Maunakea and the Roque de Los Muchachos sites: Dry events statistics, atmospheric transmission and atmospheric radiance, a comparative study

THIRTY METER TELESCOPE

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Introduction

Precipitable water vapor measurements (PWV) at Maunakea, and the Observatorio Roque de los Muchachos (ORM) have been analyzed to learn the occurrence of dry, PWV < 2 mm, content in the atmospheric column. Additionally, we used the reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) database to independently characterize the circulation of dry air conditions at the ORM observatory site. Adequate forecasting of the dry events can help in support of adaptive queue scheduling of astronomical observations in the infrared, at bands susceptible to strong atmospheric absorption, or sensitive to high thermal background, such as M and L bands. Thus allowing a higher scientific productivity of TMT. A comparison of the dry events statistics, as well as atmospheric transmission and atmospheric radiance is provided for the two potential TMT sites. **The 13N site for TMT at Maunakea is located at 4.050 m altitude, while the alternate site at ORM is at about 2.250 m altitude in the island of La Palma in the Canary Islands.**

A limiting factor in the observation at mid-infrared wavelengths (3 μm to 26 μm) from ground-based observatories is the water vapor in the atmosphere. Due to water vapor absorption and added noise in the detectors from atmospheric thermal emission.

Methodology

PWV ≤ 2 mm statistics:

- Surface weather parameters data (T, P, RH), gathered at the Nordic Optical Telescope, Observatorio Roque de los Muchachos (ORM) site, in the period 1997-2016 were used to compute the surface water vapor density (rho_w). The value of rho_w multiplied by a water scale height (h_0=1.8km) allows an estimation of precipitable water vapor (PWV). This assumption is valid if the upper atmosphere layers are couple or correlated with the surface layer. When a long enough data series of PWV is not available, and the sites are dry and free of extensive and tall vegetation, this procedure can be used to infer PWV (Otarola et al., 2010).
- In a second step, this data set was examined to identify all those periods when the proxy-PWV was at or lower than 2 mm and for at least two consecutive hours.
- In a final step, the total number of hours in a given month, in the period 1997-2016 were added up. This provides an input as to understand:
  - a) **The frequency of dry period (with PWV ≤ 2 mm) for at least 2 continuous hours, and**
  - b) **How that frequency changes through the year**.

Since both, the 13N site in Maunakea and the ORM site in the Canary Islands, are of interest as potential sites for the TMT, the PWV data series as inferred from measurements of the 225 GHz optical depth at the SMA site in Maunakea, was used to estimate the same statistics as listed in the bullets a) and b) above. This allows to compare both sites with respect to the frequency of dry periods.

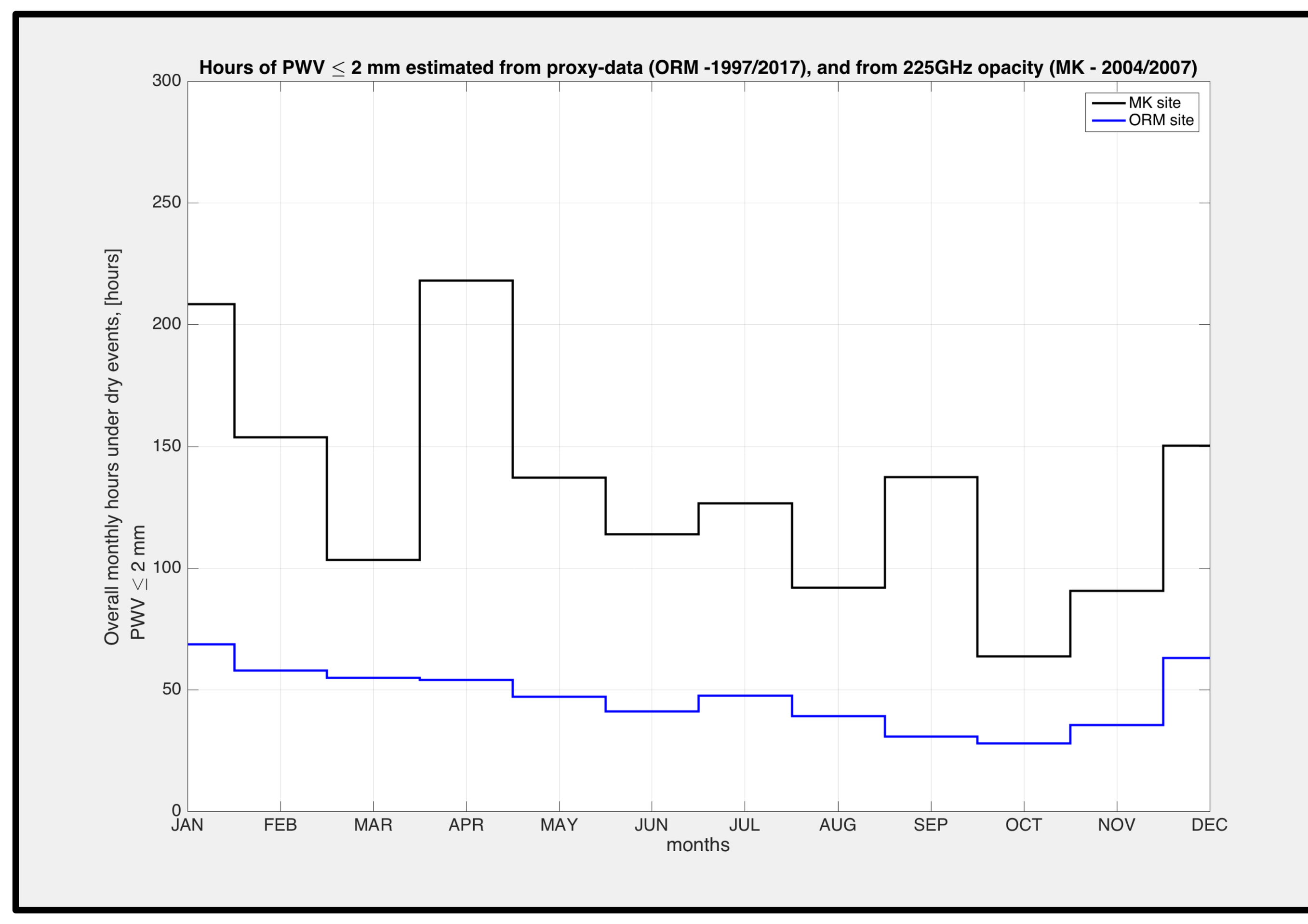
Atmospheric Radiance in the L', M', N and Q bands

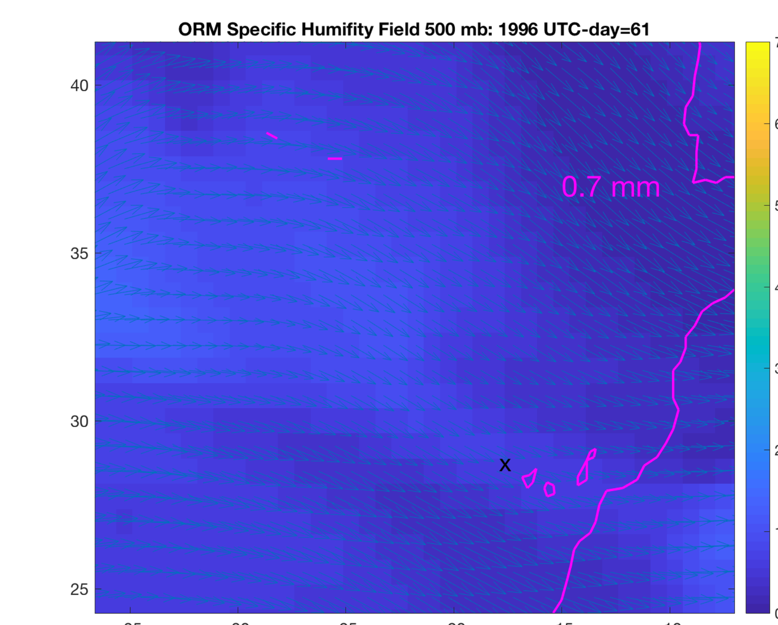
- For the second part of this study, the radiosonde soundings launched from nearby sounding stations (Quimar in Canary Islands, and Hilo in Hawai'i) were analyzed to produce monthly and annual means of the vertical profile of T, P and water vapor density.
- This information was fed into a layer-by-layer line-by-line radiative transfer model (NIRFIRmod) of the Earth's atmosphere, and used to compute the atmospheric radiance in various spectral bands of interest in the mid-IR.
- Comparative results for both sites are presented.

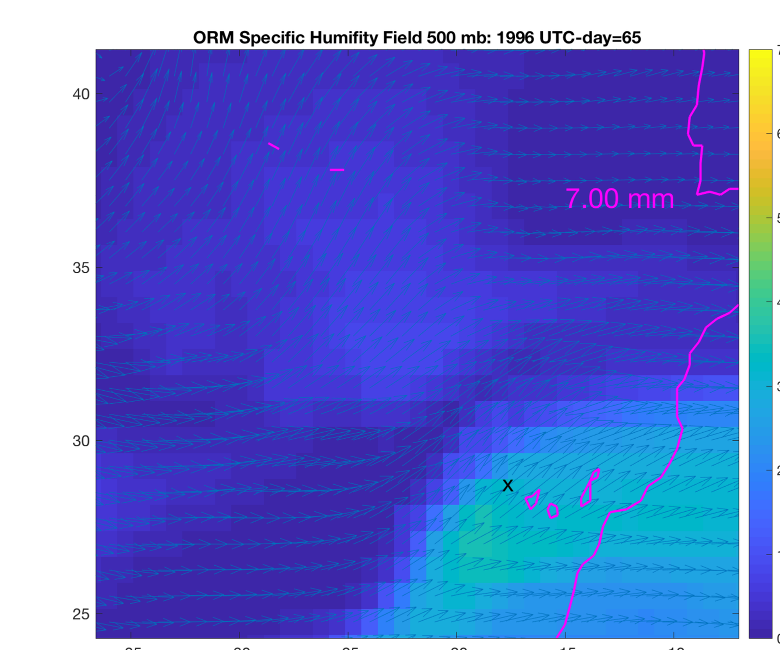
References

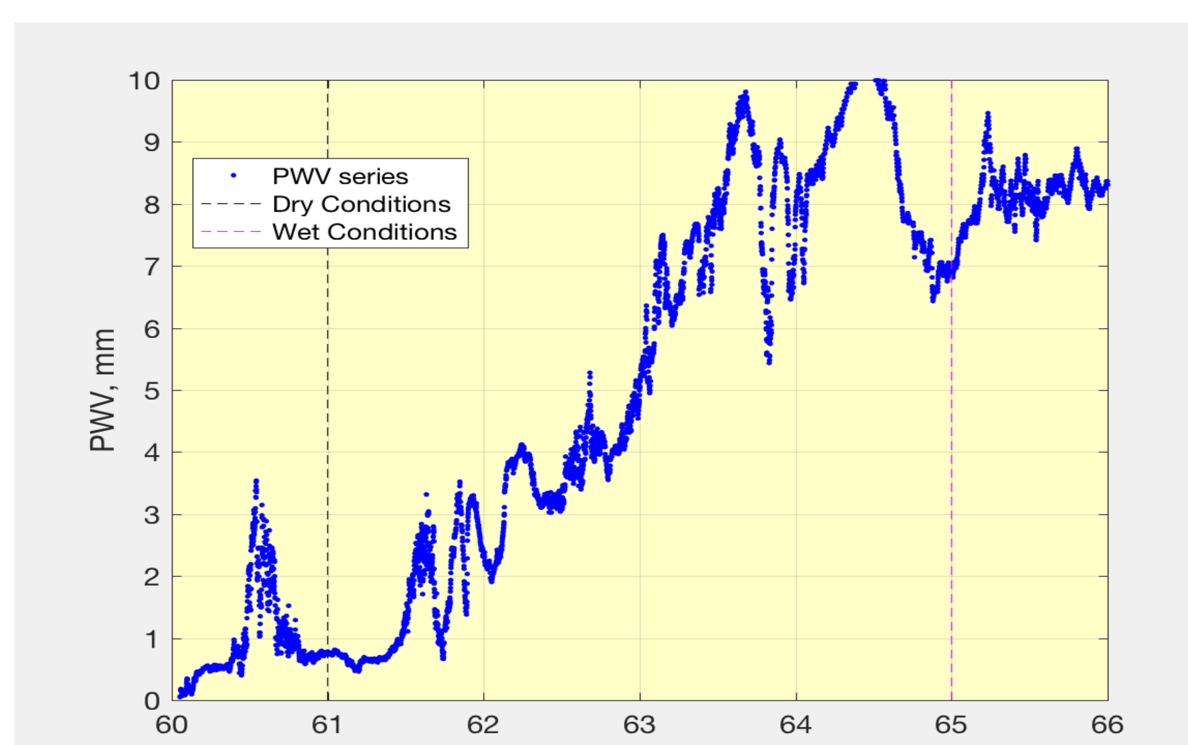
Otarola et al., PASP, **122** (2010)
Otarola, A., Richter, M., Packham, C., and Chun, M., J. Of Physics: Conference Series (2015)
Pérez-Jordán et al. MNRAS, **452** (2015)
Tokunaga, A.T., Simons, D.A. and Vacca, W.D., PASP, **114** (2002)

Statistics of low PWV at the ORM and Maunakea sites





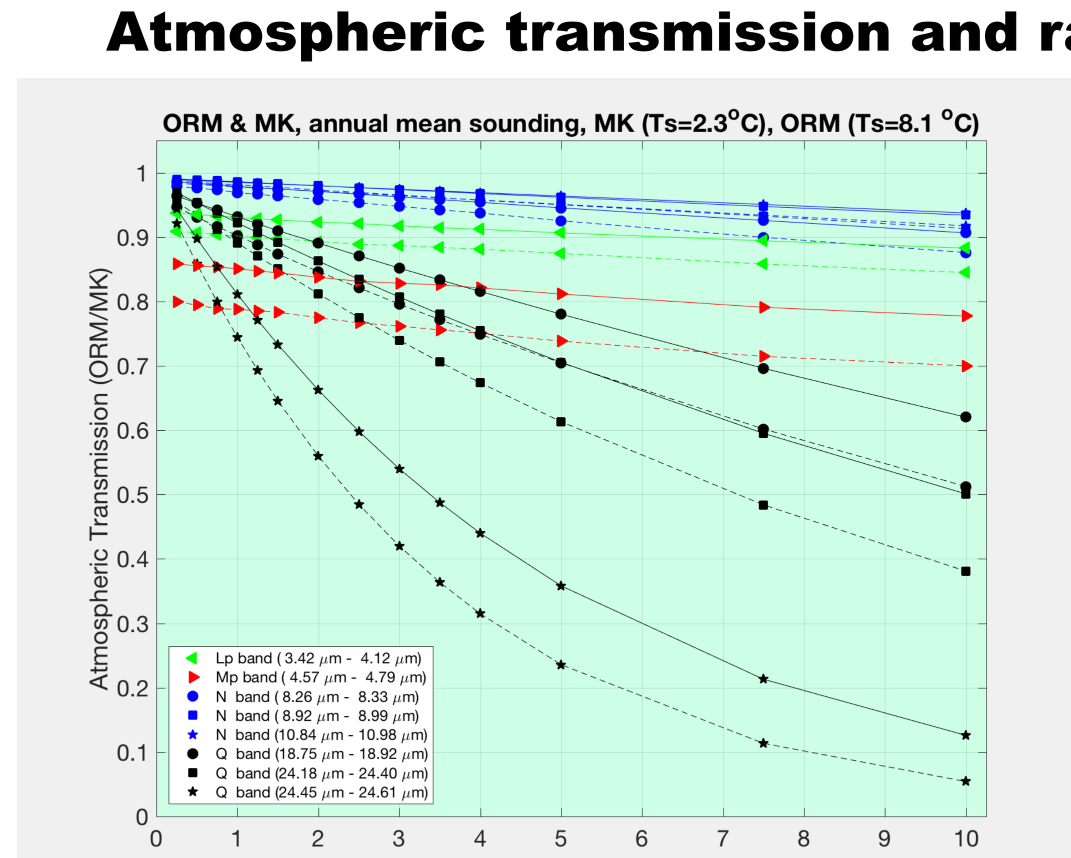


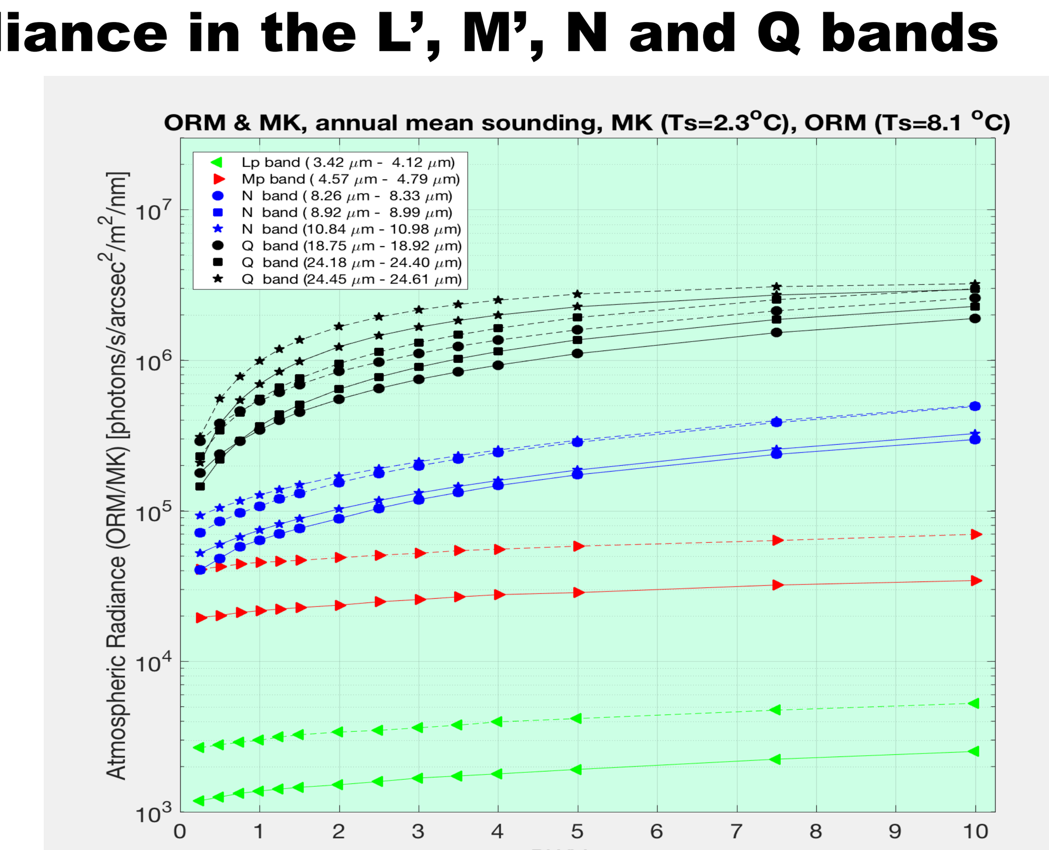


Similar conditions of dry and wet flow have been investigated for the Maunakea site, where cold/dry conditions are typical of flow from the northern latitudes (NE), while warm/wet conditions occur for SW mean atmospheric flow (Otarola et al., 2015).

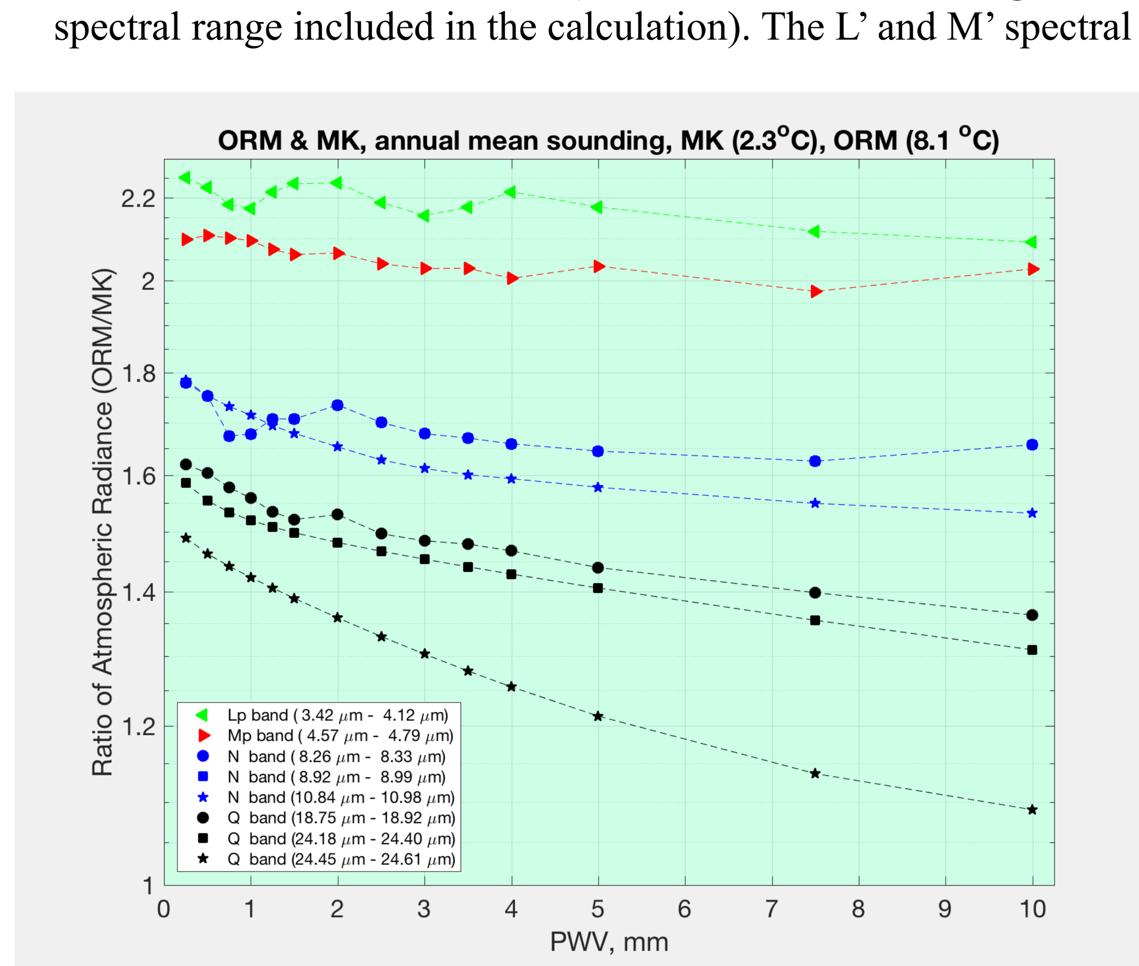
Can the dry events be forecasted?
Indeed, this example shows a period with a substantial change in PWV. We looked at the 500 mm specific humidity field (extracted from the ECMWF database) for two days, March 1st and March 5th, 1996, that show a dry and wet case, respectively.
Is quite clear to see that dry (and likely cold) conditions arise at the ORM site when the mean flow is from NE, while wetter and likely warmer conditions take place when the mean flow is from SW. An ongoing effort for Adequate PWV forecasting at ORM is reported in the Work of Pérez-Jordán et al., (2015).

Atmospheric transmission and radiance in the L', M', N and Q bands





A multi-layer, line-by-line radiative transfer model (NIRFIRmod, Otarola et al., 2015), updated with the HITRAN spectral lines information as 2016, including the most abundant Earth's atmospheric molecules (all isotopes of H_2O, CO_2, O_3, CH_4, N_2O, CO, O_2) was used to compute the median for the atmospheric transmission and atmospheric radiance, **at zenith**, at various spectral bands of interest in the mid-IR (**solid lines/Maunakea**; **segmented lines/ORM**, see insert in the figures for details of the spectral range included in the calculation). The L' and M' spectral range as defined in the work of Tokunaga et al. (2002).



How the ORM and Maunakea sites compare?
In the L' and M' spectral bands, the atmospheric radiance is is about a factor of 2.1 higher than at Maunakea.
This is explained chiefly by the lower elevation of the site (i.e. thicker atmosphere) as well as the larger background temperatures. The ratio of atmospheric radiances in the N band (less prone to the effects of atmospheric absorption, as show in the transmission plot) is about 1.7 larger at ORM. However, the Q bands, due to strong water vapor absorption, are only open for exceptional dry (PWV < 2 mm) and cold conditions that occur about 20% in the winter time, while at the Maunakea site (because of its higher altitude) occur about 50% of the time.

LMN bands observations can be successfully carried out at both locations and can be optimized with the help of a suitable mesoscale weather forecasting tool together with adaptive queue scheduling. Thus, helping to maximize the scientific productivity of TMT.