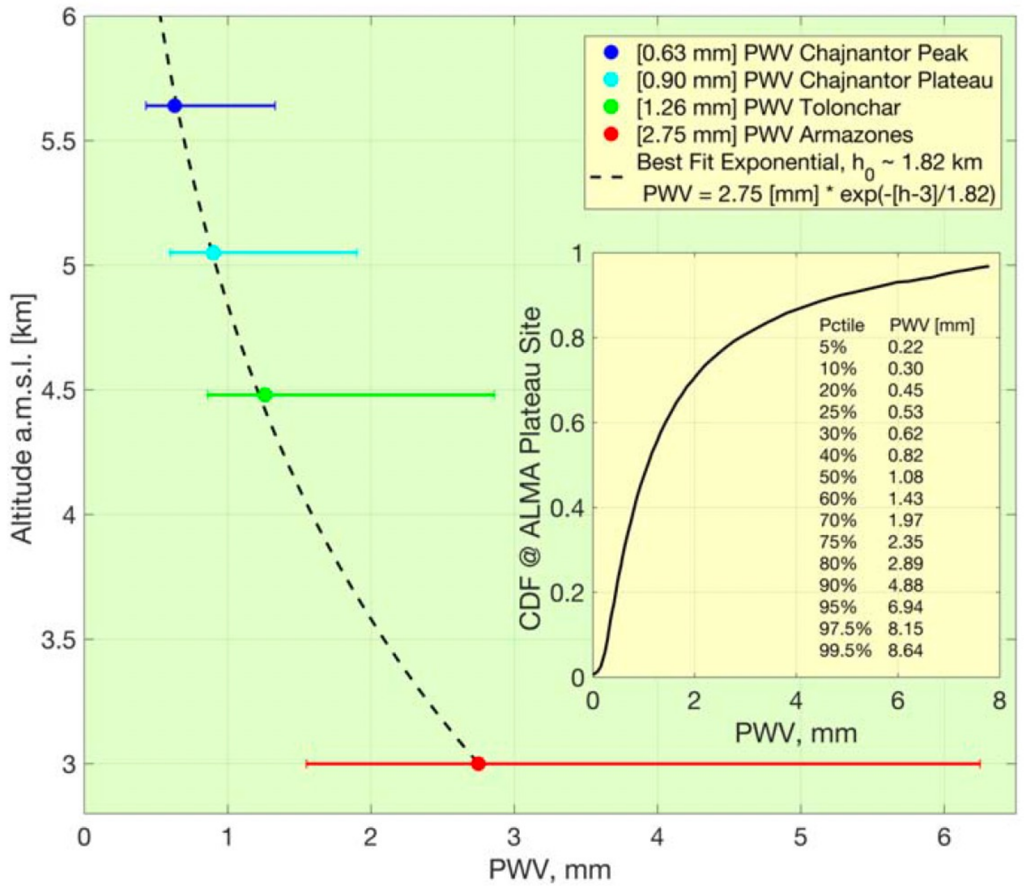


Figure 2. PWV as a function of altitude from 762 radiosondes. The insert shows the long-term statistics of PWV measured at the Chajnantor Plateau. The error bars show the 25 and 75 percentile levels.

Otarola, De Breuck, Travouillon, et al., PASP 2019

Air temperature gradients in 1-hour time scales

- As its expected, the largest temperature gradients are measured during sunrise and sunset times

- *A structure, such as a telescope, exposed to the environmental conditions will be subjected to changes in air temperature*
- *The relevant timescale of the temperature gradients will depend on the thermal inertia of the materials, i.e., their ability to absorb and conduct the heat*

- temperature gradients are found
  - **50% quartile: in the range 0.4 °C/hour to 0.7 °C/hour**
  - **75% quartile in the range 0.9 °C/hour to 1.5 °C/hour**

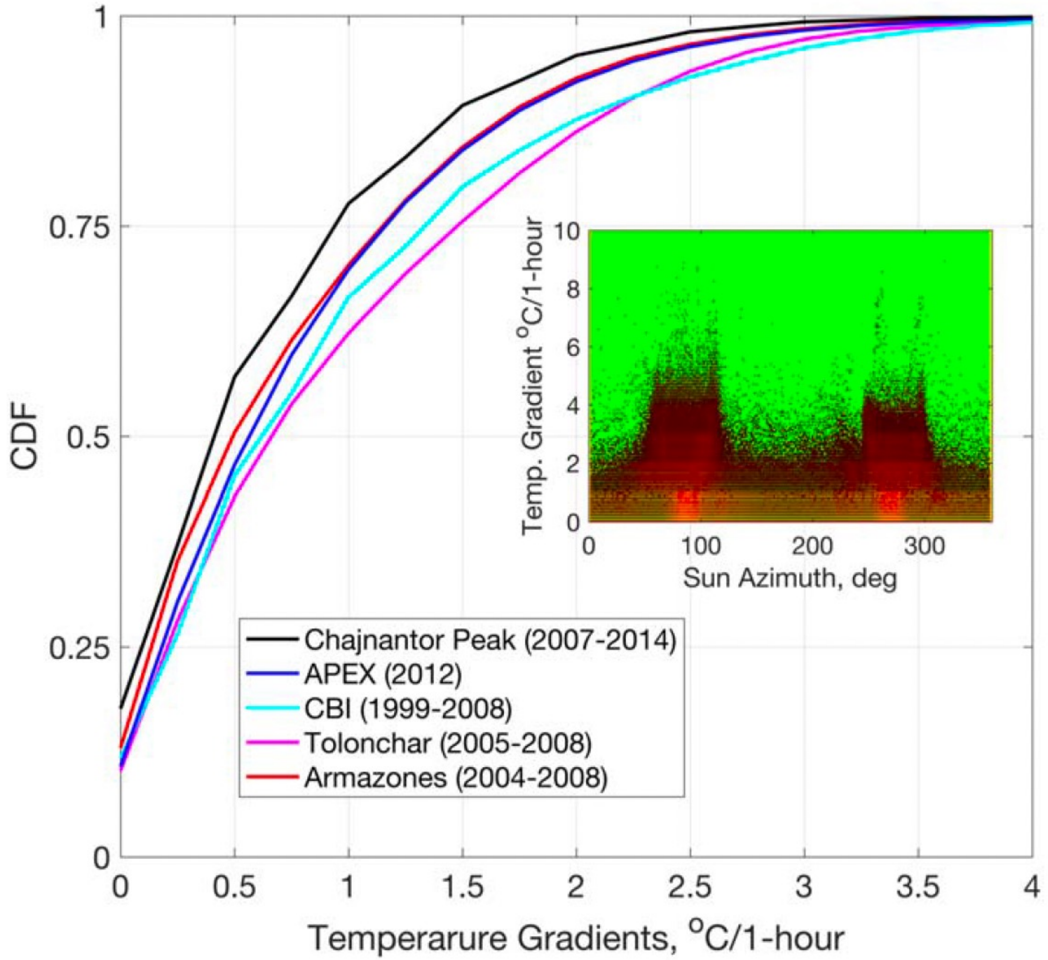


Figure 13. Temperature gradients in 1-hour (sites as shown in Figure 12).

Otarola, De Breuck, Travouillon, et al., PASP 2019

Daily max wind speed: recurrent period

- The **ALMA project book includes the following requirement:**
  - 4.2.1.3 Maximum Wind Velocity: The **antenna must survive 65 m/sec (145 mph) without damage when positioned in its stow position**.

- Our analysis of daily maximum wind speeds, from the Cosmic Background Imager meteorological record shows a maximum wind speed in 50 years of ~ 51 m/s, 55 m/s in 200 years.

- There is a chance of ~64% probability that the maximum speed (expected for 50 years) indeed occur during that period. **There is a chance of 22% that a maximum 200-years recurrent event occur in 50 years period**.

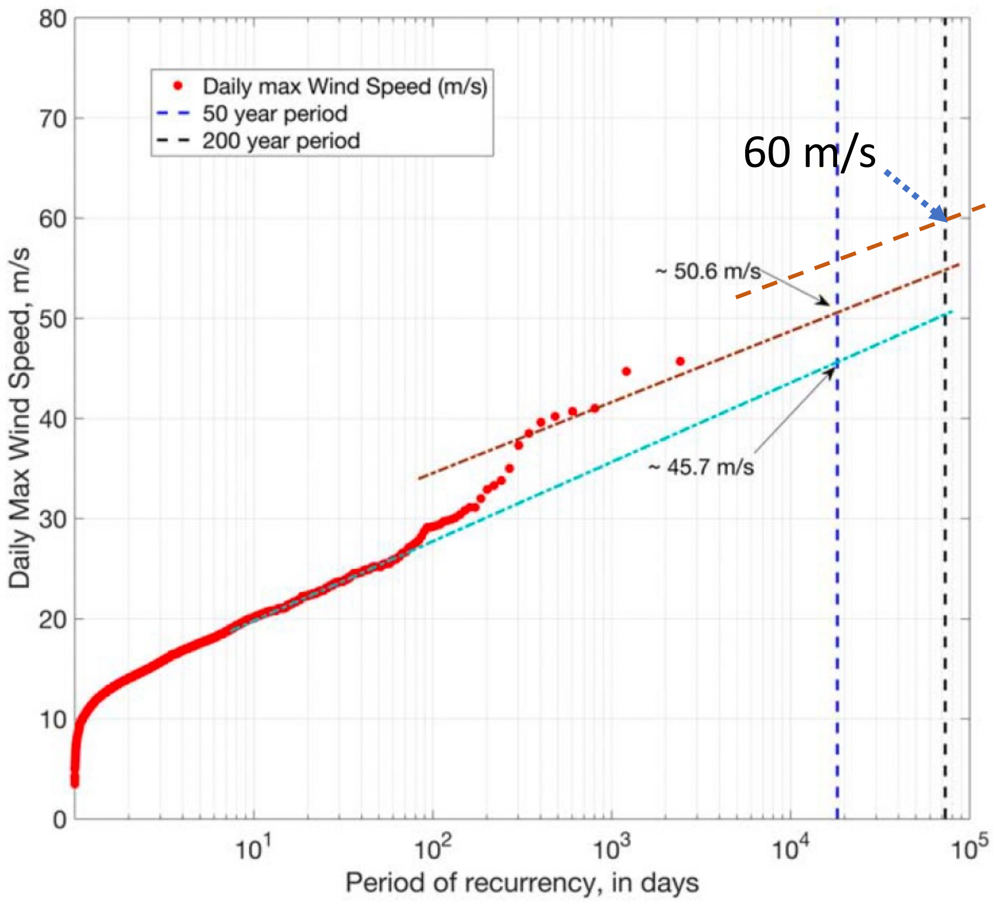
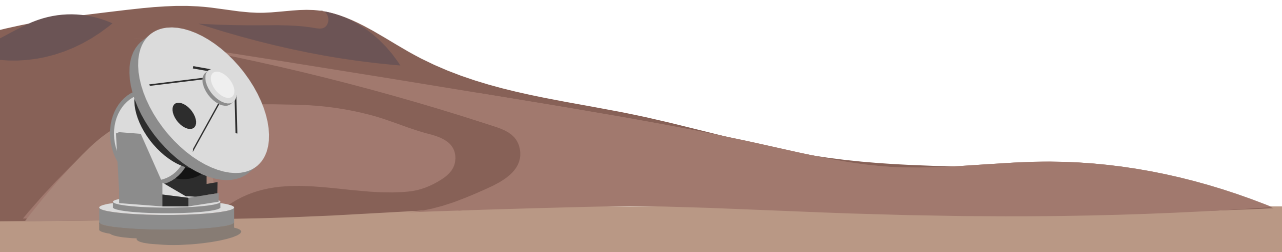


Figure 9. Period of recurrence for daily maximum wind speed at the Chajnantor plateau (CBI site).

Otarola, De Breuck, Travouillon, et al., PASP 2019

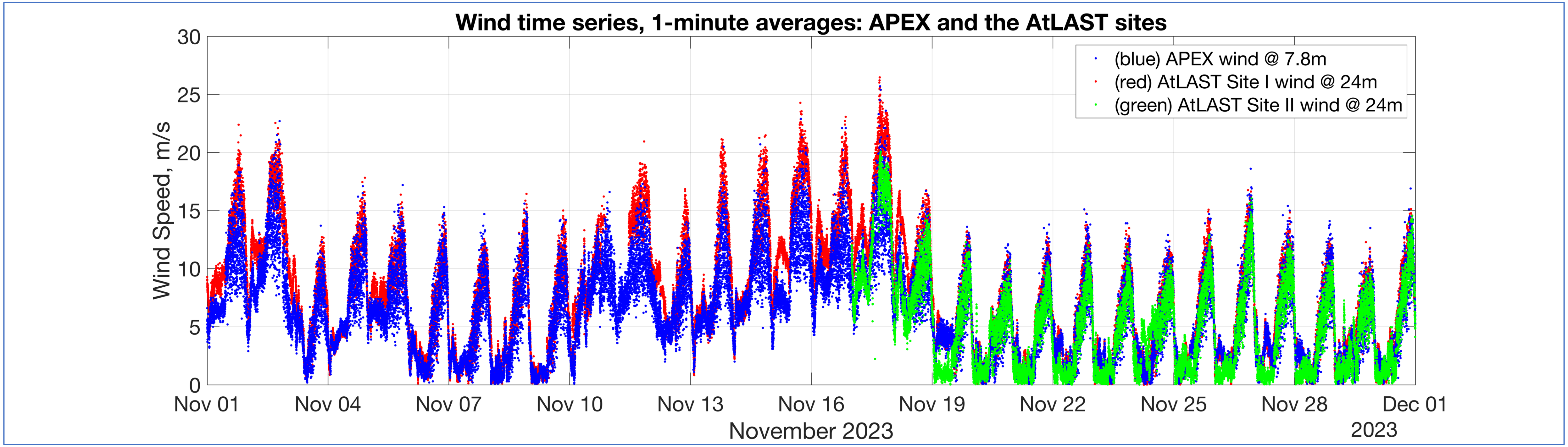
Wind characteristics of the AtLAST Site I and II from preliminary analysis of the data



The APEX and the AtLAST wind for crosscheck

- **Blue : wind speed at APEX measured at 7.8m above ground level**
- **Red : AtLAST site I, measured at 24m level**
- **Green: AtLAST site II, measured at 24m level**

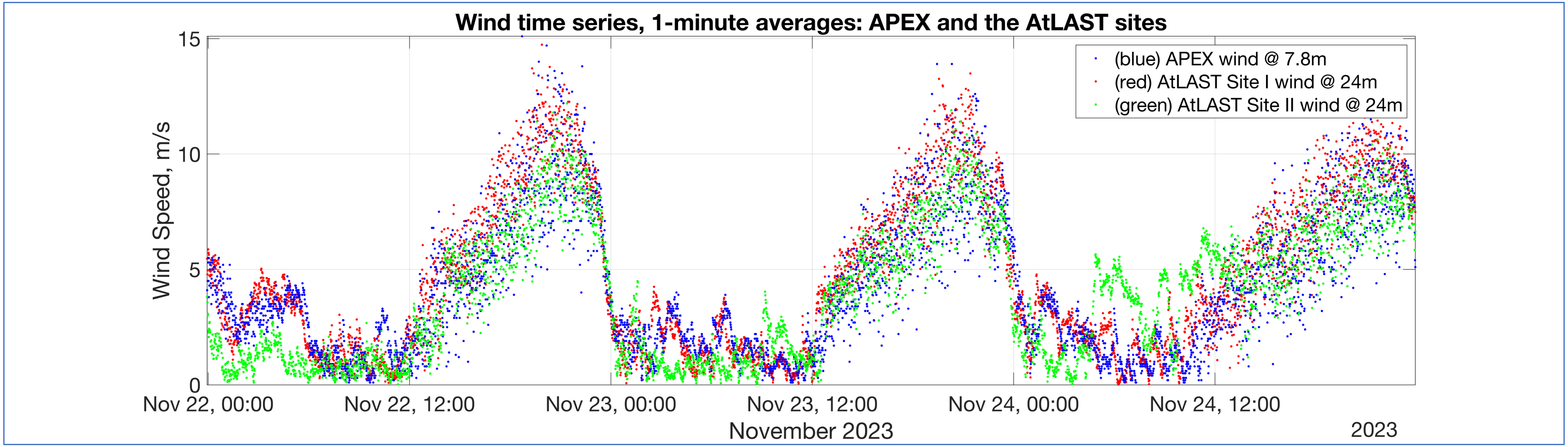
Anemometer working at Site II
since about mid November 2023



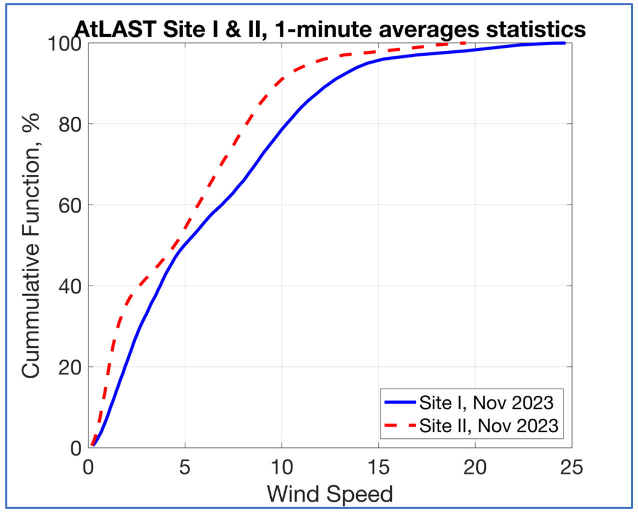
The APEX and the AtLAST wind for crosscheck

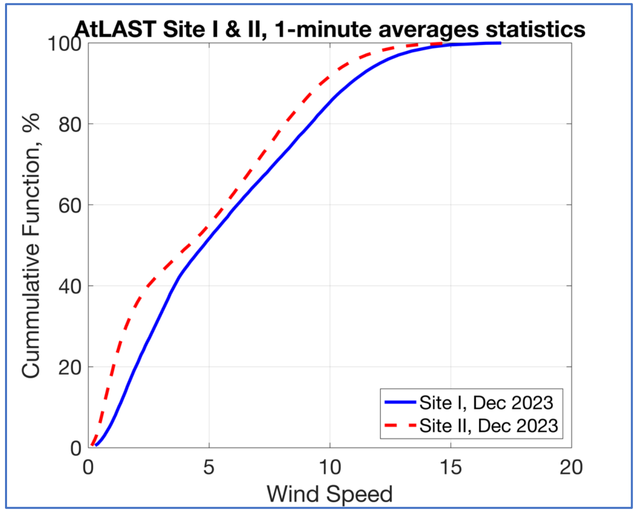
- **The AtLAST Site I and the APEX site follow each other well**
- **The differences seen in Site II at lower wind may be related to a differences in wind direction at nighttime (driven by its location)**

Anemometer working at Site II since about mid November 2023



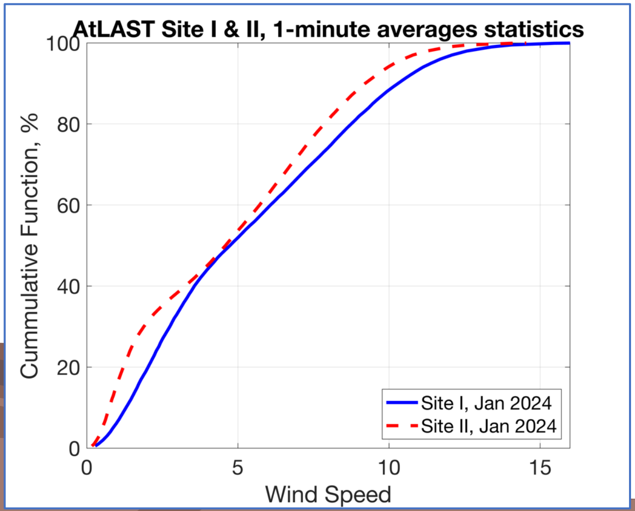
AtLAST Site I and II Wind Speed (1-min averages)

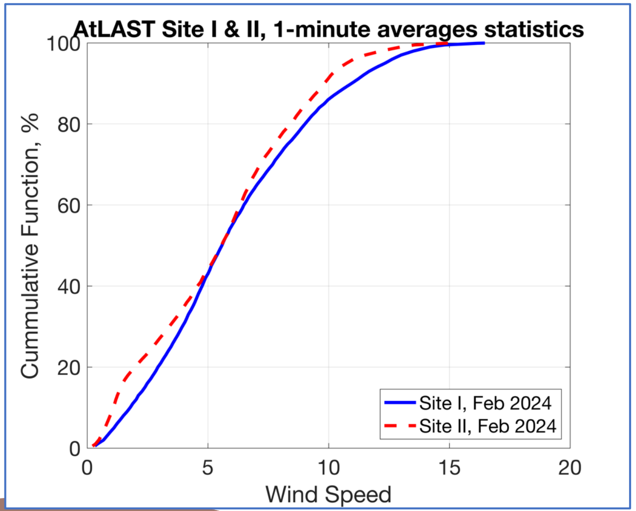


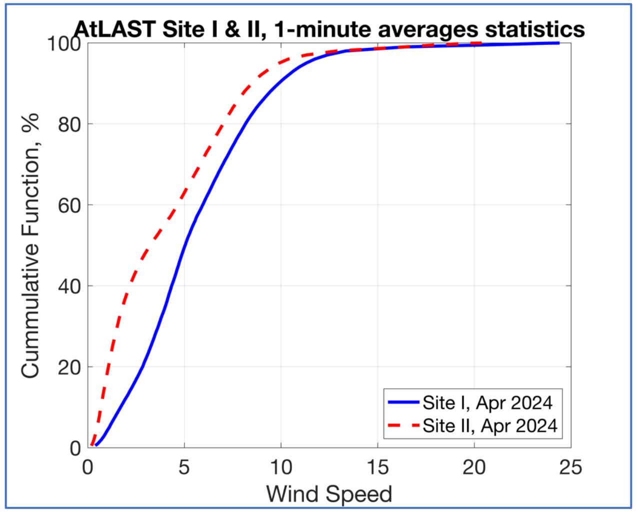


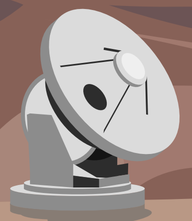
- **In general Site II shows relatively lower wind strength**
- **What matters is the percentage of the time the wind is below a critical value**
  - **For instance, the maximum wind speed for which to achieve an accurate pointing of the AtLAST antenna during science observations**
- **For 9 m/s average wind – the difference between sites can be 5% - 10% range**

Only for data in common periods

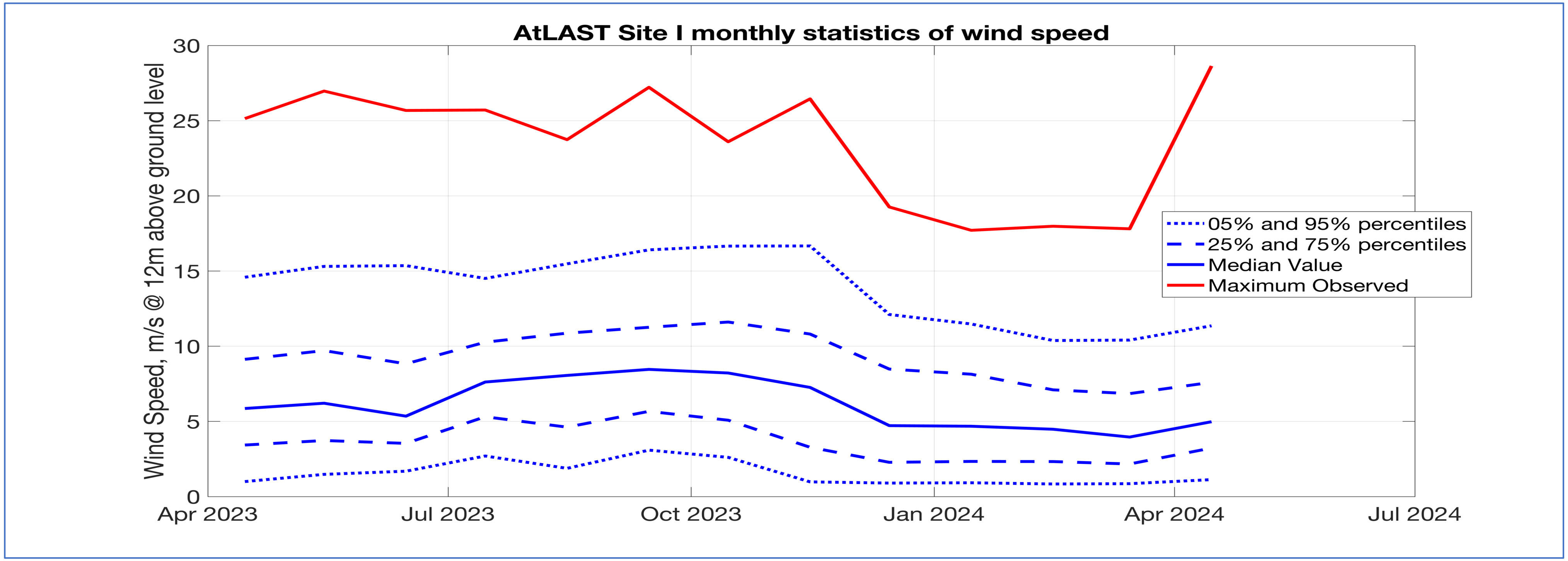








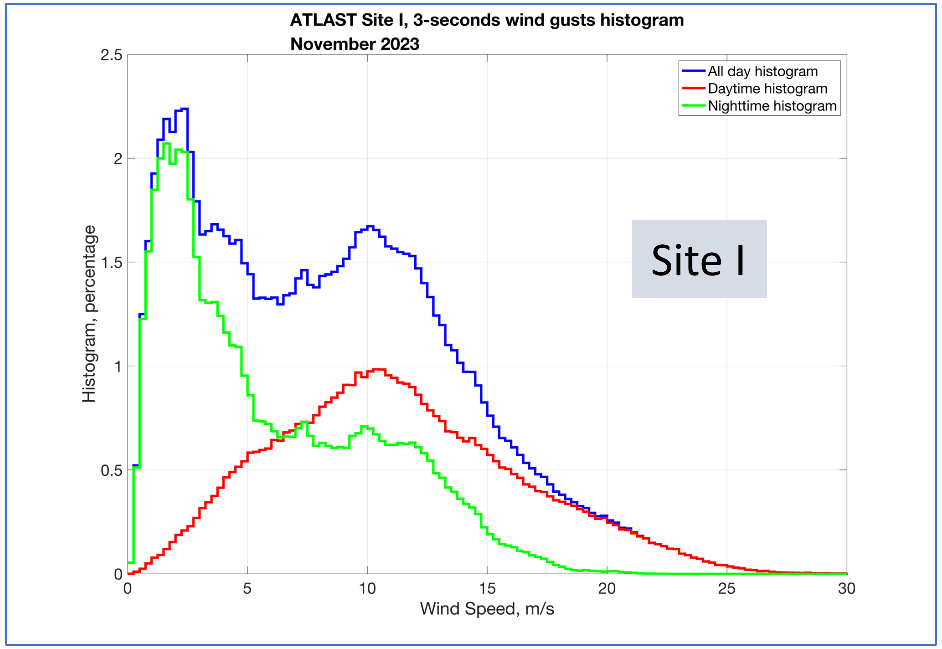
AtLAST Site I annual wind statistics (1-min averages)

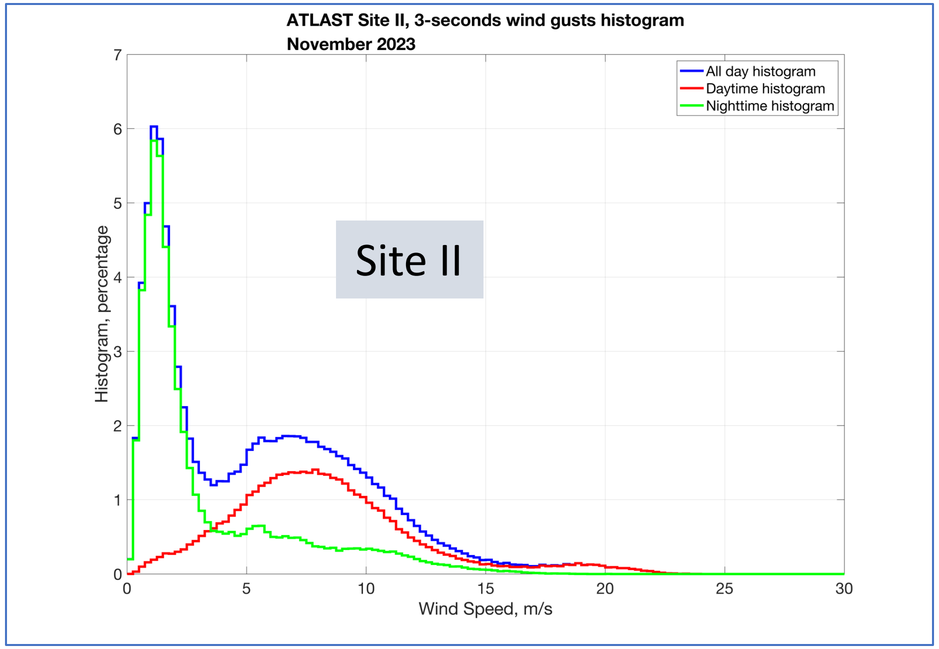


- The RM Young sonic anemometer at 12m above surface level has worked reliably for more than a year already

- **Question: What averaging time will be required to better predict (or define) the AtLAST antenna operational performance?**
  - **X Number of gusts above 15 m/s in a period of 30-min?**

AtLAST Site I and II Wind Histograms (example)





Only for the period in common

- **The histograms shows clearly the effect of two underlying distributions**
  - **daytime, with stronger winds**
  - **nighttime, with mild winds**
- **Site II shows a larger proportion of low-wind condition**
  - **The site is sheltered by the Toco-Chajnantor ridge**

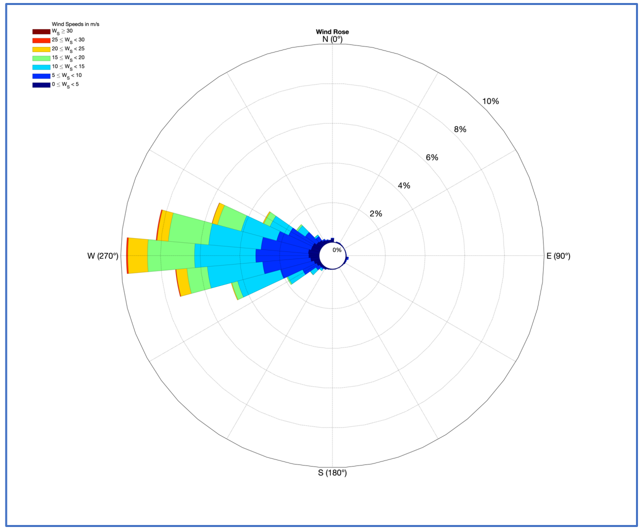
AtLAST Site I and II Wind Direction

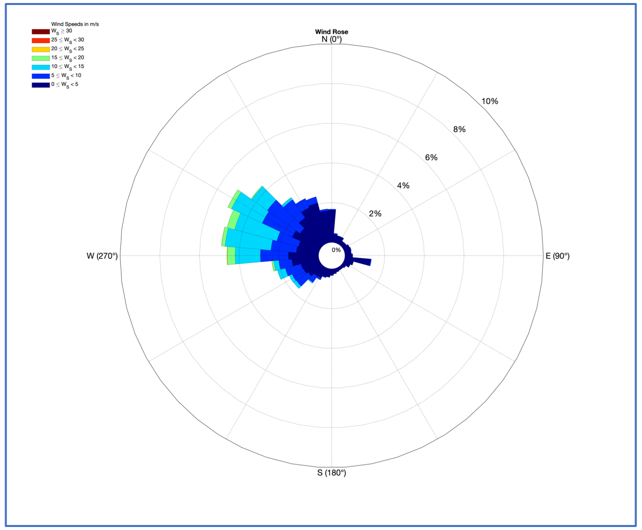
- The **dominant wind condition** at the Chajnantor plateau is **mainly from the West**
- Site shows a somewhat higher larger proportion of higher wind gusts

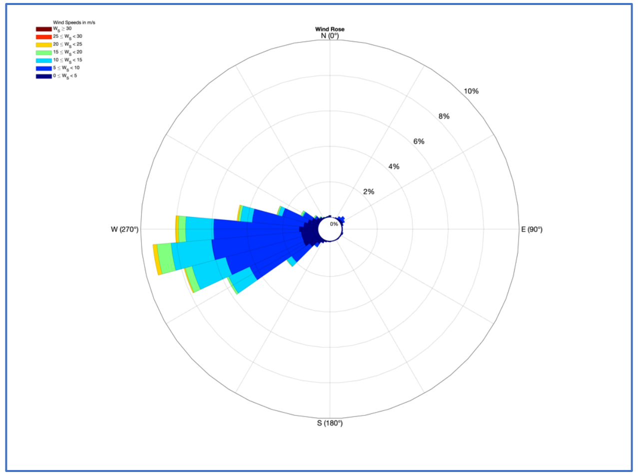
- The Site II shows the clear pattern of wind from the North and Northeast at nighttime
  - **This is likely due to the effect of katabatic winds**. I.e. cold air is denser and runs down the slope of the surrounding mountain ridge

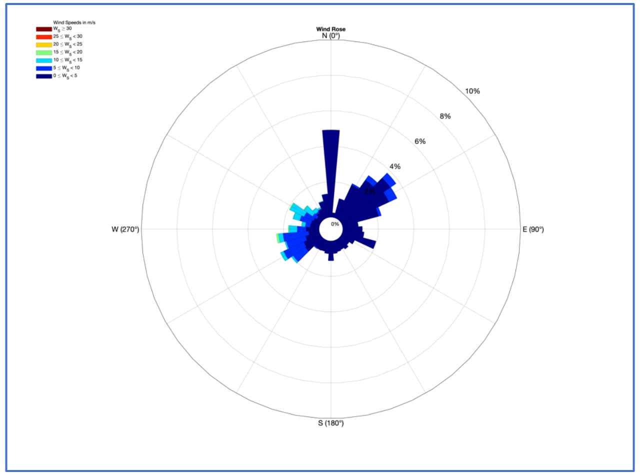
Daytime Windrose

Nightime Windrose









What about the vertical profile of the horizontal wind

Vertical Profile of the Horizontal Wind (This needs a lot more work)

- Site I is equipped with two wind anemometers
    - One located at 12 meters above the surface and another at 24 meters

- The goals is to estimate of how much stronger the wind would be at the height of the AtLAST antenna (35 m or so, for the height of the elevation axis)

- **Ideally, we should have measured the wind speed directly at the height of interest for AtLAST**
    - **The limiting factor was the cost for construction of a taller meteorological tower**

The log wind profile, under neutral atmospheric boundary layer

$$U_h = \frac{u_{*,0}}{k} log\left(\frac{h}{z_0}\right) + \text{phi(h)}$$

All goes down to know the values of u* and z0
And the k constant (from theory), k = 0.4

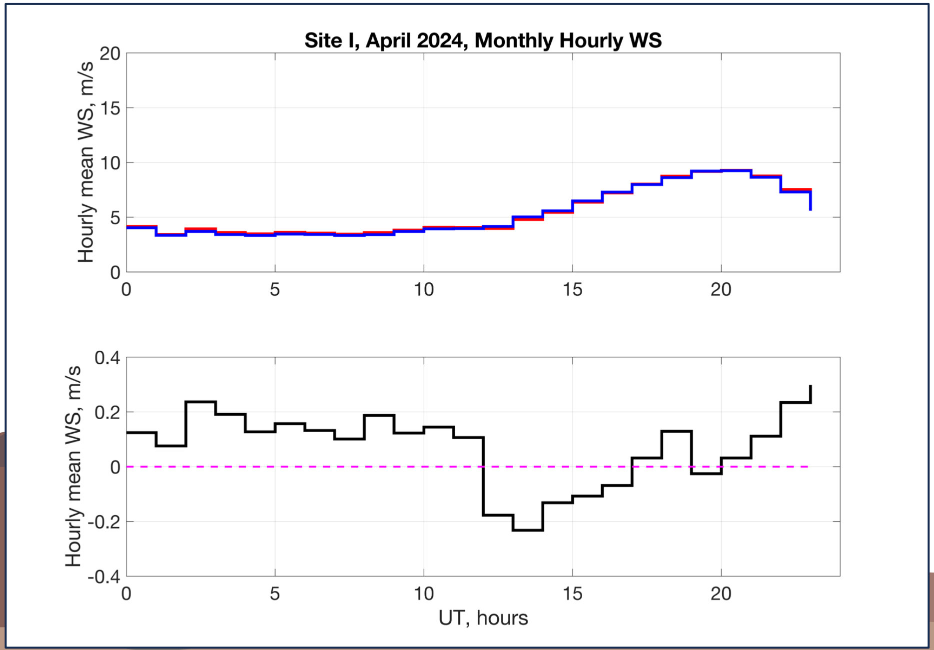
Phi(h) a function needed when temperature profile departs from neutral conditions of the atmosphere

First approach has been to learn the value of the friction velocity from differences in wind speed measured at thhe two heights, 12m, and 24m

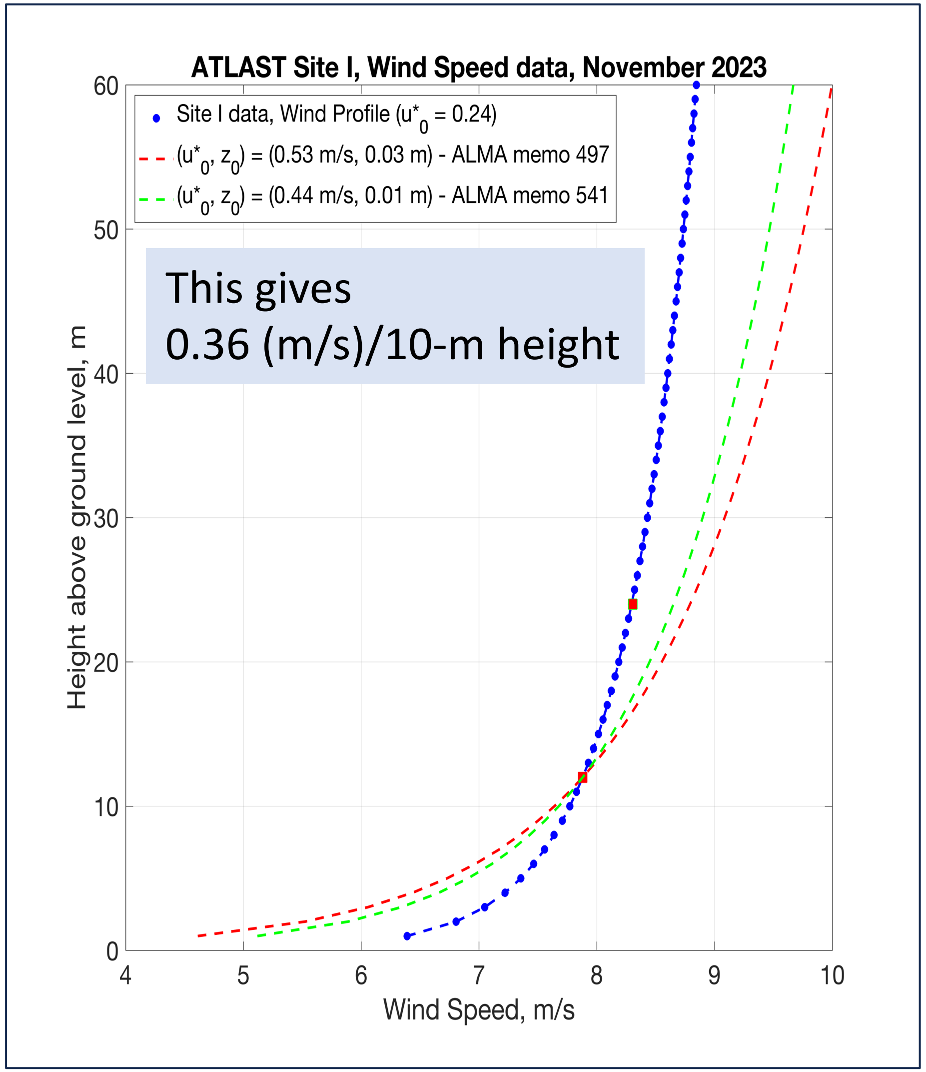
$$u_{*,0} = k \, \frac{U_{24m} - U_{12m}}{\log(24) - \log(12)}$$

Vertical Profile of the Horizontal Wind (This needs a lot more work)

- The data shows that the wind speed measured at 24m is preferably larger than that at 12m during night time hours
  - **But night time is when the wind over the site is lower anyways**
- During daytime, the mean wind at 24m seems 3% lower. This may be due to the fact the logarithmic wind profile only apply during neutral conditions of the atmosphere: not during hours when thermal convection is taking place.



Mean Vertical Profile Month of November, 2023



Vertical Profile of the Horizontal Wind (This needs a lot of more work)

Otarola, De Breuck, Travouillon, et al., PASP 2019

- Vertical profiles of wind from radiosondes
  - Launched from the Chajnantor site

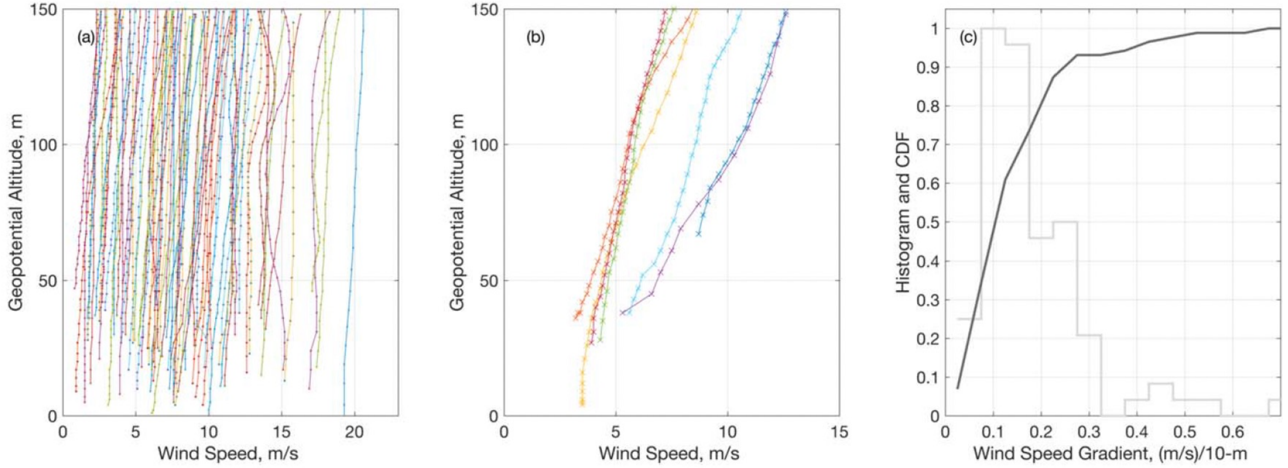
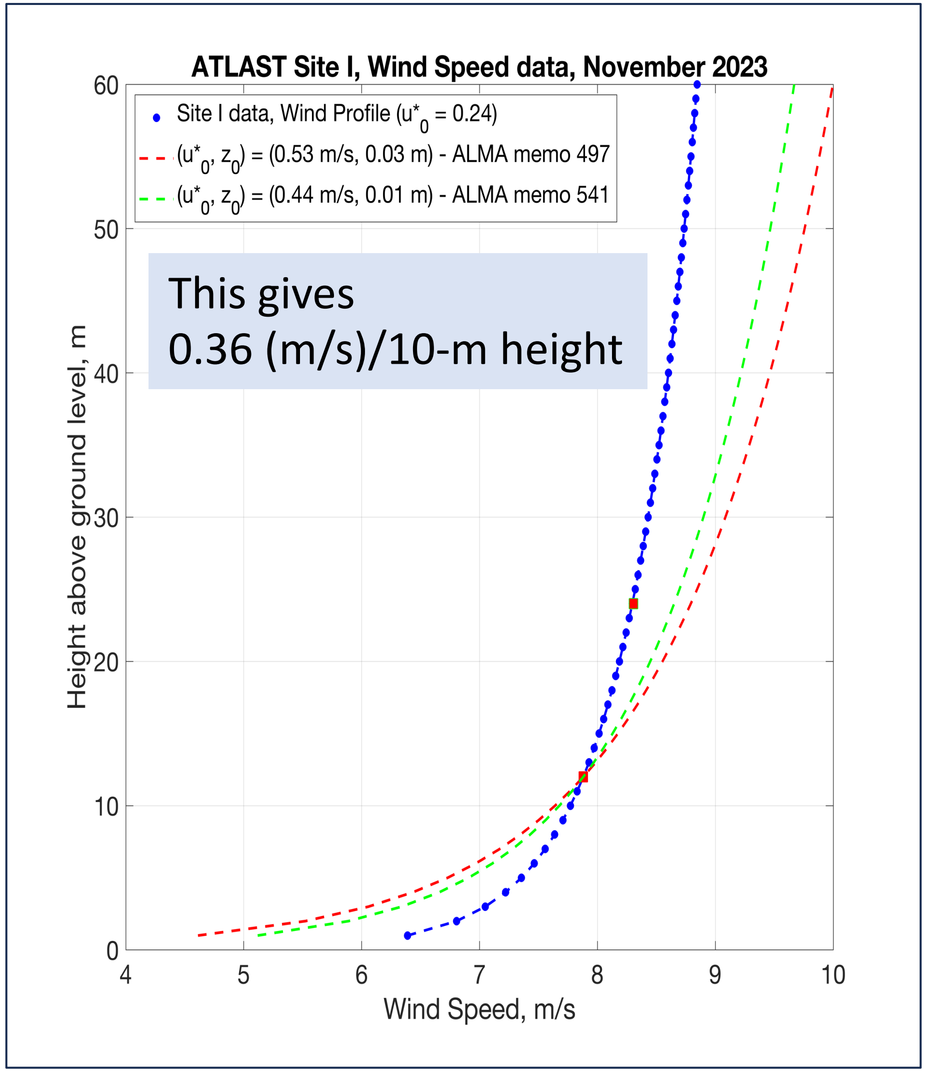
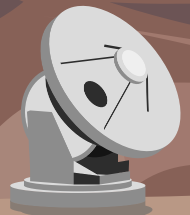


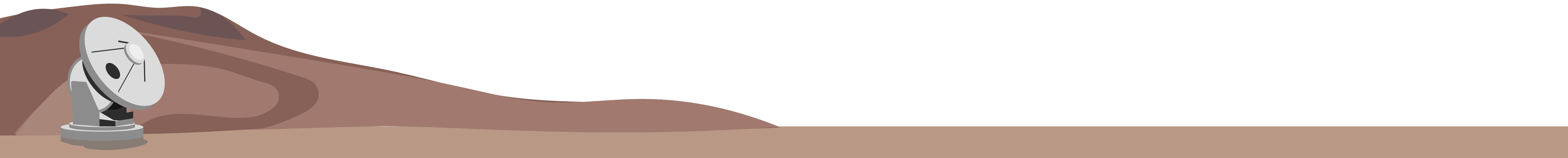
Figure 8. Wind speed as a function of altitude above surface (Chajnantor Plateau) from 122 radiosonde soundings launched in 2000 and 2001. Panel (a) shows the soundings (84 in total) in which the wind speed gradient in the section from surface up to 150 m (above ground level) is positive and up to 0.25 (m/s) per each 10 m of altitude (i.e., wind speed increases with altitude). Panel (b) shows only those cases in which the vertical gradient of wind speed (in the section from surface up to 150 m above ground level) was the largest and higher than 0.25 (m/s) per each 10 m of altitude (6 cases). Panel (c) Shows the histogram and cumulative density function (CDF) of the wind speed vertical gradient in units of (m/s) per each 10-m of vertical distance. The median vertical wind gradient is 0.10 m/s per each 10-m of height. The maximum vertical wind speed gradient from the radiosonde soundings give 0.66 m/s per each 10-m of height.

Out of 122 soundings
84 showed a positive increase of wind
38 showed a neutral or negative vertical gradient

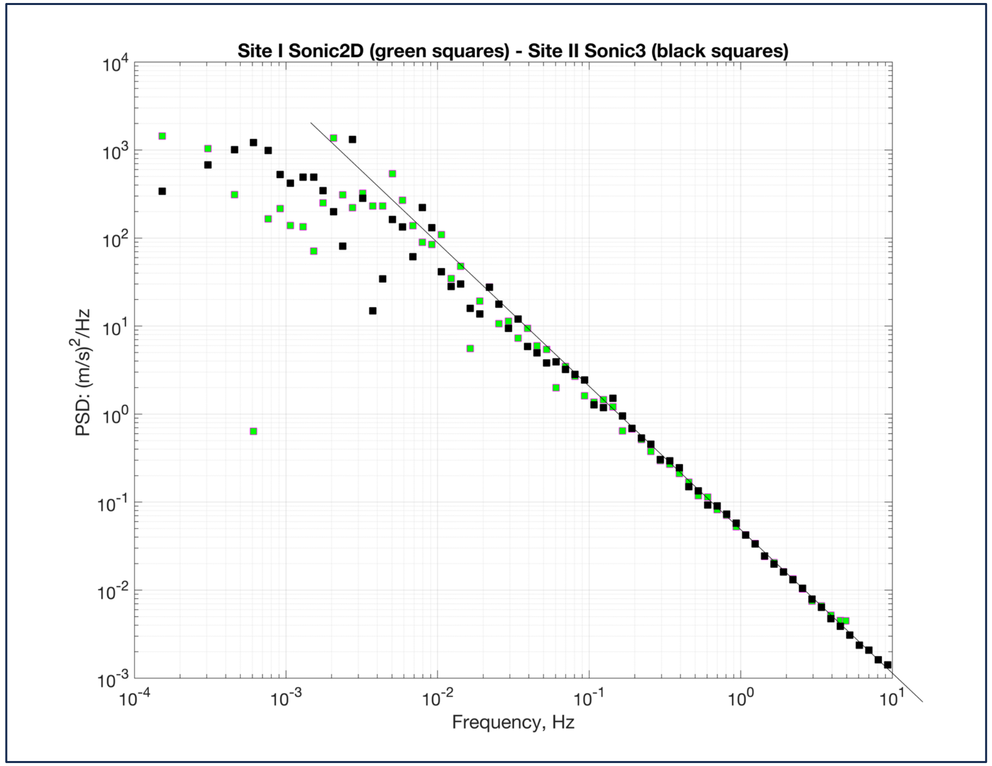




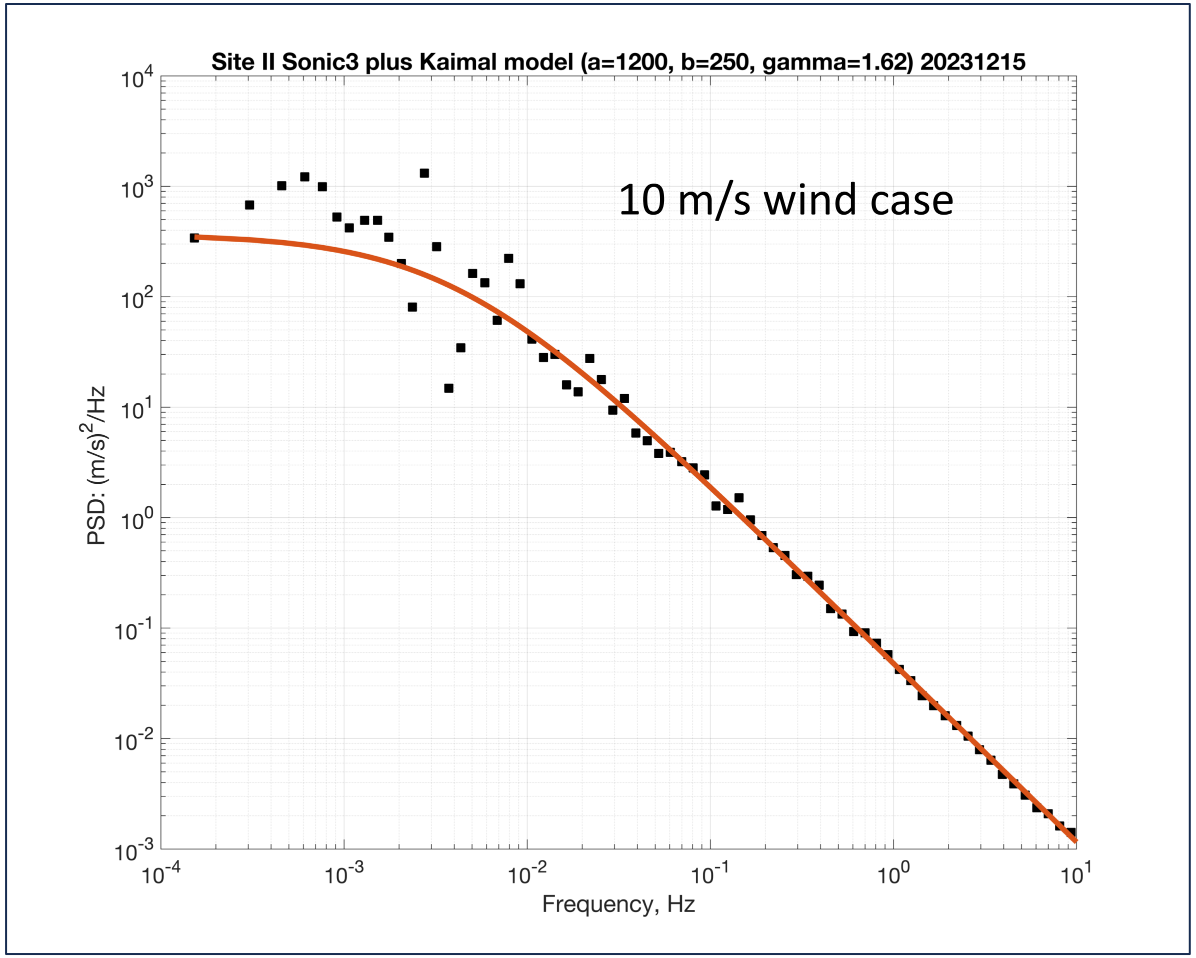
The power spectral density of wind speed



Site I & Site II: using sonic 2D and 3D anemometers



The power spectral density out of the wind speed of the 12-m (Site I), and 24-m (site II) height anemometers match quiet well.



$$S(z = 24m, f) = \frac{u_{*,0}}{f} \frac{1200f}{(1 + 250f)^{5/3}}$$

Main Conclusions (so far)

Conclusions

- Temperature conditions range from -20 to 15 Celsius degrees
- Coldest period is June thru August (not wonder, is the austral wintertime)
- The windiest period is May thru September: the 75% of wind speed is already ~ 11 m/s (daytime)
- The wind speed trend for APEX, AtLAST Site I and II agree well, differences are attributed to spatial location
- In general, the wind speed of Site II is somewhat lower than in Site I
  - So far, the fraction of data below 9 m/s is larger at Site II when compared to Site I
  - **However: A full year of data would be required to make a better assessment**. At Site II data from the windiest month has not been obtained yet
- During daytime, the prevailing wind-direction at Site I and Site II is from west
  - Site II differs in prevailing wind direction at nighttime – is likely dominated by downslope flow a nearby mountain ridge
- Regarding the vertical profile of the horizontal wind speed (Site I)
  - The data needs more analysis, the average profile of November 2023 can be modelled with an increase of 0.36 (m/s) per each 10-m. Implying the mean wind at 35 m height could be ~0.8 m/s larger than what we measured at 12m
- **The power spectral density of the horizontal wind speed seems well behave. We need to look at a large amount of data as to obtain a model that can be used for engineering finite-element-model analysis**

ALMA Antenna requirements: for reference

- 4.2.1.3 Maximum Wind Velocity: The antenna must survive 65 m/sec (145 mph) without damage when
- positioned in its stow position.
- 4.2.1.4 Temperature: The antenna must operate correctly in the temperature range -20 C to 20 C. It must survive without damage the range -30 C to 40 C. The annual average temperature on the site is -4 C
- 4.2.1.5 Precipitation: Annual precipitation on the site is in the range 10 cm to 30 cm per year. Most of this falls as snow but thunderstorms do occur and so brief periods of heavy rain and hail are possible. The antenna must be designed to survive, without damage, the following conditions: maximum rate of rainfall 5 cm/hr, hailstones 2 cm diameter at 25 m/s, snow load 100 kg/sq.m on reflector surface, radial ice on a exposed surfaces 1 cm. Surface heating to prevent snow and ice buildup not required.
- 4.2.1.6 Humidity: The monthly average humidity in the summer (January) is 53% and in the winter (June) it is 31%. The annual average is 39%. The monthly average water vapor pressure in the summer (January) is 4.0 hPa (4 gm/sq.cm) and in the winter (July) it is 1.2 hPa. The annual average is 2.3 hPa.
- 4.2.1.7 Insolation: The site location on the southern tropic, the high altitude and low water vapor result in insolation rates amongst the highest in the world. The median midday solar flux in the wavelength range 0.3-60 micrometers for the months of December and June are 1290 w/sq.m and 840 w/sq.m respectively. Ultraviolet radiation will be approximately 70% higher than at sea-level.
- 4.2.1.8 Lightning. Thunderstorms occur on the site so the antenna must be equipped with a lightning protection system

- 4.2.6 Pointing Accuracy
- A pointing accuracy in "offset" pointing mode (calibrator 2 deg away every 15 minutes of time) of 1/30th primary beamwidth rms at 300 GHz is required. The antenna specification is 0.6 arcsec RSS for offset pointing, 2.0 arcsec RSS for absolute pointing. At night this accuracy is to be achieved in a wind of 9.0 m/s which is the 90th percentile wind for nighttime (2000 hrs to 0800 hrs) observing. During the day this accuracy is to be achieved for any orientation of solar illumination in a wind of 6 m/s