IRMOS Stroke Requirements

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MOAO Tweeter Stroke Requirements

Aperture Averaged Tweeter Stroke Requirements

For the full MOAO capability for IRMOS, we contemplate placing a common mode correction on the woofer and compensating for the remaining error using tweeters in the spectrograph arms. The tweeter stroke requirement will depend on location within the field of view as well as turbulence conditions and zenith angle. Given the technological readiness level of MEMS, minimizing the tweeter stroke will strengthen the IRMOS concept.

In this note, we consider different classes of correction to apply to the woofer. One possibility is to apply a ground layer correction and allow the tweeters to compensate for all turbulence above the ground layer. At the opposite extreme, one could place a correction on the woofer that would compensate an on-axis star. In this architecture, the tweeter stroke requirement increases with angular offset from this star due to the effects of anisoplanatism. Figures 1 - 5 illustrate the residual stroke that a tweeter must correct as a function of angular offset, zenith angle, and turbulence conditions for these two architectures. These curves were generated using covariance functionality in Arroyo. The calculations were performed using three Gemini GLAO turbulence profiles whose properties are listed in Table 1.

Practically speaking, the actuator count on the woofer will limit our ability to perfectly compensate an on-axis star, due to residual fitting error. The effects of OPD due to residual fitting error are listed in Table 2 for 30x30, 60x60 and 100x100 actuator count mirrors. In all cases, the contribution to the tweeter stroke budget from residual fitting error is small compared to that from correcting the residual wavefront errors not compensated by the woofer. (Note - divide the numbers in the table by 2 to go from OPD to stroke.)

My conclusion in looking at these curves are that placing an on-axis correction onto a common mode woofer is strongly favored from a number of different perspectives. First, this correction is quite good at minimizing tweeter stroke over the entire 5 arcminute IRMOS field, and yields residuals that are less than those of the ground layer woofer correction everywhere in the field, at all zenith angles and under all turbulence conditions. Note that the residual stroke is about

.8 μm under typical conditions at z=30, and increase to 1 μm under bad turbulence conditions. If one demands a 5 sigma safety margin over the RMS stroke, then this corresponds to a tweeter stroke of 4 to 5 μm. But a 5 sigma safety margin would seem to me to be overkill for a near diffraction limited instrument intended for IFU spectroscopy. Assuming a 4 sigma safety margin, IRMOS can operate down to z=60 under typical conditions, and to z=30 under bad conditions.

Second, consider a situation in which one may wish to run IRIS at the same time as IRMOS. One can place the best on-axis correction onto the woofer and run a downstream MEMS device in open loop to compensate for residual fitting error. From Table 2, we see that the residual stroke due to fitting error from a 30x30 actuator mirror is of order 200 nm or less. This minimizes the stroke requirement for this MEMS device, leaving as little wavefront error as possible to be compensated in open loop. The low stroke requirement on this device may also facilitate a higher actuator count, leading to a smaller error budget for the on-axis performance. At the same time, the entire IRMOS field remains accessable for observations.

Third, consider a situation where MEMS devices are limited in their available stroke (or at least where the Project Office cannot be persuaded that MEMS devices are not limited in their available stroke). In poor turbulence conditions or at large zenith angles where the tweeter stroke requirement exceeds the available MEMS stroke, a common mode ground layer correction fails catastrophically throughout the entire 5 arcminute field. In contrast, the on-axis correction may fail at the perimeter of the field, but the center of the field will still be accessable for observations.

Let me comment on the availability of a classical piezostack DM with the necessary stroke to serve as the woofer. The project office is aiming to procure a 60x60 actuator DM with 8 microns stroke at first light, and combine this in series with a 4 micron stroke 36x36 actuator DM to get a total of 12 microns of stroke. At some time in the future, the plan is to acquire an adaptive secondary in order to meet the NFIRAOS SRD specs. The ESO planet finder has let a contract for a 41x41 actuator DM with a goal of 10 microns of stroke. And Xinetics advertises a 941 actuator DM with 8 microns stroke on its webpage. These mirrors are all 5-7 mm pitch, and their overall size is commensurate with the Offner design.

From the IRMOS perspective, it should suffice to procure a woofer with 12 microns of stroke, since this is what NFIRAOS is proposing for first light. Available stroke increases with actuator pitch, and so it would make sense to relax the actuator count until the mirror can deliver 12 microns of stroke. This has the effect of offloading residual fitting error onto the MEMS devices. But for actuator counts of 30x30 or more, this stroke is a small fraction of the combined errors due to focal and angular anisoplanatism. If you believe one can procure something like a 30x30 actuator, 12 micron stroke piezostack DM, and you believe that MEMS devices can compensate about 1 micron RMS of surface error in open loop, then a common woofer IRMOS architecture addresses the stroke requirements over the full 5 arcminute field. Again, insufficient stroke or inability to perform open loop control with sufficient accuracy degrades the field of view from the perimeter inwards.

Lastly, note that the project is psychologically prepared to build an AO relay based on classical piezostack DM technology. This Offner relay supports a 5 arcminute field of view, whereas NFIRAOS does not. For NFIRAOS to meet its ultimate error budget the project also requires an AM2. I'm not aware of any backup plan for NFIRAOS if an AM2 is deemed too expensive. In its final configuration, NFIRAOS requires three adaptive mirrors to compensate a 30" field of view.

The relay proposed here uses two adaptive mirrors. The Offner relay feeding a single downstream MEMS device may or may not meet the 133 nm error budget at first light. The uncertainties in this error budget lie in the availability of high actuator count MEMS and the feasability of open loop control of 200 nm of RMS stroke. Given the level of MEMS expertise in LAO, I think that this organization should weigh in on these two issues.

For those who like tables, Table 3 attempts to compare the stroke budget situation for IRMOS and NFIRAOS options. For those who prefer bullets, I've enumerated the advantages of the common mode woofer architecture below.

A common mode woofer architecture for IRMOS has the following properties:

- Requires a single, classical piezostack 30x30 actuator DM with 12 μm of stroke.
- Requires a single interferometer to monitor the surface of this DM.
- Will operate with 4 μm stroke MEMS device over the entire 5' field under almost all observing conditions.
- Can utilize the same MEMS devices to achieve excellent sky coverage through AO compensation of IR TT stars.
- Can simultaneously feed IRIS using a 1 μm stroke MEMS device running in open loop to compensate about 200 nm of RMS stroke arising from the woofer's residual fitting error.
- May deliver the SRD error budget for IRIS at first light, depending on the availability of a 100x100 actuator, 1 μm stroke MEMS device.

Height (meters)	Good $C_n^2 \Delta z$ $(m^{2/3})$	Typical $C_n^2 \Delta z$ $(m^{2/3})$	Bad $C_n^2 \Delta z$ $(m^{2/3})$
0	9.26e-14	7.04e-14	1.38e-13
25	1.83e-14	2.25e-14	1.08e-13
50	5.74e-15	1.35e-14	1.53e-13
100	3.62e-15	1.24e-14	1.58e-13
200	6.14e-15	1.99e-14	1.03e-13
400	9.60e-15	2.87e-14	6.46e-14
800	1.18e-14	3.02e-14	7.29e-14
1600	9.13e-15	1.75e-14	6.77e-14
3400	2.95e-14	6.97e-14	2.00e-13
6000	1.44e-14	5.47e-14	7.95e-14
7600	1.01e-14	1.95e-14	2.84e-14
13300	2.98e-14	1.30e-14	7.70e-15
16000	6.15e-15	1.31e-14	4.81e-15
r_0	.187 cm	.144 cm	.072 cm
Seeing	.55 arcsec	.713 arcsec	1.42 arcsec
θ_0	2.38 arcsec	2.13 arcsec	1.92 arcsec
d_0	4.30 meters	3.75 meters	3.20 meters

Table 1: Gemini good, typical and bad turbulence profiles. Turbulence parameters are quoted at a wavelength of .5 μm.

	Good	**Typical**	**Bad**
30x30, z=0	171	213	375
30x30, z=30	184	229	402
30x30, z=60	242	302	530
60x60, z=0	96	120	210
60x60, z=30	103	129	226
60x60, z=60	135	169	297
100x100, z=0	63	78	137
100x100, z=30	67	84	148
100x100, z=60	89	111	194

Table 2: Residual fitting error in nanometers for 30x30, 60x60, and 100x100 actuator mirrors at a range of zenith angles under a variety of turbulence conditions. A fitting error coefficient of .28 was assumed in the calculation. For a common mode woofer architecture with a 30x30 actuator DM, the residual fitting error that the tweeter must compensate is only a small fraction of the residual errors due to anisoplanatism shown in the figures above. Residual fitting error terms for 60x60 and 100x100 actuator mirrors are also shown, to give an idea of the overall error budget term from residual fitting delivered by the combined woofer/tweeter system. (NOTE - to get stroke, divide these numbers by two.)

	IRMOS w/ common woofer	**IRMOS w/ separate woofers**	**NFIRAOS**
Field of Regard	5’	?	2’
Woofer type	1 Piezo DM	20 Bimorphs	2 Piezo DMs
Woofer order of correction	30x30	6x6	60x60/36x36
Woofer stroke	12 μm	?	8 μm / 4 μm
Woofer surface measurement	1 interferometer	20 interferometers	None
Tweeter type	MEMS	MEMS	None
Tweeter order of correction	60x60	60x60	None
Tweeter stroke	4 μm	?	None
133 nm upgrade path	MEMS	MEMS	AM2
Upgrade requirement	100x100 MEMS w/ 1 μm stroke	100x100 MEMS w/ 10 μm stroke	30x30 AM2
RMS open loop stroke (IRIS)	0.1 μm	?	None
RMS open loop stroke (IRMOS)	1 μm	?	None

Table 3: Adaptive mirror technology for different AO system architectures.

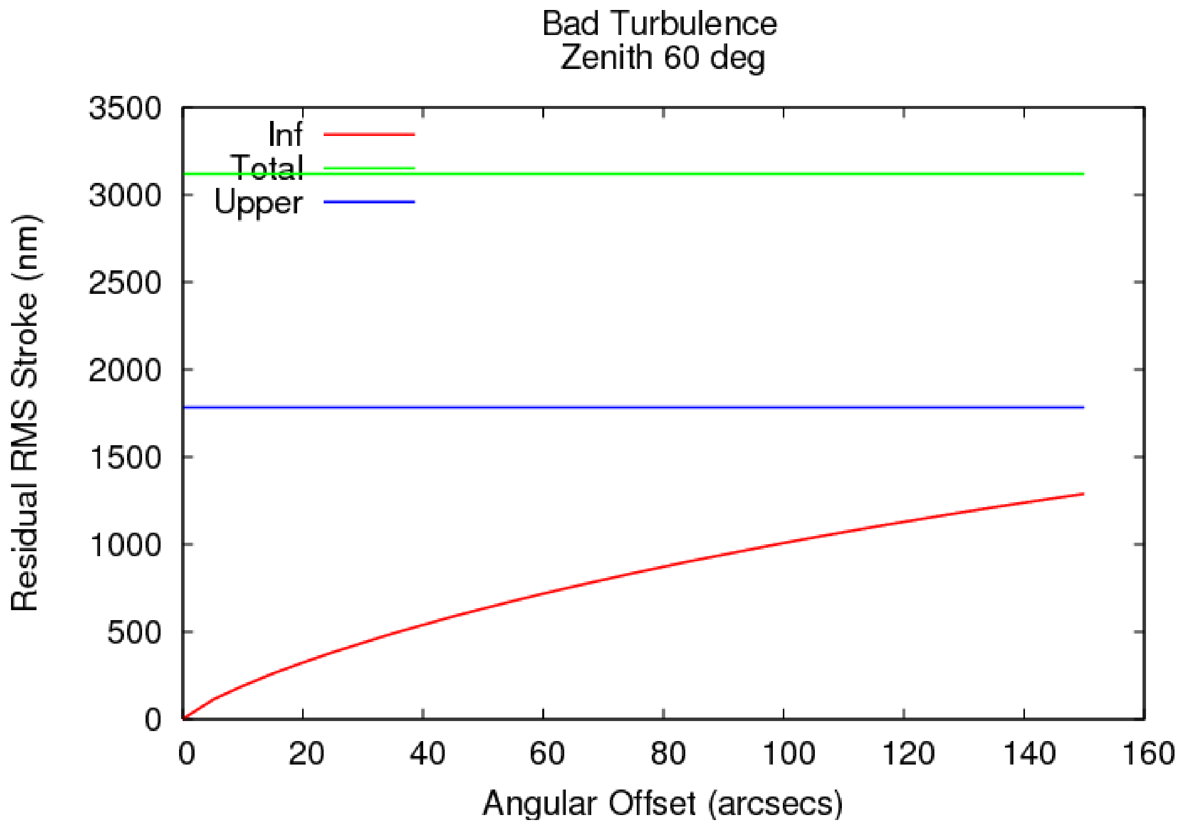

Figure 1: RMS residual stroke vs angular offset from the point of best woofer correction. The highest horizontal line is the RMS OPD required to compensate a science target, and is uniform over the field. The next horizontal line is the residual OPD required if a ground layer woofer correction is applied. This curve is computed assuming that all turbulence up to 800 meters has been corrected by the woofer, and that this correction is valid at all angular offsets. The curve corresponds to the integrated turbulence above 800 meters, which must be compensated by the tweeters. The final curve shows the residual stroke assuming that a correction has been placed on the woofer to perfectly compensate a source at infinite range. These curves do not include the effects of residual fitting error from the woofer. For a woofer with an actuator count of 30x30 correcting a source at infinite range, residual fitting error amounts to less than 200 nm of RMS surface.

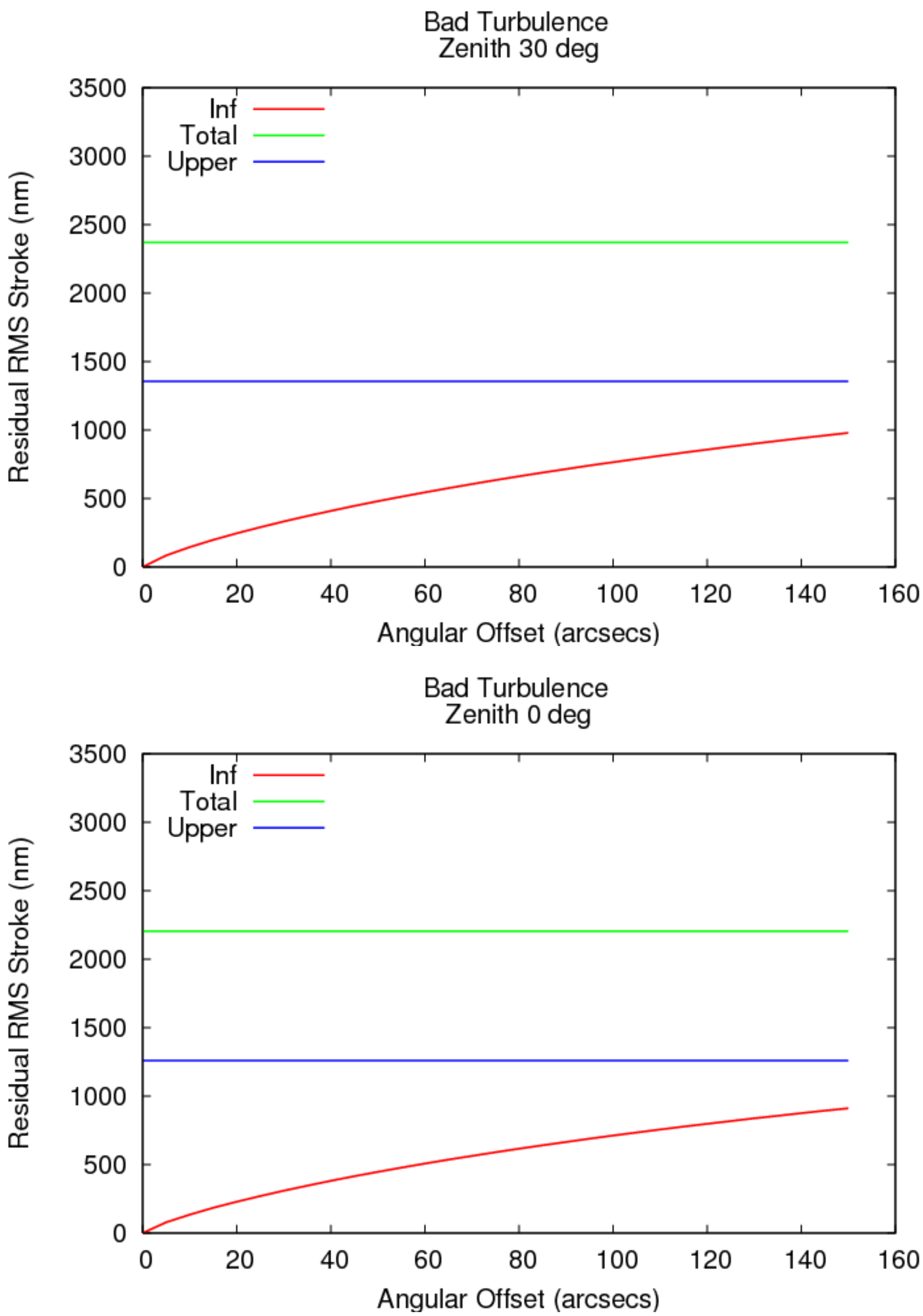

Figure 2: Caption as for Figure 1.

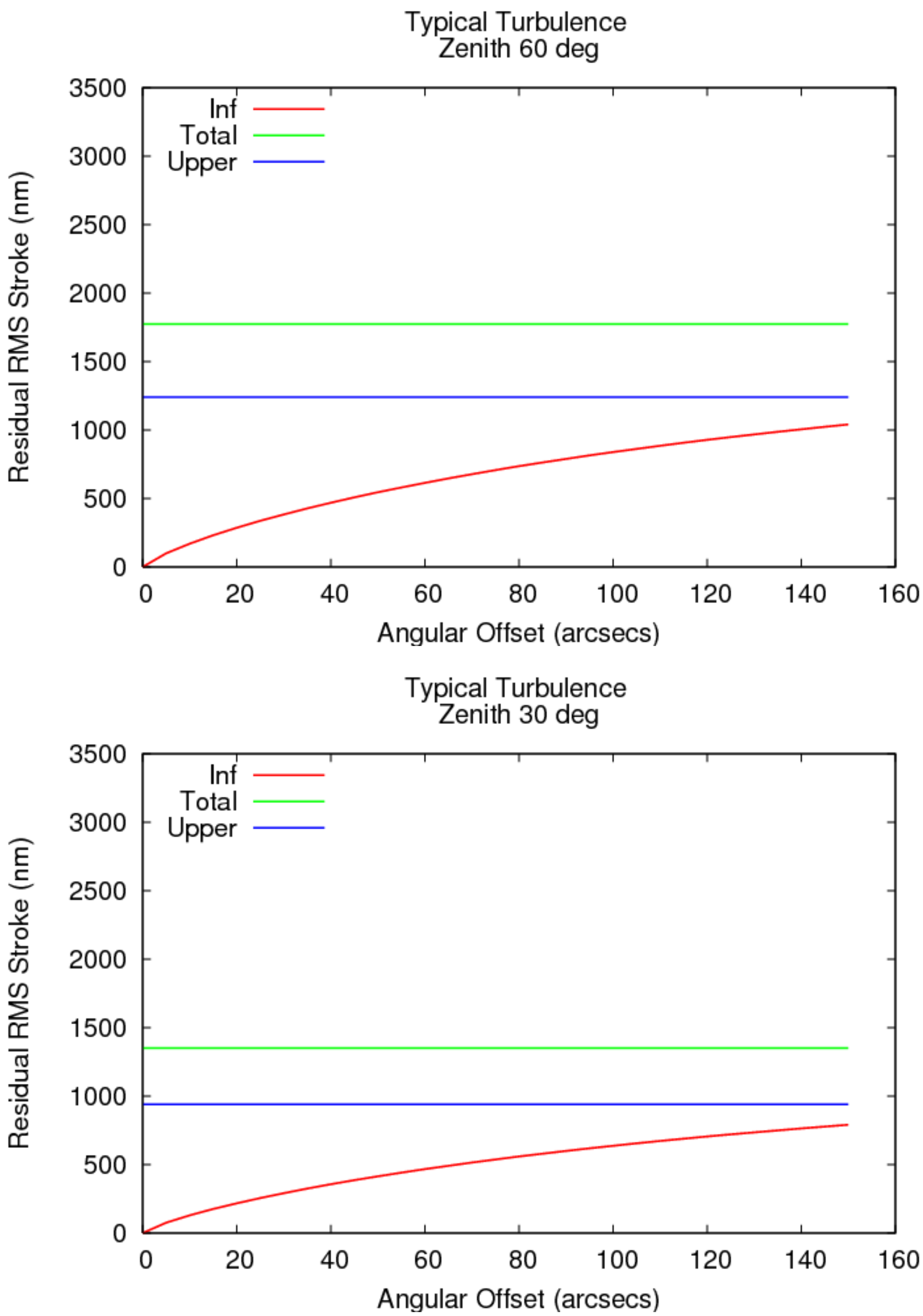

Figure 3: Caption as for Figure 1.

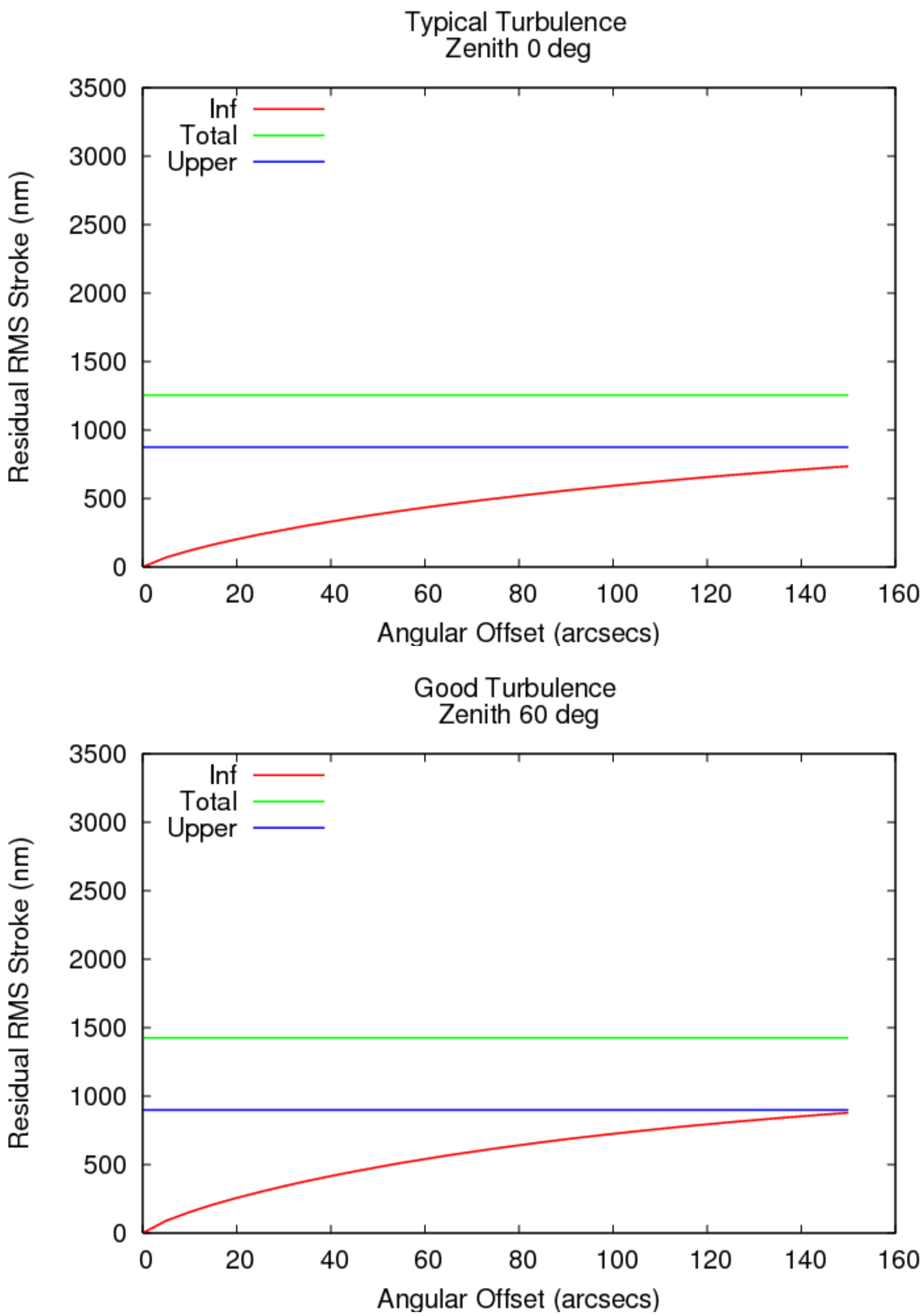

Figure 4: Caption as for Figure 1.

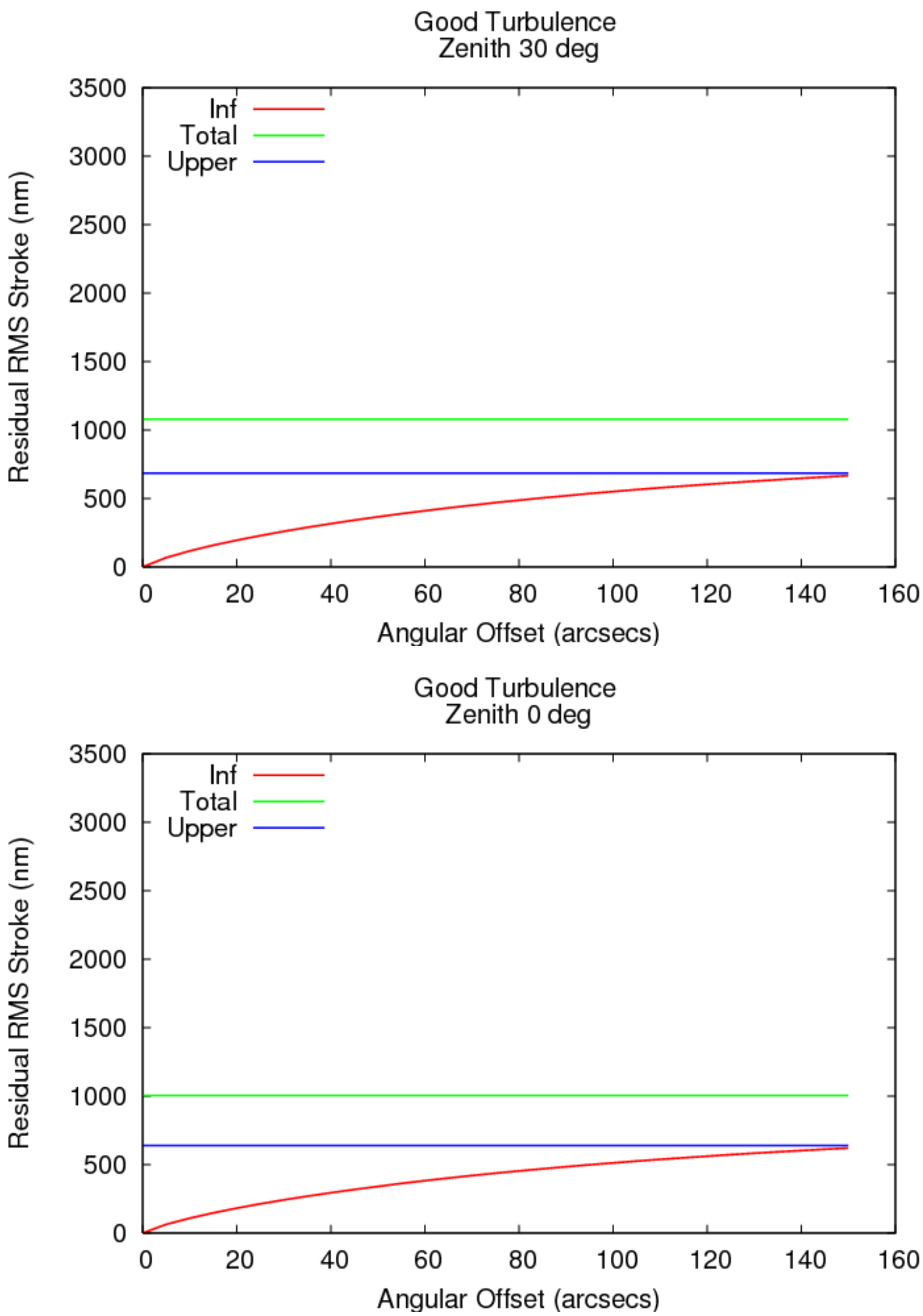

Figure 5: Caption as for Figure 1.