# Giant Magellan Telescope Site Testing Summary

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**Abstract:** Cerro Las Campanas located at Las Campanas Observatory (LCO) in Chile has been selected as the site for the Giant Magellan Telescope. We report results obtained since the commencement, in 2005, of a systematic site testing survey of potential GMT sites at LCO. Meteorological data (cloud cover, temperature, pressure, wind, and humidity) and DIMM seeing data have been obtained at three potential sites, and are compared with identical data taken at the site of the twin Magellan 6.5m telescopes. In addition, measurements of the turbulence profile of the free-atmosphere above LCO have been collected with a MASS-DIMM. Furthermore, we consider photometric quality, light pollution, and precipitable water vapor (PWV). LCO, and Co. Las Campanas in particular, have dark skies, little or no risk of future light pollution, excellent seeing, moderate winds, PWV adequate for mid-IR astronomy during a reasonable fraction of the nights, and a high fraction of clear nights overall. Finally, Co. Las Campanas meets or exceeds all the defined science requirements.

## Las Campanas Observatory: The GMT Site

*LCO is a developed site with a 40 year history of excellence*

- Light pollution is negligible and should stay that way for decades to come
- Photometric fraction is 60-65%, with 80-85% suitable for astronomy
- Quality of the seeing is as good or better than that at any other developed site in Chile
- Weather pattern has been stable over the past 30+ years
- Southern hemisphere location provides strong scientific synergy with existing and future facilities (Magellan, ALMA, LSST, SKA)
- Carnegie has clear legal access to the site
- Well-understood and economical operations costs

## Sites within the LCO Property

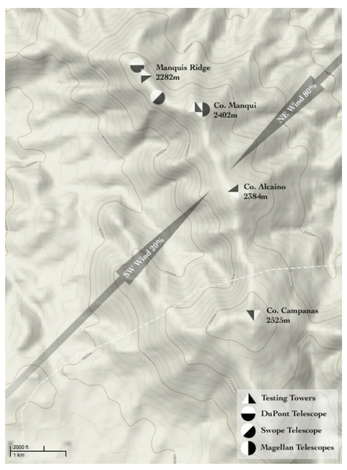




**Figure 1:** Las Campanas Observatory

Cerro Las Campanas:
- Longitude 70º 41.0 W
- Latitude 29º 02.9' S
- Elevation 2551 m
- Highest peak on LCO ridge

The GMT site testing effort has concentrated on identifying the best peak within LCO in terms of seeing and wind speed

**Figure 2:** Topographic representation of the main 4 sites. The location of the instruments as well as the two main wind directions are also shown.

## LCO Site Characterization and Instrumentation

- An extensive site testing program that commenced in 2005 has been completed at LCO to identify the best available location for the GMT
  - Meteorological data (pressure, temperature, wind, and humidity)
  - Seeing measurements
  - Turbulence profiling of the free atmosphere
  - PWV monitoring
  - Cloud cover and light pollution monitoring
- Historical data from 30+ years of operation at LCO provide insight on the long-term stability of the site

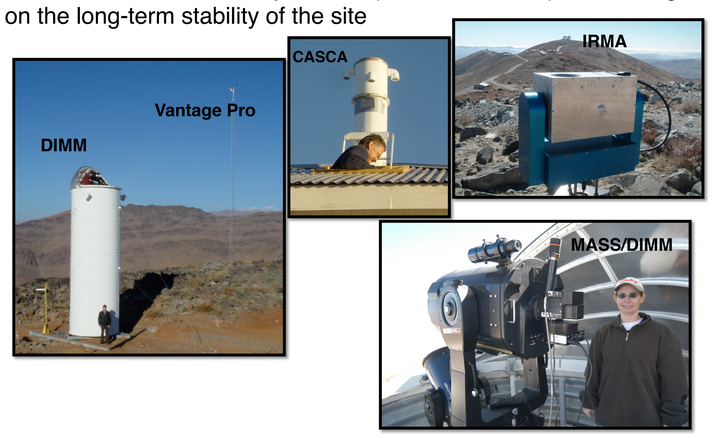
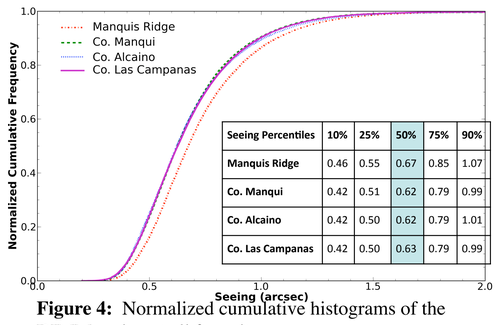



**Figure 3:** Photos of instrumentation in clockwise order: DIMM for seeing, Vantage Pro for meteorological data, CASCA for all sky images, IRMA for PWV and MASS-DIMM for turbulence profiling of the free atmosphere

## Seeing Statistics 2005-2008

- Data drawn from 422 concurrent nights
- Manquis Ridge is notably worse than the other three sites
- *No evidence that seeing has evolved over 20+ years*
- *All sites except Manquis Ridge surpass the GMT Science Requirement (median seeing < 0.65 arcsec)*




| Seeing Percentiles | 10% | 25% | 50% | 75% | 90% |
|---|---|---|---|---|---|
| Manquis Ridge | 0.46 | 0.55 | 0.67 | 0.85 | 1.07 |
| Co. Manqui | 0.42 | 0.51 | 0.62 | 0.79 | 0.99 |
| Co. Alcaino | 0.42 | 0.50 | 0.62 | 0.79 | 1.01 |
| Co. Las Campanas | 0.42 | 0.50 | 0.63 | 0.79 | 0.99 |

**Figure 4:** Normalized cumulative histograms of the DIMM seeing at all four sites.

**Table 1**: Seeing, in arcsec, statistics for the 4 sites

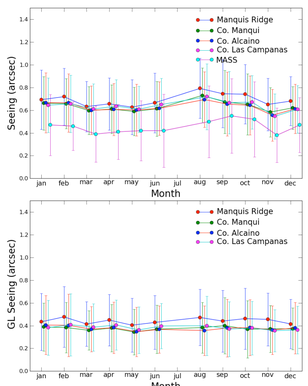



**Figure 5**: **top**: Total seeing at all four sites and free atmosphere seeing derived from MASS as a function of month. Circles are the median seeing, and the error bars denote the standard deviation within a month. For clarity, the data for each site have been offset by 0.1 month from each other. July data have been removed due to the lack of sufficient data during that month. **bottom**: Ground layer seeing as derived from DIMM-MASS at all four sites as a function of month. The small seasonal variation in total seeing is due to the free atmosphere.

## Meteorological Characteristics

- Clear fraction – 64±4%
- Usable fraction – 80±4%
- Both exceed the GMT science requirement

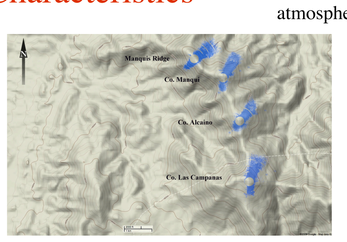



**Figure 8:** The wind roses for each of the four sites. The wind rose shows the amplitude and direction for each wind measurement. One can clearly see the bimodality of the wind direction and site-to-site variations due to local topography.

| GMT Site Testing (2005-2008): Wind speed data (in m/s) on nights suitable for astronomy | | | | | | |
|---|---|---|---|---|---|---|
| | Percentiles | | | | | |
| **Site** | **25%** | **50%** | **75%** | **95%** | **97%** | **99%** |
| Manquis Ridge | 3.1 | 5.4 | 8.9 | 13.4 | 14.8 | 17.0 |
| Cerro Manqui | 3.1 | 5.8 | 9.4 | 14.8 | 15.6 | 17.9 |
| Cerro Alcaino | 2.7 | 4.9 | 8.0 | 13.0 | 13.9 | 15.6 |
| Cerro Las Campanas | 3.6 | 6.3 | 9.8 | 15.6 | 17.4 | 19.7 |

**Table 3:** Wind speed statistics for all four sites. GMT Science Requirement: < 3% loss of clear time to high winds. Notes: (1) 17.4 m/s = 39 mph; (2) weather stations mounted on 10 m towers.

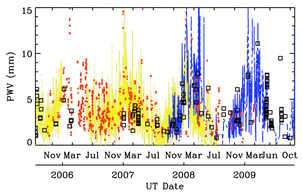



**Figure 9:** PWV as a function of time for a variety of sources at LCO and La Silla. The open boxes are MIKE spectra measured with the updated Brault method at LCO. The blue lines are IRMA data taken at LCO and calibrated with MIKE data. The red points are FEROS data from La Silla. The yellow lines are from the Erasmus model for the GOES-8 satellite (corrected by subtracting 2.5 mm as the median difference between the GOES-8 and FEROS medians at La Silla).

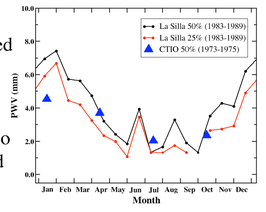



**Figure 10:** Lines show results from PWV measurements carried out at La Silla from 1983-1989 as part of the ESO VLT site survey. Points show PWV measurements from Cerro Tololo for 10/73-5/75 from Hansen and Ciamanque.

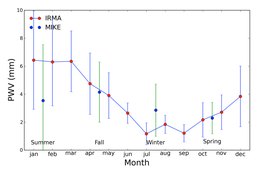



**Figure 11:** Monthly variation in calibrated IRMA PWV and seasonal variation in MIKE PWV. Points are monthly or seasonal medians with standard deviation within that time period shown as error bars.

- Measurements made at CTIO (2210 m elevation; 125 km south of LCO) and La Silla (2347 m elevation; 24 km south of LCO) provide consistent picture of expected PWV properties at LCO – see figures 9, 10, and 11.

| Season | 10% | 25% | 50% | 75% | 90% | % < 1.5 mm | Samples |
|---|---|---|---|---|---|---|---|
| All | 1.2 | 2.1 | 3.7 | 6.1 | 8.2 | 15 | 186300 |
| Winter | 0.5 | 0.9 | 1.4 | 2.0 | 2.7 | 55 | 13312 |
| Spring | 1.0 | 1.4 | 2.1 | 3.2 | 4.2 | 28 | 58594 |
| Summer | 2.0 | 3.0 | 5.1 | 7.1 | 10.0 | 4 | 48633 |
| Fall | 2.9 | 3.7 | 4.8 | 6.6 | 8.2 | 3 | 65761 |

**Table 4:** Clear nighttime calibrated IRMA PWV (mm) statistics. GMT Science Requirement: PWV < 1.5 mm for 10% of the clear time. 10% of clear winter nights are below 1.5 mm for the entire night

## Ground Layer and Free Atmosphere Seeing

**Table 2:** Seeing, in arcsec, statistics in the ground layer and free atmosphere.

| Seeing Percentiles | 10% | 25% | 50% | 75% | 90% |
|---|---|---|---|---|---|
| Manquis Ridge | 0.20 | 0.31 | 0.44 | 0.59 | 0.79 |
| Co. Manqui | 0.18 | 0.27 | 0.37 | 0.50 | 0.67 |
| Co. Alcaino | 0.17 | 0.27 | 0.38 | 0.52 | 0.72 |
| Co. Las Campanas | 0.17 | 0.27 | 0.38 | 0.52 | 0.71 |
| MASS Free Atmosphere | 0.24 | 0.32 | 0.45 | 0.63 | 0.85 |

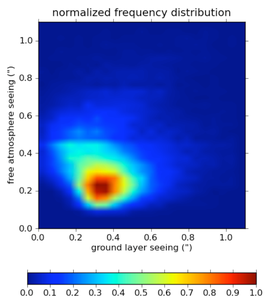



**Figure 6:** Image showing the two dimensional histogram of the ground layer and free atmosphere seeing, with a color map for bin population.

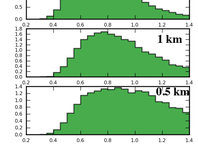



**Figure 7:** Normalized histograms of total seeing with maximum turbulence found in the different layers.

- The best seeing occurs when the turbulence is up high – see figure 7.
- The poorer total seeing observed at Manquis Ridge is almost certainly due to worse ground layer seeing –see table 1.
- Strong cut-off in FA near 0.1" while almost no lower cut-off for GL – see figure 6.

## Conclusions

**Table 5:** Comparison of GMT Site Requirements with Site Testing Results

| Property | Requirement (Goal) | Manquis Ridge | Co. Manqui | Co. Alcaino | Co. Las Campanas |
|---|---|---|---|---|---|
| **Clear (%)** | >60 (>70) | 64±4 | | | |
| **Clear + Partly Clear (%)** | >70 (>80) | 80±4 | | | |
| **Wind Speed > 15.6 m/s (%)*** | <3 | 2 | 3 | 1 | 5 |
| **Percentile with PWV < 1.5 mm** | 10th (15th) | 15th | | | |
| **Median FWHM Seeing (")** | <0.65 (≤0.5) | 0.67 | 0.62 | 0.62 | 0.63 |

*Current Magellan wind limit is 15.6 m/s
*GMT will require a wind limit of 17.4 m/s

## Site Topography

- If Co. Alcaino were cleared to accommodate the GMT, the large change in the topography would likely render the site characterization meaningless.
- Co. Las Campanas has the best layout for a large telescope


**Figure 12:** Photo of Cos. Alcaino (foreground) and Las Campanas (background). The amount of earth removal necessary for GMT is indicated in yellow

## The Case for Cerro Las Campanas

*Cerro Las Campanas is the ideal site for GMT*
- Dark skies and little to no risk of future light pollution
- Seeing is superb
- Clear and usable fractions exceed science requirements
- Low PWV conditions meet science requirements and goal
- It has the best layout for a large telescope

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Comprehensive characterization of astronomical sites, Kislovodsk, Russia. 4–9 October 2010

This work would nothave been possible without the diligent efforts of the LCO technical staff and site testing operator, Cesar Muena