W. M. KECK OBSERVATORY

Accessing the Mauna Kea Thirty Meter Telescope Seeing & Weather Data

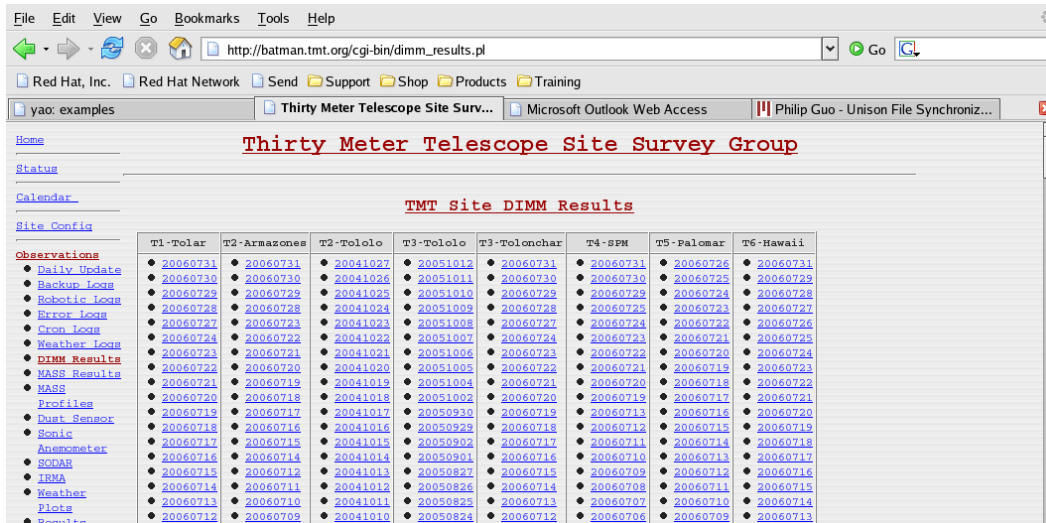## KECK ADAPTIVE OPTICS NOTE 420

Christopher Neyman
August 2, 2006

ABSTRACT

The following note contains a brief description of how to access the Thirty Meter Telescope seeing monitor archive over the Internet. I describe the format of the DIMM, MASS, and weather data files. I also describe how to obtain wind speed profiles from the National Weather Service archive of balloon flights. The last section gives the method I have used to relate profile information to integrated turbulence quantities such as the Fried parameter, r_0, and Greenwood frequency, f_G.

1. Introduction

As part of the Thirty Meter Telescope (TMT) site selection process, the TMT has installed robotic telescopes that measure the atmospheric turbulence at several sites around the world. See the paper by Riddle[1], Schöck, and Skidmore for additional details about the telescopes and data acquisition system. The TMT seeing monitor on Mauna Kea is at a site that is designated 13 North (13N). This site is located approximately 400 meters west and 100 meters down slope from the Keck domes. The Robotic telescope consists of a DIMM unit and a MASS unit. The DIMM measures the seeing (see papers by Sarazin[2] and Tokavinin[3]). The MASS makes low resolution measurements of the distribution of turbulence profile, $C_n^2(h)$ (see Tokovinin[4] and also http://www.ctio.noao.edu/~atokovin/profiler/index.html). The installation also houses a weather station that records the surface wind speed, wind direction, humidity, temperature, and barometric pressure. Seeing and weather data are logged approximately every two minutes during the night.

Figure 1. The TMT site monitor DIMM results page. The entries in the table indicated with the format Year Month Day a link to the data file with that date's data. The links at the left of the page can also be followed to the MASS profiles; MASS results, weather logs, and error logs.

2. TMT Data Mirror at Keck and Accessing Data over the Internet

The TMT site survey group has generously allowed the Keck engineering team to use the data recorded on Mauna Kea for modeling NGAO and analysis of AO operational issues. We have not been granted access to any data from the Chilean sites. This data is proprietary information of TMT, they ask that we not distribute the information from the 13N site to other groups outside of Keck. They have also asked us not to publish results in journals or at conferences without first obtaining permission from the TMT. Questions about distribution of data should be directed to Matthias Schöck at mschoeck@astro.caltech.edu. My experience to date has been that all reasonable requests for use and redistribution of data have been approved by TMT.

The data files can be accessed over the Internet from either of these two sites.

Local 13N site:	http://128.171.116.58:24680/obs.php
TMT site selection server:	http://batman.tmt.org

These sites can be accessed with the username T6_group, see the author for the password. The DIMM results page of the TMT central server is shown in Figure 1. The links at the left of the page can also be followed to the MASS profile, MASS results, weather station, and error log pages. The results files for the DIMM, MASS results, and MASS profiles can be found in /Observations/T6-Hawaii/Results/ directory on the central TMT server. The file organization is slightly different between the local and central sites but the links from the home page are labeled and easy to follow. The results files contain the calibrated and post processed data from each instrument at approximately two minute intervals. All DIMM and MASS results files are columnar ASCII text files. Files indicate a placeholder for future data with four dashes (----). Data that is incorrect due to instrument malfunction or is out of range is indicated with both –NaN and NaN.

The author has started to mirror the TMT site on one of the Linux workstations; the repository includes all DIMM, MASS, MASS profile, and weather station data for the period June 25, 2005, through August 1, 2006. The entire archive is only about 100 MB of disk space.

2.1. DIMM File Format

The DIMM results files are named by the following convention, **results.TMTDIMM.T6-Hawaii.YearMonthDate**. The file extension is the local date (not UT). For example, the file **results.TMTDIMM.T6-Hawaii.20060731** is a DIMM file recorded on Monday July 31, 2006, local time; the UT date would have been August 1, 2006. The DIMM results files contain a two-line header followed by column delimited text data. An example file is shown in Figure 2. The first 10 columns of the data file contain the information most useful for analysis of seeing. The first 6 columns are: date and time, (UT not local time), the target star name is in columns 7 and 8, while column 9 contains the airmass of the observation, the next two columns contain seeing in units of arc seconds calculated by two methods labeled 2pt and 6pt. The methods differ in how the seeing measurement is extrapolated to zero exposure time. I typically use the 6pt method; the difference between the two measurements is usually small, of the order 50 milli arc seconds or less. Both seeing measurements are at a reference wavelength of 500 nm and correct to zenith.

The rest of the columns are fluxes for the two apertures and the background, scintillation in the two apertures, Strehl for the two apertures, the number of data points that were taken and that were good, the peak flux in the apertures, star position information, the exposure time (always 5ms), and the dark frame file. The star position is the measure of how the stars wandered on the CCD during the DIMM exposure: center of aperture 1 and 2, the separation between them, and the initial and final (S*i and S*f) positions of the apertures.

File   Edit   View   Go   Bookmarks   Tools   Help

http://batman.tmt.org/Observations/T6-Hawaii/Results/results.TMTDIMM.T6-Hawaii.20060731   Go

Red Hat, Inc.   Red Hat Network   Send   Support   Shop   Products   Training

yao: examples   http://batman.tm...-Hawaii.20060731   Google   Philip Guo - Unison File Synchroniz...

# Date	Time	Star	airmass	Seeing [as] 6-pt 2-pt	Fluxes S1 S2	BG	Scintillation S1 S2	Strehl S1 S2	Points good all	Peak Flux S1 S2	Star Positions S1 S2 sep S1i S2i S1f S2f	exp [ms]	Dark File
2006 08 01	06 10 32	Bet Oph	1.095	1.571 1.551	15141 14470	39	0.022 0.023	0.60 0.63	5969 6000	5317 5202	50.1 70.6 20.5 49.9 71.0 52.2 72.9	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 11 56	Bet Oph	1.093	1.619 1.576	14860 14305	37	0.023 0.027	0.61 0.63	5970 6000	5253 5146	35.4 55.9 20.4 35.8 56.2 36.9 57.5	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 13 19	Bet Oph	1.091	1.371 1.357	15652 15008	38	0.020 0.023	0.62 0.65	5958 6000	5582 5474	37.6 57.8 20.2 37.4 57.9 38.6 59.4	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 14 42	Bet Oph	1.088	1.988 1.963	14642 14060	35	0.029 0.031	0.58 0.61	5971 6000	5034 4925	40.5 60.7 20.3 40.5 60.6 41.7 61.0	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 16 05	Bet Oph	1.086	1.273 1.266	14829 14203	37	0.024 0.027	0.62 0.65	5968 6000	5303 5217	41.3 61.5 20.2 40.8 60.5 42.1 62.7	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 17 28	Bet Oph	1.084	1.247 1.237	14355 13833	30	0.021 0.024	0.62 0.66	5968 6000	5172 5101	40.3 60.4 20.2 41.3 61.7 39.7 60.0	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 18 51	Bet Oph	1.082	1.149 1.121	14791 14210	34	0.021 0.025	0.63 0.66	5969 6000	5341 5268	41.6 61.7 20.1 41.0 61.2 43.2 63.5	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 21 31	Bet Oph	1.079	1.205 1.191	16395 15756	38	0.023 0.025	0.63 0.66	5954 6000	5938 5837	40.5 60.5 20.0 40.7 60.5 41.6 61.6	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 22 55	Bet Oph	1.077	1.509 1.478	15454 14801	39	0.022 0.026	0.61 0.64	5963 6000	5498 5378	40.0 59.9 20.0 40.3 59.7 41.3 61.4	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 24 19	Bet Oph	1.075	1.472 1.433	15323 14701	37	0.024 0.027	0.62 0.65	5970 6000	5480 5369	41.4 61.5 20.1 41.1 61.6 43.0 63.0	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 25 42	Bet Oph	1.073	1.588 1.569	15780 15106	40	0.024 0.028	0.61 0.63	5959 6000	5576 5455	41.9 61.9 20.1 42.9 62.9 42.2 62.9	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 27 07	Bet Oph	1.072	1.301 1.277	15358 14652	34	0.022 0.024	0.63 0.66	5969 6000	5541 5405	41.4 61.5 20.1 40.3 60.2 43.8 64.0	5	dimm.T6-Hawaii.20060801.054952.
2006 08 01	06 28 31	Bet Oph	1.070	1.416 1.394	15962 15283	34	0.021 0.023	0.62 0.65	5959 6000	5692 5587	40.0 60.2 20.2 39.6 60.3 40.3 60.5	5	dimm.T6-Hawaii.20060801.054952.

Find: -i   Find Next   Find Previous   Highlight   Match case

Done

Figure 2. Sample DIMM result file from the TMT seeing monitor, the file is from August 1, 2006, (UT). Seeing is zenith corrected and the reference wavelength is 500 nm.

The DIMM instrument makes an integrated seeing measurement for the entire atmosphere, i.e from the telescope entrance to the top the stratosphere (~30 km). The DIMM measures the image motion of a single star at high speed with two subapertures; the differential image motion is a measure of the strength of the atmospheric turbulence and is independent of windshake and telescope tracking errors. For the TMT DIMM, the seeing measurement is given at the reference wavelength of 500 nm and corrected to zenith. The seeing is given as a FWHM in arc seconds. The seeing can be converted to an r_0 by using the formula[2,3]

$$FWHM = \frac{0.98\lambda}{r_0}.$$ (1)

2.2. MASS Profile Data Format

The MASS profile data is contained in the same directory as the DIMM data on both the local and the central data servers. The MASS profile files are designated **results.TMTMASS_profile.T6-Hawaii.YearMonthDate**. As with the DIMM files, the file extension is the local time and date (not UT). An example file is shown in Figure 3. The columns 1-6 are UT year, date, and time. The next column is a letter code that denotes the fitting method used to estimate the atmospheric profile, X is a fit to six layers with fixed altitudes; L is for a fit to 3 layers with varying layer altitudes. Column 8 is the number of levels used in the fit either 3 or 6. Column 9 is a chi-squared number for the turbulence layer fit (experts at the TMT claim it can be ignored). Column 10 is the MASS free atmosphere seeing in units of arc seconds. Note that free atmosphere seeing does not include turbulence below about 0.5 km which is often the dominant contribution to total seeing. The next columns (11-22) will contain pairs of numbers corresponding to fitted altitudes and integrated turbulence of the atmospheric profile. For the X line, there are six layer altitude, 0.5, 1.0, 2.0, 4.0, 8.0, and 16.0 km, and after each layer altitude is the integrated C_n^2 in that layer, in units of m$^{1/3}$. The L line values are the results from a fit to both the turbulence strength and layer altitudes, results are given in the same units as the X line fits. The author has only used the X profiles to date. Like the DIMM data, the MASS results are referenced to a wavelength of 500 nm and zenith corrected. The MASS layer altitudes are referenced to the telescope entrance pupil not mean sea level.

The MASS unit measures the atmospheric turbulence by estimating the integrated turbulence in several discrete layers depending on the method used for the analysis. One should be clear that the MASS does not report $C_n^2(h)$, but several integrals of the form:

$$\int_{i_{th}-layer} C_n^2(h)w(h)dh \quad . \qquad\qquad (2)$$

The integration in equation (2) is centered about the layer heights reported in the data file. The weight function $w(h)$ is an idealized MASS instrument response function. It is a triangular function that is unity at h_i dropping linearly to zero at $2h_i$ and $h_i/2$ (or zero for the lowest altitude layer). More details can be found in the paper by Tokovinin[4].

Figure 3. A sample MASS profile data file, tthe columns are UT year, date, and time. Next is a letter code that denotes the fitting method; X is a fit to five fixed layers, L is fit to three layers with varying altitude and turbulence strength. The next column is the number of profile layers that were fit. The following column is a chi-squared estimate of the fit. Next is the MASS free atmospheric seeing in units of arc seconds. The next columns will contain pairs of numbers corresponding to altitude and integrated turbulence (see text for details). MASS data is zenith corrected and given at reference wavelength of 500 nm.

2.3. MASS Results File Format

The MASS results files are contained in the same directory as the DIMM and MASS profile data on both the local and the central data servers. The MASS results files are designated **results.TMTMASS.T6-Hawaii.YearMonthDate**. As with the DIMM files, the file name extension is the local year, month, and date (not UT). An example file is shown in Figure 4. Columns 1-6 are the UT year, date and time. The free atmosphere seeing in column seven is computed directly from the scintillation measurements. The free atmospheric seeing reported in the MASS profile data file is the result of integrating the turbulence profile fits. Usually the three free atmospheric seeing values are in close agreement, and this might be useful as an indicator of fit quality. Column 19 is the isoplanatic angle in arc seconds. Column 23 is the τ_0 given in milliseconds. The other columns are diagnostics of the MASS unit and can be ignored.

Figure 4. Sample MASS file; Columns 1-6 are the UT year, date, and time. The free seeing in column seven is computed directly from the scintillation measurements. Column 19 is the isoplanatic angle in arc seconds. Column 23 is the τ_0 given in milliseconds. The other columns are diagnostics of the MASS unit and can be ignored. MASS summary data is referenced to 500 nm wavelength and zenith corrected.

2.4. TMT Weather Station File Format

The TMT weather station files are located in the weather directory on both the local and central TMT sites. Weather station files are designated **weather_station.T6-Hawaii.YearMonthDay**. Weather data is logged 24 hours a day. A new file is created at sunrise each day and the archive is labeled with the local year, month, and date. A sample data file is shown in Figure 5. Weather data files have a one-line header. The first 6 columns are the UT year, date, and time. Weather data is given in the next five columns: air temperature in degrees Celsius, relative humidity, wind speed, wind direction, and atmospheric pressure.

Figure 5. A sample weather station data file from the TMT site monitor.

3. Balloon Weather Data from the Hilo and Lihue Airports

The National Weather Service launches balloons from the Hilo and Lihue (Kauai) Airports at 0 and 12 hours UT each day. The data are archived at http://weather.uwyo.edu/upperair/sounding.html. The JAVA form on this web page can be used to query the database for atmospheric information from the balloon launches. The data file is returned as an html page, the results include: atmospheric pressure, altitude (ref. to mean sea level), wind speed and direction. The data are unevenly spaced in altitude because the balloons rate of ascent through the atmosphere is uncontrolled. The data are typically spaced between 100m and 500m in altitude. A sample screen shot of the data file is shown in Figure 6.
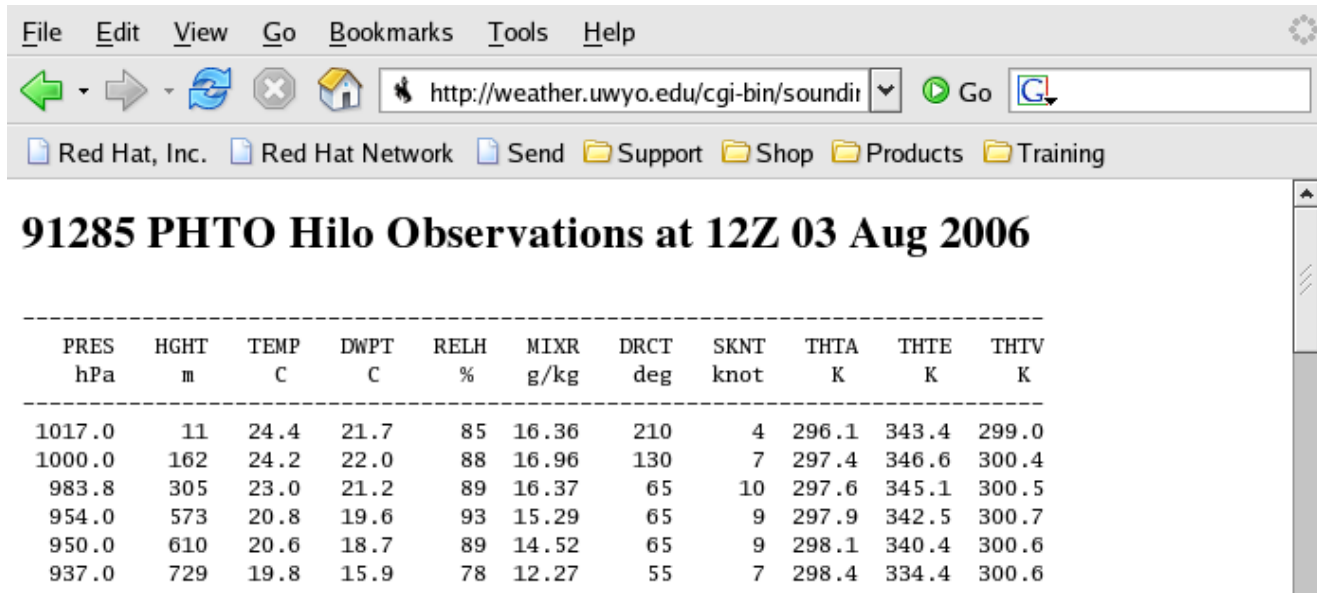
Figure 6. Sample data file from Hilo balloon launch, from Aug 03 2006 (UT). Columns are barometric pressure, height, temperature, dew point, relative humidity, mixing ratio, wind direction and wind speed, in knots. Note one knot = 1 nautical mile/hour = 0.5144 m/s.

4. Preliminary Calculation of Integrated Turbulence Parameters

My method for calculating r_0 uses the DIMM data files 6 point seeing measurement and equation (1). When calculating integrated turbulence parameters such as d_0 or the isoplanatic angel (θ_0), where the ground layer drops out of the calculation, I use the MASS 6 layer profile. I have treated the MASS layers as delta functions centered at the peaks of the ideal MASS response functions[4]. The definitions in appendix A are used to calculate d_0 and θ_0. It may be better to convolve the turbulence with the MASS triangle response functions, but I have used this simpler method to date.

For turbulence parameters that depend on the wind profile, such as the Greenwood frequency, I have used the balloon data from the Hilo Airport. I interpolate this data using the 3 nearest balloon flights to the time stamp of the MASS data. The ground wind speed is taken from the weather data files and interpolated to the same time stamps as the MASS data. The difference between the integral of the MASS profile and integrated turbulence from the DIMM can be used to infer the strength of the ground layer. The integrated turbulence is calculated from the DIMM seeing, the definition of r_0 and equation (1). So far this method has been successful, I have not encountered any profiles with negative turbulence ground layers. I assume that the ground layer is located at an altitude of 0 m above the seeing monitor telescopes. Since the MASS and DIMM data are not synchronous in time, I interpolate the DIMM data to the MASS time stamps. The combined wind and turbulence profiles are integrated using the formula in the appendix A to calculate the Greenwood frequency.

Appendix A. Formulas for the Computation of Key Atmospheric Parameters

Standard formulas for r_0, d_0, θ_0, and the f_G may be found in Hardy[5]. The turbulence profile is $C_n^2(h)$ and the wind speed profile is given by $v(h)$. The reference wavelength λ is typically 500 nm, although other wavelengths can be used. When observing at zenith the following definitions hold:

6

$$r_0 = \left[0.4233 \left(\frac{2\pi}{\lambda} \right)^2 \int C_n^2(h)dh \right]^{-3/5},$$

$$\vartheta_0 = \left[2.914 \left(\frac{2\pi}{\lambda} \right)^2 \int C_n^2(h)h^{5/3}dh \right]^{-3/5},$$

$$f_G = 0.2549 \left[\left(\frac{2\pi}{\lambda} \right)^2 \int C_n^2(h)v(h)^{5/3}dh \right]^{3/5}.$$

When observing with laser guide stars d_0, is a function of the altitude of the laser guide star, H. I typically quote d_0 for a guide star altitude of 90 km above the telescope. When H is larger than about 30 km, then d_0 can be approximated by,

$$d_0 = \left[\left(\frac{2\pi}{\lambda} \right)^2 \left(0.5H^{-5/3} \int C_n^2(h)h^{5/3}dh - 0.452H^{-2} \int C_n^2(h)h^2dh \right) \right]^{-3/5}.$$

References

1. R. Riddle, M. Schöck, W. Skidmore, "The Thirty Meter Telescope site testing robotic computer system", Space Telescopes and Instrumentation II: Ultraviolet to Gamma Ray. Edited by M. Turner; and G. Hasinger, Proceedings of the SPIE, **6267** (2006).
2. M. Sarazin and F. Roddier, "ESO differential image motion monitor", Astron. & Astrophys., **227**, 294-300 (1990).
3. A. Tokovinin, "From Differential Image Motion to Seeing", PASP, **114**, 1156-1166, (2002).
4. A. Tokovinin, V. Kornilov, N. Shatsky, O. Voziakova, "Restoration of turbulence profiles from scintillation indices", Mon. Not. R. Aston. Soc., **343**, 891-899 (2003).
5. J. Hardy, Adaptive Optics for Astronomical Telescope (New York, NY Oxford University Press), 1998