Characterizing the TMT Site Selection Equipment

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for the TMT Site Selection Team

Symposium on Seeing
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The Candidate Sites

Tolar (2290m)  
Northern Chile

San Pedro Mártir (2830m)  
Baja California, Mexico

Armazones (3064m)  
Northern Chile

Tolonchar (4480m)  
Northern Chile

Mauna Kea 13 N  
(4050m), Hawaii
The Instruments

- IRMA Water Vapor Radiometers
- Weather Stations
- All-Sky Cameras
- MASS/DIMM Telescopes
- SODAR Acoustic Sounders
- Dust Sensors
- IRMA Water Vapor Radiometers
- Sonic Anemometers
- Weather Stations
Principles of TMT site characterization
  – Comparison of candidate sites with identical equipment
  – Results not useful unless we know the errors bars
  – Instruments need to be calibrated by comparison with each other and, if possible, with other instruments

Computation Fluid Dynamics (CFD) modelling
  – See talk by Konstantinos Vogiatzis

Cloud cover and PWV analysis
  – D. André Erasmus satellite studies; results verification and longer temporal baseline
## Instrument Calibrations

### Turbulence Instruments

<table>
<thead>
<tr>
<th></th>
<th>Relative Error</th>
<th>Absolute Accuracy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIMM</strong> (see presentation by Warren Skidmore)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeing</td>
<td>0.02”</td>
<td>similar</td>
<td></td>
</tr>
<tr>
<td>Isoplanatic angle</td>
<td>---</td>
<td>---</td>
<td>Used for verification of MASS only</td>
</tr>
<tr>
<td>Coherence time</td>
<td>---</td>
<td>---</td>
<td>Currently not implemented</td>
</tr>
<tr>
<td><strong>MASS</strong> (see presentation by Sebastian Els)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free-atm. seeing</td>
<td>0.05”</td>
<td>similar</td>
<td>Dominated by low layer precision</td>
</tr>
<tr>
<td>Indiv. layer seeing</td>
<td>&lt;0.1”</td>
<td>&lt;0.1”</td>
<td></td>
</tr>
<tr>
<td>Isoplanatic angle</td>
<td>0.01”</td>
<td>&lt;0.2”</td>
<td></td>
</tr>
<tr>
<td>Coherence time</td>
<td>≈20%</td>
<td>≈20%</td>
<td>Estimate of MASS team (not yet implemented)</td>
</tr>
<tr>
<td>Transparency</td>
<td>&lt;0.1mag</td>
<td>&lt;0.1mag</td>
<td></td>
</tr>
<tr>
<td><strong>SODARs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground layer seeing</td>
<td>10%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Individual layer seeing</td>
<td>depends on conditions</td>
<td></td>
<td>Structures, noise sources cause problems</td>
</tr>
<tr>
<td>Wind profiles</td>
<td>20%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td><strong>Sonic anemometers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbulence strength</td>
<td>tbd</td>
<td>tbd</td>
<td></td>
</tr>
<tr>
<td>Wind speed</td>
<td>&lt;15%</td>
<td>&lt;15%</td>
<td></td>
</tr>
<tr>
<td>Wind direction</td>
<td>few deg</td>
<td>few deg</td>
<td>Dominated by setup precision</td>
</tr>
<tr>
<td>Sonic temperature</td>
<td>&lt;2° K</td>
<td>&lt;2° K</td>
<td>Offsets between instruments exist</td>
</tr>
</tbody>
</table>

**Note:** Error bars given are on the statistical properties, not individual data points.
After careful independent calibration, there is good agreement (on the $<10\%$ level) between SODARs, MASS and DIMM for median turbulence profiles.

These are different study periods of a few months each, representing very different ground layer strengths. They are not representative for the conditions at the TMT candidate sites. Only simultaneous MASS, DIMM & SODAR data are used.
# Instrument Calibrations

## Other Instruments

<table>
<thead>
<tr>
<th>Relative Error</th>
<th>Absolute Accuracy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>&lt;15%</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>Wind direction</td>
<td>few deg</td>
<td>few deg</td>
</tr>
<tr>
<td>Temperature</td>
<td>&lt;0.1° K</td>
<td>&lt;0.1° K</td>
</tr>
<tr>
<td>Humidity</td>
<td>&lt;5%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Pressure</td>
<td>5 hPa</td>
<td>5 hPa</td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Precipitation</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Heat flux</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Net radiation</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>IRMA PWV radiometer</td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>PWV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust sensor</td>
<td></td>
<td>Particle count 10%</td>
</tr>
<tr>
<td>All-sky camera</td>
<td></td>
<td>Cloud cover 2%</td>
</tr>
<tr>
<td>Transparency</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Light pollution</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Sky brightness</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
Combined SFAS-XFAS profiles can be compared with GL turbulence obtained from DIMM and MASS. Such comparisons quantify the relative error of the SODAR data and the noise level.

Successful identification and removal of white noise in the SODAR data.

Generally, agreement within 10 – 20 % between the instruments. But: problems at sites with structures, trees, etc.